PASSIVE AND LOW ENERGY ARCHITECTURE

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ANNUAL AWARDS

1982 E Maxwell Fry and Jane B Drew, England

PREFACE

The International Conference on Passive and Low Energy Architecture - "INTERNATIONAL PLEA 83" - was held in Greece on the island of Crete at Rethimnon, between June 28 and July, 1983.

The purpose of this Second International PLEA Conference was to continue the forum which originally started at Miami Beach in 1981 and was followed by PLEA 82 in Bermuda. PLEA 82 confirmed the need for an annual forum to exchange information on developments in research, design, materials, construction techniques, education, teaching methods, tools and other topics related to the use of clean and renewable energy in built environments. Subsequent PLEA meetings will be held in other regions of the world, so as to make the forum available to a larger audience and to further expand international contributions and the range of topics covered. In this we solicit the assistance of all interested organisations and individuals.

The organising committee acknowledges, with gratitude,

the sponsorship of the Greek Government through the Ministry for Planning, Housing and Environment, the Ministry for Research and Technology and the Ministry of Culture and Sciences, without which this meeting could not have been held.

the generous subsidy of the proceedings by H.R.H. Prince Abdulaziz bin Mishal bin Abdulaziz and appreciates his interest in solar energy.

In particular, the undersigned wishes to express his personal gratitude to Simos Yannas, Maria and Thalis Argyropoulos for their painstaking work in putting PLEA 83 together.

Arthur Bowen
General Chairman
International PLEA Organisation

INTRODUCTION

'Passive', 'solar', 'low energy' architecture is still some way from being standard practice, and is yet to find an articulate form of expression. But, however we may choose to describe such architecture, it has come a long way (in less than a decade) and amidst the deepest of crises in architectural thought and practice. The progress in the last few years has come from the realisation that passive heating and cooling apply to every climate and under many different forms; also, as a result of the availability of analytical tools for use by designers. Even more significant is the emergence of an increasingly international field. An important sign of this progress in Europe is the abandonment of cookbook solutions, - of large, expensive new houses on large suburban sites, based on early American examples - for design techniques which are suited to the urban character and climates of this continent.

Perhaps the single greatest problem at this time in the development of architectural uses of solar energy is still the lack of design information. Good design handbooks are yet to come and the poor substitutes with which designers have to cope age rapidly and are far from comprehensive. Solar conferences, on the other hand, though abundant, suffer from fragmentation and compartmentalization. Often a feast for the researcher in search of highly specialised data, they can be a nightmare for the designer seeking a synthesis across many and diverse disciplines. Architects, - the design professionals perhaps least equipped for, but most enthusiastic about, passive and low energy design, - are bearing much of this frustration.

This conference cannot expect to substitute for or simulate a design handbook. It does aim, however, to act as a forum for energy conscious designers, - architects, engineers, planners, - and is structured to present information in a form that is directly relevant to them. The topics of the conference are grouped under four areas : building projects and case studies; research and development; design aids; and, management. These are also the sections of this book.

The first section, which is also the largest, brings together papers dealing with case studies of individual buildings or groups of buildings, completed or to be built, and of community planning. This section contains some forty papers arranged in four groups, including chapters on vernacular architecture and on planning and urban design. The case studies cover examples from thirteen countries in Europe, North and Latin America, North Africa, the Middle East and Asia.

The second section contains papers reporting on experimental work and on technical developments with passive and low energy systems and components. Papers on related topics are placed sequentially within the section and the order is from general to specific.

The third section concentrates on the ill-defined but crucial to designers, area of design aids. What constitutes a (useful) design aid, where and for whom are open questions which this conference aims to address in some detail during its roundtable discussions. Papers included in this section have been selected on the criterion that they describe a procedure of analysis or provide guidelines for analysis or design. About half of the papers are on computer models and these are conveniently grouped together as such. The remainder are arranged in a sequence which follows the order in which they might be used as aids during design.

The fourth section pulls together papers dealing with aspects of implementation and management including the topics of international programmes, education and the training of design professionals.

A number of invited papers are also included in each section and these are generally wider in scope and aimed as reviews of, or introductions to, topics within the section. Inevitably, as with any large conference, the list of topics is neither fully comprehensive nor absolute and many papers fall in between topics or also touch upon the topics of other sections.

The papers for this conference were selected from among some 150 abstracts that were sumbitted for initial review by colleagues from 23 countries. These abstracts were submitted within a period of less than three months from the initial call for papers in October 1982. This is perhaps indicative of the need for communication felt by colleagues throughout the world. The deadlines authors have had to comply with for this publication were much more stringent than usual. I wish to express the gratitude of the organisers to authors who have made such great efforts to work to these deadlines. Also, our most sincere apologies to those colleagues in Italy and Greece who, due to delays in the national mail delivery services, did not receive the publisher's material in time to meet the publication deadline.

Inevitably, with most authors writing in a language other than their own, many papers reached us which abounded in idiosyncratic spelling, unfortunately, much too late to be returned for corrections. As many of these corrections as were feasible have been made and a few of these papers were substantially edited and retyped. A number of papers felt to be beyond repair were excluded from the book.

Throughout the book the majority of authors use S.I. units except for a few authors from North America. These had to be left unchanged and I apologise for the inconsistency.

I wish to thank Anna Douglas, Maria Argyropoulos and Caroline Lee for their assistance with corrections and typing of manuscripts.

Simos Yannas
London
10 May 1983

BIOCLIMATIC ARCHITECTURE UNDER MEDITERRANEAN CLIMATE

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ABSTRACT

Our work started in 1976 with the rehabilitation of an ancient building in mediterranean climate. At that time, the main concern was to integrate the passive solar architecture in the socio-cultural context, e.g., Les Perdrigals. Another aspect of our work is designing greenhouses for new buildings or retrofits. In a mountain climate, a two storeygreenhouse will be presented. The use of sun as natural lighting and energy source is demonstrated in a partly underground single family dwelling. First example of a low cost housing program is described. Our project for the new Préfecture in Montpellier focused on extensive utilization of daylighting systems. The approach of this project will be presented.

KEYWORDS

Bioclimatic,passive solar architecture;greenhouses;low cost housing; daylighting systems.

INTRODUCTION

New technology has freed man from the constraints of his environment. He has been able to take advantage of the technological advances to improve not only his living conditions but also to escape the restrictions imposed by the environment. The result has been modern architecture which totally neglects problems of energy. Its aim has been mainly to develop standardized industrial techniques which can be applied anywhere to create an international type of architecture. Rising costs of energy may lead us to a salutary reexamination of this trend. Faced by such problems, we took a look at vernacular architecture. In the beginning, when the function of shelter was to serve only the very basic needs of life, environment was the overuling factor of the morphology of a dwelling. Physical, geographical, climatic and geological parameters were the determining factors in the choice of the type of shelter with the materials available for its construction. These various factors associated with the socio-economic and cultural characteristics of an area produced what is recognized now as regional architecture. Our first work was strongly influenced by the vernacular architecture of our region (Languedoc), and we will show then how it evolved.

LES PERDRIGALS

Our approach for the first house, Les Perdrigals, was to take into consideration environmental and socio-economical factors. To these, we added our concern for energy conservation by looking in depth at geographic and climatic factors, (insolation, wind, temperature), including a priority for solar energy collection in our design. Analysis of the regional architecture demonstrated the following main characteristics: a- protection against the prevailing wind by the choice of orientation and morphology of the building, b- organization of outside protected areas, c- use of natural cool air systems by cross ventilations, d- seasonal internal migrations. These components were applied together with devices to optimize solar gains and minimize heat losses. The architecturalresult is actually very close to the regional architecture (fig. 1).

THE SOLAR GREENHOUSE

Another aspect of our work is designing greenhouses for new buildings or retrofits. We shall attempt to show constraints and needs to be taken into consideration when constructing a solar greenhouse by describing the steps followed in the planning and the construction of retrofit greenhouses. Our approach is based on 3 main aspects: function, architecture and thermal control. Of these the most important is the first.

The conditions required by plants are different from those of man. Temperature and hygrometry will vary as a function of whether the greenhouse will be semi-habitable or strictly for horticulture. Therefore the first step is to clearly define the function of the greenhouse since this will greatly influence its conceptualization. Architectural design is the next important factor, because the greenhouse must be adapted to the existing building while still facing south. The morphology and aspect of the building will influence those of the greenhouse. Moreover, the choice of materials will be based on its design.

Thermal control within the greenhouse, the third parameter to be studied, is not only related to the use, but also to such factors as climate. Ensuing problems are essentially overheating and cool ing, ventilation, stratification and energy storage.

The "Maison du Lac" greenhouse was built as a part of the renovation of an old house. It was essentially designed for habitation. The 2 level area connects externally with the old building between the family room on the ground-floor and the living room on the first floor. The old walls, insulated from the outside (except for those directly adjacent to the greenhouse) form the storage element. The greenhouse is built from redwood with single glazing and the solid portions are insulated pressed board panels. The greenhouse does not have nocturnal insulation, fluid insulation has been considered but not implemented. Caloric input of the greenhouse is manually controlled by the inhabitants (doors, windows on both levels), (fig. 2)

THE ANHOUR-EOLE HOUSE

This house is a reflection of the evolution of our present research. We designed a compact plan for energy efficiency. The sun entering the house is used as a source of heating, (direct gain), and as a mean of lighting (indirect gain). The dwelling is located in a pine grove, on a south-facing slope. We took adavantage of a natural clearing in which to build the house. The desire to integrate the building into its environment led to a house completely buried on the north side and partially buried on the East and West. This results in efficient protection against temperature losses due to prevailing noth-west wind. The building steps down to the South which despite its compact plan allows sunlight and energy into every level of the building,(fig. 3). The house is built in cast-in-place concrete with exterior insulation. Special care has been given to the finish carpentry work, especially windows and skylights. These are equipped with insulated movable shutters which reflect sun outside in the summer and inside in winter.

LOW COST HOUSING

So far, we described individual dwellings, where motivated people, concerned about energy saving, had the necessary funds to realize their ideas. If this situation was a chance for designers to improve their skills, it nevertheless became clear rapidly that energy conscious design should cover a much larger housing market. Well-integrated buildings using solar energy had also to be designed for low income housing. The idea was promoted by the deciders, the politics and the administration. The Office Public d'HLM de l'Aude (Public Office of Low Income Housing) has made pioneering work in that direction. They launch a program for bioclimatic low cost housing with 3 objectives:
a- to promote the development of small clusters of low cost housing using bioclimatic design criteria, integrated to villages and towns of the administrative region.
b- to revitalize the local building trades by this new market well adapted to their structures.
c- to improve architectural and thermal quality of low cost housing.
The first project we designed was for a small community and fullfilled these objectives: the rather compact building takes advantage of the south-west slope of the site. The small programm could be handled by qualified local enterprises. And the thermal characteristic of the heat losses (coefficient g) is of 0.9 and that of energetic needs (coefficient b) is of 0.4, when the maximal required legal values are respectively 1 and 0.7.
Direct gain systems were used, partly as clearstory with inside automated insulated shutters. The garages are part of the building and protect the entrance airlock and hall. The domestic hot water systems work on thermosyphon separately for each apartment, yet are grouped together on the south elevation, (fig. 4).

THE USE OF NATURAL DAYLIGHTING IN ADMINISTRATIVE BUILDINGS

Studies undertaken during the last ten years for administrative buildings in Europe and the United-States have revealed that energy consumption for daylighting represents 50 to 60 % of energy costs. Artificial daylighting in public buildings during the summer has the added drawback of increasing the need for air conditionning. Such findings

have recently spurred the search for new systems for improving natural lighting in these buildings.
Within the context of a national contest for the design of the new Préfecture of Montpellier, our team (1) wished to apply this new concept of daylighting. We applied our research to the project keeping in mind the following goals: a- integration of urban development and environment requirements, b- keeping with the demands imposed by the overall construction project while maximizing functional potential, c- demonstration that the preferential use of bioclimatic architecture in Languedoc-Roussillon region, where solar energetic resources are frequently overlooked, would contribute to reducing the region demands on imported energy supplies.

Architectural responses

1 - Site integration: in the design, incorporation of variations in site configuration as the existing wooden areas (and some to be planted) protect the building from the predominant north-west and north-north-east winds. In addition, the design of a low and compact building recessed into the ground will help reduce heat losses.
2 - Orientation: in spite of the land configuration and orientation, building lay-out resulted in a significant portion of south elevations. This enables good winter exposure and easy protection from the sun during the summer. The east and south-east elevations presented problems for direct sun exposure and natural lighting which were solved by placing horizontal sunshadings.
3 - Light-shelves: they are architectural elements designed for capturing sunlight and controlling its way into the buildings as a function of season changes. They are designed to avoid direct lighting in working areas. In winter, the curved portion of the light-shelf reflects slightly inclined sun-ray towards the center of the building. The rays hitting the horizontal part are immediately reflected into the slanted ceiling. In spring and autumn, sunlight penetrating the center of the building remains constant but that which falls on the horizontal portion is reflected several times to decrease its intensity. During summer, heat and light are in excess and the light shelf is designated to deflect most of the incident light towards the outside , (fig. 5).
4 - Light-passageways: they are created by a centrally located passageway in each building and covered by a transparent vault. They provide the main communicating passage which links the ground-floor of the various buildings to the vertical axes of circulation (i.e. staircases, elevators). Reflectors from the light-passageways provide natural light for the central areas of the building. In winter, warm air stratified in the upper part of the light-passageway isrecovered and blown into the slab between the ground-floor and the first floor, thereby conserving excess calories. During summer, large openings in the transparent vault produce rapid evacuation of heat from the building by natural convection. Efficiency was enhanced by thermo regulation offered by the massive concrete structure of the light-passageway which also can be ventilated at night to dischargeexcess heat from the building, (fig. 5).

(1) The SOLERGIE team , architects: Blanc, Dauvergne, Rigaill, Rey, Caremoli, Miramond, Gerber, Pous, Wursteisen, Knyszewski.

Design tools

The design of the windows on south, east and west elevations and their solar protection was based on graphic studies using the angle of iso-tronsmission ond the trocings of the obstructions on the sun's course at the given latitude. This resulted in hourly and monthly recordings of direct energy transmitted during a theoretical day (clear sky conditions).
The light shelves were designed ofter a complete review of the state of art in natural lighting (Proceedings of the VIth National Passive Solar Conference, 1981).
This was followed by o trial study using a 1/50 model of building. This model wos useful in determining the configuration of the building i.e. the central patio, its covering and the office space. This was analyzed to ensure the compatibility with the available height beneath the floors, the slope of the ceiling and the exterior projection of the south wall light-shelf. Test trials were performed under natural sky conditions.
For occurate determination of heating and air conditionning needs and a precise prediction of energy consumption, we used the american CALECO-DOE 2 program presently available in France. This program seemed the most suited for simuloting large buildings and public buildings. It responds to chonges in the internal lood (people, lighting, equipment) and intermittent use of such buildings. The simulation has shown that approximately 50 % of the building needs are supplied by solar energy in form of direct gain and daylighting for the winter season. No air conditionning equipment is needed for the office space except those with special equipment.

REFERENCES

Proc. of the VIth National Passive Solar Conference,(1981), Vol. 6, Eds. Hayes J. ond Kolar W., SERI , U.S.A.

Fig. 1. Les Perdrigals. View from East.

Fig. 2. Maison du Lac. View from South.

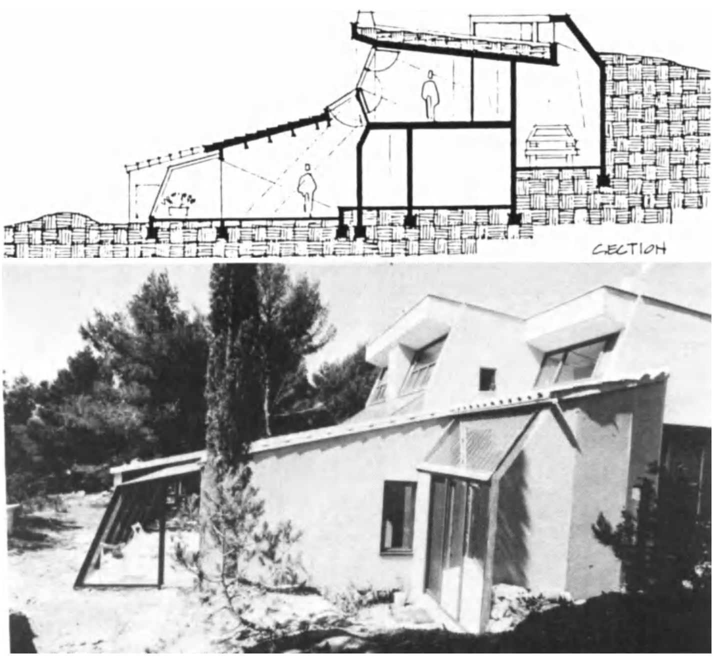

Fig. 3. The Anhour-Eole House. Section and view from East.

Fig. 4. Low Cost Housing Project. Views of Model.

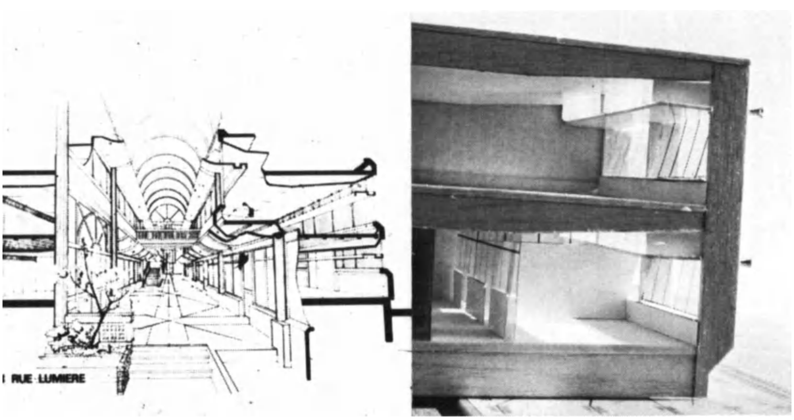

Fig. 5. View of Passageway and Simulation model.

PASSIVE AND LOW ENERGY DESIGN

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Solar Energy Developments is a consultancy working closely with an architectural practice Dominic Michaelis Associates but also at times working with other architects and engineers. This paper illustrates work carried out over the past ten years by the combined practices.

Solar Energy Developments was set up in 1974, by Steven Szokolay, Giovanni Simoni and myself. Steven had designed the active system for the first Milton Keynes Solar House, whereas I had designed a passive solar house in France, near Avignon.

The practice rapidly developed, under a contract from a gas company, the Calor Group, to investigate the possibility of developing active systems for the typical U.K. house. These studies, backed by the U.K. Department of Energy and the building contractor John Laing, led us to construct a monitored group of nine houses, three monitored, three with $20m^2$ of panels and heat pumps and three with $40m^2$ of collector and a $2m^3$ water storage system.

In parallel with this, we developed an air handling system for space heating and this system was employed in two houses in France, one in Italy and also in a greenhouse in Italy.

Our experience with active systems led us more and more to see that the inherent complexities of these were costly and unreliable because never properly understood, and possibly understandable by the end user, the householder.

In 1976, we initiated a parallel program with a large U.K. construction company to investigate the potential of passive solar energy to the typical U.K. house. The project showed very favourable results, theoretically on a par with present day active systems, and was to investigate the four recognised passive solar modes: direct gain, trombe wall, water wall and conservatory. The scheme was approved by the EEC and the U.K. Department of Energy but because of administration tangles, never got built and could therefore never be assessed.

We did however, manage to build three passive solar houses, L shaped with conservatories, next to our previous development in Milton Keynes, and hope to get some comparative results.

Before leaving Milton Keynes, I should describe the hybrid solar house that we designed for the exhibition called Homeworld '81. This house comprises of a strong passive component, in the North buffering, and South glazing to a conservatory, protected from summer sun by louvres and a planted screen. The two level conservatory provided a substantial contribution to the heat of all the living and bed rooms, whilst the active panels are above the louvres and are linked to a heat of fusion store. In this house, passive has priority as it always shall whilst active is the back-up, here already chemical, and in its next generation, one hopes, interseasonal.

And before leaving the U.K., I would like to illustrate an industrial passive solar project which we have just completed in Stockport. The micro-chip industry is heavy on R & D and management and its production areas are relatively small. We planned all offices to the south, and with services, around the perimeter. A fan driven system takes any excess solar heat from the office spaces to heat the production space. In summer, the system becomes a forced recirculation, fresh air ventilation system.

The production space is lit by diffused south lighting rather than the conventional energy losing north light. The client firm J.E.L. Energy Conservation Services Ltd., specialises in energy control systems and considerable energy savings are expected from zone temperatures control, light modulation etc. We feel that this system has considerable replication potential.

The lack of solar funds in the U.K., more than the illusory lack of solar energy led us to work abroad principally in France and Italy.

In France, our solar work came through competition. With Gilles Bouchez, we won the French Department of the Environment competition HOT 5, with our Solstice 1 house. Four prototypes have been built in the new town of Melun Senart. It is an "assisted green house system", with excess heat stored in a rock store central drum, which also houses the fireplace and boiler with their flues so that it recovers their waste heat and forms the hot core of the house.

The green house folds away in summer to give way to a ground patio and Loggias.

With Gilles Bouchez again, we entered the "5000 Solar House", and our entry with Kaufman and Broad as contractors, Solstice 2, was accepted. This is an L shaped house planned around a two storey covered court again, totally glazed to the south. This collector is also the focus of the house, which thermally acts as the store. The system had to be capable of providing 30% of the thermal requirements of the house. We hope to build some Solstice 2 houses during this coming year.

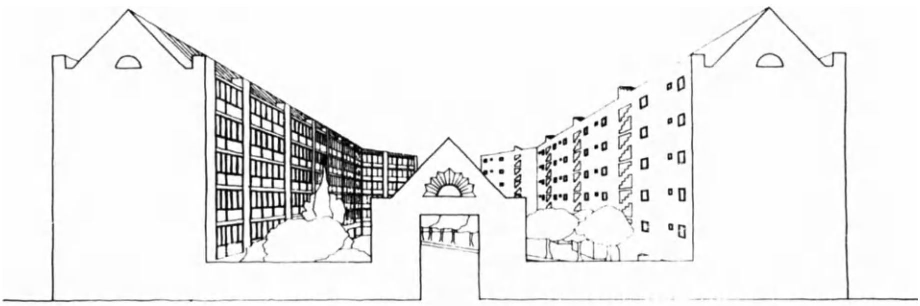
In Italy, we were nominated as consultants to AGIP - Jacorossi and in particular worked with Ing. Luigi Cuozzo of their energy saving agency APRE.

We were commissioned to design some low cost housing units in Pisa and Sienna, to conform to the very strict regulations of the Instituto Autonomo Casa Populare. Our prototypical design was in Pisa for a group of two slabs orientated in a southerly direction and spaced so that the overall overshadowing during the year was minimised and that all principal rooms faced south, staircases and service rooms facing north. The south facade was treated like a continuous greenhouse, the upper part sliding away in summer to form a glazed balcony.

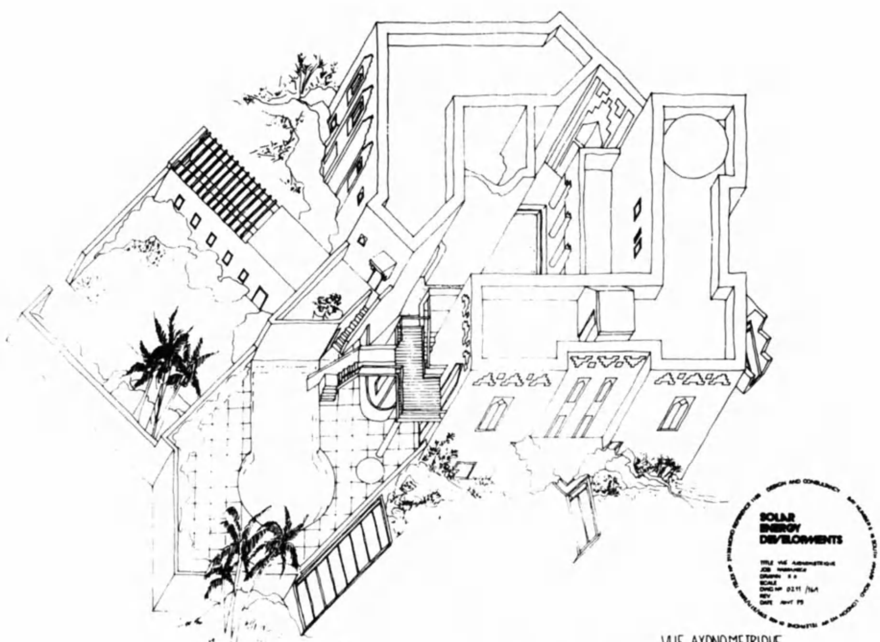
The first building in Pisa is now commissioned and about to be occupied. It comprises of 50 flats. The Sienna building is on site.

At lower latitudes, the other problem is not only heating but also cooling. We have designed a house currently on site in Marrakech, Morocco, where we are using local construction, but introducing solar induced draughts in hollow outer walls to insulate and cool the house by drawing dry air through humid porous clay pipes. This evaporative cooling, combined with the double envelope construction together with traditional Riad planning is already proving to be effective in creating a cool environment in an arid climate. In winter, the hollow walls are used as heaters and linked to the house.

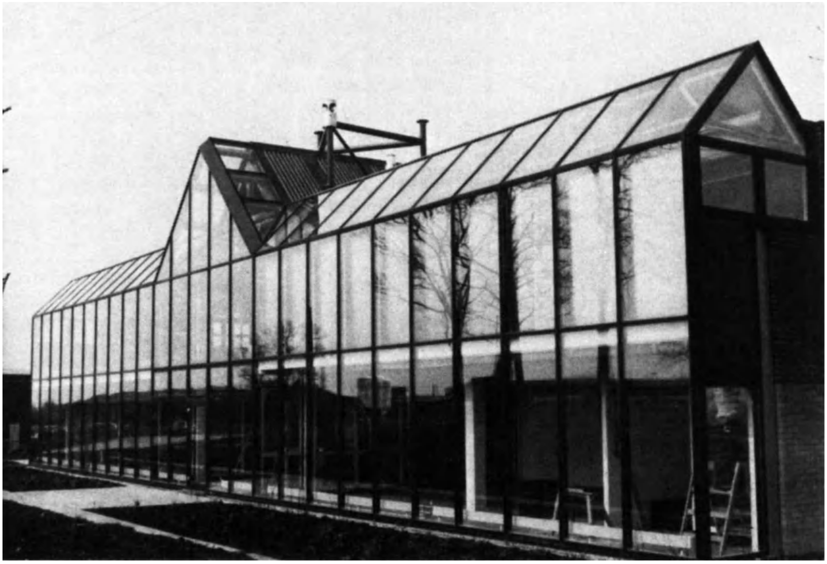
Thermosyphon solar panels are used for hot water, swimming pool and Hammam.



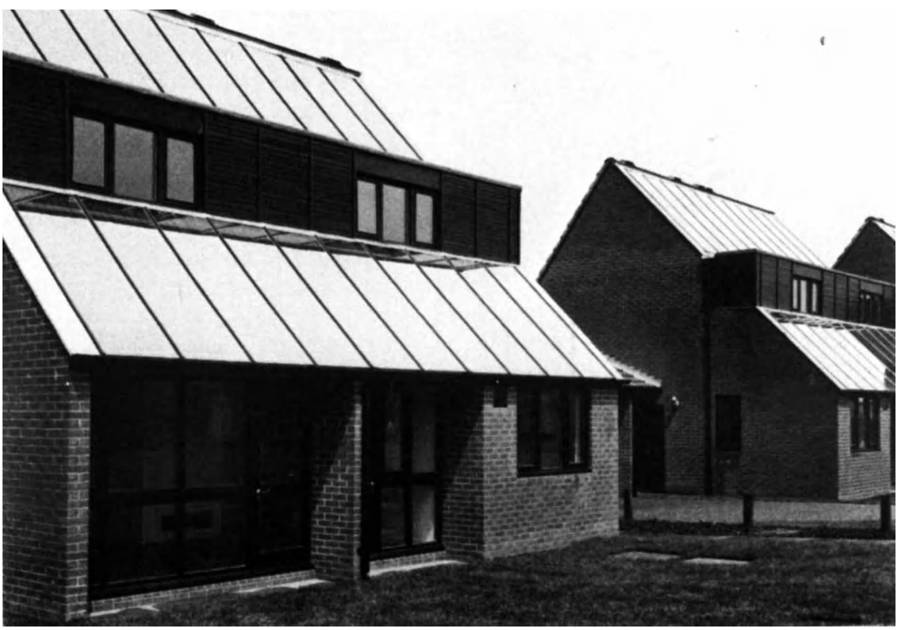
LOW COST HOUSING PISA



HOUSE IN MARRAKECH, MORROCCO



JEL Factory Stockport



Linford Houses (John Laing Contractor)

HOT Competition Solstice 1

Homeworld House, Milton Keynes

TOWARDS A BETTER UNDERSTANDING OF CLIMATE RESPECTING DESIGN

P. A. Page

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U.K.

ABSTRACT

This paper describes in outline the principles and attributes of energy conscious design in two school buildings given as case studies:

(i) a new-build low energy Primary School (St.Johns) at Clacton, Essex where a solar selective approach combined with a ground water-to-water heat pump installation supplying underfloor and controlled ventilation heating system has strongly influenced the resulting design;

(ii) an extended (4 to 6 forms of entry) and refurbished Secondary School, Thorpe Bay High, Essex where courtyard infill techniques and glazed canopies with selective glazing combine with conventional conservation measures to reduce the energy consumption value by 20%.

KEYWORDS

Solar passive design; selective mode; dynamic thermal analysis; multi-variate decision-making; optima selection; ground water-to-water heat pumps; solar-convector wall; ventilation heat recovery; covered courtyards, conservatories and atria.

INTRODUCTION

The purpose of this paper is to demonstrate by way of example options open to the designer to take a solar selective approach in two different school design situations relative to U.K. experience:-

(i) In new-build where options theoretically are relatively open subject to energy economics and budgetary constraints and

(ii) in existing building stock where options are constrained by earlier decision-making invariably of the 'exclusive' kind.

In (i) the extent to which in practical terms a solar passive approach could be adopted for a new Primary School without compromising users' expectations is examined.

For (ii) where built form and orientation have been pre-determined by way of an earlier non-selective commitment, falling school rolls, the rationalisation of accommodation together with refurbishment, allow energy sensible redesign to be under-taken by way of retro-fit, in which some aspects of 'selective' solar design can be made to contribute to the overall improvement of the performance of the building. The integration of new accommodation with that existing, particularly courtyard enclosures, discrete infilling techniques with glazed corridors offer mutual energy benefits, new with old, serving to upgrade the overall thermal performance of the whole, reducing conventional energy demand.

GENERAL PRINCIPLES

Climate respecting principles are not new. They are implicit in the 'timeless way of building[1] and are to be found in Marcus Vitruvius Pollio's dictum on Climate as Determining the Style of the House, 'how we ought to make our houses conform to the physical qualities of nations with due regard to the course of the sun and to climate'.[2]

To make buildings less energy dependent in conventional terms these principles need to be adopted a priori in order to design building envelopes capable of modifying the thermal effect of the external environment as optimally as possible, achieving at the same time desired standards of environmental comfort as efficiently as possible with only that plant necessary acting as fine control over fluctuations in the internal climate. In this way the passive elements of the design minimise the call for additional heating and cooling requirement over fortuitous losses and gains.

Accepting that 'every building is a solar building' the extent to which any building accepts or rejects solar influence depends upon the energy balance established at the external surface of the building. The skill with which a designer can utilise solar heat to advantage lies in the manipulation of form, fabric and fenestration of the building. Exposure of surfaces to the solar path controls ultimately the degree of solar contribution. The balance between day-time gains and night-time losses will depend upon the storage and stabilisation characteristics of the building fabric. Whether the daytime collection system is beneficial or not depends upon external temperature, sunshine levels and the thermodynamic properties of the collection system combining to exceed or fall short of the indoor temperature requirements.

Factors governing the energy consumption of a building can for convenience be classified under the following headings - Climate, Shape and Orientation, Volume, Area and Position of Glazing, Insulation Standard and Thermal Capacity, Ventilation, Internal Heat Gains, Pattern of Use, Comfort Levels, Efficiency of Heat Generation and Utilisation.

Guidelines for environmental design and fuel conservation in Educational Buildings in England and Wales have been laid down by the Department of Education and Science in Building Bulletin 55, together with a calculation technique for instantaneous energy design evaluation related to an annual energy consumption value measured in primary energy units (PEU) set out in Design Note 17. This technique ignores the influence of solar radiation income and can only be used for comparative purposes. However Building Bulletin 55 does state for a typical school that 'if the building and system of heating could be designed to capture and make use of all available solar radiation, it would appear that about 30% of heating requirements could be provided in this way'. It does not state how this might be done.

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[1] Alexander, C., (1979) The Timeless Way of Building, Oxford University Press, New York.

[2] Vitruvius. (1 BC) Book VI The Ten Books on Architecture.

Steady-state evaluation ignores the transient characteristics of the building as a dynamic climate modifier. All the inaccuracies of the maximum rate calculation fall out on the safe side.

To attest solar income as insolation, where as much as 40-50% of energy requirement might be attributable directly to orientation, dynamic thermal analysis is a prerequisite. Only in this way can the properties of thermal diffusivity be represented and the impact upon design evaluated. For this purpose the County Architects Department uses the Response Factor Tas° (Thermal Analysis System) Program[3] with Kew 1966 weather data.

For ambient energy gains, both radiant and convective, deriving from solar, occupants, lighting and other miscellaneous sources to be of value in low-energy buildings they must be both of a suitable magnitude and duration, occurring when and where they are wanted or be capable of being transferred. To capture these adventitious gains both the building and associated plant must be able to respond sensitively and efficiently. Expectations of such gains for a typical school of 1500 sq. m. (300 pupils) are given in Table 1.

TABLE 1. Ambient Energy Gains in a Typical School for 300 pupils.

GAIN TYPE/UNITS	kWh/day JAN. MAR. OCT.	Watts/person ADULT/CHILD	kWh/sq.m./annum
SOLAR	100 250		
OCCUPANTS		DES 70 CIBS 80 Siviour 80/60	
LIGHTING			12.6
SMALL POWER			3

Percentage heat losses for a typical school are given in Figure 1.

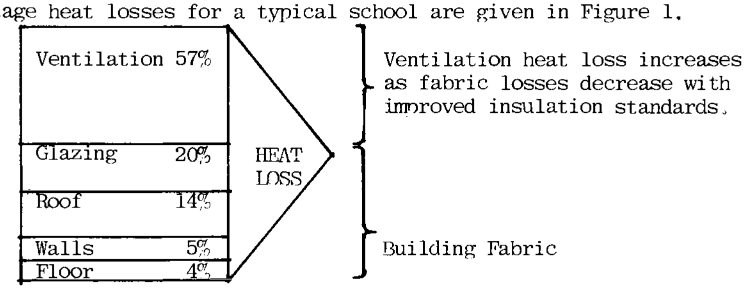

Fig. 1. Heat loss components as comparative ratios for a typical school.

Solar Availability

Crude solar viability indices for Essex, 51°30' - 52°N by 0° - 1°15'E, may be taken

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[3] Jones, A.M., H. Mellor and P. Cassidy
Jones Cassidy Mellor Ltd., Wharley End, Cranfield, Bedford.

between figures given for East Anglia and the Thames Valley in Table 2. Viability figures are obtained by dividing solar radiation available by degree days for the area of interest. The figures are given as a scale of reference only for comparative purposes. The method is used by Oppenheim (1981) as an indexing system for the U.K.[4] noting that a European Index should be available in the near future. The 20-year average heating season degree day total for Essex is 2148.

TABLE 2 Solar Viability Figures for Essex

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
East Anglia	40.5	11.4	3.5	1.8	1.7	3.8	7.1	13.8	32.2	115.8
Thames Valley	50.0	12.5	3.1	1.4	1.6	3.6	8.1	16.1	38.1	134.5

The heating season total therefore for Essex might be taken as about 125 with an average daily total of global radiation on a horizontal plane in January of 0.6 kWh/m^2. The winter climate reference is mild.

Within this context a design brief was formulated for a new primary school on a green-field site, with a specified design objective that the form and fabric of the resulting building must be capable of maximising the beneficial aspects of the radiative environment, at the same time minimising the disbenefits, within acceptable cost - limits and user constraints, the total system meeting an energy design value no greater than 85 w/m^2 (floor area) PEU - almost half that allowed by the maximum value criterion set by the DES.

CLACTON (ST. JOHNS) NEW PRIMARY SCHOOL. CASE STUDY I.
51°47'N. 1°08'E (S.E. England, coastal)

The project herein described represents the first instalment (240 place) of a 420 place Primary School.

Accepting the EDV (energy design value) target as set, the form of the initial concept depicted in Figure 2 was that of an earth sheltered building with those elements of higher energy dependency in the plan exposed to the influence of the sun path and others less demanding located on the protected NE and NW flanks, the S facing flank acting as a solar wall. In exploring a viable solar passive envelope the designers accepted the conclusions of an earlier study by Cole (1974)[5] for the DES that (a) the use of solar radiation in conjunction with other fortuitous gains as the only means of heating a school building is not a viable proposition (given the allowable cost limits and permissible user regimes) (b) solar radiation input should not be made a critical feature in the design (c) the manner in which collection of solar radiation is incorporated with the design should be simple.

Evaluation of the earth-sheltered approach in energy cost benefit terms showed savings in the order of 30% per annum, however the capital on-costs for support and fabric protection for the building compared with an 'above ground' building could not be substantiated. The earth-protected evaluation, dynamically predicted, did provide a model for exploring different construction types in the search for an equivalent 'above ground' building with corresponding attributes. With the form established, thermal modelling ranged from 'heavyweight' to 'lightweight' solutions.

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[4] Oppenheim, D., (1981) Small Solar Buildings in Cool Northern Climates. The Architectural Press Ltd., London.
[5] Cole, R.J., Feasibility Study for a Low Energy School. UWIST. (Unpublished).

Detailed evaluation has been given by King (1981) elsewhere.[6]

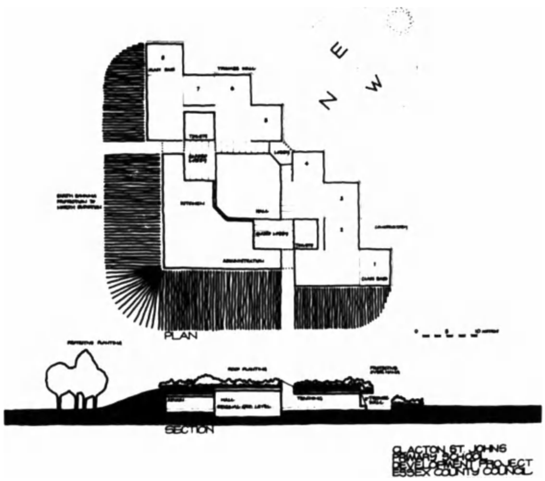

Fig. 2. Initial Earth-sheltered Concept

Model annual consumption estimates on a comparative basis are given in Figure 3.

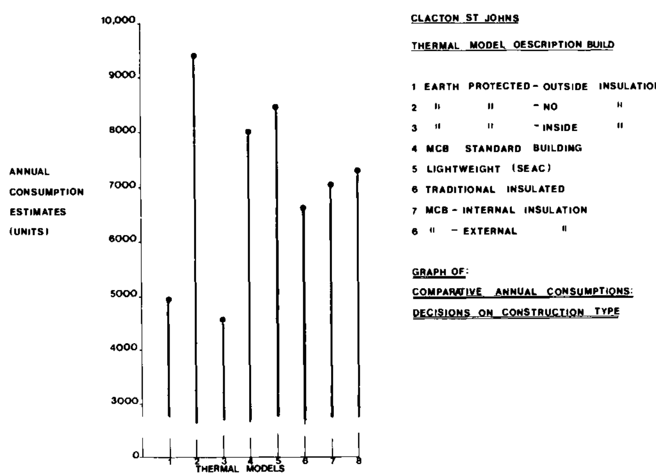

Fig. 3. Model Annual Consumption Estimates

Thermal model 3, earth-protected with interior insulation, provided the best annual

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[6]King, B., (1981). Computer-aided Energy-conscious Design: Primary School. The International Journal of Ambient Energy, Vol. 2. No. 1., 23-30.

consumption value of the eight construction types tested. It was towards meeting this performance standard that the surface solution was directed.

With the general distribution of spaces acceptable to the client, occupation, lighting and heating patterns could be established in sufficient detail to simulate the school in operation. Teaching spaces, organised in pairs - an educational requirement range along the southern flank of the building, each having a sunny aspect. The less important areas are located on the sheltered NE and NW sides. The hall, very much a focal point, is located in the middle. Figure 4 shows the finished plan form and an axonometric view.

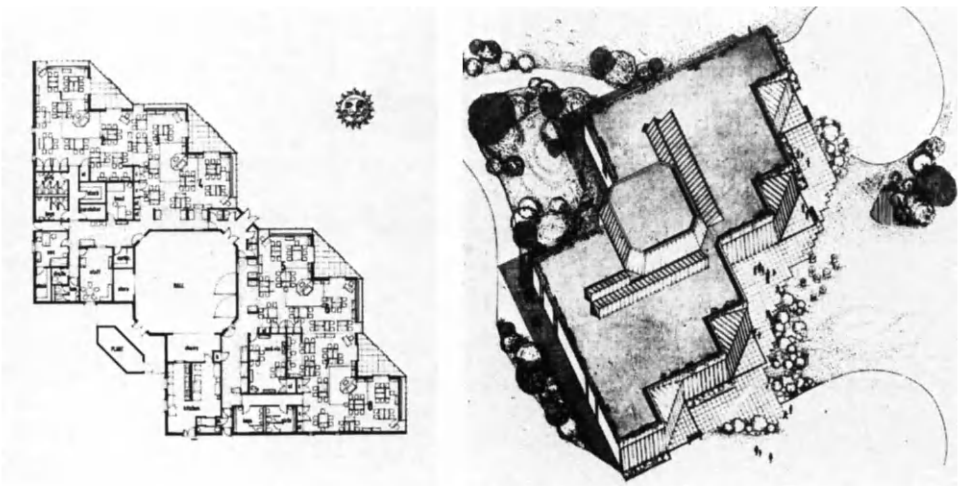

Fig. 4. Plan and Axonometric View

Consideration could then be given to the finer points of affordable insulation standards for walls, roof and floor and the design of fenestration on a comparative basis.

The dominance of the south facing flank offered the greatest potential for the positive collection of solar energy arriving at the building. The wall is designed as a fully integrated cladding system in patent glazing, inclined to the low-angle sun, part solar wall (40%), part normal glazing for daylight (10%), part conservatory (50%). The solar wall performs as a rapid response passive collector (as opposed to the heat store approach) in order to identify quickly the energy collection and introduce beneficial gains during the time of greatest need when occupied. During summer the wall is designed to work in reverse as a solar powered extraction system. When beneficial, solar heated air from the conservatories is transferred to the adjacent teaching spaces. In the other walls losses are reduced by restricting glazing, improving the insulation standard and keeping entrances to a minimum with draught-proof lobbies. The roof area is insulated to a high degree with SE and SW facing rooflights to admit sunlight and natural lighting to the deeper planned spaces.

From site investigation it was found that ground water suitable for extraction was available at a depth of six metres. This presented an attractive low grade energy source suitable for heat pump application having a relatively stable and reasonable temperature around 8-10^{o}C. A water-to-water heat pump installation was also attractive in the context of developing experience, air-to-air systems having been installed at Roach Vale County Primary School[7] and an air-to-water application at Walton The Gunfleet School[8]. Low flow temperatures acceptable to the heat pump system were sympathetic to a split heating system, underfloor providing the radiant component and warm air the convective part. The latter afforded the opportunity for heat recovery from the ventilation air while elevated fabric temperatures associated with underfloor heating offset radiant chill effects, the response of the system being closely matched to the response of the building. Figures 5 and 6 show schematics of the system under wintertime and summertime conditions.

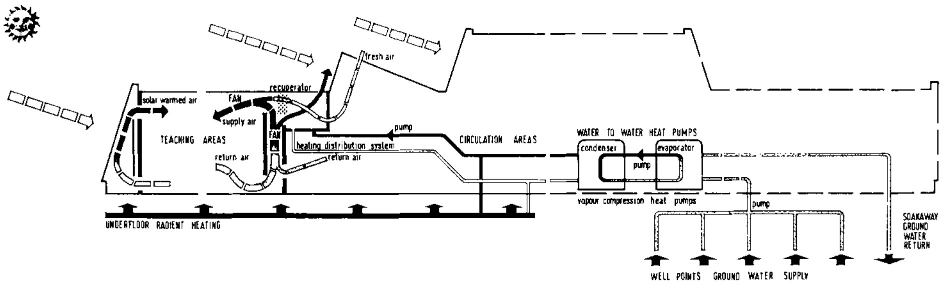

Fig. 5. WINTERTIME: Combined Radiant & Convective Heating

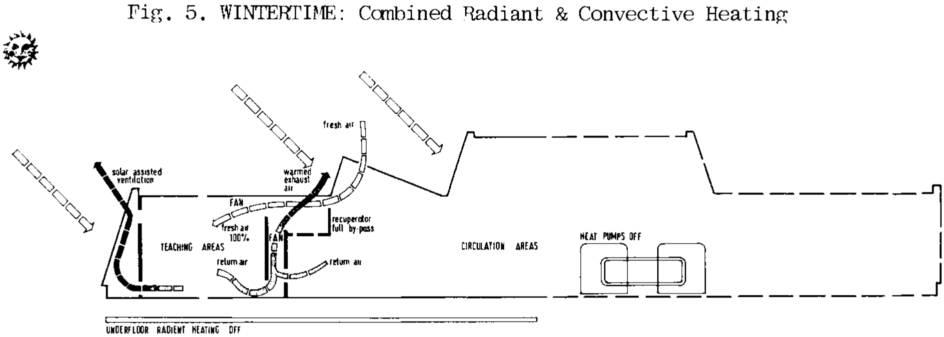

Fig. 6. SUMMERTIME: Full Mechanical & Natural Ventilation

The calculated EDV (DES formula) for the design adopted achieved 79 w/m^2 (floor area) PEU which more than met the target value of 85 w/m^2 (floor area) PEU as the design objective. The school, not yet to design occupancy, has experienced its first heating season and appears capable of living up to design expectations.

Ventilation requirements and energy demand are being studied by the Building Research Establishment, Garston, under the U.K. Department of Energy (ETSU) Demonstration Project Scheme.

[7] and [8] For brief descriptions see - In, Kasabov, G, (1979) (Ed.) Buildings the Key to Energy Conservation, Issues and Case Studies The RIBA Energy Group, London, pp. 40-42.

THORPE BAY HIGH SCHOOL. CASE STUDY II.
$51^{o}32'$N. $0^{o}48'$E (S.E. England, coastal)

The Thorpe Bay High School development results from the rationalisation of Secondary School accommodation in the Southend Area where the decision has been taken to amalgamate one School (Southchurch Hall Boys) with another (Dowsett High for Girls) by extending the Dowsett premises from 4 F.E. (forms of entry) to a 6 F.E. co-educational Comprehensive School.

Exploiting this situation a number of opportunities arise for making energy savings -

(i) assuming the Authority does not retain the Southchurch Hall premises for another use, a direct saving results from the closure of a thermally inefficient school with a heating bill of £9000 per annum,

(ii) for the application of normal energy conservation measures, - improved fabric insulation, draught stripping, better controls, zoning, improved plant efficiency - to the existing Dowsett School with a current heating bill of £15,000 per annum,

(iii) to redesign the Dowsett accommodation and make the extra provisions in an 'energy sensible' manner.

Adverse features of the Dowsett School can be identified as follows

- Pavilion planning with unprotected internal courtyards
- High external wall-to-floor ratios
- Excessive glazing levels
- Unprotected external circulation areas leading to high infiltration rates
- Lack of zone control.

Ignoring the potential of (iii) a totally exclusive approach could have been made by extending the pavilion planning principle already adopted in order to satisfy the additional accommodation wanted. This would have denied the mutuality of protection afforded by adopting an 'infill technique' in the existing courtyards, three of which are contained on all four sides by single-storey teaching accommodation, the fourth, a large open cross-circulation space, flanked on the NW side by a two-storey teaching block. Benefits from infill and courtyard protection must arise from improved fabric insulation and reduced infiltration.

The Dowsett School (before remodelling) provided 5140 sq. m. of teaching accommodation for 600 pupils with a calculated heat load of 715 kW.

The Thorpe Bay School (after remodelling and extension) will provide 6548 sq. m. of teaching accommodation (excluding 400 sq. m. of glazed unheated courtyard and circulation spaces) with a calculated heat load of 706 kW and a new Sports Hall of 65 kW giving a nett reduction of 9 kW (excluding the Sports Hall) achieved by 'insertion' of the new teaching accommodation with basic energy conservation measures undertaken to improve the existing Dowsett fabric. With engineering improvements such as optimum start, circuit pumps and controls, weather compensation and local controls it is confidently expected that the fuel consumption of the Thorpe Bay provision including the Sports Hall will not exceed that of the former Dowsett School. From this the value of the engineering measures can be assessed as a 56 kW load saving. The calculated load breakdown is given in Table 3.

TABLE 3 Dowsett/Thorpe Bay Heating Loads (kW)

ZONE	DOWSETT	THORPE BAY
A Practical Wing	194	188
B Dining/Drama & Music	66	56
C Gymnasium & Changing	80	68
D Lower School & Kitchen	150	130
E Administration	50	42
F Existing Teaching Block	175	146
G New Teaching Block	-	76
	715	706
H New Sports Hall	-	65
	715	771

Had the additional accommodation been provided in pavilion plan form to the existing Dowsett standard the total heat load would have been in the order of 900 kW.

Estimates of energy costs and the savings likely to be achieved using the infill technique providing (a) better fabric insulation and improved space utilisation are given in Table 4 and (b) the benefit of reduced infiltration rates due to rationalisation of external doors and protection from courtyard covering in Table 5.

TABLE 4 (a) Energy Costs and Savings related to Dowsett Fuel Bill as Design Base: Type 1.

Design Base	kWh/m^2 PEU	Assessed Fuel Cost per Annum	Annual Savings	Savings Over 5 Year Period
1	234.2	£15000	0	0
2	207.9	£13270	£1730	£8650
3	194.3	£12450	£2550	£12750
4	185.4	£11880	£3120	£15600

2. Dowsett remodelled to include courtyard covering.
3. " " " " " " plus occupied courtyard.
4. " " " " " " " " "
plus insulation of low level glazing.

The figures give measures of improvement based on undertaking design assumption 2 - 4.

TABLE 5 (b) Energy Cost Savings relating to Reduced Air Infiltration

Air Infiltration Reduction on Design Base 1.	Fuel Cost Reduction £	Savings over 5 yr. Period (ECC Payback criterion) £
1 a.c./hr.	1275	6375

Introducing accommodation into the courtyard spaces not only reduces the amount of external wall area but is an economic way of creating new accommodation. Where courtyard spaces are covered with translucent roofs and the enclosures remain unheated, the quality of the internal environment needs careful examination to determine the actual usefulness in the context of resultant conditions.

Detailed dynamic analyses of the performance of the glazed links in conjunction with the surrounding spaces were done using the Tas^{o} Program. Although calculations show only small energy savings attributable, in the order of 1%, the probable reduction in air change rates in winter will inevitably result in higher space temperatures with correspondingly reduced heat losses from the surrounding rooms as a result of warmer infiltration air. This would be consistent with Baker's (1982) findings in his paper on 'Mass Optimisation in Conservatories', that for a 'low energy' dwelling in a temperate climate, the main role of the conservatory will be in providing ventilation pre-heating.[9] Summertime overheating conditions are given in Table 6.

TABLE 6 Glazed Links: Summertime Temperatures °C.
A - Main Spine, B - Corridor

Glass Type	June Temps. A	June Temps. B	August Temps. A	August Temps. B	ACH
Clear	33	43	38	50	3
	28	31	33	36.5	20
Reflective Solar	28	35	32.5	40	3
Control. em. 0.3	25	28	30	33	20

To control summertime overheating the use of reflective solar control glass is proposed in conjunction with natural and mechanical ventilation giving air change rates between 3 and 20 ACH.

For the larger courtyard, different geometries of roof covering were modelled. During winter conditions an all-glazed courtyard roof with minimum air change rate (¼ ACH) gave the lowest energy demand. Summer environmental conditions can be managed with solar control glass using mechanical ventilation with 4 - 10 ACH capacity extracting at temperatures 28 - 33°C and natural ventilation from 23 - 28°C. Class bases adjacent can have openable courtyard windows to provide first stage ventilation with second stage through ventilation provided by external windows. In integrating the new accommodation with the existing, the new work upgrades the existing in many respects. Using the infill technique the external wall area (excluding the Sports Hall) has not been increased, both the aspect and wall-to-floor ratios have been improved and no additional heat generation plant is required. Approximately 400 sq. m. of glazed, protected circulation area have been achieved with better than ambient conditions during the heating season. The contract is due to be completed September 1983 with amalgamation complete September 1984.

In looking for the contribution[10] of atria or courtyard enclosure to the energy budget of an existing building many factors impinge, not least the quality of space desired by enclosure, the thermal properties of the existing building and the solar sensitivity of the geometry that can be employed.

Both the energy benefit and other attributes are the subject of a pilot study to be funded by the SERC and conducted by the Martin Centre, University of Cambridge in conjunction with Essex County Council under the heading 'Courtyards, The Case for Enclosure'.

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[9] Baker, N., (1982) Mass Optimisation in Conservatories, Cannes Symposium.

[10] Simplistic model evaluations of Atria Performance are given by Baker, N., 1982 Fig. 8. in The Thermal Performance of Large Glazed Spaces, Cannes Symposium Proceedings.

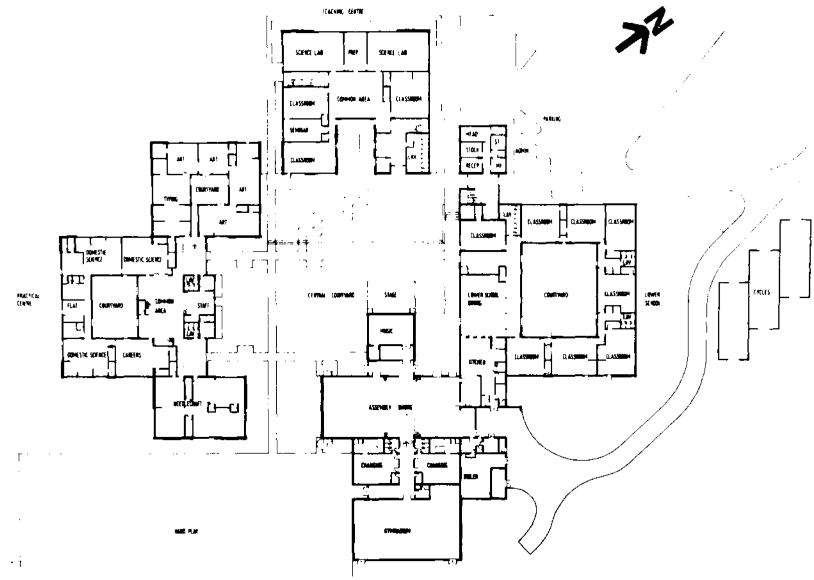

Fig. 7. Dowsett School 4 F.E. Plan

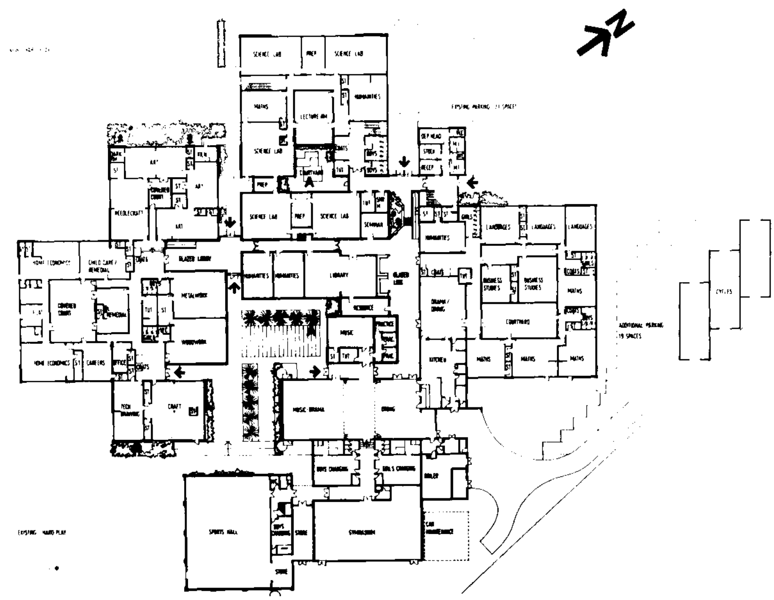

Fig. 8. Thorpe Bay School 6 F.E. Plan

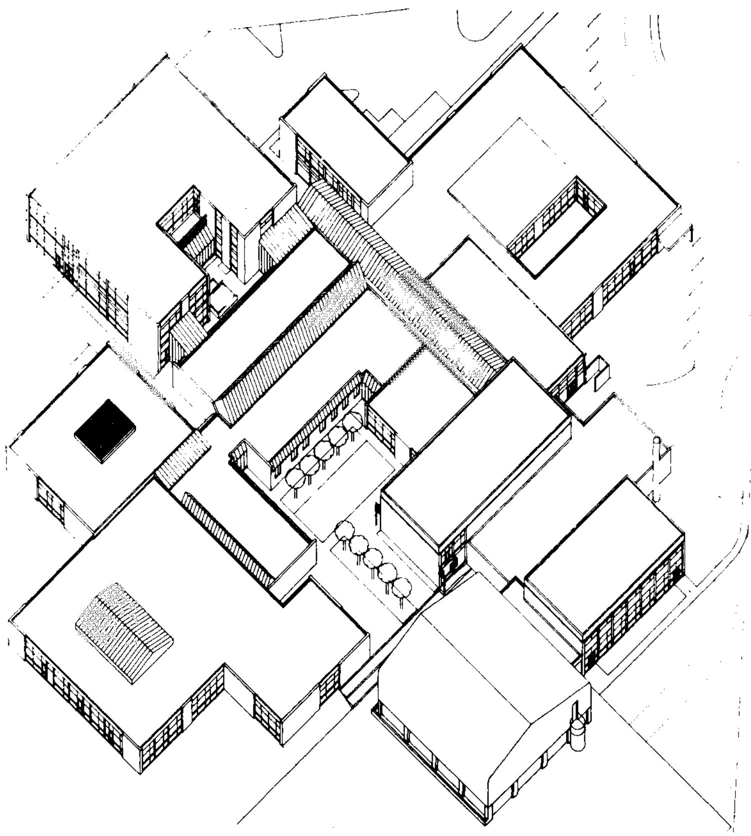

Fig. 9. Thorpe Bay School: Axonometric View Showing Courtyard Enclosures, Glazed Spine and Corridor Links

SUMMARY

In Case Study I, although a 'selective' approach to the form and fabric specification minimises the applied energy requirement in the first instance, the overall efficiency of the system is dependent upon engineering performance to achieve the energy saving defined by the criterion standard. (This has been recognised in the CIBS Journal's Building Services Award 1982 for Energy Use in Buildings.) However the extent to which energy economy should be systems' dependent is an arguable point.

In Case Study II, the 'exclusivity' of the original design curtails the extent to which a wholly 'selective' approach can be taken, but opportunities do exist in which energy, technical and organisational benefits can result.

As in all energy conservation matters relating to user-response unless all user expectations are adequately met then to use Koestler's words 'there is a degree of misery where all quantitative comparisons cease to mean anything.'

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THREE SOLAR BUILDINGS : PASSIVE AND LOW ENERGY ARCHITECTURE IN SOUTHERN FRANCE

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ABSTRACT

Our research has been to evolve simple methods of **using** solar energy by adapting architectural design rather than using complex mechanical systems which cost more to give the same performance.

KEYWORDS

Bioclimatical architecture direct using of solar energy thermic inertia outside insulation, trombe walls glass houses.architectural design.

PRIMARY SCHOOL

FRANCE

PAU

HEDAS 'S BUILDING

FRANCE

PAU

BENCOCO

FRANCE

PAU

PRIMARY SCHOOL AND NURSERY LAND : FRANCE TOWN : PAU

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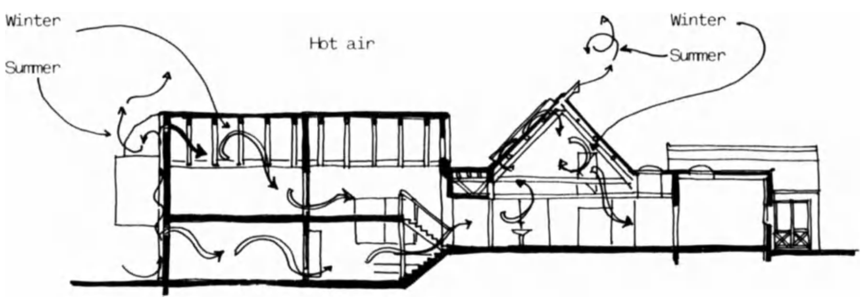
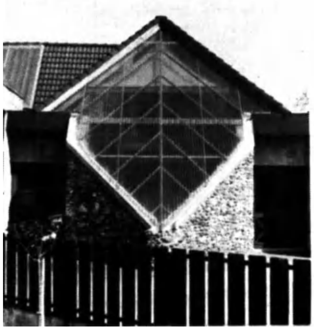
This project consists of a nursery school, a primary school and a children's centre, grouped together on a large piece of land (10 000 sq. metres) in the town centre. This central location enables the school buildings to be in close communication with the other public facilities of the district : town hall, parks, post office, church and shops.
The buildings are constructed on the northern part of the land, leaving the space to the south clear for the playgrounds, a pedestrian street, two workshops built under a bank of earth and a bank planted with trees to act as a sound barrier running along the railway. This arrangement opens up a space whichis extremely valuable in an urban environment (adventure playground, kindergarten, etc...).
The main outline of the project was decided upon after consultation with local councillors, parents, teachers and other social and cultural workers in the course of preparatory work sessions with the architects.
The nursery school consists of three classrooms (=525 sq. m.) and a multi-purpose hall. The primary school consists of 6 classrooms (745 sq. m.), spread out over three split-levels, and a multi-purpose hall. It includes the children's centre (280 sq. m.). Theses two sites of buildings are arranged around a patio and it is possible to go from one to the other by way of the first-floor library and teachers offices. A concrete structure supports lamellates arches which form the vaults and triangular wooden trusses for the main roofs.
The walls, made of breeze-blocks, are insulated on the outside and covered with asbestos sheeting, cement, wooden boards or panelling, according to the different façades. Calculations of relative costs showed that double-glazing or insulating shutters were unnecessary.
Solar energy is supplied from three sources : directly from the south-facing glass roofs with 45 ° slope ; from the solar panels on the classroom walls (170 sq. m.) ; and, finally, from the southern slope of the main-roof.
Regulations stipulate that 13 cubic metres of air must be renewed per occupant per hour. It is therefore

logical to heat the new air coming from the outside: this is collected at the foot of the solar walls of the classrooms and is heated as it rises up the heat-absorbing metal sheet before being distributed at the top of the classrooms. The air is extracted through grating at the base of the north-facing walls. The wall holding the solar panels is insulated. The transparent part of these solar panels is made of extruded plastic resin, for reasons of safety and cost. Only the air is heated, not the stonework ; calculation showed that a trombe wall type solution was of little use for classrooms which in general, are not used at night. The solar panel on the southern slope of the main roof of the primary school works on the same principle, with the extra aerotherm ventilator sucking in hot air and constituting the sole means of distributing the heat. In the summer, openings at the top of the solar walls and chimneys at the top of the solar panels ; the rooms are supplied with fresh air through openings in the east and west walls. Extra heating can be provided in the classrooms by means of gas-fired heating with thermostatically controlled radiators.
The techniques adopted here are designed above all to make immediate use of sunlight and deliberately neglect the stocking of solar energy. This option can be explained in terms of the difficulty of designing satisfactory and economical storage systems for periods longer than 12 hours – which would be necessary here since the buildings are used exclusively in the daytime. In general, known and well-tried construction elements have been used in the systems chosen here. The extra cost for solar heating (without deducting the savings made in roofing by the installation of solar panels on the roof) is in the region of 140 000 French Francs, or about 4 % of the overall budget (F 3 600 000).



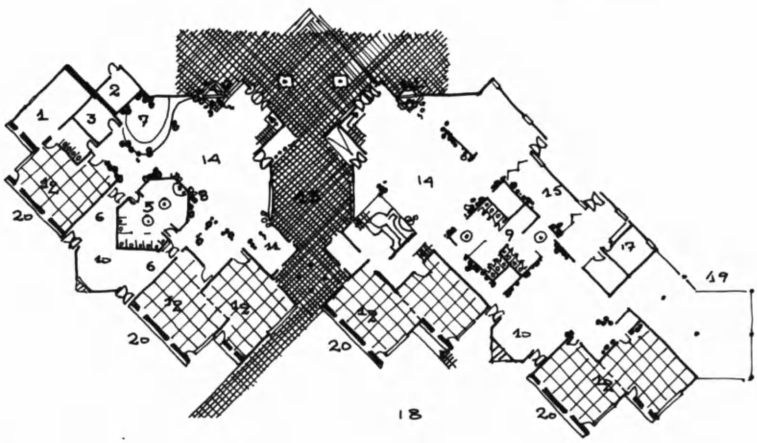
Estimated savings are about the equivalent of 7 000 litres of heating-oil per year, which amounts to over 10 000 francs at today's prices. Such advantageous economic considerations should not however obscure what the designers considered to be the essential issue in this project : designing spaces for children.



← Glasshouse

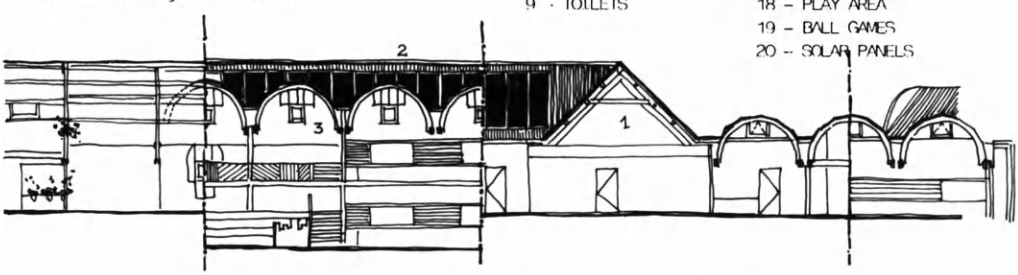
Roof solar collectors →

PLAN



Passive underground studios

1 DORMITORY
2 BOILER ROOM
3 - STORAGE
4 - KINDERGARDEN
5 - CHANGING ROOMS
6 - PLAYROOM
7 -- FOYER
8 INERTIAL STORAGE
9 - TOILETS
10 GLASSHOUSE
11 - TEA ROOM
12 – CLASSROOMS
13 -- PATIO
14 - MULTI PURPOSE ROOM
15 - WORKSHOPS
16 SICK-BAY
17 -- DARKROOM
18 – PLAY AREA
19 – BALL GAMES
20 -- SOLAR PANELS



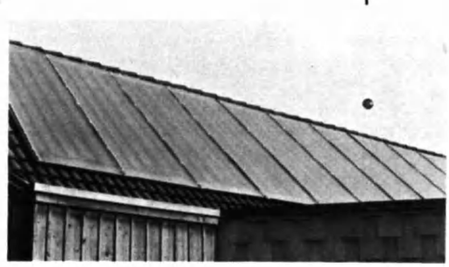
Sections 1: 250

1 Pitched roofs over play and multi-purpose spaces

2 Solar collectors

3 **Vaulted timber ceilings over classrooms**

4 Glazed circulation/buffer zones



Roof solar collectors

HEDAS 'S BUILDING : LAND : FRANCE TOWN : PAU

ARCHITECTS : Apostolos THOMAS 11; av du 18ème R.I. 64000 PAU Tél : 82.93.89 (59)
Daniel LARTIGUE
Agnès FRAPIN

THERMICIEN : J. Pierre GRUET 6, bd Champetiers de Ribes 64000 PAU Tél: 62.27.82 (59)

	APPARTMENT 1	2	3
Volume heated	324,00 m3	450,00 m3	430 m3
Livable space	120,00 m2	167 m2	167 m2
Inertia	heavy	heavy	heavy
Thermic energy requirement without solar input	12 931 KWH	16 142 KWH	16 836 KWH
Glasshouse input	1 254 "	1 205 "	1 100 "
Direct input	2 311 "	3 966 "	5 253 "
Inertial thermic energy input	3 043 "	4 023 "	3 629 "
Total passive energy input	6 323 "	6 946 "	9 982 "
Coef. G	0,71 W/ M3 K	0,64 W/M3K	0,70 W/M3K
Coef. B	0,35 W/M3K	0,27 W/M3K	0,28 W/M3K

THE HEDAS APPARTMENT BLOCK   LAND : FRANCE   TOWN : PAU

ARCHITECTURAL DESIGN

The architectural design is the result of the collective work of the future inhabitants, including the architect himself.
It is based on three major objectives :
1 . To design a building in which the appartments are each different and correspond as closely as possible to the life styles of each family.
2 . To design a building in which the architecture is integrated as completely as possible into the urban environment.
3 . To design a building which is as economical as possible in terms of heating and, above all, to make maximum use of solar energy.

1st OBJECTIVE : APPARTMENTS WHICH ARE DIFFERENT

The building is on five levels, plus a garage level. Each level has an outdoor terrace or a garden. In almost all our plans, we have tried to eliminate as far as possible the partitioning up of space and the existence of passageways (corridors). Life is organized around the main rooms in which daily occupations take place (living-room, conservatory, terrace, kitchen). The children have a level to themselves, to which a separate door provides access ; this includes their own play area. Spaces are provided for common requirements and activities at level O (garage space, etc...).

2nd OBJECTIVE : INTEGRATION

The differentiated design of the different levels and the use of elements such as conservatory, terrace and glass walls have made it possible tocreate a rhythm of architectonic movements which we consider to be in harmony with the existing architectural environment. This integration in the environment is further attested by the nature, texture, values and colours of the materials we have used.

3rd OBJECTIVE : ECONOMICAL HEATING AND SOLAR ENERGY

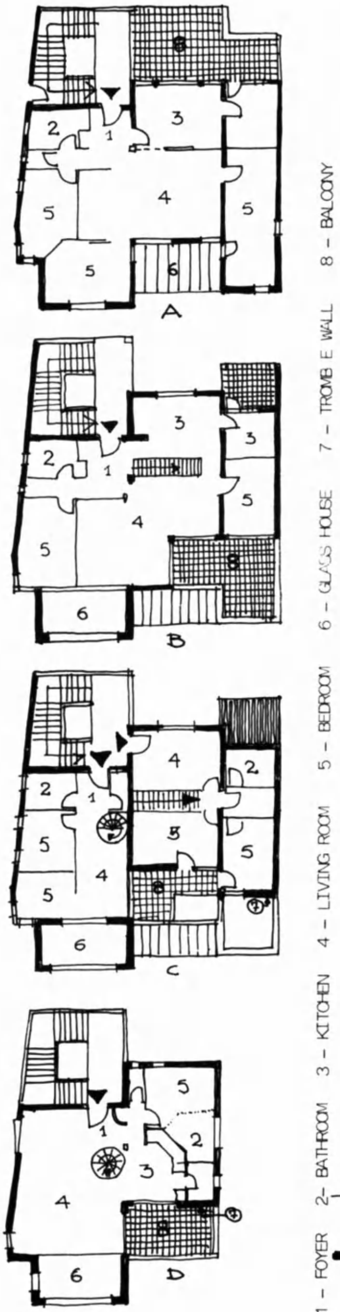
The architect's experience in this area enabled the group to determine basic options from the outset with regard to the economical use of energy in general :
a) the creation of a high level of thermic inertia and highly efficient insulation,
b) the maximum use of solar energy.

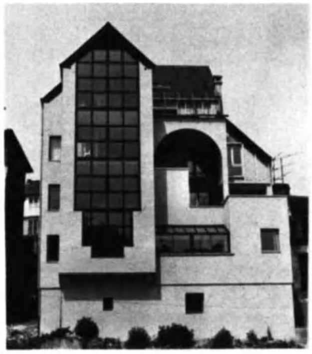
a) THERMIC INERTIA AND INSULATION

The whole building is insulated on the outside. The insulation consists of semi-rigide fibre glass 10 cm. thick, with 3 cm. air circulation and 3 cm. of roughcast (see drawing N°). The windows are all vacuum double-glazed. This insulation on the outside considerably increases the building's inertia, since the supporting structure (flooring, beams and walls) contributes to this inertia.

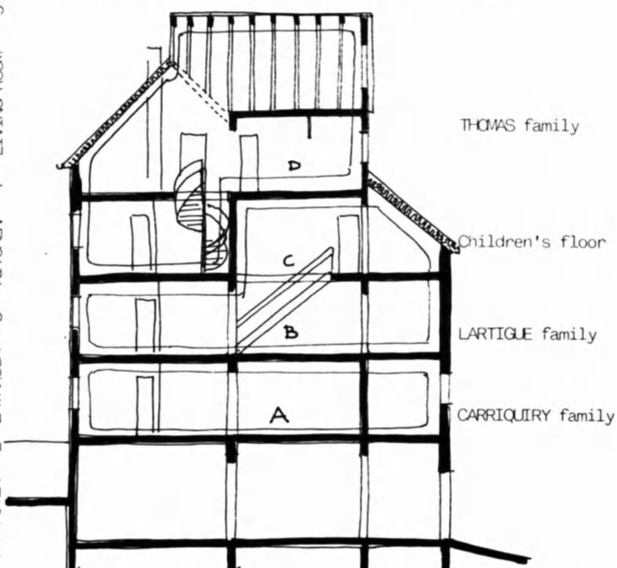
b) SOLAR ENERGY

In order to use solar energy, we have opened the south-facing area of the building as much as possible. The openings have been made through the conservatories or bay windows, as well as through TROMBE walls. We have learnt from experience that the solution of using TROMBE walls in an appartment building insulated from the outside is far from satisfactory. Independent mechanical ventilation systems guarantee adequate air replacement. In the winter, a thick, dark-coloured curtain is placed in front of the openings to prevent loss of heat by radiation at night. In the summer, overheating is prevented by air circulation : fresh air comes in from the north side and hot air escapes through openings designed for this purpose at the top of the conservatories and bay windows. Blinds will provide sufficient shade to eliminate solar radiation.





South facade



BENOOOO

AGREED MODEL

NATIONAL CONCOUR 1980 5000 SOLAR HOUSES FRANCE

ARCHITECTS : Apostolos THOMAS - J. Paul LOUBES
11, av. du 18ème R.I. 64000 PAU FRANCE
Tél : (16 - 59) 82.93.89
THERMICIEN : Michel LAVILLE and E.E.E.
LACQ 64000 FRANCE

DESCRIPTIVE SUMMARY

Passive solar **heated building**
Sunlight absorption by glasshouse system on two levels
1) Stockage wall connected to glasshouse
2) Internal stockage system connected to the heat regulation fan which inturn is connected to glasshouse.

IN SUMMER
1) Natural heat control : shadow area cast **over** catchment walls is increased due to roof extension Sunlight absorption is decreased.
2) Manual heat control : opening of heat exits placed at the top of the glasshouse structure. Shutter system.

IN WINTER
Regulation of solar input by the **transfer** of heat to the inertial stockage unit within and by the action of the thermostatically controlled ventilation unit.

ENERGETIC EVALUATION

On the basis of a five/roomed flat in the **Paris** area.

BUILDING CARACTERISTICS

VOLUME HEATED : 270 m3
LIVABLE SPACE : 99 m2
NON HEATED VOLUME : 40 m3

THERMIC ENERGY REQUIREMENTS WITHOUT SOLAR INPUT	17 204
GLASSHOUSE INPUT	5 618
DIRECT INPUT	1 211
TOTAL PASSIVE ENERGY INPUT	6 829
ACTIVE ENERGY INPUT (from mecanical ventilation unit)	810
TOTAL SOLAR ENERGY INPUT	7 639
THERMIC ENERGY REQUIREMENTS WITH SOLAR INPUT	9 565
G COEFFICIENT WITHOUT SOLAR INPUT	1,058
G " WITH SOLAR INPUT	0.588

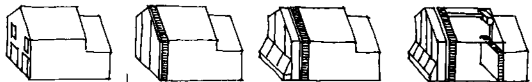
ADDITIONAL HEATING SYSTEM

Method of distribution + diffusion :
Hot water **radiators** with thermostatic control
Nature : **Gas-fired** boiler system.

HEATER CONSUMPTION	12 743KWH
OTHER ELECTRICAL CONSUMPTION	40KWH
SANITARY SYSTEM CONSUMPTION	4 386KWH
TOTAL CONSUMPTION	17 179KWH

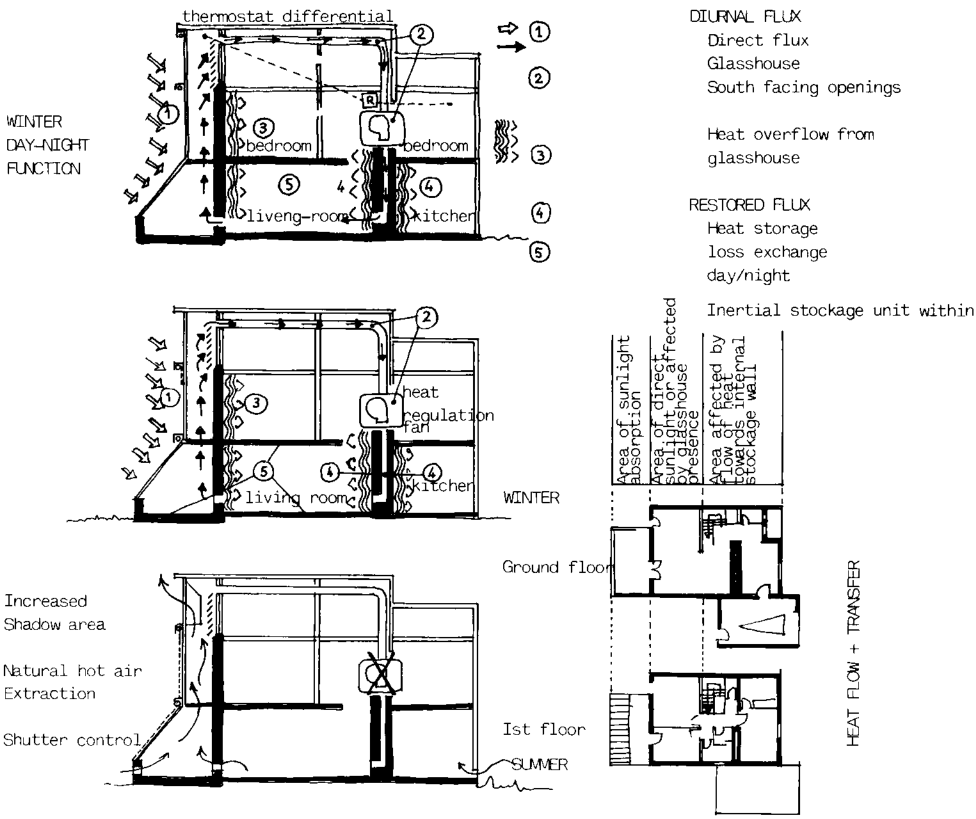
ENERGETIC EVALUATION STANDARDS FOR PARIS ZONE

COEFFICENT G	1,06
THERMIC ENERGY REQUIREMENTS FOR HEATING PURPOSES (KWH)	17 200
USEFUL SOLAR INPUTS FOR HEATING FOR SANITARY SYSTEM (KWH)	7 600KWH
ADDITIONAL HEATING SYSTEM : GAS	
DOMESTIC HEATING INPUT (KWH)	9 600
HOT WATER SYSTEM (KWH)	2 500

Helio Technical Features	Compact volume-try Good insulation **Appropriate** Siting	Plain glass Surface Stockage Wall	Glasshousse Stockage **wall**	Hot air extractor inertial stockage
Diagramatic Shape				
Degrees of Complexity	Module 5 rooms	**Ist degree**	2nd degree	3rd degree
Solar energy Input (PARIS)	14 %	32 %	40 %	45 %

BENCOCO

Proposed Model



44 BIOCLIMATIC FLATS AT RIGNANO SULL' ARNO IN TUSCANY

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Florence, Italy

ABSTRACT

The realization of 44 bioclimatic dwelling units at Rignano sull'Arno, Florence, is described here. The work has the outlines of an emerging solar architecture, conceived according to the will of the client - Coop. "Helios 78" - to build multifamily residences and facilities, with modern distribution scheme and with low cost of management, by using renewable energy systems.
Site and climate analysis, architectural and technical research are described; photos and drawings of the work are presented.
The bioclimatic features of the work and solar systems are briefly described.

KEYWORDS

Bioclimatic design; solar architecture; direct gain passive systems; domestic hot water components integrated.

Fig. 1 - General view from South-West

INTRODUCTION

At present the design of low energy buildings is a real answer to the energy problem in housing. The use of solar systems, both passive and active, becomes more convenient in bioclimatic buildings that have been conceived already as low energy houses.
For the architects the project of Rignano has been an interesting experience of energy conscious building design, to realize an efficient solar architecture with simple climatization techniques and well habitable houses at the same time.
In fact these buildings combine technical and formal innovations in the aesthetic and social outlines of modern architecture, with technical and climatic elements designed according to the Tuscan culture of housing.
Even the choice of the technological solutions of the solar climatization systems to fit on has been not at all easy and sometimes constrained, because of the renunciation to use more evolved passive systems, like built-in wall air collectors or like air channels built into the beams.
In fact the project has been run within outlines of technological simplicity, to keep the building within reach of the contractors that operate in our region, and without peculiar difficulties for the structural designer.
So that one of the aims of the work has been to realize good energy performance by using usual architectural elements, assembled with energy consciousness.
Designers are: G. Papasogli, M. Tanzi, D. Parigi and the author for the bioclimatic design of architecture and solar systems.

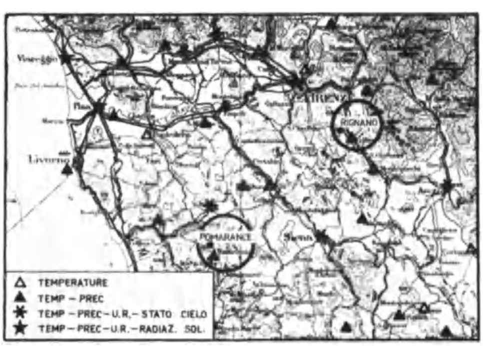

Fig. 2
Worksite location, orography and surrounding weather stations.

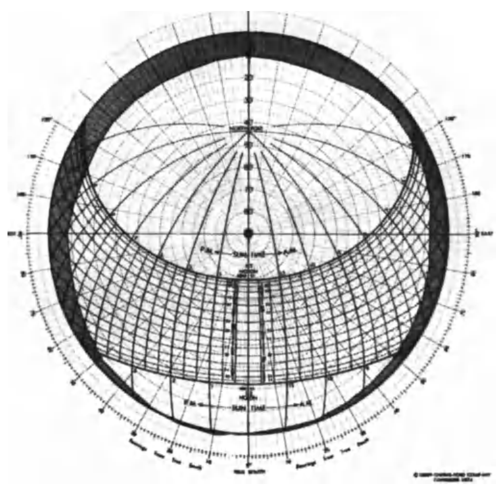

Fig. 3
Local horizon and sunpath of the site.

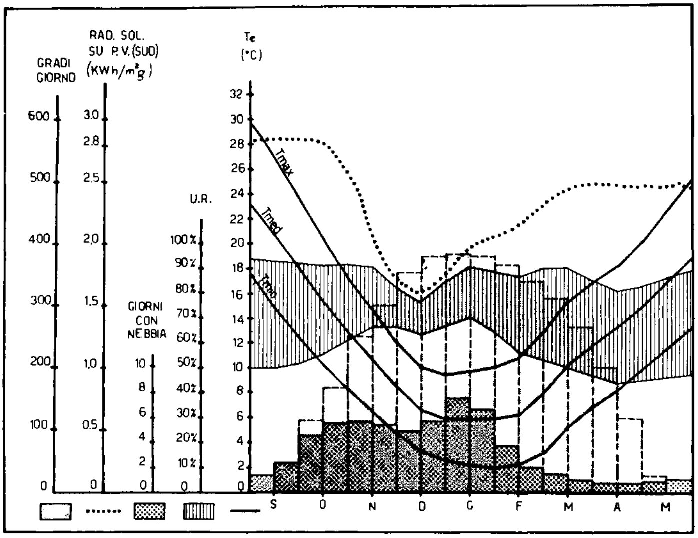

Fig. 4 - Local climate analysis.

THE BIOCLIMATIC DESIGN

The design process developed according to the following rules of residential settlement bioclimatic design:

- local climate, site and environment factors analysis,
- study of housing layout and aggregation type for winter sun exposure and summer shading,
- study of interior arrangement as regards comfort,
- choice of low cost flexible building technique with appropriate thermophysical characteristics,
- design of simple solar systems for passive climatization,
- design of built-in solar roof collectors for domestic hot water,
- design of highly efficient and reliable auxiliary heating system able to work in connection with the passive system.

The building site is bioclimatically excellent: facing SSE, slightly sloping about 12 per cent and protected from the North winds by the existing hills and vegetation (Fig. 1-2). This site feature ameliorates the local climate conditions, and the ground level higher then the close river Arno prevents the site from the persistent winter fog.
The local climate analysis presented some difficulties for the lack of close weather stations. So that a representative climate reference year has been generated by analizing the fortnightly average values of the surrounding weather stations, later corrected by direct observations of the local environment factors (Fig. 3-4).
The housing layout on the ground and the optimum aggregation of the houses have been fixed to get maximum winter sunshine.

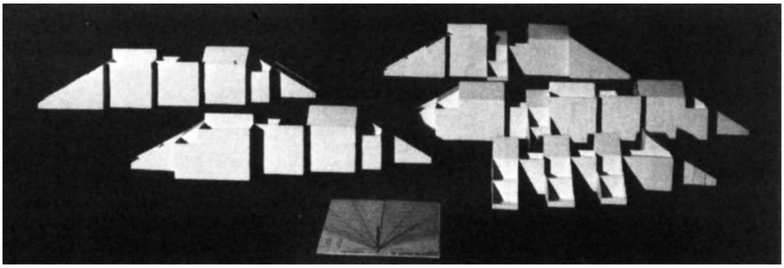

Fig. 5 - Shadow test of the models layout on December 21st at 2 p.m.

This operation has been done during design process by means of some sectional models, lighted by a lamp that simulates the sun position in winter, within ±45° degrees azimuth from South direction (Fig.5). The approved housing layout consists of 5 blocks, two and three floors high, disposed E-W with wide fronts facing the South, spaced enough to avoid shadows.
Each block is a sort of row-house aggregation, whose shape and interior space arrangement have been conceived to get high solar heat

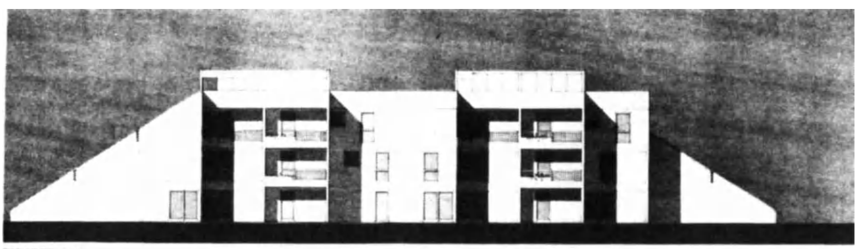

Fig. 6 - South elevation of block "B"

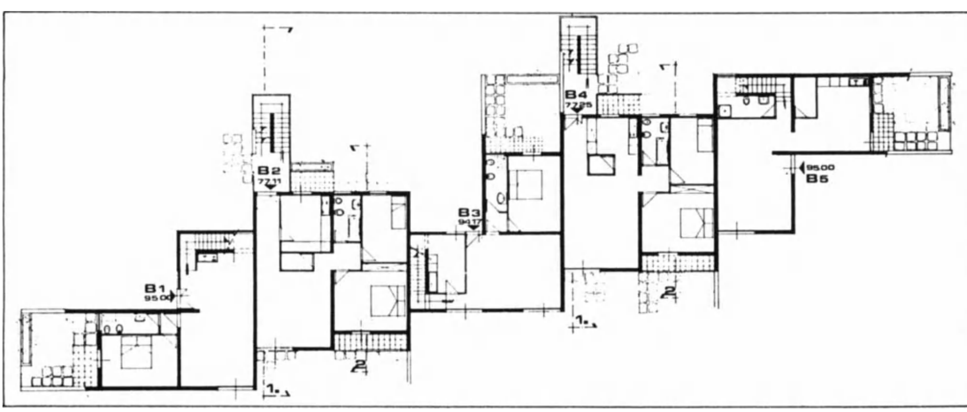

Fig. 7 - Ground floor plan of block "B"

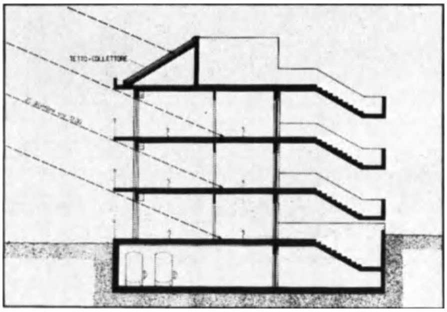

Fig. 8 - Cross section S-N

gain in winter and good indoor comfort in summer.
So the deep livingrooms and the main bedrooms have wide windows facing the South to let the winter sun penetrate deeply into the room; the heat collected is distributed in the other rooms by indoor ventilation.
On summer afternoons, the South windows are shadowed by the staggered front and balconies (Fig 6-7-8), and interior comfort is improved by cross ventilation, induced by the small windows facing the North.
The direct gain system for passive climatization has been chosen for its simplicity of realization and management, after several technical and economic evaluations, run by the designers the client and the contractor together. Especially the criterion prevailed to give the user a simple and durable passive system to manage.
Small rooms and facilities are sited on the North side.
The staircase is built externally on the North side, to act as a shelter for winter wind.
A flexible and low cost building technique, with appropriate thermophysical performances has been chosen. The outer walls are made of insulated blocks, with polystyrene inserted in the exterior cavity, to increase the U-value and the available interior heat storage at the same time (Fig. 9-10).
The good performance of this technique has been estimated by computer numerical simulation of the quantity of auxiliary energy, to be supplied during 50 winter days of the local reference-year for three different insulation techniques (Fig. 11).

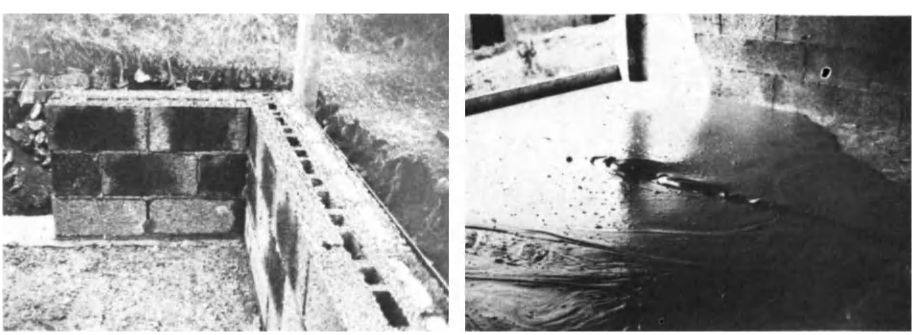

Fig. 9 - Insulation techniques used in the outer walls (insulating blocks with polystyrene) and ground floors (foam cement).

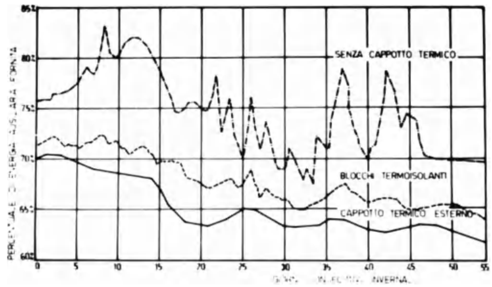

Fig. 11
Evaluation of % of auxiliary energy to be supplied in 50 days for 3 different outer walls types

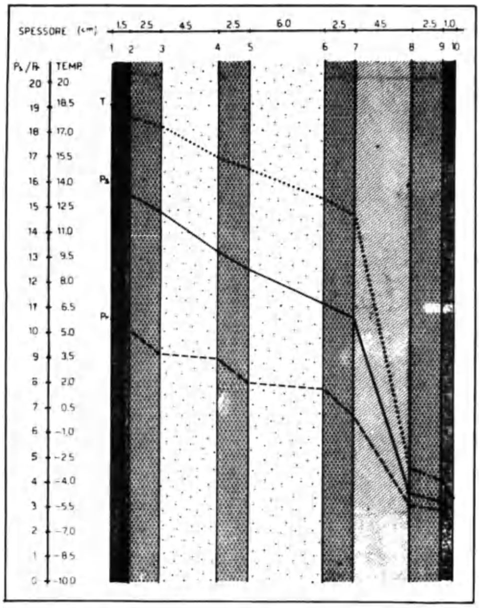

Fig. 10
Glaser curve of the outer walls. No condensations detected.

Coverings, terraces and groundfloors are highly insulated with polystyrene and foam cement, and the average G-value of each block is 0.824 $Wm^{-3}°C^{-1}$.
Auxiliary heating is supplied by a traditional system, equipped with individual gas furnace and heat radiators. Differential thermoregulation is provided in each sunny room by thermostatic valves, and a central thermostat with nightly reduction is provided too. This simple solution has proved to be conveniently energy saving at low cost of realization, and fitting to act promptly in connection with the direct gain passive system.

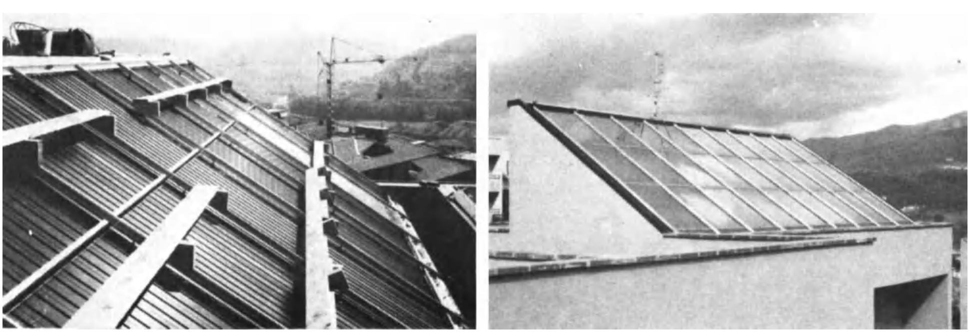

Fig. 12
One of the hot water roof collectors on building and completed.

THE SOLAR HOT WATER SYSTEM

Domestic hot water is supplied by 6 roof-collectors each of them is 9.90 x 4.90 mts. wide - one for each block - acting as coverings and specially designed by the author for this work.
The absorbers are made of high thickness extruded aluminium plates with special design for good heat transfer. The hot water storage is centralized in two tanks at different temperature, to utilize any solar fraction, and distributed to the single houses.
Eventually the auxiliary water heating to reach a desired higher temperature is supplied in every flat by the individual gas furnace automatically put in circuit by a thermostatic valve.
This solution let every user to pay only his own extra energy really consumed.

PERFORMANCES

The energy balance of a typical block is shown in Fig. 13.
The graph shows two space heating loads, according to two different G-value, both the maximum legal allowed one and the actually realized one. Indoor heat and solar direct gains are shown, evaluated by the Los Alamos Laboratories procedure for passive systems predictions.

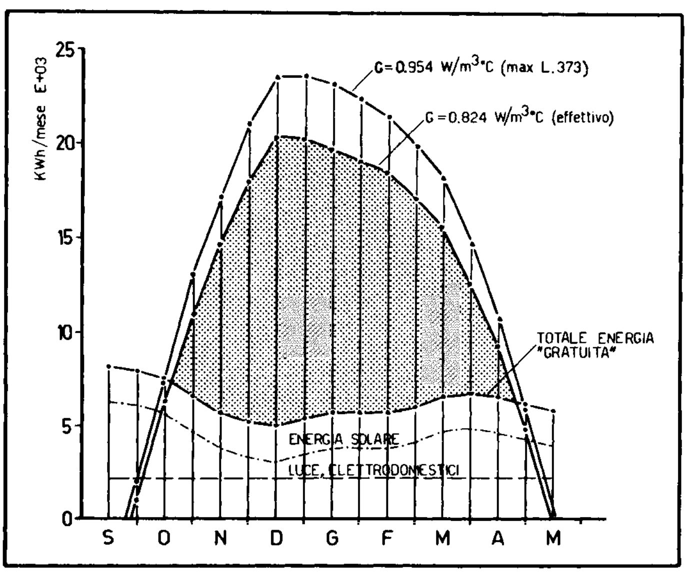

Fig. 13
Block "B" performances evaluation: space heating loads with legal and actual G-values, indoor heat and solar direct gains.

The dotted area indicates the auxiliary energy to be supplied for space heating, and the heating period results shorter.
The hot water solar heating fraction is expected to be 68 per cent yearly, as evaluated by f-chart.
The whole money saving is expected to be about 197 $ for every flat that is about 53 per cent of the same volume buildings without the energy saving devices.
Three flats are intended to be monitored as a sample to verify comfort conditions and energy saving expectations.

In conclusion the 44 bioclimatic houses built at Rignano sull'Arno are a research experience toward a bioclimatic architecture, that embodies architectural-functionalistic and technical-energetic features, realized by using traditional elements with energy saving consciousness.

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PERFORMANCE EVALUATION OF A "COCOONED" OFFICE BUILDING IN A COLD CLIMATE INTEGRATING PASSIVE SOLAR TECHNIQUES WITH MODERN TECHNOLOGY

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ABSTRACT

The performance evaluation of the RPI passive solar Visitors Information Center (VIC) has an actual yearly total energy use of 172 MBtu/yr, or on a per unit floor area basis, 33.28 kBtu/ft^2-yr. This represents a 70% reduction in total energy consumption compared to a similar non-solar building designed under the same energy conservation building code. The actual performance of the VIC is within 2% of the simulated performance used during the design phase. The design of the VIC utilizes timeless passive solar heating, cooling and daylighting techniques, but integrated within a high technology building context. Passive systems are integrated with a complex set of energy flow controls and HVAC back-up systems. Occupants are provided with multiple-comfort-options including personalized comfort systems.

The findings associated with this project suggest a new use of passive solar techniques through the use of "Comfort Optimization Membranes". These membranes, spaces in themselves, utilize renewable forms of energy, contain numerous energy flow controls and sensing devices to reduce the impact of microclimate liabilities and maximize the use of renewable energies. The VIC is one application of the Comfort Optimization Membrane concept and suggests a potential for new form-giving architectural elements. This concept integrates passive and active technologies and simultaneously modulates thermal, visual, and oral comfort.

KEYWORDS

Passive Solar Heating; Natural Ventilation; Daylighting; Personalized Comfort Systems; Comfort Optimization Membrane; Energy Flow Controls; Multiple Comfort Options; Performance Evaluation.

INTRODUCTION

Rensselaer Polytechnic Institute (RPI) in Troy, New York began the design of the Visitors Information Center project in May 1979. In addition to housing the Campus Security Office (24 hour occupancy), the building was to serve as a "front door" to the campus, i.e., to provide conference rooms, reception spaces for visitors, and exhibition space. Given the technological orientation of RPI, the Client, the design had to demonstrate what a technological university can do with one of its own buildings in terms of energy conscious design. In October 1979, RPI received notification that its proposal for a Design Assistance and Demonstration grant from the U.S. Department of Energy (DOE) had been accepted. The purpose of the DOE grant was to demonstrate the use of passive solar systems in commercial buildings. In January 1981, the building was completed. Since January 1982, the building's thermal and daylighting performance has been carefully monitored as part of the Performance Evaluation Phase of the DOE Passive Solar Commercial Buildings Program.

This paper presents: design objectives, building description, the monitoring system, overall performance, and suggests the further development of "Comfort Optimization Membranes". The thesis of this paper claims that in commercial buildings the use of passive solar systems is most effective when they are integrated with energy flow controls, HVAC systems, and building form.

DESIGN OBJECTIVES AND PARAMETERS

The design program specified 4,000 ft^2 of commercial office space, full year occupancy, 24 hours per day. DOE was primarily interested in demonstrating the use of passive solar systems in commercial buildings while RPI was interested in the potential of modern energy technologies appropriate for buildings and people. These two sets of expectations were not always in agreement. In addition, the design team, all RPI faculty and staff, introduced its own ideas of energy conscious design. The design team wanted to find a new meaning for an age-old set of passive solar techniques within a modern architectural context. All of these expectations had to be accomplished within the environmental context of an existing campus and a building budget of $360,000.00, which included a 15% increase over conventional construction costs to cover the cost of innovations in energy conscious design. This meant that $47,000 was available for incorporating ideas which otherwise would not have been designed.

Troy, New York is at a Latitude of 42.72° North, a longitude of 74°, an elevation of 275 feet, has 6,888 heating degree days, and 654 cooling degree days. The average radiation is 306 langley/day, mean temperature is 49.1°F, and the mean sky cover is 0.67. Prevailing summer winds are South and Southwest, while prevailing winter winds are West and Northwest.

The functional aspects of the program suggested an average day-time occupancy of 10 employees and night-time occupancy of 2 to 4 employees. The functional pattern implied intermittant office occupancy, since security and safety personnel are required to spend considerable time away from their offices. As a Visitors Information Center it was difficult to predict the people-traffic through the building. The public spaces had to be designed for large-group social events, meetings and exhibits, without a specific use-schedule.

Initial program and microclimate analysis suggested that this design program did not represent a typical small office building or internal load dominated comfort conditions. Use of the LCR method (Balcomb, 1980) and economic analysis in the conceptual design phase suggested that a "sunspace" passive solar system appeared as an appropriate and affordable passive solar strategy. The design team also subscribed to the concept that people, not buildings, consume energy. Consequently, it was deemed desirable to allow the occupant to contribute to the energy-efficient operation of the building, and to provide the means for occupants to achieve their own thermal, visual, and oral comfort levels.

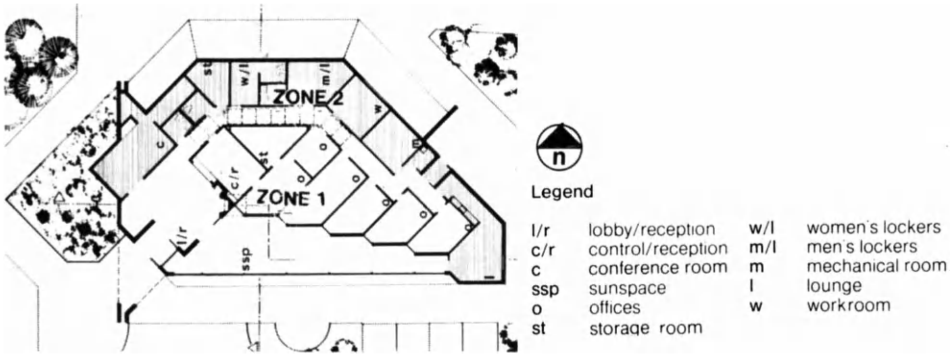

Fig. 1. Floor Plan

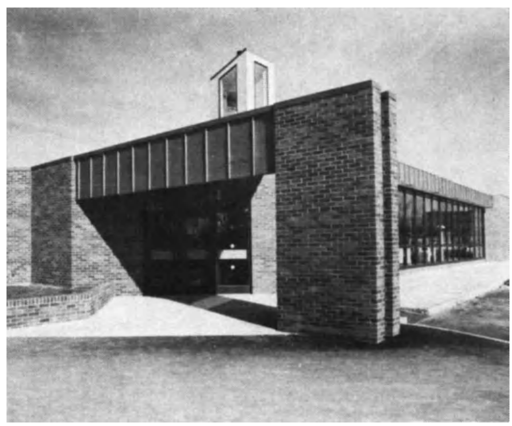

Illustration 1. West and South Elevation

BUILDING DESCRIPTION

A schematic of the VIC's floor plan is shown in Fig. 1. The building's large South elevation accommodates a sunspace to collect and store solar energy in the sunspace floor slab and a system of mass wall segments (Illustrations 1 and 2). Infrequently used spaces, which do not have critical thermal requirements, are located along the earth-bermed northern perimeter. This northern region, functions as a thermal cocoon forms part of the Comfort Optimization Membrane, and is called zone 2. Unfortunately, office space has been added to this north-wall region during the latter stages of construction, replacing previously thermally insensitive areas. The interior is a cocooned central zone of thermally sensitive office spaces, zone 1. The thermally controlled floor area is 401 m^2 (4,300 ft^2) and the total floor area, including the uncontrolled sunspace is 484 m^2 (5,200 ft^2). The sunspace glazing area is 63 m^2 (690 ft^2). The sunspace area forms the remaining portion of the thermal cocoon.

All auxiliary energy consumption is electric. A variable air volume system, integrated with an electrical resistance heating element and a cooling coil, provides

Illustration 2. Sunspace

Illustration 3. Hallway with Reflectors and Moveable Insulation

for back-up heating and cooling. Individual spaces such as offices, locker rooms, and lounge are supplied with radiant heating panels (personalized comfort systems) to provide supplemental heating when occupied. Individual comfort control systems within offices are moveable to align with varying furniture arrangements and are controlled through manually operated timer-switch. When the building is on night-setback the occupant can achieve thermal comfort without switching the HVAC system to day-time operation. Night-setback can be overridden manually if the building has full-time occupancy at odd working hours.

Moveable insulation with controls in the sunspace are designed to maintain comfortable temperature in the sunspace, to prevent heat loss, to provide shading in the summer, and to modulate daylighting. Stored energy in the mass walls transfers to the interior to adjacent spaces in the evening. Operable openings in the glass wall of the sunspace, the office windows, and the light/vent tower (also containing an exhaust fan) create a thermosiphoning effect for natural ventilation and space cooling during the summer.

The central hallway, (Illustration 3) with skylights and adjustable curved reflectors on the exterior, function as a daylighting and direct gain system. Moveable insulation at the skylights is manually operated to control heat loss, and reflectors function as skylight-shading devices in the summer. Clerestory windows located in the north-wall separating the hallway from zone 2 allow penetration of direct gain radiation for heating and daylighting in zone 2. Thermal mass walls located along the northern perimeter are insulated on the outside between the berm and the wall, providing additional thermal mass in zone 2.

Daylighting for offices is provided through the sunspace and the office windows located between the mass walls. In addition, the light/vent tower transfers daylight to the lobby and to the sunspace. When the thermal curtains of the sunspace are in their down-position, sufficient daylight is provided through the light/vent tower to prevent the need for electric lighting.

DESCRIPTION OF COMFORT SYSTEMS

One of the building's design features is the integration of the passive solar systems with the HVAC and the energy flow control systems. In the winter-time, warm air can be drawn from the sunspace, through the HVAC system and delivered to individual offices calling for heat. As long as the temperature in the sunspace or other regions in the building is 10°F above thermostat setting, the energy flow control system will draw upon the free and stored heat from the sunspace, hallway, or other building regions with excess heat.

An occupant within an office has multiple comfort options to achieve thermal, visual, and oral comfort. In addition to individual thermostats, windows to the sunspace are operable to allow natural convection; radiant panels can be actuated for variable times; and, each office has two operable components to gain heat convectively, depending on internal noise conditions.

In the summer a cocooned office interior is protected from any direct solar gain. An enthalpy controlled economizer cycle provides night-flush cooling with the light/vent tower exhaust fan assisting when necessary. During the day natural thermosiphoning keeps the sunspace cool with the air-intake located at the bottom of the sunspace glazing. If the sunspace temperature exceeds 85°F an air intake damper, located on the northside of the sunspace wall, opens,the light/vent tower fan is actuated, and warm air is expelled to the exterior. During the day when ambient conditions exceed the ability of natural cooling the refrigeration cycle is actuated.

As presently designed, the occupant can modulate thermostats, windows, radiant heating panels, electric lighting, and night setback override. In addition, the occupant can override the moveable insulation/shading device in the sunspace and the exhaust fan inthe light/vent tower.

The sunspace and zone 2 with their integral energy flow controls and thermal mass surround the thermally, orally, and visually sensitive office interior. This spatial region constitutes a comfort optimization membrane modulating comfort conditions, acting as a conduit for moving "thermal fluid" to various regions in the building. The membrane also modulates daylighting, stores energy, and through various types of sensing devices and programmable controls, located in the interior, can respond to the dynamic conditions presented by occupant, context, and nature.

DESCRIPTION OF THE MONITORING SYSTEM

Three types of variables are measured: temperature, solar irradiation, and electrical energy consumption. The temperature transducers are manufactured by Analogue Devices, Model AD590. Measurement of insolation is done by the Li-Cor LI-200s. Energy consumption is determined by Ohio Semitronics PC5 series Hall Effect AC Watt

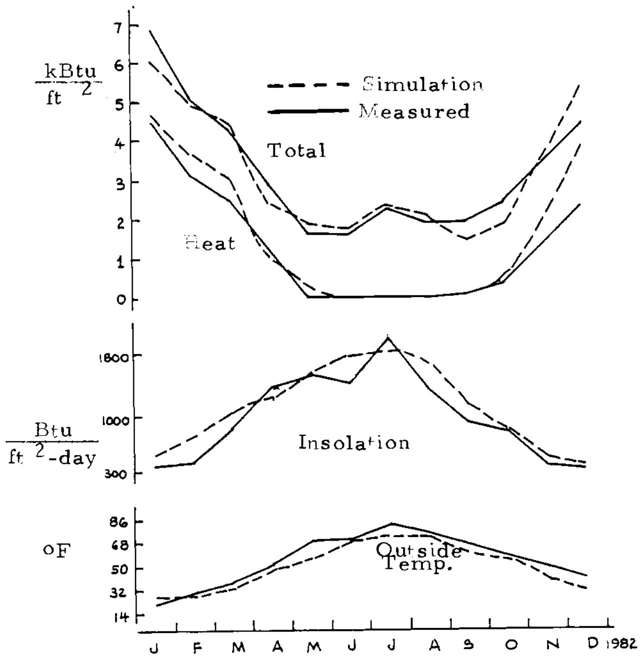

Fig. 2. Comparison of Simulated to Measured Performance: Month-by-Month Energy Use for 1982

TABLE 1 Simulated and Actual Yearly Energy

Purpose	Simulated	Actual
Energy Use Total		
Heating	96.7 MBtu/yr.	80.6 MBtu/yr.
Cooling	11.7 MBtu/yr.	6.1 MBtu/yr.
Lighting	33.1 MBtu/yr.	51.8 MBtu/yr.
HVAC	35.5 MBtu/yr.	34.6 MBtu/yr.
Total	177.0 MBtu/yr.	173.1 MBtu/yr.
Maximum Allowable By Energy Code		561.0 MBtu/yr.
Energy Use per Unit Gross Floor Area		
Heating	18.6 $kBtu/ft^2$-yr.	15.5 $kBtu/ft^2$-yr.
Cooling	2.25 $kBtu/ft^2$-yr.	1.16 $kBtu/ft^2$-yr.
Lighting	6.35 $kBtu/ft^2$-yr.	9.96 $kBtu/ft^2$-yr.
HVAC	6.82 $kBtu/ft^2$-yr.	6.66 $kBtu/ft^2$-yr.
Total	34.02 $kBtu/ft^2$-yr.	33.28 $kBtu/ft^2$-yr.
Maximum Allowable By Energy Code		108.0 $kBtu/ft^2$-yr.

Transducers. The monitoring system is controlled by the Aeolian Kinetics PDL-24 Data Logger. All variables are scanned each 30 s and the averaged results printed each hour. Energy (in kW-H) is determined by integration of the power consumption (in kW) over each hour interval. Hourly values are printed on paper tape and stored in tape cassettes. (Tichy, 1981).

The following air temperatures are measured: outside environment, sunspace, two interior (zone 1) offices, and a room against the North-wall (zone 2). Three mass wall temperatures are measured. Outside horizontal solar irradiation and vertical solar irradiation on the sunspace mass wall are monitored. Electrical energy consumption is measured for heating (the sum of the air duct coil, baseboard heaters, and radiant panels), air conditioning, inside lighting, outside lighting, and HVAC/ventilation equipment. (Tichy, 1982)

OVERALL PERFORMANCE

Overall thermal performance on a month-by-month basis for 1982 is depicted in Fig. 2. The increase in average outside air temperature and horizontal insolation from January to December is also shown. The units shown are average daily consumption of energy (Btu) per unit gross floor area (ft^2) for each month.

Note that auxiliary heating is by far the largest component of total energy use, approximately 47% on a yearly average, and is slightly larger than 3% of the total energy use. Lighting and HVAC equipment are relatively constant throughout the year and typically comprise 50% of the total energy usage. (see Table 1) The dashed lines in Fig. 2 provide a comparison of simulated performance used during the design phases, to actual performance (solid lines). During the design phase, an "in-house" computer simulation tool was developed. (Kroner, 1980; Tichy, 1981). The program solves 12 implicit one-dimensional energy balance equations hour-by-hour for a year using a simple matrix inversion algorithm. The following variables are treated as hour-by-hour program inputs; outside temperature, horizontal insolation, zone 1 and 2 thermostat set points, and energy loads due to lighting, occupants, HVAC equipment, and other miscellaneous equipment. The weather inputs (outside temperature and insolation) are obtained from a specially prepared "design year" tape of average months in Albany, New York, between 1970-1976. Hour-by-hour program outputs are heating (or cooling) by zone, and temperature of the nodes.

The simulation used an infiltration/ventilation rate of one air change/h, and thermostat set points of 72°F for zone 1 (day and night), 72°F for zone 2 (day), and 55°F for zone 2 (night). For these conditions, simulated and actual heating and total energy use are compared in Fig. 2. The results are in substantial agreement. It is important to note that the weather used in the simulation is, of course, not the same as the actual weather.

Actual yearly energy consumption is shown in Table 1. Results are also shown in a percent floor area basis and are compared to the maximum energy consumption allowed by the New York State Energy Conservation Construction Code. The energy performance of the RPI Visitors Information Center demonstrates that the building, as currently designed and operated, saves 70% of the total energy a non-solar energy-efficient building would consume.

CONCLUSIONS

Over the past two years, the RPI design team has observed several significant aspects related to the thermal behaviour of the building and its occupants. The building's energy performance is highly dependent on the user. For example, daylighting measurements indicate that sufficient daylighting is available, even with overcast sky conditions, where task-lighting would be sufficient, yet, overhead ceiling lights are left on. Lighting energy consumption is 36% higher than predicted. When zone 2 is on night-setback (55°F) occupants continuously leave doors open to that region, creating increased heating energy consumption. Bathroom fans, which must be integral with light-switching, are left on, when not occupied. Despite extensive educational seminars, informing the user how to work with the building to achieve comfort and energy conservation, the design team feels that greater energy savings are possible, than presently indicated, through improved user participation. Despite the influence of the occupant and user operation variations: thermostat settings, manual control of heaters, infiltration due to increased building access and egress, the "bottom line" is a 2% variation between simulated and actual measurements. This, combined with a 70% reduction in energy consumption over similar energy efficient non-solar buildings is, nevertheless, a respectable performance.

The building's energy performance has also convinced the design team that the "cocoon approach", referred to as the comfort optimization membrane, represents a great potential for moving the state-of-the-art in passive solar systems forward. The Northern perimeter and sunspace in the VIC function as a membrane by: modulating energy flows, acting as a conduit for thermal energy fluids, housing a host of complex energy flow controls, isolating noise, controlling daylighting and accommodating human activities. Given the dynamic characteristics of a microclimate and the unpredictable needs of the occupant, conventional building enclosures, designed as statis envelopes, have a limited comfort response potential. Comfort Optimization Membranes, if continuously explored as a new architectural design element, can provide greater levels of thermal, visual, and oral comfort and energy conservation than present-day techniques. A conventional building envelope, with its narrow dimension and complex set of performance expectations, has limitations as we move into the future. Comfort optimization membranes such as demonstrated in the RPI Visitors Information Center, the Hooker Chemical Building in Buffalo, NY, and other such projects, are pointing the way to a new comfort design vocabulary. Increasing the performance potential of spatial enclosures will improve the comfort response potential of buildings, provide more efficient ways of utilizing renewable forms of energy, and create new architectural forms.

The RPI Visitors Information Center has been equipped to allow the use of the building as a testing laboratory and the design team continues to explore the impact of one particular type of comfort optimization membrane.

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PASSIVE AND LOW ENERGY RESIDENTIAL/OFFICE BUILDING FOR USE AS A SOLAR DEMONSTRATION FACILITY AT ARIZONA STATE UNIVERSITY

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ABSTRACT

The constructed building consisted of a two-story solution to simulate a single family solar demonstration residence for later conversion to a research office. The design providing some 2000 sq. ft. of building floor area with 1000 sq. ft. roof area, which greatly minimized the cooling requirement contributed by the roof. The solar heat gain to the building envelope was controlled by reduction of glazing. Relatively extensive south - facing glazing was used for direct gain heating in winter, but it was shaded carefully to minimize summer cooling load with a mechanical owning system. Recognizing that earth - integrated architecture further contributed to a reduction in the cooling load, the first floor of the building was designed to be partially below grade. The cross section of the room is rectangular, with essentially a one-room deep floor plan, and a mezzanine which allows effective utilization of passive heating solar systems. The 800 sq. ft. south wall designed to be removable and modularized to provide a research capability for introducing both active and passive heating systems in future years, was replaced by a fixed panel design by the construction manager and contractor during construction without consultation to the architect. Other features were similarly altered as reported below.

INTRODUCTION

The original design of the integrated mechanical architectural energy efficient solar demonstration facility was to provide an aesthetically pleasing home which would operate at a moderate to low cost compatible with present electric utility rates. After a demonstration period of two years it will be converted to research laboratory for graduate students if major impediments caused by unauthorized design charges and a lack of funding for instrumentation are overcome.

Figures 1, 2. Views of the Building

PROJECT CONCEPT

To help cope with increasing heating and cooling costs, energy efficient concepts for housing comprising both passive and active systems have been considered for adoption to many areas of the arid southwest of the United States. This Project, recently completed, will be capable of simulating a number of these concepts - - direct gain, hot water heating, pool heating, air collection, Trombe walls, earth integration, landscape conservation and photovoltaic application. The building is shown in Figure I. The simulated house was designed to be instrumented and able to quantify these energy related concepts with the placement of over 200 thermocouples. Specifically, this paper will address the architectural and mechanical design for the building with regard to energy conservation as well as ancillary aspects of landscaping habitability, and energy rate structures (See Figure I).

BACKGROUND

In developing a program for the design competition, won by the author for this efficient demonstration facility and future conversion to laboratory, a number of objectives were identified which required careful planning in the preliminary design stages. A prime consideration was to accomplish a practical design with which home builders and potential home owners could identify, but not necessarily duplicate. In order to accomplish this major objective the building was to be aesthetically acceptable as well as energy efficient in order to be affordable and pleasing to a prospective occupant. The solar and energy conserving devices incorporated in the design were to be both cost effective and compatible with present and future electric utility needs and rate structures in the State of Arizona. Therefore, these primary objectives were (1) to accomplish a practical design with which potential middle income home owners could identify and (2) allow the building to convert into permanent offices for a research laboratory. Ir order to accomplish these major objectives, the facility had to be aesthetically acceptable, of permanent materials, as well as energy efficient in order to allow for demonstration and conversion criteria.

LANDSCAPE ARCHITECTURE CONCEPT

Principally arid region plant materials were used with those of a deciderous classification for location in high use activity areas immediately adjacent to the swimming pool and patios. The concept provides a transitional quality between desert plantings (outside of walls, adjacent to the streets) and an oasis (interior yard exhibit and patio areas). Unfortunately, the landscape architecture concept was only partially carried out by the construction coordinator and contractor. The plant materials selected have low water demands, with those demands being met by efficient drip irrigation system and watershed controls allowing natural precipitation run - off to be concentrated in planting areas.

Plants have been located in such a fashion as to provide east and west elevation shading to supplement the "Dryvit System" (exterior finish and wall insulation) while at the same time, presenting a handsome setting for the facility and a usable year around exterior yard.

PASSIVE ARCHITECTURAL DESIGN

For this building, considerable effort was devoted to the area of passive architectural design. For example, the building simulates a two-story solution to a single family home, providing some 2000 sq. ft. of building floor area with a minimum roof area and, consequently, a minimum cooling requirement contributed by the roof.

Figure 3. Landscaping

The solar heat gain to the building envelope has been controlled by nearly eliminating east, west, and north glazing. Relatively extensive south - facing glazing is used for direct gain heating in winter, but it is shaded carefully to minimize summer cooling load. (See Figure 4, floor plans). Figure 5 shows that although

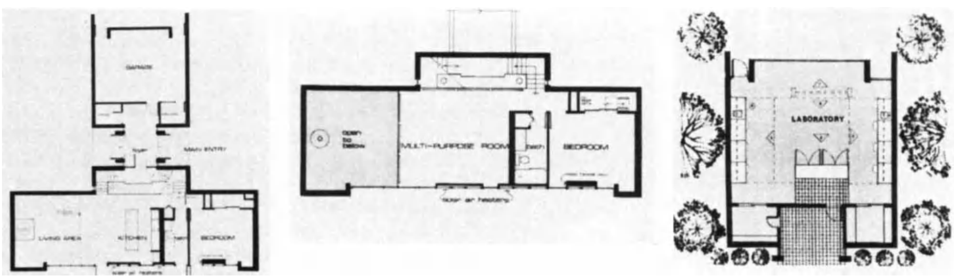

Figure 4. Floor Plans

the average daily ambient temperatures, in Phoenix, Arizona, U.S.A., may vary as much as 45°F over the year, this fluctuation is sharply dampened as depth below grade increases. This reduces the temperature differential between the exterior below - grade walls and the interior, thereby reducing the cooling loads. The walls of the building were constructed for optimum interior mass using 8 in. and 12 in thick concrete blocks with filled cavities. Exterior insulation was used to give a low overall heat transfer coefficient of approximately 0.06 Btu/(hr. ft^2.F). The exterior walls and roof were also treated with a light colored cement plaster and monofoam finishes to respectively further reduce the sol - air temperature and thus the cooling load. Surface color plays an important role in how much incident solar radiation is absorbed by the surface.

Table 1 Surface Color and Solar Radiation Absorptance

Surface Color	Absorptance
black	0.85 to 0.98
white	0.30 to 0.50

Absorptance is one of the factors affecting sol - air temperatures. Therefore, using light colored surface treatments with their low absorptance, can significantly reduce sol - air temperatures and reduce the cooling load. The roof itself is flat with a U-value of approximately 0.03 Btu/(hr.ft^2.F). The cross section of the building rectangular and a single room in depth which allows effective utilization

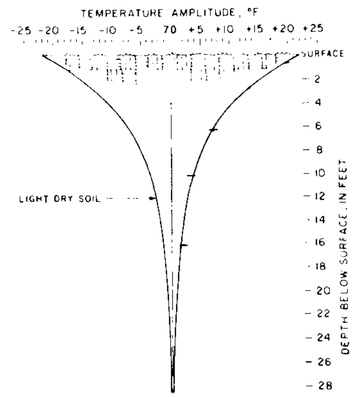

Figure 5. Phoenix Average Daily Ambient Temperature

of passive heating solar systems. The entry space is compartmentalized to provide a reception area as well as an air lock to reduce heating or cooling losses from major interior and exterior user movements. Through careful use of glass and sealants in the building envelope, the extent of infiltration loss was minimized. The 800 sq. ft south wall was not modularized as designed but will provide a limited research capability for introducing variations in both active and passive heating systems for future years. The original design called for a modular "plugin" south wall to be expanded in 9 ft by 12 ft increments or smaller units to provide studies of greenhouse effects, clear view collection and other passive solar heating systems as well as space expansion. Again, this design feature was drastically altered and virtually eliminated during construction phase by the manager and contractor, under separate contract to the University administration, and without consulation with the architect or engineers. Equipment specified which resulted in further energy conservation was: 1) the use of a microwave oven in the home (microwave ovens can reduce load by 2.8 kW.): 2) A highly energy - efficient refrigerator: 3) Magnawave range top (Magnawave Heating is a unique cooking method which heats cookware directly -- the cooking surface operates cooler than ordinary range tops and uses energy only where it is needed.): 4) fluorescent lighting throughout 5) clerestory rather than direct sky lighting, 6) a drip - type irrigation system for plant materials, 7) solar cells to operate emergency lighting and air circulating fans, 8) an outside air source fireplace two stories in height to maximize air distribution to both levels, 9) the use of a solar oven on the south patio (solar ovens can realize savings in two ways: (a) no energy is required to cook food, (b) no internal load is generated, thus reducing cooling load.): 10) minimal carpeted surfaces on the ceramic tile ground floor: and 11) selection of skeletan furniture with minimal padding to optimize direct solar gain functioning.

The entire simulated demonstration residence, for conversion to offices and the mock garage to a laboratory office, was designed for the use of graduate students concentrating on arid region housing. (See Figures 6, 7).

THE SOLAR/MECHANICAL SYSTEMS

The focus of the home is its energy systems. The most cost - effective application of solar energy at the present time is the production of domestic hot water. The energy - efficient home will be equipped with a nominal 35 sq. ft. collector, necessary pumps, controls, plumbing and storage tank to provide 90 percent of the

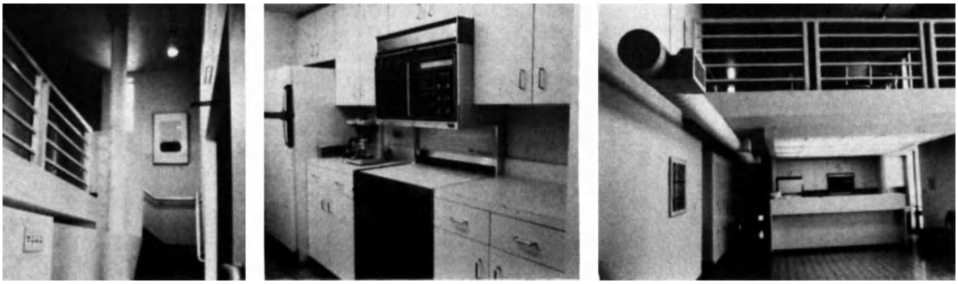

Figure 6. Views of the Kitchen, Mezzanines

Figure 7. Entrance Air Lock Space, South Wall Shading, Office.

annual water heating needs of a family of three. The system was developed under a Department of Energy contract by Arizona State University for home owner do-it-yourself application with Dr. Stanley Mumma as Principal Investigator. The south wall of the building provides 200 sq. ft. of active warm air solar collectors with a rock bed storage subsystem. A second option in the south wall is 200 sq. ft. of direct gain vertical windows. The third option is 100 sq. ft. of Trombe masonry wall with the solid wall itself being approximately 10 in. thick.

After careful consideration, it was decided not to attempt the use of absorption cooling because this is not cost - effective at the present time. Instead using a pool as a water source, a water-to-air heat pump was designed to be used to provide both summer cooling and auxiliary winter heating by Professor John Yellot. This design was also rejected by the construction managers in favor of a "York" heat pump without consultation. A feature of the house is the presence of a small swimming pool just outside the south wall which is common to the region. The pool was designed to provide water which would not be hotter than 84 F for condensing the refrigerant in the summer and not colder than 55 F for evaporating the refrigerant in the winter. The coefficient of performance of the designed heat pump system was expected to be much higher than the C.O.P. of the air-to-air heat pumps which are now very widely used in Arizona, and the mid - summer load on the electric utility would have been substantially lower than the load imposed by an air - cooled compression chiller. As stated previously, this system was changed during construction and a retrofit is necessary to test the original concept. Also, defrosting will not be encountered. The rock - bed which will provide heat storage in winter and will be used for storing "coolth" in summer, thus providing an opportunity for a relatively small heat - pump to run for longer periods of time, at off - peak hours.

Auxiliary space heating is provided by a custom wood - burning fireplace which can be used for both enjoyment and comfort. A microprocess, or, currently under development by a local electric utility company to control demand through load shedding, will be utilized to minimize adverse demand upon the utility. The possibilities of employing evaporation have been considered carefully and the air - handling and rock - bed system will have sufficient flexibility to allow indirect evaporative cooling to be used to supplement the heat pump's compression refrigeration.

TABLE 2 Energy Calculations

	Areas, U-Values, and "Ux A" Products		
Surface	Area(ft^2)	U-Value $\left(\frac{Btu\ h}{ft^2.F}\right)$	UxA $\left(\frac{Btu\ h}{F}\right)$
Ceiling	855	0.032	27.5
Above-grade walls (excluding South)	1053	0.053	55.8
Below-grade walls	634	0.050	31.7
Glazing (single, excluding South)	63	1.10	69.5
Floor slab	870	0.03	26.1
South wall			
Trombe wall	69	0.33	22.8
Air Heaters	138	0.07	9.7
Direct Gain	185	0.49 day	90.7 day
		0.42 night	77.7
Muntins & Mullions	99	0.57	56.4
Glass Frames	107	1.18	126.3
Opaque	69	0.15	10.4
Doors	75	0.38	28.6
TOTAL:			
Above grade	3583		491.2
Below grade	634		57.8

From the preceding table, the conduction exchanges are found by:

$$\text{Conduction Load} = U \times A \times \Delta t \ (\text{Btu/hr})$$

where Δt is the difference between the ambient and interior temperatures.

Also contributing to the building's heating or cooling load are internal heat generation, infiltration, and solar heat gains. The appropriate computations for these factors follow in the next section.

DESIGN SYSTEM HOME COMPATIBILITY WITH THE ELECTRIC UTILITIES

In considering the compatibility of the energy systems in the house with the use of electricity, it is important to distinguish between electrical demand and electrical consumption. Presently, residential electricity is sold by kW hours consumed rather than by demand in the Phoenix metropolitan area. However, in order to encourage better load management, the utilities are presently proposing new rate structures. One such structure would employ the demand rates with following monthly schedule: \$ 5.03/kW - summer, \$ 2.00/KW - winter, and \$ 3.00/KW - spring and fall. The energy cost would be \$ 0.0183/KWh. Another method which seems to have a great deal of popularity with the regulatory bodies is time - of - day pricing. At the present time, Arizona Public Service, which will provide electricity for this experimental home, has presented the previously described demand rate schedule to the State's regulatory body.

INTERNAL HEAT GENERATION

The heat generated by electrical equipment appliances, and people comprise the internal heat gains. In this study, the equipment is assumed to contribute 1708 Btu/hr(500 watts) and four people are assumed to each contribute 500 Btu/hr(147 watts).

Thus the total internal generation is 3705 Btu/hr(1088 watts) or 88,992 Btu/day.

INFILTRATION

The load from infiltration of outdoor air is found by:

$$\text{Infiltration Load} = \text{Volume of house} \times \text{no. of air changes/hr.} \times \frac{CP}{V} \times \Delta t \text{ (Btu/hr)}$$

where V = specific load volume, ft/lb, and CP is the specific heat of air. The house's volume is 13,700 ft3, and, because of its tight construction and well-sealed doors and windows, 0.5 air change/hr, is assumed. Values for the infiltration loads follow in Tables 3 through 7:

SOLAR HEAT GAINS

The solar heat gains that penetrate into the building vary throughout the day and year. This amount of heat can be estimated by:

Solar Gain = S.H.G.F. x S.C. x A

where S.H.G.F. is the day long ASHRAE solar Heat Gain Factor, S.C. is the Shading Coefficient appropriate for the type of glazing, and A is the area of the glazing that is sunlit. This areavaries greatly over the day and is significantly affected by overhangs and other shading devices. Estimations of the solar gains also are shown in the following tables:

TABLE 3 Summary of Average Summer Day Total Cooling Load Btu/Day

	Summer Average Day Summary	
All Units (Btu/Day)	Single Glazed	Double Glazed
2 Conduction Gains	176,897	115,432
2 Infiltration Gains	82,605	82,605
2 Solar Gains	105,288	90,730
2 Internal Gains	88,995	88,995
Total Cooling Load Btu/Day	453,785	377,762

TABLE 4 Summary of a Summer Design Day Total Cooling Load Btu/Day

Summer Design Day Summary

All Units (Btu/Day)	Single Glazed	Double Glazed
2 Conduction Gains	353,793	230,864
2 Infiltration Gains	165,210	165,210
2 Solar Gains	105,288	90,730
2 Internal Gains	88,995	88,995
Total Cooling Load Btu/Day	713,286	575,799

TABLE 5 Summary of Average Winter Day Net Heat Available for Storage

All Units (Btu/Day)	Single Glazed	Double Glazed
2 Conduction Losses	235,862	154,118
2 Infiltration Losses	110,120	110,120
2 Solar Gains	358,424	308,855
Air Heater Gains	177,706	177,706
Trombe Wall Gain	71,083	71,083
Internal Gain	88,995	88,995
Net Heat Available For Storage	+350,226	+382,401

TABLE 6 Summary of a Winter Design Day Net External Heating Requirement

All Units (Btu/Day)	Single Glazed	Double Glazed
2 Conduction Losses	448,136	292,823
2 Infiltration Losses	209,227	209,227
2 Solar Gains	358,424	308,855
Air Heater Gains	159,907	159,907
Trombe Wall Gain	71,083	71,083
Internal Gain	88,995	88,995
Net External Heating Required	-21,046	-126,790

TOTAL LOAD

The total heating or cooling load on any day is the sum of the above factors over the 24-hour period. These calculations have been carried out for a typical day of each month: the results for January 21 and July 21 are shown in Figures 8 and 9. Computations for both single and double glazing are included.

COSTS

The projected construction costs for the laboratory facility ($350,000 US) were reported at nearly double this figure ($600,000) as a result of employing a contractor and construction manager on a cost-plus basis to speed completion of construction and direct materials purchases rather than rely upon less efficient but free labor from trade apprentice training programs and a manufacturers solicitation program previously developed by the architecture and engineering team.

TABLE 7 Heating Gain Potential for the Entire House
Jan. 21st and July 21st

	Clear		Solar Gray	
January 21st t = 20°F	n=1	n=2	n=1	n=2
I Gain				
Solar	151,340	303,181	262,009 *2= 52,402)	209,607 *2= 41,921)
Trombe Wall	71,083	71,083	71,083 (*.2=14,217)	71,083
Air Heaters	160,000	160,000	160,000	16,000
II Conduction Loss	235,362	154,118	235,862	154,118
III Infiltration Loss of air change/hour)	55,040	55,050	55,040	55,040
Net Q for storage	232,021	325,106	202,130	231,532
July 21st t = 15°F				
I Solar Gain	103,356	89,062	76,967	61,374
II Conduction Gain	176,897	115,589	176,897	115,589
III Infiltration Gain of air change/hour)	44,397	44,397	44,397	44,397
Daylong total	324,650	249,048	298,261	221,560
Hourly Average	13,527	10,377	12,428	9,230

CONCLUSIONS AND RECOMMENDATIONS

Although the energy efficient house will provide almost 100 percent of its heating requirements from its passive and active solar systems, a heat pump will be used as the back-up, primarily because refrigeration will be needed for summer cooling to attain comfort in Arizona's (monsoon) season. Proper use of the rock - bed heat storage system will obviate the need for running the heat - pump when the local utility is experiencing peak winter loads for space heating by conventional resistance heaters. Similarly, the system provides for essentially 100 percent of the solar hot water, again minimizing the demand upon the utility and reducing consumer demand charge.

Although the constructed facility will allow for testing and demonstration, many important features e.g. demountable and expandible south wall; Trombe wall passive dampers; pool water source heat pump system; "clear view" collector system; and others were entirely eliminated or severely altered by the contractor and construction manager in order to speed up construction. It is therefore recommended that similar projects undertaken by others in the future make every attempt to not allow their original design to be corrupted for the sake of expediency nor delegate design decisions to construction managers.

If all homes in the Valley were to utilize the principles and various features incorporated in this demonstration facility instead of conventional housing systems it would be feasible to generate an energy demand savings of 4000 megawatts. The test results of the energy efficient home design should confirm a significant reduction in demand for energy consumption and the annual operating costs of the system.

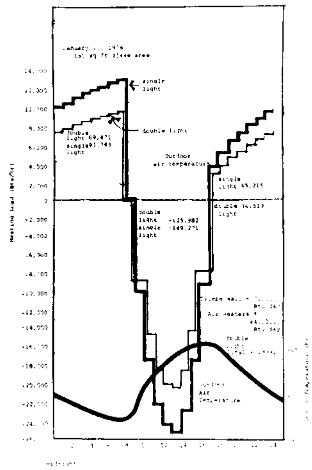

Figure 8. Heating Load Vs. Time 3 Air Heaters
(Neglects air heaters and Trombe Wall)
ASU Energy Efficient House.

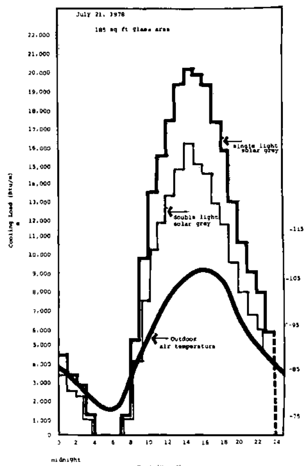

Figure 9. Cooling Load Vs. Time
ASU Energy Efficient House

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THREE SOLAR AIR HEATED HOUSES AT PETERBOROUGH WITH SUNSPACES

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ABSTRACT

The design of an active air heating system with $32m^2$ of on-site collectors and $4m^3$ of thermal storage is described. The eight operating modes are summarised. The design of the sunspaces attached to the three terraced houses is discussed together with a calculation of their performance using Method 5000.

KEYWORDS

Solar, active, passive, simulation, design, low-energy, air, collector

INTRODUCTION

In 1969 Alex Pike started a group at Cambridge University concerned with entirely self-sufficient housing. Designs were produced for the Cambridge Autarkic House, and contained an attached sunspace from which a family would retreat in adverse weather. This concept of a passive collector which is insulated from the house at night has been a strong driving force in passive design.

In 1979 the local authority at Peterborough (100 kms north east of London) asked John Littler, then a member of the Cambridge Group, to cooperate in the design of a low energy house.

The terrace of three, two storey, 5 person, 4 bedroomed houses, is the outcome then of concepts prevailing in 1979. Each house has the south facade wholly glazed: on the ground floor with a sunspace, on the first floor and roof with $32m^2$ of air cooled collectors which form the walling and roofing.

Heated air is used directly to warm the house, or heats a thermal store, and/or the domestic hot water. House and conservatory ventilation employs the passive chimney effect of the collectors in summer. The eight modes of the system (space heating $\pm$ gas back up, hot water storage, ventilation etc), are chosen by a microprocessor so that the controls are transparent to the occupants, who merely contend with a 7 day clock and thermostat.

Major aspects of the design were chosen before sophisticated computer models were widely available, but currently SUNCODE is used to recommend changes which can be implemented in the finished terrace.

The European Commission is supporting the monitoring and evaluation.

PASSIVE HEATING

The plan in Figure 1 illustrates the south facing sunspace, of internal width 6.3m, vertical glazed area $14.5m^2$, and sloping (25°) glazed area $15.7m^2$. The conservatory roof is clear for daylighting reasons, under the heavily overcast winter skies of northern Europe. The floor is of 65mm uninsulated concrete and the end walls of 225mm brick.

The plan indicates single glazed doors of total transparent area $4.4m^2$, which admit warm air to the living room. The conservatory is constructed to the same high specifications as the house. Sealed louvres in its internal and external doors can be adjusted to induce house ventilation primarily via the sunspace, thus preheating the fresh air.

Table 1 summarises calculations using Method 5000.

TABLE 1 Annual Space Heating Demand in GJ

House of Figure 1,	with occupants, but no active or passive systems except direct gain	10250
ditto. -	with sunspace described in text	9800
ditto. -	with sunspace having double glazed doors to living room	8500
ditto. -	with sunspace having an insulated roof	9000

ACTIVE HEATING

$32m^2$ of air cooled modular prefabricated metal ducts (1400 x 2500 x 35 mm) are slotted together and anchored at one end to the timber house frame. The other end slides in a slotted mounting to allow for expansion. Patent, single, tempered glazing completes the waterproof skin to the house, and covers the metal, which arrives on site with a flat black hot finish. Wide stubs lead air from the feeder duct (22mm x 200mm) running inside the 6.3m width of the conservatory roof, to the header duct in the insulated roof space. Hot ducts in the house are sprayed with 25mm of polyurethane, and all joints are very carefully sealed with aluminium tape. The design collector flow rate is $20m^3/m^2h$. This low flow is chosen to achieve an acceptable speed in ducts of acceptable size and cost. A fusible link (released above $120^\circ C$) opens a safety damper to ambient, to protect the system in case of failure (see 1 in Figure 2). The air stream passes first over a transfer coil to the domestic hot water (2 in Figure 2), and then via a fan to either the heat store (3) or the living room (4). Auxiliary heat from a gas boiler (5) can be introduced at point 6 in the diagram. In the evenings, a second fan reverses the air flow through the heat store to warm the rooms. The store consists of 1800 pierced bricks stacked over a plenum which encourages even air flow over the large surface area.

CONTROL SYSTEM

For a solar heating system to be successful it must be accepted by the building's occupants. Our way of achieving this is to make the solar controls user-transparent, so that they appear like those of a conventional central heating system.

A microprocessor based controller operates a 7 day clock and room thermostat, and handles all decisions about how best to use the solar hardware. The processor receives eight temperatures: bottom of domestic hot water tank; top of DHW tank; air feed to room grilles; bottom of heat store; top of heat store; collector outlet; and ambient temperature and living space temperature.

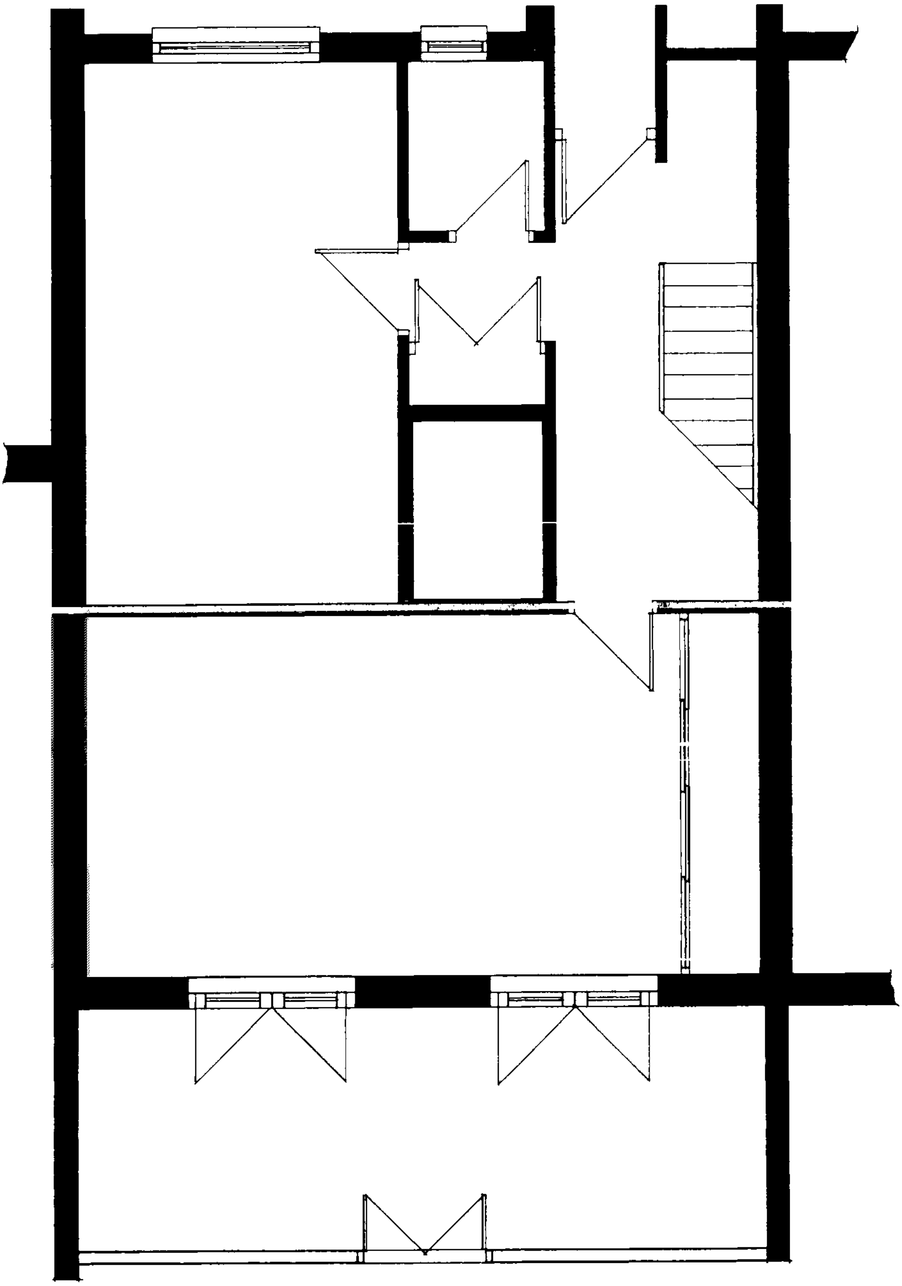

Fig. 1. Ground floor plan of the Peterborough houses.

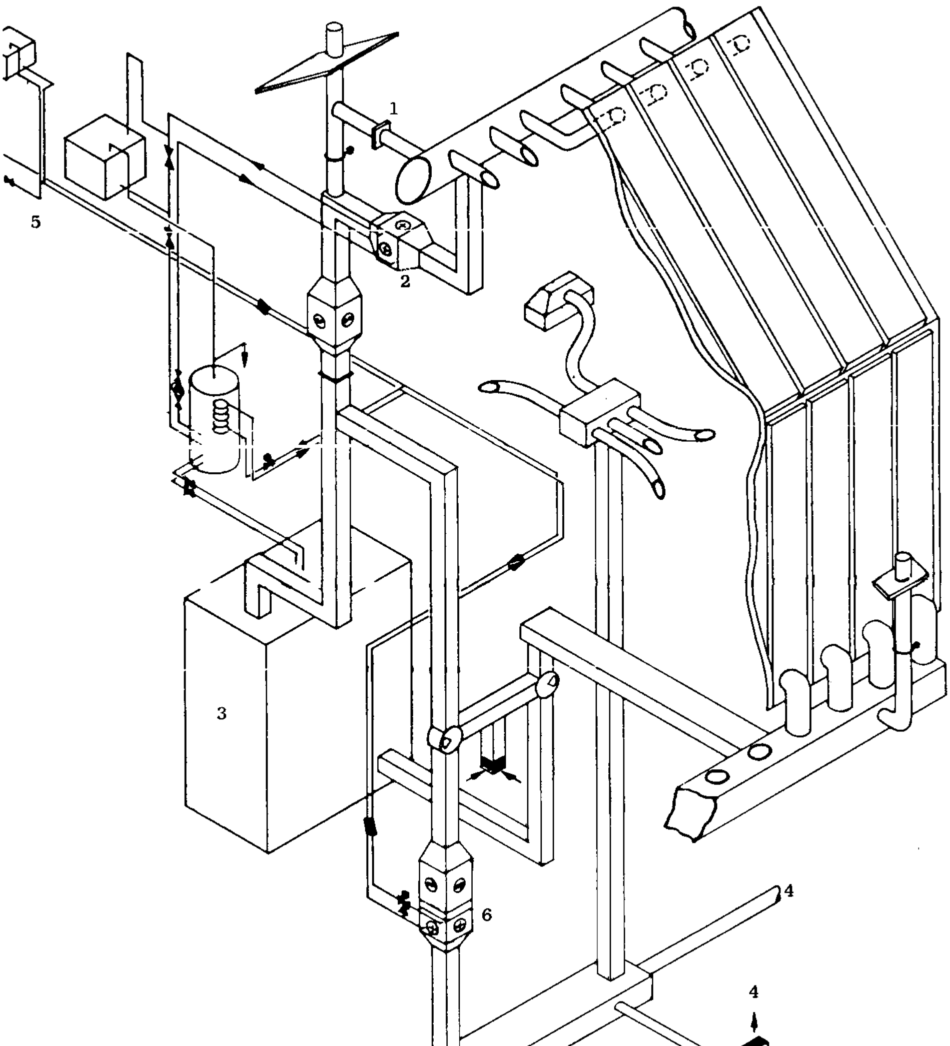

Fig. 2. Axonometric of the solar heating system in the houses.

The operating configurations are:

Mode 1	Collector vents to ambient and thermosiphoning hot air stream heats DHW
Mode 2	Collector heats DHW via a closed thermosiphoning air loop
Mode 3	Collector heats store and DHW using a fan
Mode 4	Store heats rooms (with fan)
Mode 5A	Collector heats rooms with gas top up available (with fan)
Mode 5B	Collector heats rooms without the option of top up (with fan)
Mode 6A	Gas boiler heats rooms (with fan)
Mode 6B	Gas boiler heats rooms with collector preheat (without collector fan)

Two modes are expected to prove particularly useful in northern climates where the system would otherwise be under utilised. 5B applies to the wings of the heating season, when the solar system will endeavour to heat the living space but will not call for gas top up. In 6B sufficient air is drawn into the collectors (from the conservatory or ambient) to meet the ventilation requirement. In many circumstances the collector thus preheats the air and slightly pressurises the house, thus preventing infiltration from ambient.

MONITORING SYSTEM

A Microdata 1600 records 100 channels on cassette, and the data is archived on DEC tape.

SOLAR HOUSE FOR HOT AND HUMID CLIMATE

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ABSTRACT

A Solar house was constructed using passive and active devices to provide comfortable conditions throughout the year in Baroda, where climate is hot and humid. The main features incorporated in the construction of the house include roof lawns, optimized overhangs, cavity type walls, verandahs and east west orientation of the building to reduce heat load. Attention has also been given to landscaping for adding to the comfort. The owner's experience has been quite satisfactory.

KEYWORDS

Passive systems; roof lawns; orientation; Solar hot water system; Solar cooker; photovoltaic systems; hollow walls; greenhouse; special windows.

INTRODUCTION

In recent years, attention has been focussed on passive devices to reduce energy requirements of a house in addition to the use of active Solar systems. In contrast to active Solar systems, passive systems require very careful attention to the details of construction of the house, as well as to the location and the characteristics of the climate. One has to take into consideration whether cooling or heating has to be the dominant feature. In cold climates, the predominant factor is the space heating, while in hotter climates, cooling becomes the predominant one. The climate in Baroda is usually comfortable in winter but is hot during summer months and therefore uncomfortable. The passive systems incorporated in the design of this Solar house are, therefore, predominantly based on cooling requirements.

CLIMATE IN BARODA

Baroda is in Gujarat State of India and is located at 22° north and 73° east, and the mean sea level height is 35m. The temperatures in winter are in the range of about 10 to 30°C and usually, the houses are comfortable if windows and doors are closed. The temperatures in summer rise to as high as 40 to 44°C and this is the most uncomfortable season. In summer, the relative humidities also reach high levels of 60 to 70%. The wind velocities in summer are about 8 to 10m/sec and wind direction is from south-west or west. The wind velocities in winter are low at a level of 3 to 4m/sec and normal wind direction from north and north-east. (Sharma, Ali, 1969).

DESIGN PHILOSOPHY

The most important consideration in the building design has been creating comfortable conditions throughout the year without using any active systems such as, electric heaters or air-conditioners. The other factors such as hot water requirements as well as electricity needs for operating various devices such as lights, radios, etc. are also taken into consideration. The house has been designed for a family of 4 to 6 members and has one drawing room, a kitchen, a master bedroom, a children's room and a guest room. The hot water requirement of the family is estimated to be 350 litres at 60°C for bathing as well as washing of clothes and kitchen-ware.

The electricity requirements for light, fans and entertainment equipment is estimated to be about 3 kW-hr/day. This requirement does not include the electricity required for operating the refrigerator or kitchen equipment.

As described in the preceeding paragraphs, predominant consideration in designing the passive systems was creating comfortable conditions during summer as well as in winter. Since summer weather is very hot and humid, the major consideration has been to reduce the heat loads into the buildings as well as making the maximum use of natural winds.

The Solar load or roof and walls of the building were analysed for summer conditions in Baroda and it was found that for same surface area, the roof is responsible for more than 50% of the Solar heat load, while east and west walls contribute about 20% each. The north wall contributes about 4% while south wall contributes only 2% of the heat load. (Mani, 1980).

These factors as well as climatic conditions were taken into consideration in working out the detailed design of the Solar house. The design details are described in the following :

Orientation

An east-west orientation has been selected for the building to reduce the east and west wall areas and thereby to reduce the Solar load on the building.

Verandahs

East/west walls of ground floor have extended verandahs which reduce Solar load on these walls to almost zero. The verandah on east side is used for sitting and relaxing in open air and a swinging sofa is provided for comfort. On west side, the verandah partly covers the washing area and accommodates a Solar greenhouse. The Solar greenhouse is used mainly for the purpose of drying clothes and is often used for drying of papads, chillies and similar items. These details can be seen in Fig.1.

Walls

The north and south walls contribute very little to the heat load of the building. Overhangs provided for these walls effectively reduce the Solar load, and therefore, these walls are constructed in the normal fashion. The east wall on ground floor is covered by a verandah and therefore, does not need any special construction. The portion of the west wall adjoining the greenhouse is covered with foamed polyester to reduce heat load from hot greenhouse into the bedroom. The east and west walls on the first floor do not have extended verandahs for aesthetic reasons and, therefore, are constructed hollow to reduce the heat load. These details can be seen from Fig.1 and Fig.2.

Roof

The roof is responsible for nearly 50% of the heat load and, therefore, needs most careful consideration. After carefully evaluating all other options such as heavier insulation, hollow construction, roof pond, etc. we have selected roof lawns for its effectiveness and aesthetic appeal. All exposed roof areas on first and second floor are covered with lawn. The roof is first covered with a plastic sheet and then a layer of soil is given for preparation of lawn. Thus, chances of water leakages are avoided.

Landscaping

In addition to the features described above, the house is surrounded by judiciously arranged trees, ponds and lawns. The lawns are provided all around the house to reduce reflected radiation as well as to cool to some extent the fresh air from entering the house. Tall trees are provided on east sides to avoid direct Sun in the verandah. On west side, only small shrubs are provided so as not to obstruct the westerly winds.

Windows And Doors

The location of windows and doors are decided with a view to allow natural wind movement through the rooms. Since the wind direction is from west or south-west, wherever possible, windows and doors are provided in the direction of the wind.

The features described above are general and are used in the overall design of the building. In living room and kitchen, additional special features are incorporated to improve the comfort conditions. Active Solar systems are also built in to provide hot water and electricity. These systems and the special features are described in the following.

GROUND FLOOR PLAN OF SOLAR HOUSE

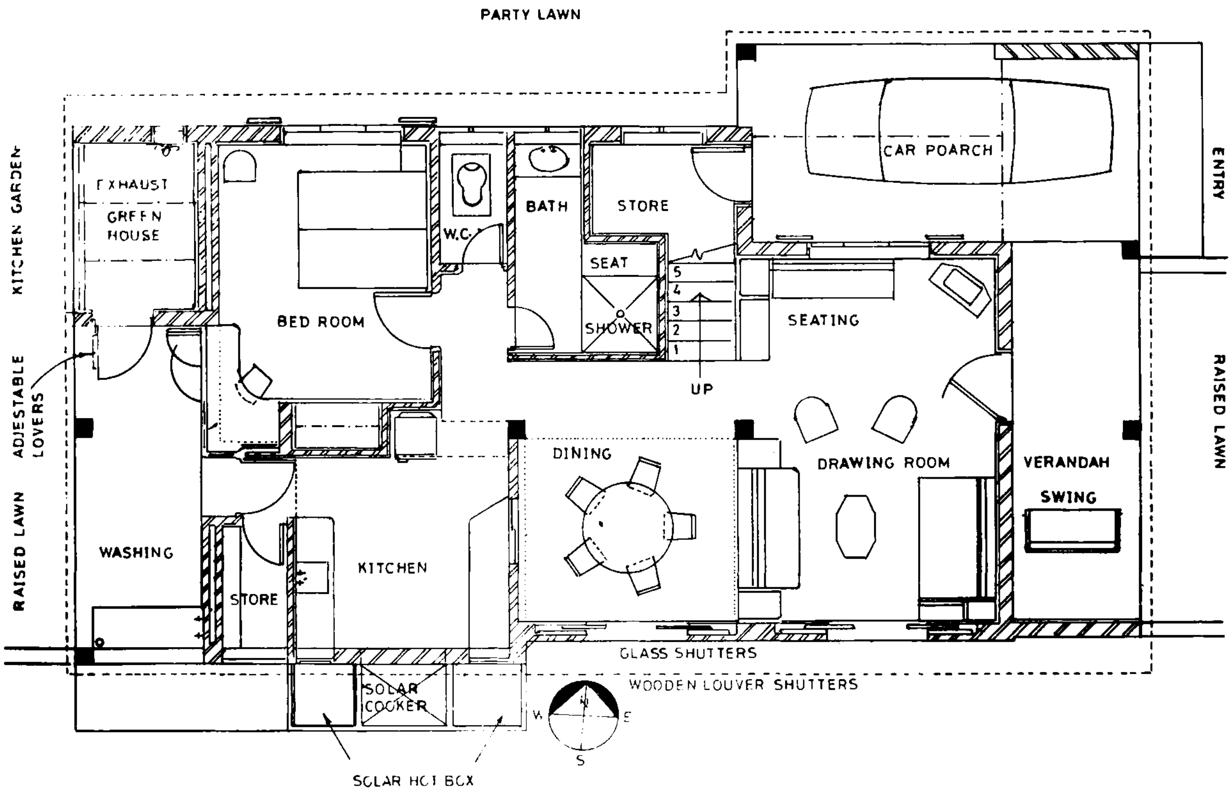

Fig.1. Ground floor plan of 'Solar House'

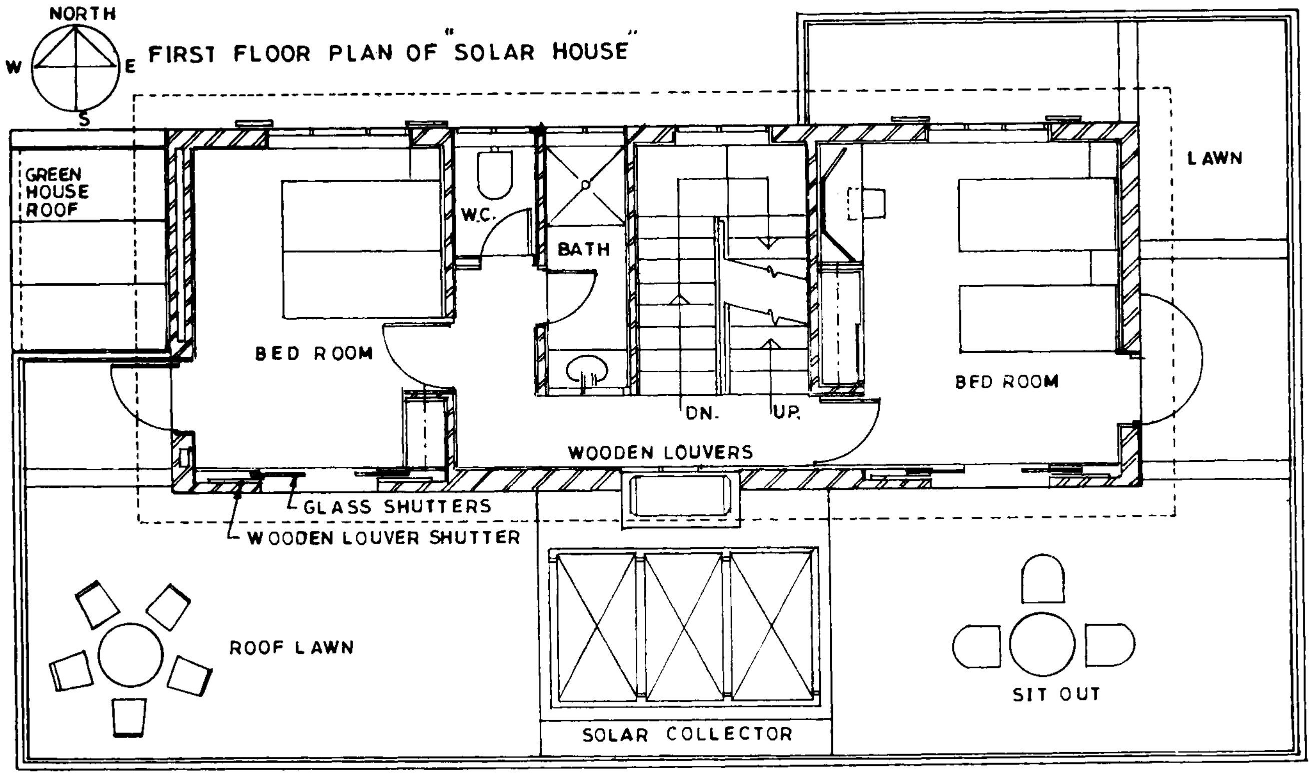

Fig.2. First floor plan of 'Solar House'

KITCHEN

The kitchen is usually the most uncomfortable place because of all the heat generated during cooking. Special attention has, therefore, been given to the kitchen to create comfortable conditions.

The outside ambient air is humid and any further addition of moisture would normally become uncomfortable, but when such air is admitted to kitchen, it will be further heated and the relative humidity will be lowered. It is expected that this condition will be more comfortable than hot and dry condition which normally exists.

The kitchen is, therefore, planned with floor level air entry which can be controlled by means of dampers. The air is made to flow over a pond of water and is thus cooled before it enters the kitchen. A chimney has been provided in the kitchen to remove hot air and allow better air circulation.

A few innovations have been added to the kitchen to use Solar energy to the most possible extent. The kitchen is planned to have a south facing wall and a Solar cooker is incorporated which can be operated from within the kitchen without having to go outside. On both sides of the Solar cooker, Solar hot boxes are provided for keeping the food warm. All these features can be seen in Fig.3 and Fig.4.

LIVING-ROOM

The living room has a large south facing wall and large windows are provided to admit summer wind as well as winter Sun rays. The windows have two sliding doors. One door is glass-paned to be used in winter when Sun rays are to be admitted, but no wind. The other door is with wooden louvers which allow wind to pass through, but shut off the summer glare.

A part of the ceiling is inclined to accommodate a thermosyphon Solar hot water system. The system capacity is 350 litres per day and provides hot water at 60°C.

SOLAR PHOTOVOLTAIC SYSTEM

A small Solar photovoltaic system is used in the building to power lighting, fans and entertainment equipment. The main purpose was to establish the reliability and usefulness of photovoltaic system rather than economics.

The photovoltaic system output is connected to 24V storage batteries through electronic regulators. The batteries in turn are connected to an invertor to provide 220V AC output. This has been done in order to keep Solar system compatible with the grid supply. For the purpose of power distribution, the entire house is divided into four convenient zones with changeover switch from the mains to Solar for each zone. Thus, any of the four zones could be connected to Solar photovoltaic system whenever desired.

The Solar panels can provide about 1500 W-hrs per day, but because of low efficiency of the available inverters only 750 W-hrs per day can

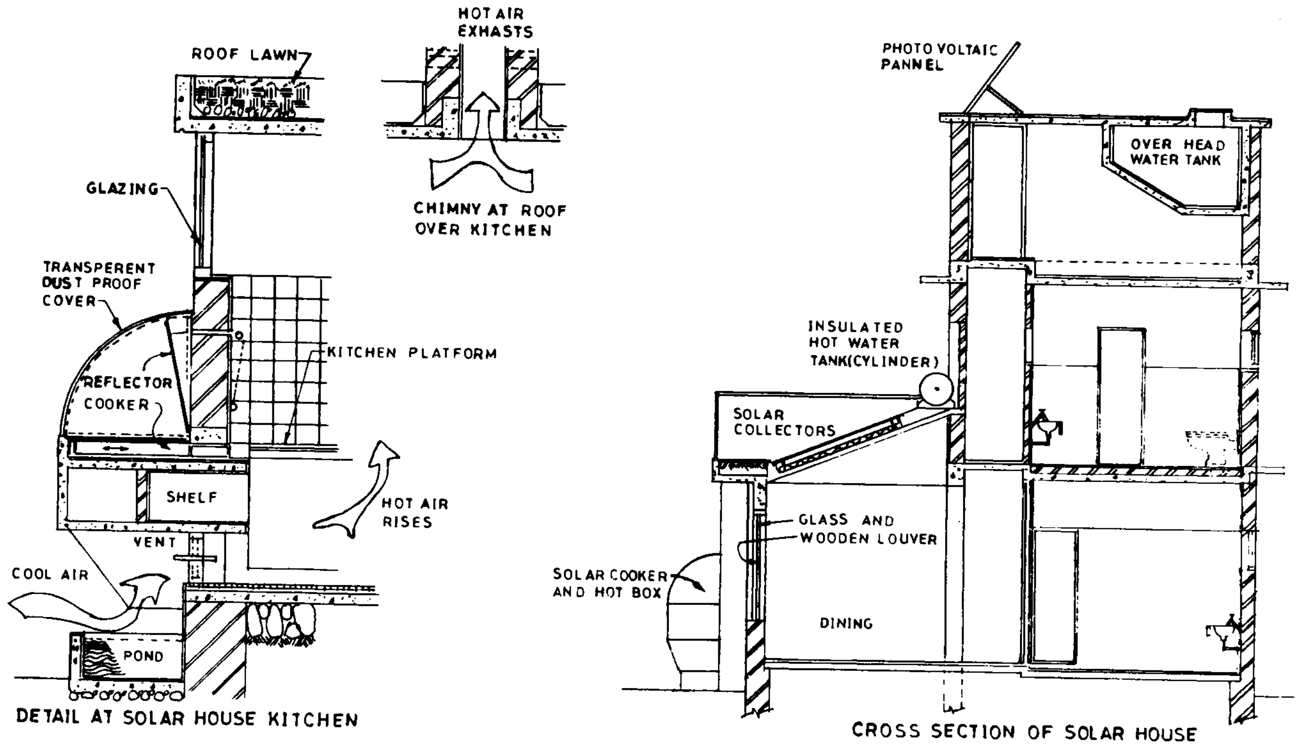

Fig.3. Cross-sectional details of 'Solar House'

be used. An improved design of inverter is being planned to increase the overall system efficiency to provide a net output of 1000 W-hrs. per day.

OWNER'S OBSERVATION

During the last one year or so of occupation, Solar house has been found to be quite comfortable. On the whole, the passive systems have worked well though, some improvements could be made. From a comparative study of the room temperatures of the Solar house, and those of a conventionally constructed building nearby, it was observed that the room temperature in Solar house was as much as 5°C to 6°C lower during summer. The main contributing factor is the roof lawns which have significantly reduced the Solar load.

In summer the louvered doors on all windows were used to shut off Sun rays while allowing air circulation during the day. During night, the windows were fully opened to allow maximum air circulation. The fans were not required to be used during most of the summer nights. It is felt that air movement would have been better if the building was rotated clockwise by 7 to 10°.

The hot water system has always provided adequate output to date. The electrical back-up has not been connected and the system capacity has been adequate to meet all demands even though both the bathrooms as well as kitchen and wash areas have been connected to the system. No maintenance has been required so far.

The Solar cookers as well as hot boxes have performed well except for some problems encountered for evening meals. It has been possible to cook all cereals and vegetables in the Solar cooker for the morning meals. Initially, there were slight problems of movement of cooker trays, but these have been solved by using rollers underneath for smooth movement. The Solar greenhouse has normally resulted in equal or slightly faster drying than outdoors. The major advantage has been the aesthetics of not having the clothes hanging all over the place.

The photovoltaic system is working well though it can meet only a small portion of the total requirement.

The overall energy requirements have come down from a level of about 200 kW-hrs a month to about 140 kW-hrs a month. The major contribution to these savings have been from comfortable conditions obtained by passive systems. The photovoltaic systems have contributed on the whole about 15 to 20 kW-hrs a month.

CONCLUSIONS

1. The passive systems incorporated in the building have been more than adequate in providing comfort.

2. The roof lawns are very effective in reducing heat load on a building. In addition, they are aesthetically attractive.

3. The natural air circulation through the rooms has been adequate. It could have been improved by turning the building through 7 to 10° to bring it in line with the more predominant wind direction.

4. The louvered and glass paned doors of the windows have been very effective in controlling the room conditions.

5. The lawns all around the building have reduced glare and reflected sunlight to a significant extent and have added to comfort.

6. The Solar hot water system based on thermosyphone principle has been more than adequate to meet all hot water needs even during winter.

7. It has been possible to use Solar cooker effectively for morning meals.

8. The photovoltaic system has worked satisfactorily without problems. The contribution of this system to overall energy requirements is comparatively small.

Fig.4. Photograph of 'Solar House'

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PHOTOVOLTAIC EQUIPPED PARKING AND SHADE STRUCTURE
KING ABDULAZIZ INTERNATIONAL AIRPORT
JEDDAH, SAUDI ARABIA

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ABSTRACT

This project marries the most current solar technology with an equally exciting structural system. The space frame provides an architecturally integrated response to functional needs and technical requirements. It is a culturally responsive prototype. The electric system in one day collects, stores and makes available enough solar-produced power to light the entire 88,504 sq.ft. parking for 5 consecutive nights.Adjacent to the 1,760 solar panels, flush mounted shade panels arranged in a repetitive, geometric pattern suggest islamic art forms. Together they provide 80% of shade in intentional geometric shapes. The carefully designed space frame geometry is capable of taking any orientation without any self-shading and to accomodate future combinations of solar thermal/photovoltaic arrays.

KEYWORDS

Photovoltaic; space frame; solar energy; architectural integration; shade structure.

INTRODUCTION

The Kingdom of Saudi Arabia holds a dominant position in energy supply since it is one of the largest oil producing country in the world. The revenues from oil sales are the primary source of income in the Kingdom. The country's leaders are dramatically aware of an urgent need for diversification in the economy as well as capitalizing on the present assets. Major agricultural and industrial undertakings have materialized as part of the five year development plans. Similarly, the Kingdom has repeatedly shown its commitment in researching further its other natural resources: mainly solar energy.

Such investigations are carried out primarily at three levels: inter-governmental agencies, (e.g. Solaris project US-Saudi Arabia), government sponsored research in universities and private sectors (e.g. SANCST [1]) and governmental/privately financed commercial applications.

* Swiss Society of Engineers and Architects
[1] Saudi Arabian National Council for Science and Technology.

The photovoltaic project at the King Abdulaziz International Airport described in this paper falls in the last category. Al-Daryyah Institute[2] was approached by Arco Solar Inc. to explore the possibilities of a photovoltaic application in Jeddah. An adequate site was selected on the airport grounds near the supporting facilities area. An approximately 210 car park in front of the administration building needed to be shaded. In November 1979 it was decided to erect a shade structure and to locate the solar panels on top. (Fig.1)

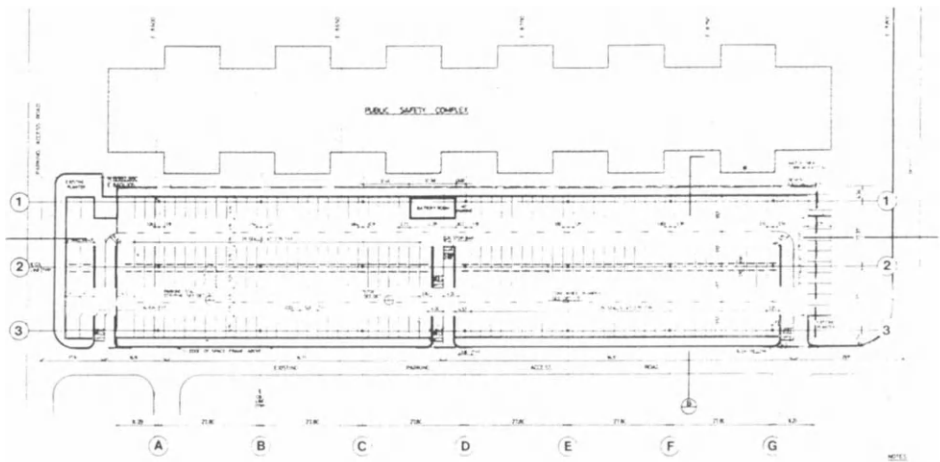


Fig.1 Parking general layout. (North up 20° to the right)

The power generated by the photovoltaic demonstration is primarily used to light the parking and pavement at night and, at a later date, if additional power is made available it could be used for the airport's emergency system.

Arco Solar Inc. in the capacity of Prime Contractor selected Solar Resources Inc., presently R.S.A. Architects in Los Angeles, as the architects of the project. Functional and conceptual criteria were developed and defined from the very start of the project in order to create a dramatic, yet practical, demonstration of the capabilities of directly created solar energy. Both objectives are best served if the structure on which the panels are installed, makes a positive architectural and environmental contribution to its intended location. It was, therefore decided to propose to the client, International Airports Projects [3], an architecturally responsive solution: a space frame structure with an integrated energy system and shading panels.

THE ARCHITECTURE

The marketability of a new technology, such as photovoltaic, can be successful only to the extent that architectural considerations are given from the conceptualization stage of the product itself. Once the product is on the market, it becomes the architect's responsibility to understand, integrate and, if desired enhance the specific features and special characteristics into the design.

2 Non-profit organization to promote solar energy in Saudi Arabia.

3 Ministry of Defence and Aviation.

In the photovoltaic parking shade structure, realistic functional and conceptual criteria incorporating operational, technical and sociological parameters were developed.

Light technology and light structure.

The space frame structural form was selected to respond to the difficult problem of covering a very large automobile parking area. As architectural technology, the space frame is a contemporary equivalent to the leading edge nature of photovoltaic. The structure is lightweight, appropriate to solar panels which themselves weigh only 3 pounds per sq.ft. (14.6 Kg/m^2). The space frame was accepted by the client as a viable alternative to the airport's parking standard design of precast concrete double-tee beams.

Sun motion and appropriate geometry.

Jeddah is located on the West coast of Saudi Arabia at 21.4^o North latitude. The sun's altitude varies throughout the year between approximately 88^o alt. 0^o az. in June at noon and 44.8^o alt. in Dec.at noon. The azimuth angles for the month of June are between 65.98^o at 600 hoursand 294.95^o at 1900 hours.

Since the photovoltaic cells are connected in series it was of primary importance to avoid any shade from the structure to be cast onto the panels. For economic reasons and design flexibility it was decided to allow 8 to 12 panels to be wired in series to form one array.(Fig.2)

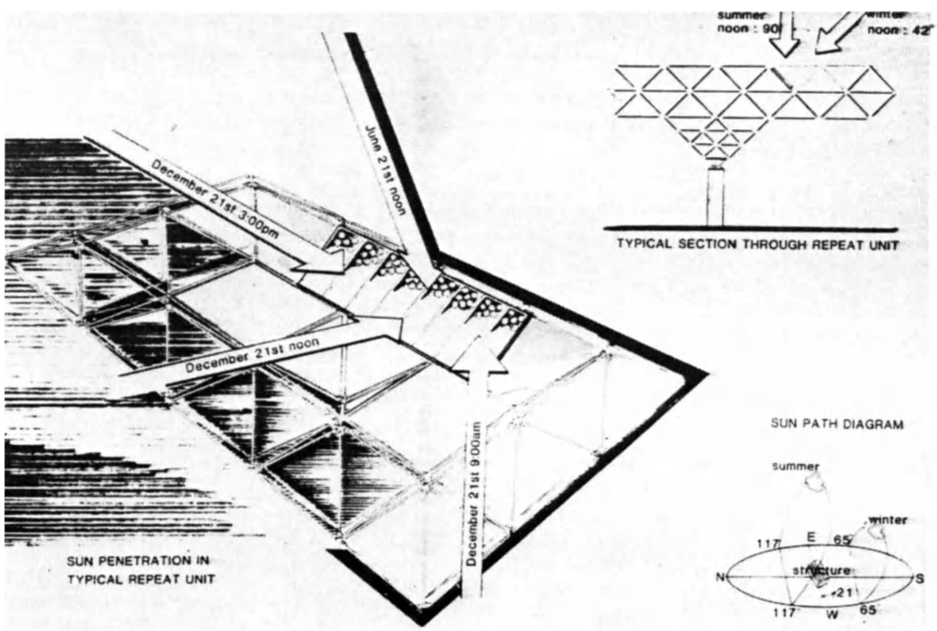


Fig. 2 The geometry : no self-shading throughout the year.

The combination of structural requirements and solar orientation resulted in the decision to use a double layered space frame with an equatorial chord at mid-height. The upper part of the space frame became the support structure of the photovoltaic arrays and adjacent flush mounted shade panels. This structural system was also selected because it satisfied the requirements of total integration and optimal flexibility. The 22.8 ft. square (6.95m) structural module gives total freedom for any orientation: two equal 22.8 ft.x11.4ft. (6.95m x 3.475m) receptacles are created -in dividing the basic square in half- with either a North-South or East-West predominant orientation. Thus maximizing solar exposure for any given site.

Open structure and integrated elements.

At the time, this project was the largest photovoltaic application in the world. It was decided to make an architectural demonstration of a perfect marriage between a new technology and an eminently flexible structural system. All components were integrated within the open structure : photovoltaic and shade panels, conduits, light fixtures and junction boxes. In addition, the careful location of all elements within the intricate but simple geometry, allows the viewer to be "educated" about the system from down below. The solar panels can be seen through the shade panels as being the collecting devices. (Fig.3). Colour coated rigid conduits and J-Box, clamp mounted to the equatorial chords, indicate whether the power is going from the arrays to the storage or from the batteries to the light fixtures.

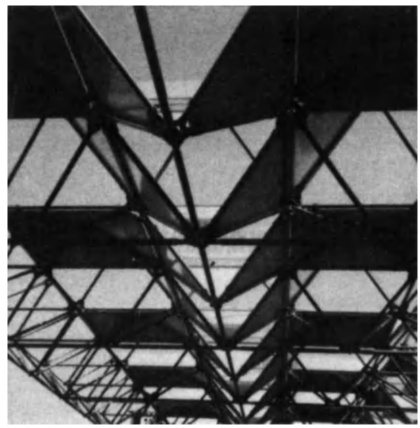


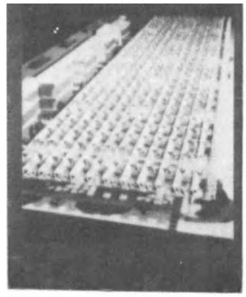
Fig.3 The photovoltaic panels: view from below.

Light and shade versus sun collection.

The frame's structural module was designed according to the required solar access. The patterns created by the structure were further studied considering local traditional Islamic imagery. Whereas the function of the structure is to provide shade during hot summer days, it simultaneously collects solar radiations , converts them into electricity, to be reused at night for a specific purpose: lighting the car park. Light therefore, was, as it is in most hot climates, a major architectural design constraint. This opportunity was taken by creating a garland of light within the structure and the dark surrounding buildings by studying diurnal and nocturnal light and shadow effects.

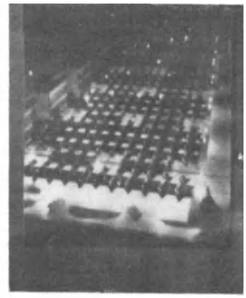
While experiencing parking during office hours, the user discovers the imagery of the roof structure's coloured panels alluding to the light and shade qualities of canvas covered shaded village bazaars (Fig.4). The 20 % direct radiation that filters through the structure creates a distorted negative image of struts and panels which moves at 15^{o} per hour on the asphalt black topping. The 21 tree-shaped supporting colums create unobstructed lightwells breaking the monotony of such a large area. At night the image is reversed. A viewer from a low flying airplane could observe the 88,515 sq.ft.(8223 m^2) roof structure with its rythmic repetition of opaque solids and lit voids. The light intensity varies between 5 and 15 foot-candle throughout the usable area (Fig. 5 and fig. 6).

Fig.4 Daytime view from below



DAY

Fig. 5



NIGHT

Fig.6

Day-time and night-time contrast on full model.

THE PROJECT

The area covered by the space frame measures 621.3 ft. (189.38m) by 142.45 ft.(43.42m). It is suported by 21 (3 N-S & 7 E-W) tree-shaped colums "growing" out of the frame and resting on 7ft. (2.10m) high round concrete columns. The maximum span in the East-West direction is 91.2 ft.(27.80m) and the North-South direction is 60 ft.(17.37m) Cantilevered areas are 14.24 ft. (4.34m) East-West, and 37 ft.(11.29m) North-South. (fig.7)

Fig.7 View from the S-W corner.

The tubular structure itself includes mainly two different sizes of struts: at the equatorial, upper and lower chords (approx. 2¼"-5.7cm-) and the diagonal chords (approx. 1 3/4"-4.45cm- in diameter). The upper and lower chords are tapered near the nodes. The design includes about 21 different nodes based on the same geometry. The fastening devices are galvanized nuts, bolts and washers. 16 to 24 gauge sheet metal panels are flush mounted adjacent to the solar arrays on the sloped sides of the repeat units and horizontally on the equatorial chords.

White struts with green and blue shade panels were the original selected colours. Close to the end of the project, the client insisted on having an overall sandy colour in order to avoid discolouration due to sand storms. Two hues of brown for the struts and shade panels were eventually selected. All the finishes are a high resistant electro-applied polyester powder coating.

The battery room, located on the north side of the parking center line, is a 38.3ft. (11.67m) by 16.4 ft.(5.0m) reinforced concrete masonry unit structure. The two room layout allows for battery storage and electric equipment. The exterior finishes are insulated white sandwich panels (8.2'x2'x0.15' - 2.5mx0.61mx0.05m). Two inches(5cm) rigid insulation is installed on the roof. The roofing is a four ply bitumen and aggregate 20 year roofing system. One 13,500 btu American Air Filter air conditioner is used in each room. All doorsare equipped with gravity or fixed louvers and panic bars. Paints are acid resistant. An emergency eyewash and shower are provided. The floor is brush-finish concrete sloped to the drain. The drainage system has an acid separator before it reaches the airport's main drain. (Fig.8)

Fig.8 View of the battery room.

All material used meet the airport's general specifications and, as required, either to the B.O.C.A., U.B.C. and/or National Fire Codes[4]. A primary concern of the design team was to maximize manufacturing, assembly and structure/solar interface control in the US while minimizing on-site requirements.

Full scale destruction test were carried out. At 32,500 lb/in^2, only moderate deformations occured at the upper chords and flanges.(Fig.9)

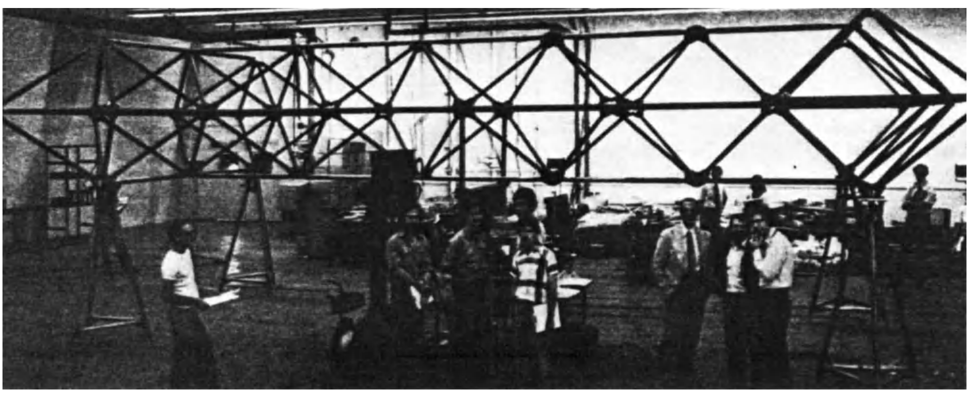


Fig. 9 Full scale model to be tested in manufacturer's factory.

THE ELECTRIC SYSTEM

The on-grade automobile shade structure in one day collects, stores and makes available enough solar produced electricity to light the entire parking area-incl. traffic signs- for five consecutive nights. Sizing computer programmes were developed and run with the Jeddah climatic characteristics. The amount of the on-the-ground light intensity, the number of light fixtures and solar panels were calculated by Arco Solar Inc. inhouse computer facilities.

The structure incorporates 1760 Arco Solar Inc. ASI 16-2000 1' x 4' (0.3mx1.22m) panels architecturally integrated within the upper chord of the space frame. One

4 American building codes and regulations.

lightweight, full perimeter aluminum frame panel has an output of approximately 35 peak watts. The 33 series-connected 4" (10 cm) diameter cells are fixes between a polymer-coated steel foil back surface and a water-white grade of tempered glass as front surface. The laminated glass is a tough protection against the frequent high relative humidity and sand storms experienced in Jeddah. The 220 arrays throughout the structure are each composed out of 8 panels. The panels are wired in series by interconnecting plastic sleeved wires. Each array has one combined output terminal per polarity located at opposite ends of the module (fig.11)

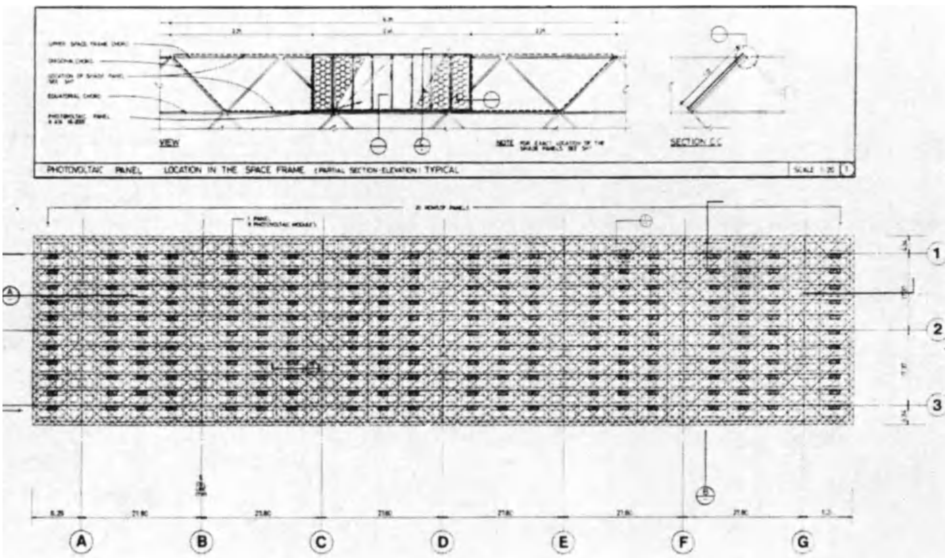


Fig. 11 Photovoltaic panel layout.

The total of 61.6 Kw generated daily are wired through colour coded rigid conduits. (Red and blue from source to storage and yellow to the light fixtures; white is neu-- tral). The clamp mounted system hangs at 8" (20cm) below the upper and equatorial chords. J-boxes, condulets, conduits follow the space frame's geometry on the horizontal and diagonal struts. From an architectural standpoint, a conscious attempt was made to use this photovoltaic demonstration as an educational tool. One can easily follow the different phases included in the system such as power generation, wiring, storage and re-use. (Fig.12)

Fig. 12 Lights & conduits

The daily produced power is stored in two rows of 6 lead-antimony batteries. The two battery strings have each 120 cells and each string is 1440 amp/hour. The specially designed battery room offers all the required conditions to ensure a proper operation of the system -room for battery maintenance,balanced temperature at 68^{o}-77^{o}F (20^{o}-25^{o}C) with two 13,500 btu solar powered air conditioners,acid separator and full operation security. The equipment room includes charge controllers, battery protectors, control panels and invertors. The direct current is inverted into alternative current and fed into the lighting system by means of two NOVA 10 KVA 240 VDC-120/240 VAC, 1 phase 60 Hz invertors.

The 116 General Electric Minimount light fixtures are dispersed in a symetrical pattern throughout the parking area. They are suspended at the nodes at the equatorial chord and provide a general illumination of between 5-15 foot-candle per sq.ft. These high pressure sodium lighting fixtures use 70 watt lamps and consume approximately 88 watts with ballast. The total hourly demand is approx. 10.2 KWH.

CONCLUSION

It took less than six month to build from start to finish and final costs have not been releasd. The project has been operational for the last year without any troubles. Regular maintenance such monthly battery checks were performed as originally scheduled. The users have expressed great satisfaction with the structure which provides adequate shade for the vehicles and the pedestrians alike. Enough lighting is provided at night to insure total security. Al-Daryyah Institute and the Director of International Airports Projects have expressed a strong interest in such a structure. They also have expressed interest for a potential follow-up in the future at the new airport in the capital city of Riyadh.

NOTES

The author of this paper was Architectural Project Manager at Solar Resources Inc. and R.S.A. Architects, Los Angeles, CA., during the entire project (1979-1981). Arco Solar Inc. was the architect's client and also prime contractor. The Owner is the Saudi Arabian Ministry of Defence and Aviation, International Airports Projects. The space frame was Synestructics Inc., Chatsworth, CA.

All measurements are given first in feet and inches and then in metric. The reason is that the basic size module, which was the ASI 16-2000 photovoltaic panel, was 1 foot by 4 feet.

This paper was written in Saudi Arabia without all the technical information available since all documents are located in the U.S. Some figures are given from memory and should be considered in an order of magnitude.

LYKOVRYSSI - A SOLAR VILLAGE NEAR ATHENS

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SUMMARY

The W. German and Greek Governments decided in 1978 to collaborate in the construction of a 435 unit Solar Village to be built near Athens. The Village includes six different heating regions ranging from centralized and decentralized active to passive system together with domestic water production. The architectural design is based on simple basic principles of energy conservation with the purpose to provide a test for further applicability. Construction is due to start during 1983 and the comparative performance of the different systems will be monitored for four years.

Greece, like many other countries, has gone a long way - in the wrong direction - since Plato quoted Socrates in giving advice as to the right way to build human settlements in order to "best make use of the sun". Throughout time vernacular architecture, by trial and error both in respect to design and the materials used, respected and utilized, to the advantage of the inhabitants, local climatic conditions. Present times, with the pressure to house large numbers at low cost, the speed of construction and above all the abundance of cheap energy, has led to the construction of buildings that, in many a case leave a lot to be desired, as far as the quality of shelter is concerned. Greece is lucky from one point of view that the climatic conditions do not necessitate construction to shelter from the extremes, neither hot or cold, but on the other hand the temperature variations from summer to winter create a problem which in its entity is both diverse and challenging.

The primary aim of Solar Village No. 3 is to reduce oil consumption. Heating needs are reduced by appropriate architectural design and passive solar measures on the one hand and optimized non-conventional active systems on the other. Domestic hot water will also be provided by both active and passive solar systems. No air conditioning has been foreseen. Instead natural ventilation will be an important feature in the project.

General view of model

The site is located in the suburb of Lykovryssi, 18 km north of central Athens. The site has an area of approximately 7,2 ha and an overall density of about 220p/ha.

A mild climate prevails in the area with a need for heating in winter (1180 degree days). In summer overheating can easily be a problem if proper measures are not taken. Due to the climate, outdoor living will be an important factor in the life pattern of the inhabitants. In general, months in which no sun is desired include June, July, August and September. May and October could use daytime collection - with storage - to moderate cool nighttime temperatures. The remaining six months will benefit from full solar access and solar heat utilization. Months in which ventilation is needed include June, July, August and September. Nighttime ventilation through a storage (capacitance) mass would be especially useful, utilizing the cooler night temperature conditions to provide a heat sink for the following summer day.

Overall bird's eye view

435 apartments will be provided in three sizes of 60-80 and 100m² with one, two and three bedrooms respectively.

Housing has been organized into neighbourhoods with childrens' play areas provided for each group. Pedestrian ways connect each neighbourhood to the centre. Vehicle movement is confined to the perimeter except for services and parking. A number of units are organized as two storey row houses.

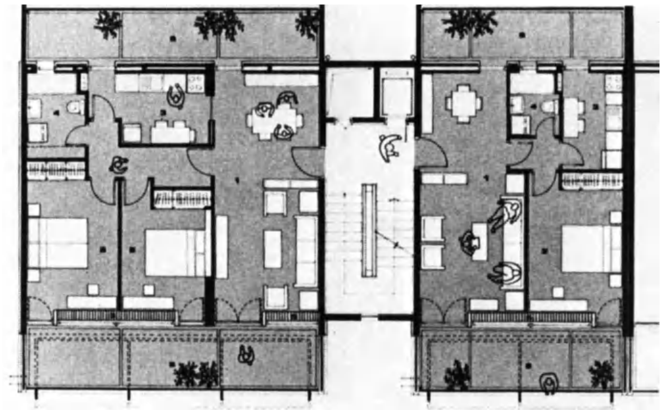
Living areas are on the ground floor opening onto private gardens to the south while three bedrooms are provided on the upper floor. Access as in all buildings is from the north side. The remaining units are developed as apartment blocks ranging from three to six storeys.

Pedestrian street with two storey row houses

Nearly all buildings are oriented due south with few exceptions to break the monotony. Spacing between buildings has been calculated but does not always allow for 100% insolation at the winter solstice because of the density of construction.

In all buildings except the two storey maisonettes, apartments are placed on either side of a stairwell and lift access point. In this way all apartments are double oriented and cross ventilation is provided. South balconies are restricted in depth for insolation reasons but are also provided on the north side for summer use. Ground floor apartments are pulled out towards the south both for aesthetic reasons, but also in order to provide covered parking space on the north side and extensive balcony space for the first floor apartments above.

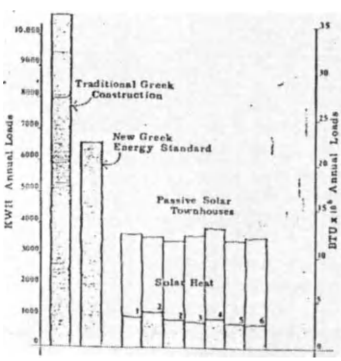
Central functions are arranged around the main square of the village which is sunken in order to create intimacy and a sense of belonging. Movement in this area is on two levels which adds to its interest and connects the sunken part to its surroundings. Included are a small shopping centre, a cafeteria, an information centre, a multipurpose hall, a library, an energy centre, a kindergarten, a primary school with playgrounds and a daycare centre.



Typical apartment floor plan

Due to increased insulations and double glazing, not common in Greece up to now, heating loads were substantially reduced to approximately 200 W/°C (2.2 W/m², °C) per unit.

Although present Greek Building Energy Standards can save over 40% of the heating energy consumed in conventional Greek housing, the basic energy conservation design for SV 3 will save an estimated 65% of conventional energy consumption. Passive solar heating, then, can meet over 70% of the remaining annual load, resulting in housing that consumes only 10% of traditional Greek construction.



Annual Auxiliary Load Comparisons of Passive Rowhouses

Various heating systems have been applied, with the main scope to be evaluated from different points of view, as efficiency, applicability, architectural implication, public acceptability, for this reason a number of alternative systems both active and passive have been included in order to be comparatively evaluated and thus recommended for future application. The regional breakdown from the heating system point of view has been incorporated within the neighbourhoods and on purpose are not distinct as such. The only criterion in their relative position was thw dependance of each region on the energy centre building.

The active systems provided within the village are:

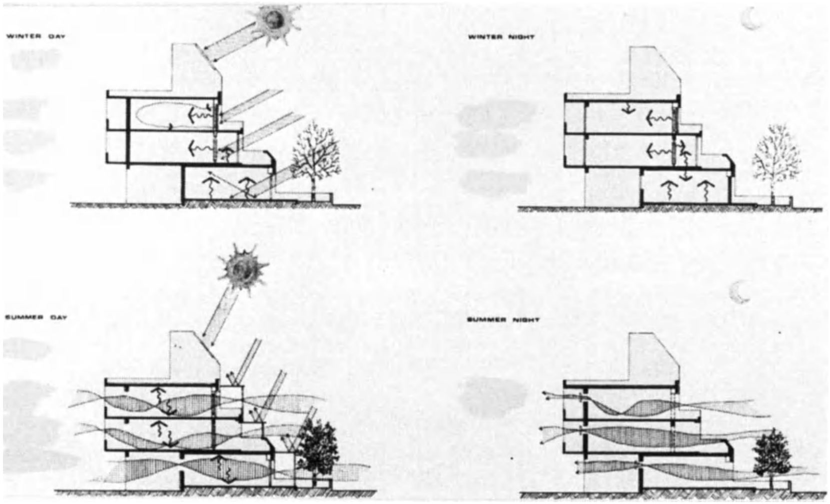
- air collector row houses with rock bed storage
- water collectors with short term water storage tanks
- water collectors with a long term water interseasonal storage of $800m^3$
- central diesel fired heat pumps
- absorber roofs with individual heat pumps

34 units of the total of 435 units will rely on energy conservation and passive solar heating systems to provide up to 100% of the winter heating demand and suppress summer discomfort to a minimum.

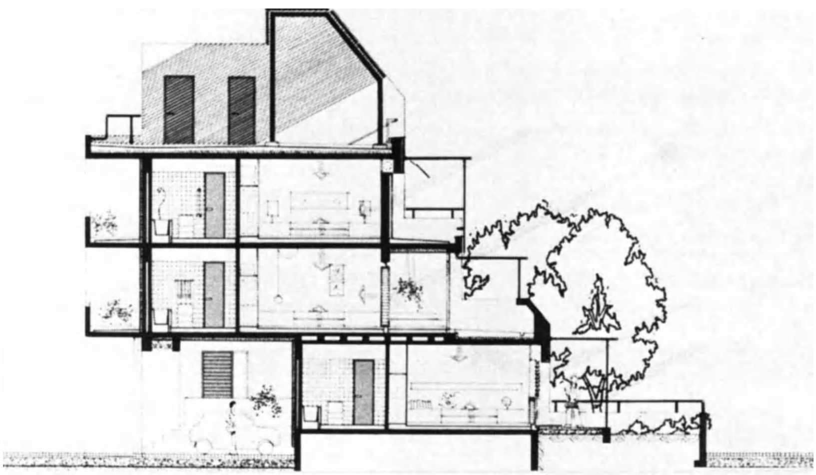
The 12 passive multifamily units and 22 passive rowhouses incorporate a composite of direct gain, indirect gain and isolated gain passive solar components to secure solar energy collection, storage and appropriately timed distribution. More specifically:

- Four direct gain water bench homes incorporate a 90 cm high, 30 cm deep water storage tank, with exterior insulation and reflector, before 30% of the glass area; and inverted venetian blinds behind the remainig windows to deflect incoming sushine to the uncluttered ceiling mass for nighttime storage.
- Four indirect gain mass wall homes incorporate full height, unvented, 30 cm deep concrete or water walls (with selective surfaces) behind 60% of the glass area; with the remaining 33% double glazed direct gain.
- Four greenhouse/mass wall homes, stack mass trombe walls over a full length one storey greenhouse.
- Four greenhouse/water wall homes incorporate a water storage at the back of a 1½ storey greenhouse for nighttime heating of adjacent living rooms and bedrooms above, with the remaining 60% of the bedroom wall as direct gain.
- Four thermosyphoning air panel (TAP) homes incorporate U-tube TAPs behind 2/3 of the south glass area to feed heat to a cored concrete ceiling slab on both floors; with direct gain windows (coupled with massive floors and walls) for the remaining glass area.
- And 2 homes with greenhouses and cored concrete slab loops for the first floor; combined with water storage walls behind 2/3 of the glass area on the second floor. This system emanated from an interest in the double envelope concept, combined with the guaranteed acceptability of greenhouses in Greece.

The twelve apartments in the passive multifamily buildings demonstrate three of these passive solar systems (in somewhat differing circumstances) placed to counterbalance the differing stresses of ground floor, middle floor and top floor locations. On the ground floor, where extra floor capacitance can be assured and kept at cooler early morning temperatures a direct gain system is used, also providing direct visual and physical access to the garden. On the middle floor, where less collection efficiency is necessary due to shared warmth above and below, a greenhouse is added, providing more usable space. On the top floor where cooler radiant ceiling temperature exist, a Trombe wall is added to provide a warm radiant wall for the apartment and then vented to feed overheated air across the ceiling mass.

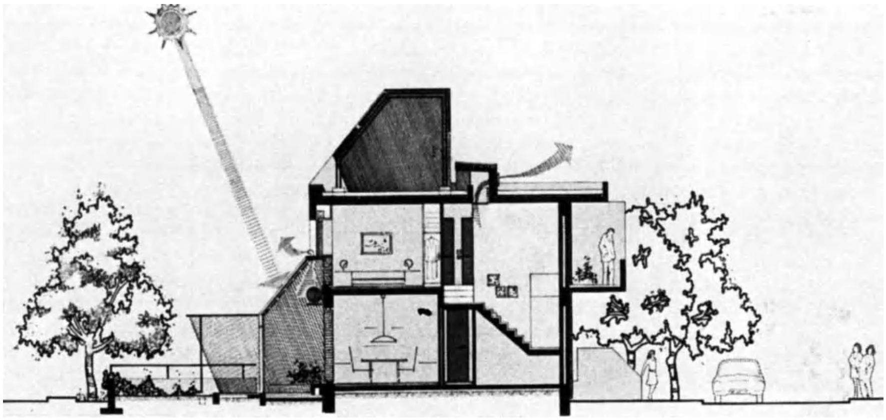


Two storey row housing -- passive mode diagrams



Three storey apartment block with passive heating - winter

Each of the passive solar homes incorporates 10 cm of exterior wall insulation, extensive plaster or marble surfaced concrete for interior capacitance, and layered window controls for winter night insulation and summer sunshading. The direct gain homes have the greatest window control system to abate the inherent overexposure, by closing thermally reflective venetian blinds inside and PVC Rolladens outside to provide R5 (composite) for winter night insulation, and by closing PVC Rolladens and canvas awnings outside to provide up to 100% shading (of direct, reflected, and diffuse sunshine) for summer day protection. In the end, only 6 distinct systems have been designed to effectively compare costs, efficiencies and acceptability for future passive solar construction in Greece.



Green house

It is critical to complete three sets of performance calculations to fully assess the success of passive homes and the relative success of one passive home over another. Peak loads clarify the impact a passive home will have on community peak power demands, and will determine auxiliary system sizing. Annual loads indicate the fuel and resulting monetary savings for the consumer, while average day (hourly) performance indicates real levels of comfort.

The peak load study of each of the passive homes, indicates a possible 30% improvement over new energy standard houses in Greece, when night insulation systems are used. This implies sliding insulation over north windows and loering Rolladens over south windows each night, and remembering to open them again in the morning. Without this caretaking, or the introduction of automation, peak loads in passive homes would equal or even surpass those of standard energy conserving homes. Peak load differences between various passive solar systems are marginal, and linked closely to wall exposure resulting from greater floor areas or end-of-the-row locations.

Annual auxiliary load calculations indicate immediately the advantages of passive solar systems showing over 80% reductions in total fuel demand over energy conserving standards. The isolated gain systems, the thermosiphoning air panel homes and the greenhouse loop homes, show the lowest annual fuel bill per m^2, since they present fully insulated south walls. Greenhouses, especially the one and a half storey greenhouse with water wall storage, retain the highest annual fuel demands, since some solar contribution is consumed by the greenhouse space itself. The Direct Gain apartments are saved from being the greatest energy loser by the increased resistance in night insulation. Meanwhile, mass trombe homes with their lesser capacitance and slower heat flux, apparently perform less well than water wall homes. Nonetheless, the annual energy demands for each of the passive homes are equally impressive enhancing eventual user acceptance.

Each passive solar system under consideration for a specific location and climate must undergo evaluation as to its physical "do ability". This factor is a composite of the system's total cost, the availability of individual material and components, and the ease of construction.

The Direct Gain System, utilizing conventional windows and concrete structure for passive solar collection and storage, shows few cost or construction complications for its present day introduction in Greece. Two critical components or passive solar products, however, are still difficult to purchase or custom build, limiting widespread use of direct gain systems. Although summer sunshading is readily available, winter night insulation in the form of insulated rolling, sliding or hinged panels is not available at all. Since the tremendous glass exposures in direct gain homes lose large amounts of heat on sunless days and every night, the necessity of night insulation is critical to system performance. For now this component must be custom built at great expense, or an existing product with inferior resistance must be used. A second direct gain product is also needed to redirect or diffuse the great amount of sunshine entering the living spaces that causes glare, fading and early overheating. The inverted venetian blind used in the SV 3 project represents one solution, reflecting sunlight to an uncluttered ceiling mass for absorption and providing simultaneous indirect lighting for the room. This product is imported and specially constructed, since normal jalousies or venetial blinds are concave in profile to reflect excessive sunshine back to the outside, defeating the solar heating system.

Indirect Gain Systems, Mass Trombe and Water Homes, demonstrate different market barriers in Greece. The vented trombe wall became almost an impossibility due to the care in construction necessary to make it a net gainer over the far simpler stagnant trombe wall. The storage tanks for the water wall homes, also present certain construction problems, constituting a completely nonconventional use of welded metal tanks and necessitating reinforced structural members. However, the costs inherent in the single glazed, selective surfaced stagnant mass walls is not excessive, the products themselves are available, and construction can proceed without special training.

The expanded indirect gain system or sunspace, introduces the additional costs of greenhouse constructions. Prefabricated greenhouses are unusual in Greece, requiring custom construction on site, though all the necessary components are available. Custom detailed framing is necessary, and eliminating thermal bridging and infiltration is a serious and costly problem.

The isolated gain system, or thermosiphoning air panel, presented the greatest cost and buildability problems for introduction in Greece. Although the air collectors themselves could eventually be factory produced, they now require careful site construction, using readily available products. The ducted, or cored concrete floor slab, however, is a very difficult component to design and construct in Greece, as are the connections between the collectors and floor storage. Nonetheless, the enclosed system offers great performance potential with little user involvement, creating possibly the best passive solar system for large scale introduction in Greece.

In conclusion cost and buildability, as well as user acceptability, created the six individual passive solar homes representing 5 distinct system types - direct gain, indirect gain (trombe walls or water walls), expanded indirect gain (occupiable/greenhouse mass walls), isolated gain (thermosiphoning air panels), and expanded isolated gain (occupiable/greenhouse thermosiphoning collectors). Narrowing the final passive alternatives further was not advisable, since the cost and construction limitations of one system type was offset by the performance limitations of another, which in turn was offset by user acceptability. These 34 passive homes will now undergo the best comparative evaluation possible through construction, ownership and use with four years of monitored performance data. The results of this evaluation will determine the appropriate passive solar system designs for future subsidized housing in Greece.

A PASSIVELY HEATED, COOLED AND LIT NURSERY SCHOOL IS COMPLETED FOR THE CHILDREN OF THE BANK OF GREECE

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ABSTRACT

The playful setting for this generation of children of the employees of the Bank of Greece will be a passively heated, cooled, and lit daycare and nursery school. Now under construction in Athens, the school's educational passive heating system incorporates thermosiphoning air panels that can breathe hot air into dragons' jaws and elephants' trunks, and trombe wall with niches to sit in for conductive and radiant warmth. Winter night insulation systems for windows are balanced by summer sunshading systems and large ventilation openings for passive cooling, giving the children a fuller understanding of day and night, summer and winter. Daylight is also mirrored, bent, diffused, and controlled to provide consistent ambient lighting levels as well as dynamic highlights for reading on the one hand, and dance on the other, for a sense of orientation, direction, and place. Outdoor play areas are diversified to provide sunny, wind protected areas for winter warmth; and breezy, shaded places for summer games, evaporatively cooled by water play, and well shaded with trellises and trees, banners and canopies. This paper will highlight the site planning, buildings, interior spaces, components and materials that were designed to make this school an education in playful and dynamic passive building design.

KEYWORDS

Passive nursery school; octagonal classrooms; 'pyramid' skylights; unvented Trombe wall; thermosiphoning air panel; direct gain collection; cross ventilation; sunshading; natural lighting; energy conservation oriented site planning.

INTRODUCTION

The urgent international need for energy conservation that emerged in the seventies raised for the first time in decades the issue of comfort in buildings as inherent to architectural decisionmaking rather than mechanical systems. The individuals who may have suffered the most from this architectural delegation of responsibility for thermal comfort, were the elderly and the very young. The very young often lost their rightful thermal comfort and delight, playing, napping and sleeping on or close to cold concrete surfaces, running in and out of overheated rooms designed to compensate for these cold mean radiant temperatures, reading in the glare of unmanaged sunlight, and steaming in summer on unshaded play areas, outside of unshaded classrooms. Rather than capturing the environmental delight of the seasons and their climates, the schoolchildren were learning of the environmental stress that climate placed on unresponsive buildings. One of the most exciting design challenges, therefore, in furthering the use of energy conservation and passive conditioning systems, is the nursery school. This nursery school for the Bank of Greece, is intended to unfold the delights of the Athens seasonal climate for 300 small children, within a building that integrates architectural decision and mechanical system to fully provide thermal comfort (air temperature, radiant temperature, humidity, air movement) and lighting comfort (ambient light, task light, artificial and daylight integration, brightness ratios, color rendition).

THE MASSING, ORIENTATION, AND SPACE ORGANIZATION DESIGNED TO MINIMIZE CLIMATIC STRESS, OPTIMIZE CLIMATIC ASSETS

The six buildings in the Bank of Greece school are clustered into a U-shaped complex, with the open side embracing the assets of winter sunshine and summer breezes, with indoor-outdoor movement designed into the most comfortable microclimates. The closed end of the complex provides protection from the northwest winter winds, placing less used spaces as buffers for the active classrooms. As shown in Fig. 1, 'Solar Windows' were constructed for each major building face, to determine the necessary separation and orientation of the clustered buildings, and the dimensioning and location of window openings for successful winter solar collection.

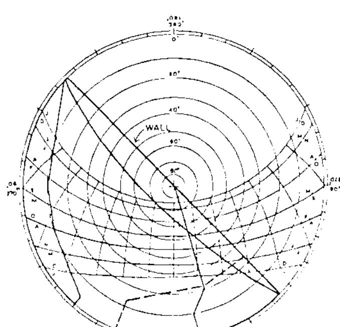

Fig. 1. Solar window

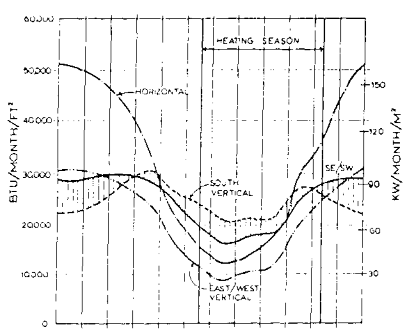

Fig. 2. Solar gain, variovs orientations

The buildings themselves are compact in form, nestling octagonal classrooms into tight units, minimizing surface exposure to all orientations except south/southeast/southwest, and shading all remaining walls with overhangs and covered walkways. The minimized surface area provides protection from winter heat loss as well as summer heat gain, allowing efficient mechanical heating in winter, and controlled ventilation in summer. The placement of the fourteen classrooms at the southern corners resulted from wind studies as well as solar radiation studies, as shown in Fig. 2, that indicated that these orientations provided the highest winter and lowest summer solar collection, as well as full summer ventilation. The remaining sides of the classrooms, then, are buffered by entries, storage rooms, service areas, and less utilized office/lounge areas, as shown in Fig. 3.

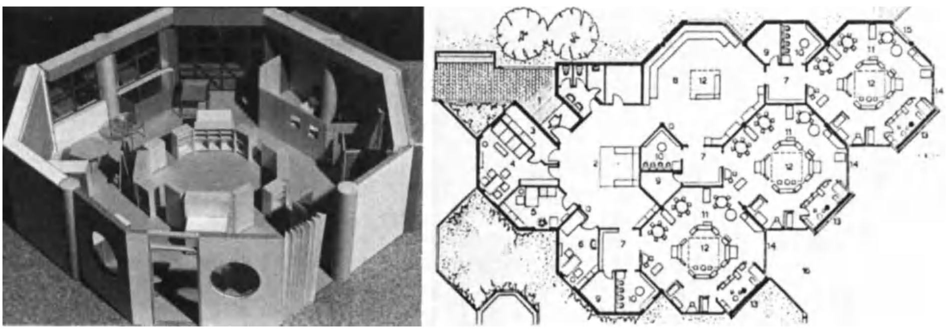

Fig. 3. Unit 5 - classroom building

ENCLOSURE AND OPENING SPECIFICATIONS REINFORCE THESE RESPONSES TO THE ASSETS AND LIABILITIES OF THE ATHENS CLIMATE

As a second step to ensure thermal comfort and energy savings, the building enclosure materials for roofs, walls and floors have been specified for long term cost effectiveness. All roof areas over heated spaces have 8 to 10 cm of polyurethane insulation, for a minimum k-value of .22 $W/m^2\,°C$. In the exterior wall construction, 20 cm masonry walls are isolated as thermal storage mass to the inside of the building, with 6 cm of polyurethane insulation k=.30 $W/m^2\,°C$ to the outside, protected by facia brick. The floors throughout the building contain radiant heating systems, and are floating on 4 cm of insulation, with 2 cm wrapping around the perimeter.

The openings, then, are consciously sized and placed, each window attempting to capture the best view and light for the function and occupancy of the space, avoiding large window areas in nonsoutherly directions, and providing heat loss and heat gain controls throughout. The fourteen classrooms have glass areas on at least two sides, usually south and east, or south and west, to provide winter sunshine and backlighting, avoiding the glare common to unidirectional window placement. A south facing central skylight has been additionally placed in each of the classrooms, to take advantage of the unobstructed solar access, providing more than adequate ambient lighting throughout the year, as well as additional winter solar heat gain. Internalized rooms and entry areas are lit with horizontal 'pyramid' skylights, greatly enhanced by the use of adjustable reflectors which provide 15-20% more direct radiation in winter, while permitting only diffuse radiation access, for ambient lighting, in summer as shown in Fig. 4.

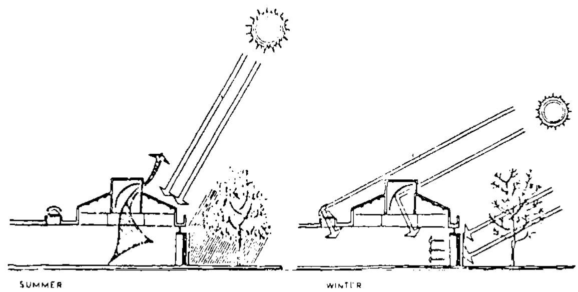

Fig. 4. Sunbenders detail

All of the gaily painted green framed windows are double glazed, to provide an exposed k-value of 3.5 $W/m^2\,°C$, with a solar transmission of t=.76, and most are operable for summer ventilation. For additional winter comfort, all of the windows in the school have exterior 'rolladens' or roll-down insulated PVC shutters which provide a combined k-value for the windows of 1.75 $W/m^2\,°C$. The most vulnerable windows to heat loss, in the central skylights, have automated interior night insulation from Thermal Technology Corporation, a four foil insulation with a k-value = 0.35 $W/m^2\,°C$. In addition to reducing peak and annual heat loss by almost 10%, both of these movable insulation systems provide blackout capability for the individual classrooms, as well as critical summer sunshading. The summer sunshading is then reinforced through the use of lace-up colorful awnings at all the large glazing areas accessing outside play, along with the shade trees and canvas kiosks that define the outside areas. When the kinetics of these colorful movable night insulation and shading systems are seen over time, the school and its indoor-outdoor activities take on a playful sense of day and night, summer and winter.

PASSIVE HEATING, COOLING AND LIGHTING SYSTEMS GUARANTEE THE COMFORT AND THE ENERGY SAVINGS, AS WELL AS TEACHING CHILDREN ABOUT THEIR ENVIRONMENT

For playful, natural heating of the Bank of Greece nursery school, three passive solar systems have been designed. The most prominent system is the unvented Trombe wall located on the exposed southeast or southwest faces in each of the classrooms. The 20 cm concrete walls have selective surface finishes to provide 95% absorptivity, while reducing emissivity to 5%. This inexpensive finish, in combination with double glazing provides the highest trombe wall performance possible without the introduction of costly night insulation. Large circular windows have been cut into the walls, very close to the floor, not only to allow the children to see out and in, but to allow them to sit within the warm radiant wall, to learn about solar collection and storage capacitance. This solar heating system is shut down in summer, with a highly reflective exterior roll down shade, gaily changing the buildings clothing as well as the view through the window.

The second passive solar heating system utilizes a thermosiphoning air panel developed by Scott Morris, to additionally heat the classrooms with the greatest surface exposure. With several layers of metal mesh laid diagonally into a 15 cm air space, the solar energy collected has a maximum absorption and transfer surface area. Cooler room air is admitted through openings at the bottom of the wall area, with solar heated air siphoning out of portholes at the top. As shown in Fig. 5, large wall graphics can incorporate this hot air supply into elephants trunks and dragons, bringing the thermosiphoned energy down to the childrens level in a gentle flexible hose. An operable exterior vent allows the panel to function as a room ventilator, continuously drawing out room air whenever bright sunshine heats up the air space.

Fig. 5. T.A.P. - Elephants, dragons

Direct gain collection through southerly windows and south facing skylights comprises the third passive solar system. Since this system also provides for natural lighting, the management and diffusion of sunlight becomes critical. Light colored linoleum on the floor, and large curved reflectors in the skylight, bounce incoming sunshine throughout the room. This diffusion is intended to guarantee multidirectional lighting against glare, as well as to utilize the extensive exposed masonry walls as direct gain solar storage. Exterior 'rolladens' have been added, as specified earlier, to allow for nighttime shutdown in winter and full shutdown of significant glass areas in summer. For the glass areas that serve as major access to outdoor play areas, colorful lace-up awnings have been incorporated.

The performance of these three systems, within the highly energy conserving building designed, has been calculated using the Balcomb LASL procedures, in combination with the PEGFIX/PEGFLOAT program. The room by room calculations indicate an annual heat loss of 26,000 KWH for each of the five classroom buildings housing approximately 75 children. This is in dramatic contrast to the 57,000 KWH estimated for traditional school construction in Athens, not to mention the vastly improved thermal comfort (including air temperature, humidity, and mean radiant temperature, air movement) and delight that has been provided. Within this tightened building, then, the children themselves contribute tremendous amounts of natural heat, estimated using the adjusted degree day method. During peak hours, the 75 children contribute up to 8°C, or a 24 hour average of 3°C. Since we are only trying to heat the room to precise comfortable temperatures during the occupied hours, an average internal heat gain of 5°C was assummed, adjusting the degree day base to 13°C, resulting in 350 HDD (°C) instead of 1187. 65% of the remaining load was met by the passive heating systems, as shown in Fig. 6, for each of the four remaining heating months. As shown in Fig. 7, then, the energy conservation and the passive solar design for this environmentally educational nursery school could result in annual heating bills of no greater than 2,600 KWH for each of the five classroom buildings, 5% to 10% of the bill expected in conventional design today.

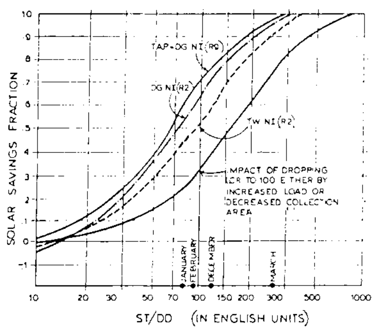

Fig. 6. Passive %

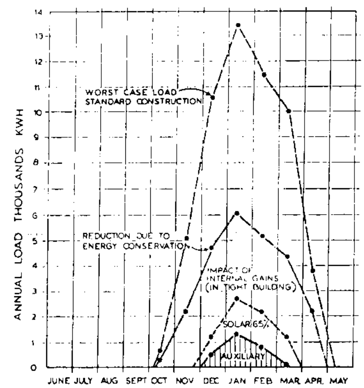

Fig. 7. Total energy estimates

Two major passive cooling systems have been incorporated into the Bank of Greece school: cross ventilation combined with thermal mass, and thourough and effective sunshading. Summer winds blowing in from the south are funneled by the building configuration into the southern windows and doors. The incoming breezes are then drawn through the classrooms and up and out the skylight openings, using the thermal stack effect to reinforce natural wind patterns. Mechanical fan assists placed within the skylight wells will guarantee this air flow even on still days, and provide additional air movement at night. This 'night flushing' is especially effective in combination with the extensive areas of exposed concrete mass, since the nighttime temperatures drop significantly on dry summer days in Athens. Summer sunshading, though not technically a cooling system, contributes so significantly to summer comfort, that its promotion as a passive cooling system is critical. In the Bank of Greece school, all of the windows can be shut down with exterior PVC rolladens. Colorful canvas awnings additionally protect the trombe walls and thermosiphoning air panels, as well as those direct gain glazing areas that are used as indoor-outdoor access. Since mechanical cooling is rarely provided in Greek schools, there are no real energy savings to be accounted for. However, the comfort provided in this Bank of Greece school, in contrast to more traditional designs, has been calculated using the PEGFIX/PEGFLOAT calculations, shutting down major glass areas with 'rolladen' and altering day and night U-values to simulate the night flushing. The resulting typical day plots, indicate that these classrooms can have interior temperatures hovering around 26 to 27°C, while unshaded and unvented classrooms will have typical July day temperatures from 30 to 32°C! The outdoor play areas to be described later, are also designed for summer comfort, combining canvas 'kiosks' and shade trees with water play areas in the path of incoming breezes, for shaded, ventilated, and evaporatively cooled outdoor games.

Natural lighting then is the third passive system to be incorporated into the Bank of Greece school. As previously described, windows are provided on at least two sides of each classroom to provide backlighting and reduce glare. Central skylights contain curved reflectors, to spread the incoming strong southerly sunlight throughout the room. Pyramid shaped horizontal skylights located in the internalized waiting and storage areas are enhanced by the use of reflectors adjusted to provide a larger cone of light within the space in winter, and to cutoff direct solar radiation in summer. All of the window areas are designed with "black-out curtains" effectively doubling as winter night insulation or summer sunshading. Assuming a 70% effectiveness for the daylighting system to displace the use of artificial lighting, considerable KW savings can be attributed to these carefully designed and controlled aperatures. Even assuming highly efficient artificial lighting at 25 W/m^2 (2.5 W/sqft), daylighting in each classroom building could displace up to 14,000 KWH of energy consumption per year. Although not as significant as heating energy savings natural lighting design commands equal attention since light quality greatly affects the visual comfort and excitement within buildings.

SITE PLANNING, LANDSCAPING AND THE DESIGN OF OUTDOOR AREAS EQUALLY SIGNIFICANT FOR ENERGY CONSERVATION, THERMAL COMFORT AND DELIGHT

The planning and landscaping of the spaces between buildings is often more valuable than the buildings themselves, not only contributing protection from winter winds and summer sun, exposure to winter sun and summer winds, but also the ability to enjoy access to the long periods of comfort for which Athens is so famous. As previously described, the U-shaped building configuration in combination with heavy planting to the north and northwest, greatly deflect the cold winter winds, helping to protect walkways, parking areas, and outdoor play areas alike. The liability of summer sunshine is also reduced through the building configuration, and extensive covered walkways, as well as through the use of awnings, shade trees, highly reflective surfaces, and canvas covered "kiosks". Most important, the outdoor areas are generous and varied as shown in Fig. 8, to maximize outdoor learning and play in comfortable periods, with the ability to change characteristics to extend the comfortable season. The trees and shrubs, grassy areas and sandy areas, water play and kiosk areas, leading up to the large outdoor theatre, each change their image and function as spring turns to summer, summer to fall and fall to winter. Representative of the delight that the site planning, landscaping and outdoor areas hope to offer the children, a large skylight in the protected entry area lights a birdcage, at the very least a musical welcome.

Fig. 8. General view of model

USER INVOLVEMENT THE KEY TO LONG TERM SUCCESS

Ultimately, the thermal and educational success of the energy conservation and passive solar system integrated in the Bank of Greece nursery school will depend on the teachers and the children. For winter comfort, the children need to understand the value of insulation against cold temperatures, be it building insulation or that provided by their own clothing, and the value of protection against the winter winds. Only the imagination of the teachers can bring alive the understanding of solar heat exploring the various storage masses, teaching the sense of time with solar controls, opening the dark classroom to the rising sun each morning, and tightly insulating the windows at night.

For summer comfort, the children will need to understand the value of shading against intensive sunshine, be it building shading or that provided by their own clothing. Again it will be dependent on the imagination of the teachers to bring alive the understanding of natural ventilation and evaporative cooling: manipulating various windows and doors and skylights to sail the building like a boat, to help the children create the maximum breeze through the spaces; seeking out the coolest places to play, places defined by shading, refreshing winds, and cool surfaces; and exploring the delight of passive cooling with water games and washed down surfaces.

The sense of light and solar time can also be a daily excitement for the children: introducing lattice work and cut-outs to create moving shadows; adding clouds of diffuse fabric and reflective banners to spread the sunlight to the furthest corners of the classroom; and using prisms of water to turn light into a rainbow of colors. A simple stick or pole and colorful chalk markings can teach the children about solar time, a sundial for the rising and setting sun in summer and winter.

In short, the building provides only an effective setting for energy efficiency, thermal comfort and delight. It is up to the teachers and children to really enjoy the months of comfortable conditions in Athens, managing the heat, the 'coolth', and the light to extend these months, while playing and learning in the dynamic environment offered by nature.

SOLAR ENERGY: A NEED FOR A NEW MENTALITY

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ABSTRACT

In this paper we are presenting an active solar house under construction in a suburb of Athens. In the beginning we attempt a very brief balance of the first decade after the 1973 crisis in the area of solar applications. Then, we describe the problems in the planning phase, in the architectural design and in the active system that was used. Theoretical results are presented in this paper but "true" performance can only be determined at least a year after it has been inhabited.

KEYWORDS

Research trends; solar mentality; government initiative; solar design problems; relation between architecture and technology; active system.

INTRODUCTION

The discovery of oil and, subsequently, that of the internal combustion engine has suspended the development of solar energy for a whole century. The 1973 oil crisis, initiated a new era of research and development in solar energy. Generally, we can distinguish two main streams of thought that guided research on solar energy during the last decade. The first visualised solar energy as a substitute for oil aiming to use it in exactly the same way. The second, on the contrary, recognised in solar energy a hope for a new life style and a renewal of man's relationship with nature.

THE SOLAR HOUSE

The Location

The house is located at Glyfada, 15 Km southeast of Athens. This suburb was originally intended for a summer vacation area. In the 1950's, however, it suffered the consequences of urbanisation and was soon transformed into a suburb of Athens. The house is situated in a lot consisting of 6 buildings sites of about 500 m^2 each. (Fig.1).

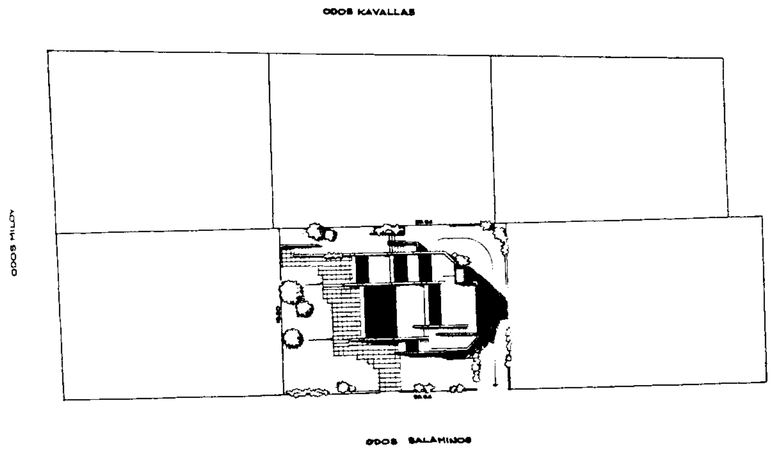

Fig. 1. Site Plan.

Position of the House on the Site

Because there is a street towards the east, the house was placed on the side parallel to the street with its main elevation facing South. This position (d of Fig. 2) still permits the main elevation of the house to be seen from the road. Other possible orientations were studied but rejected for architectural reasons or because they would conflict with the building code. (Fig. 2).

The Architecture

In spite of the changes that occured between the initial idea and the actual building (Fig. 3) we have tried to integrate technological elements with those of Mediterranean architecture and to reconcile two contradictory building elements: the cold surfaces of glass and metal with the warm traditional walls.

The distribution of living space, 230 m^2, (Fig.4) unfolds horizontally and vertically around the living-room on the ground floor. With its position in the centre and its double height, the living-room represents the connecting space of the house while at the same time by its shape it is an element that allows a direct relationship between the solar elements and the living space. In relation to the layout as Alain Herve (1980) says the inhabitants will wake up in the East, eat, laugh and sing in the South, meditate and fall asleep in the West. Whether we have accomplished our goals or not has yet to be seen when the house will be inhabited.

The Active Solar System.

The sizing of the solar heating system of the house was originally calculated with a method developed at the Ecole Superieure d'Ingenieurs de Marseille. It was also verified by simulating the function of the solar system. The climatic data used were mean values for 1975-1976.

The characteristics of the system are shown in Table 1, where h is the emission coefficient of the heating elements (floors). The main characteristic of the ESIM method is that the performance calculations concern a "mean" day of the month. The highest performance is obtained with the values shown in Table 1. The overall solar coverage of heating demands is foreseen at 71,8%. As already mentioned the values of Table I were verified analytically using a mathematical model on an hour by hour basis with the help of a computer. In this model the following characteristics are variable:

a) Of the collector system: collection area, tilt, water supply, geometrical and physical characteristics.

b) Of the storage system: volume of tank, area of heat exchanger.

c) Of the heat distribution system: type of heating units; control.

The outcome of this simulation is in accordance with the ESIM method as far as the sizing of the system is concerned. A small difference can be noticed concerning the annual percentage of performance. With the mathematical model this is 66%.

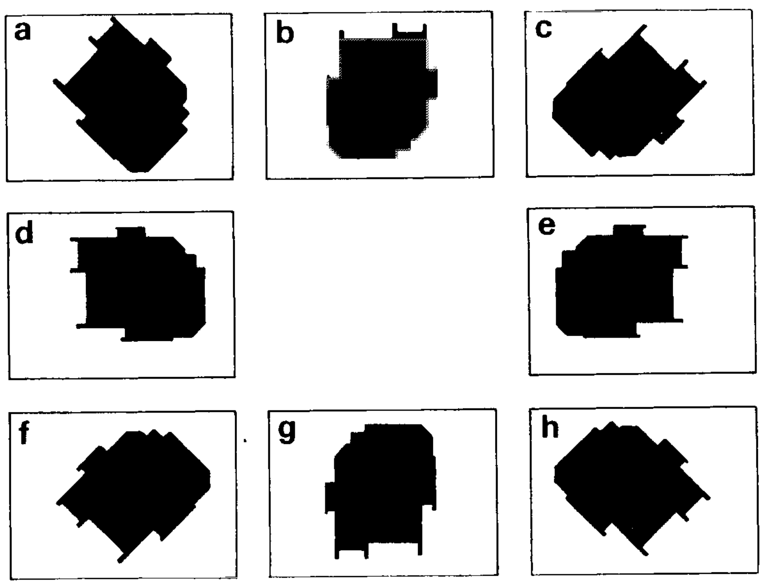

Fig. 2. Possible orientations of the building.

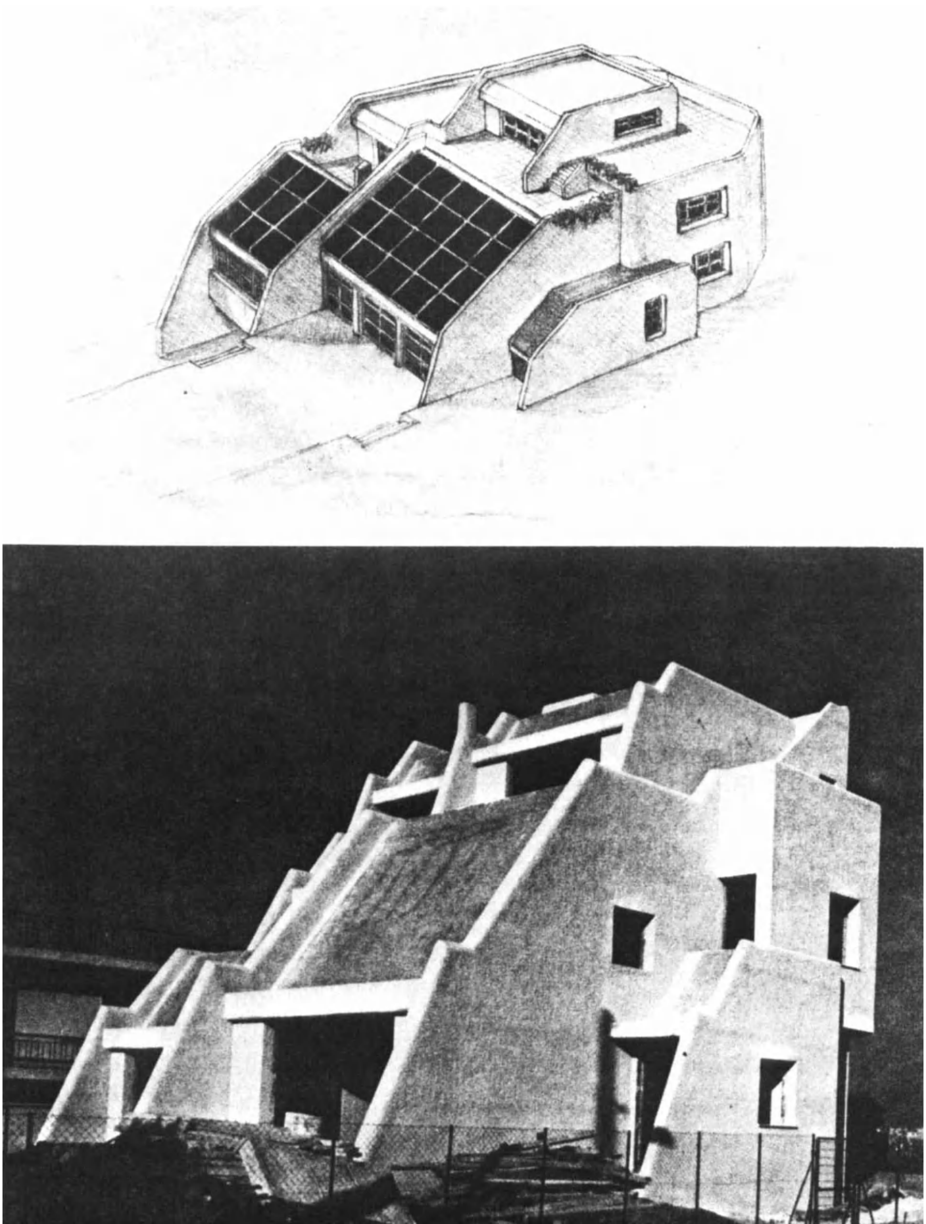

Fig. 3. Initial sketch and actual construction state.

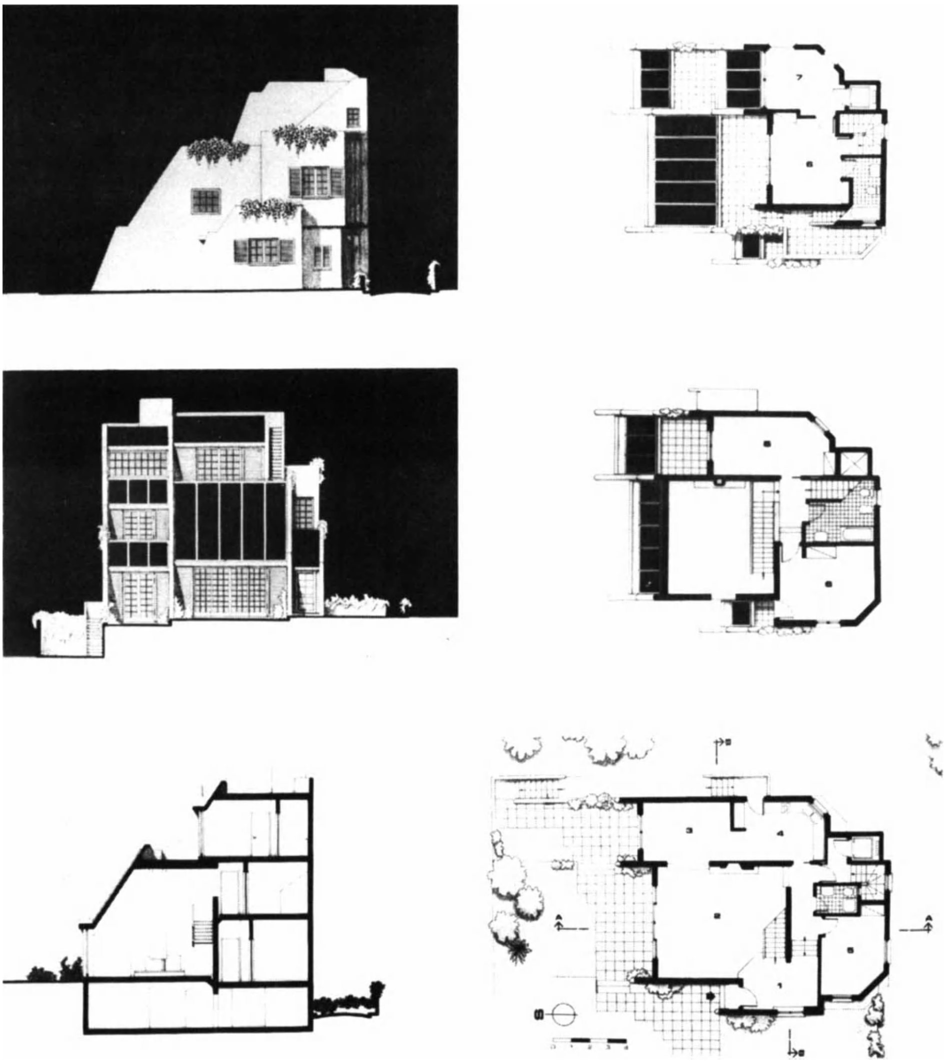

Fig. 4 . The active solar house project.

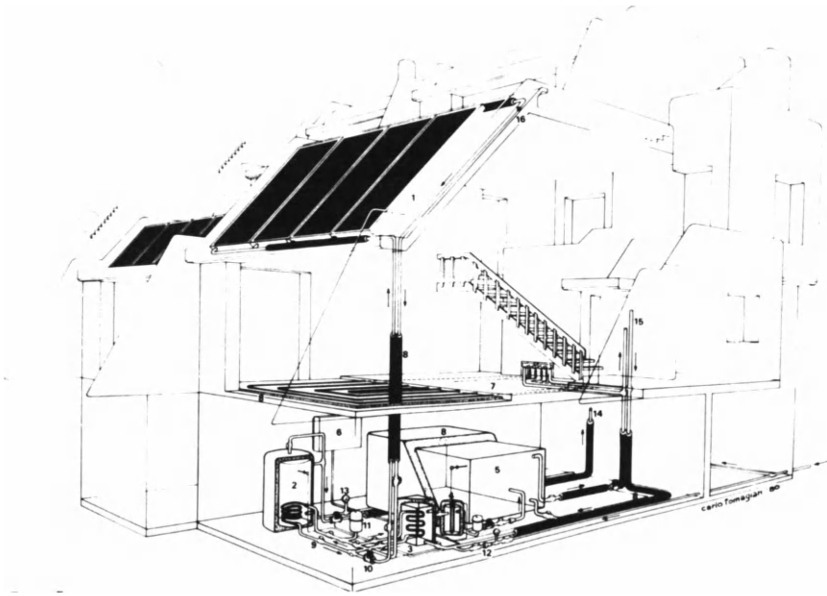

Fig. 5. Perspective diagram of the active solar heating system.

	Storage tank vol.:V=6.00 m³	Collector water supply : 70 lt/m² h Collector thermal inertia: 5 lt/m² Total coll. heat loast coeff: 9 W/mc Heat exchanger area : 16 m² Heating elements (floors)emittence coeff.: 8-12W/m²c Heat lost coefficient : G=1,00 W/m³c
Location :Glyfada, Athens	Ratio V/S : R=150 1/m²c	
House type:single house	Coefficient :h=20,0W/cm²c	
Collector area: S=40 m²	Collector tilt : 55 °	

	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	ANNUAL
DD/month (℃)	37	107	222	285	241	207	88	1187
Theoretical load (KWh/month)	400	1155	2398	3078	2602	2236	950	12819
Mean daily load (Wh/day)	12890	38520	77322	99290	92947	72115	31674	424058
Max solar rad. Em (Wh/m²c/day)	6490	5630	5097	5630	6490	6720	6290	
Mean monthly sunshine coeff. σ	0,60	0,48	0,41	0,45	0,47	0,55	0,61	
Monthly ener.coeff.e=0.75σ+0.25	0,70	0,61	0,56	0,59	0,60	0,66	0,71	
Mean solar rad Er=e.Em(Wh/m²cday)	4540	3430	2850	3320	3890	4430	4460	
Daily theor.charge Q'=Q²/s(Wh/m²cd)	322	963	1933	2482	2323	1803	792	10620
Useful solar radiation q'(Wh/m²cd)	322	963	1000	1300	1600	1605	792	7627
Monthly theor.perc. r=q/Q 100	100	100	51,7	52,4	68,9	91,5	100	71,8

Annual theoretical coverage: 71,8%	Annual savings : 9204KWH	Annual collector gain:230KW/m²

TABLE 1.

A MEDITERRANEAN LATENT HEAT SOLAR HOUSE IN "LE TIGNET"

Christophe PETITCOLLOT, Groupe d'Ecothermique
Solaire, C.N.R.S., Vence, France

SUMMARY

This solar house owes its special and original character to the fact that it is a contemporary adaptation of the system of heating through the floor used by the Romans - the hypocaust (Figs. 1,2 and 3).

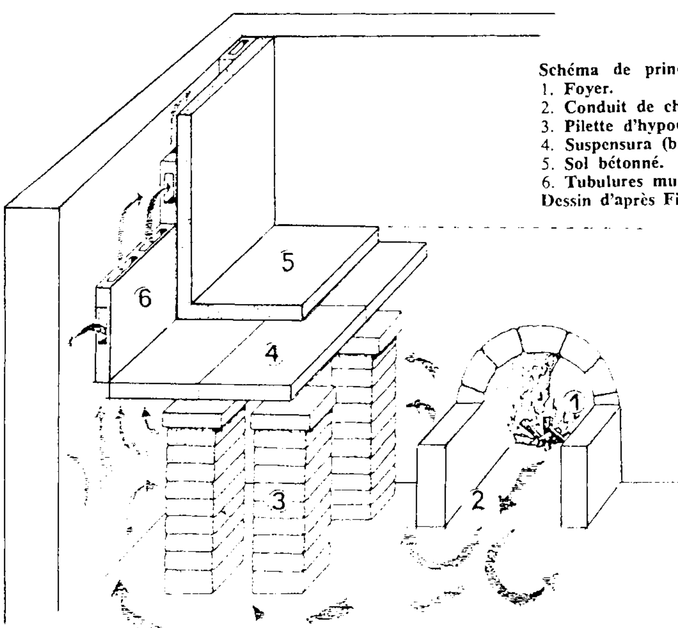

Fig. I. Hypocaust

In this hypocaust the hollow blocks of which the floor is built ("hourdis") are used as conduits (Fig. 2). The hot air is produced by a greenhouse backing on to a supporting wall (Fig. 3); and it is stocked in a latent heat material - Chliarolithe.

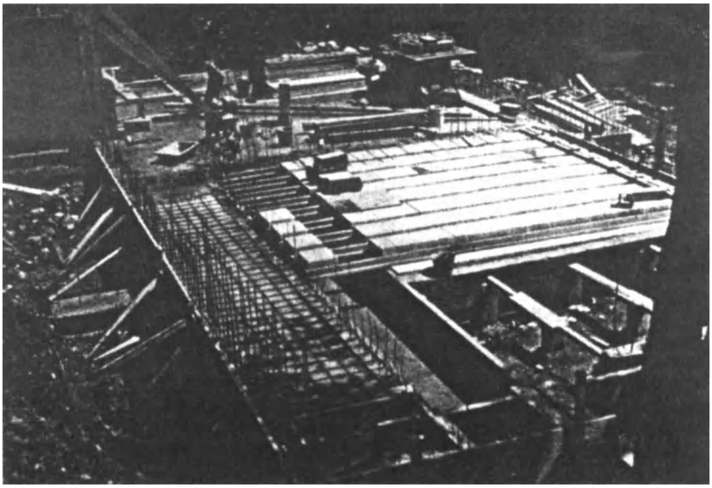

Fig. 2. Hypocaust floor of Le Tignet house.

INTRODUCTION

1. Objectives : To implement the required architectural programme, incorporating into it a solar heating system, for a budget of 650,000 French francs.

2. The programme :

Living room	25 m^2
Kitchen - dining corner	24 m^2
Mezzanine study	15 m^2
Two bedrooms	11 and 16 m^2
Two bathrooms	4.5 m^2
Closets and storage	6 m^2
Garage	18 m^2
Ground area of the house	166 m^2
Overall habitable volume	450 m^3

3. Geographical situation : The house is situated in the commune of Le Tignet, 15 kms west of Grasse, in the département of Alpes Maritimes in Southern France.

4. Site : A steeply-sloping site (60%) Facing full south. Panoramic view on the bay of Cannes, the Iles de Lérins, the Esterel mountain chain and the lake of Saint Cassien. Access from above.

5. Climatic situation : Mediterranean climate, characterized locally by sequences (in winter) of 2 or 3 days of fine weather and 2 days of bad weather.
Clear days and cloudy days are roughly equal (48% of fine days on

average over the last eleven winters).
East winds accompanied by rain and milder temperatures.
West winds (mistral) accompanied by very clear sky and low temperature in winter.

6. Administrative situation : The building regulations fix a ratio of built-up surface to the area of the site, minimum distance from neighbouring houses, maximum height, plus a series of particularly strict directives with respect to the architectural style.

7. History : - Building permit obtained 7 March 1979
   - Building operations begun 1 November 1979, followed by a two-fold collapse :
     (a) of the main contractor, leaving a "hole" of 36.500 francs (down payment on signature of contract),
     (b) of the ground, which caved in as the excavations were begun, due to underground springs, also leaving a large hole ...
   - Revision of the estimates, in order to :
     (a) keep within the original budget;
     (b) and absorb within that budget the additional excavations and foundations.
   - Only possible solution : the establishment of a building firm, the SO.C.C.A. (hiring of workers, purchase of equipment, management etc).
   - Building operations resumed 1 February 1980.

8. Personnel : Architect - Christophe Petitcollot

   Building contractor : SO.C.C.A.
   - Manager - A.M. Petitcollot
   - Direction of operations : G.Sallé

   Solar studies : Ecothermics Laboratory of the C.N.R.S. (French National Scientific Research Centre) :

   M. Schneider, J.D. Sylvain, A.Jaffrin, X.Berger.

   Thermal studies : Golfe Ingénierie - J.J.Henry.

The solar base : the hypocaust

1. The collectors : The sun's rays are collected in the first place by direct gain through 50m^2 of glass windows looking south, which provide heating in fine weather in winter until two hours after sunset (Fig. 3).
A large window on the mezzanine level ensures direct heating by the sun even when the house is closed
A greenhouse with 60 m^2 of glazing stands against the 3-metre high supporting wall of the building   The greenhouse is insulated at the back by 9 cm of aluminized glass fibre.
The absorber consists of sheets of metal, slightly tilted so as to guide the heated air towards the back of the collector. The sheets are 7 cm in front of the insulating layer; they are painted dark red

Fig. 3. South façade

2. Storage : Storage is ensured by 4.5 tonnes of chliarolithe, a latent heat fusion material (fusion temp. 28°C; L = 170 kJ/Kg) supplied by the Solvay company in the form of 225 tubes, two metres long and 9.5 cm in diameter.
   These are arranged on racks, end to end, in 12 rows of 3 tubes, leaving 3 cms between tubes (Fig. 4).
   The 141 m^2 of exchanging surface are divided by sets of baffles into 8 groups, through each of which flows a current of air (photo 20).
   This storage unit is installed in a concreted trench at the north side of the house, extending the full width (18 meters) and with a volume of 30 m^3.
   The size of the storage capacity was calculated so as the ensure that heating needs could be met for two and a half days of bad weather in winter.

3. Charging the storage batteries - Loop n° 1, from greenhouse to storage :
   The air circulates from the greenhouse to the storage unit by a distribution duct (60 X 40 cms) coming from the top part of the greenhouse and returns by a duct of 40 cm diameter at the bottom.
   This circulation normally works by thermo-syphon, but it can be boosted by a 500 W fan controlled by a differential thermostat

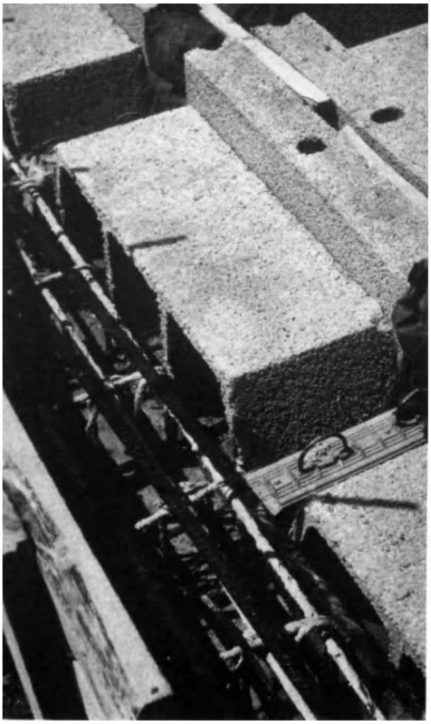

Fig. 5. Air circulating system

Fig. 4. Storage system

4. <u>Heating by the floor and the ambient air - Loop n° 2, from storage to living quarters</u> :

The air circulates from storage to the living quarters in the opposite direction, through the hollow blocks ("hourdis") beneath the floor Fig. 5.

The floor consists of 33 beams of pre-stressed reinforced concrete in the direction north-south, on which the hollow blocks are laid, with their underside insulated.

The top layer of 7 cms over the flooring blocks stores heat at about 22° which by dephasing creates an alternating effect between the two modes of heating (through the floor and by the ambient air).
The hot air leaves the flooring blocks at the south front of the house by a redistribution duct of 25 X 40 cms and joins the ambient air .

The air circulates by thermosyphon but can be boosted by a 500 W fan controlled by a differential thermostat
The hot air which has circulated through the floor is distributed at the bottom of the windows, so that heating is ensured both through the floor and by the ambient air; the relationship between the radiant temperature and the temperature of the air is thus optimal for producing a "comfortable" temperature with the least possible energy.

5. <u>Returning the air - Loop n° 3, from dwelling quarters to storage</u> :
The return flow of the air passes through a 60 X 50 cms duct of aluminized glass fibre. The flow is naturally balanced with that of the second loop by the principle of Tickelmann's loop.
The flow of air is thus uniformly distributed throughout each room from one end of the house to the other .
The ceilings of the rooms are vaulted, which helps to concentrate the thermal radiations by avoiding the stratification of the layers of air.

ARCHITECTURAL FEATURES

The house is entirely below ground level to the north and 100% glazed windows to the south (Fig. 6).
The combination of sliding windows and casements offers a variety of possibilities for ventilating the rooms.
The main entrance is on the level of the mezzanine.
The 1.5 metre overhang of the roof on the south façade cuts off the sun's rays in summer
All the dwelling rooms face full south, while the bathrooms, storage space and closets serve as a buffer zone.
Space was found for a large cellar in the foundations.
The fireplace is in the middle of the living room and the inside staircase wraps around the chimney, so that its radiant heat benefits the whole volume
This supplementary heating is in addition to the electric heaters placed in the duct by which the hot air comes out on the south side of the house (6 of 1500 W and one of 2500 W)
The window high up in the mezzanine ensures direct heat gains in winter as in summer, whether the house is occupied or not
The house is ventilated in summer by two windows at the mezzanine level facing east and west, according to the dominant winds.

COST (GROSS) OF THE SOLAR INSTALLATION

Cost of the greenhouse	23,250	French	francs
Insulation of the greenhouse	16,405	"	"
Cost of chliarolithe	17,635	"	"
Cost of electro-solar appliances and ducts	25,937	"	"
	83,227	"	"

CONCLUSION

The heating system is particularly well-suited to the local climatic and meteorological conditions.
The arrangement of the greenhouse, the storage unit and the living quarters on different levels makes possible a minimum heating by thermosyphon and, together with the mezzanine window, ensures that the internal temperature never falls below 13°C.
The solar installation covers 67% of the needs.
This type of installation has the advantage of having little effect on the architecture, which in this case has remained very Mediterranean.
As regards both the architecture and the heating system adopted in this house, the best solution seems to be to seek a contemporary adaptation of well-tried formulas.

For the owner, Mr. Golay, Director of the Observatory of Geneva, the architect Christophe Petitcollot and the Solar Ecothermics Laboratory of the C.N.R.S., the objectives have been met : the search for original solutions for thermal comfort, integration of solar heating into the architecture of the building, maximum savings on heating, the utilization on a large scale of an industrially-produced latent heating storage component and distribution of heat by means of hypocausts.

The Tignet solar house brings together a number of original techniques in a building of Mediterranean style, aesthetically attractive and pleasant to live in.

It is both a scientific and architectural experiment and an example of the integration of solar energy into the habitat.

DOCUMENTATION CONCERNING THE HOUSE

- Rapport Plan Construction :"Rapport climatique de la maison Energie Zéro" collaboration J.P. Marie
- Modelisation du fonctionnement d'une maison solaire. Stage de fin d'études à l'Ecole centrale des Arts et Manufactures. Yvan RADICCHI Juin 1979
- Concours HOT 5e session
- Concours 5000 Maisons Solaires.

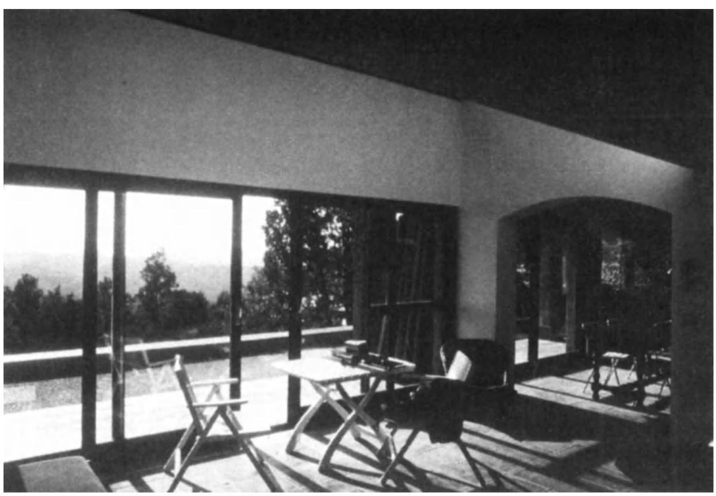

Fig. 6.

INNOVATIVE LOW ENERGY COOLING AT THE HAJ TERMINAL
King Abdulaziz International Airport, Jeddah, Saudi Arabia

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ABSTRACT

A large International Airport commenced operation in Jeddah, the western gateway to Makkah Al Mukarama in 1981. A principal feature is a building expecially erected to accommodate a flood of pilgrims who will pass through the Hajj Terminal for a short period each year. The brevity of use and the vastness of this building, accompanied by the Hajj occurring during very hot weather, called for a unique architectural solution for cooling which is described here.

KEYWORDS

Hajj Terminal, Pilgrims, Fiberglass, Teflon, Fluorocarbon, Ventilation.

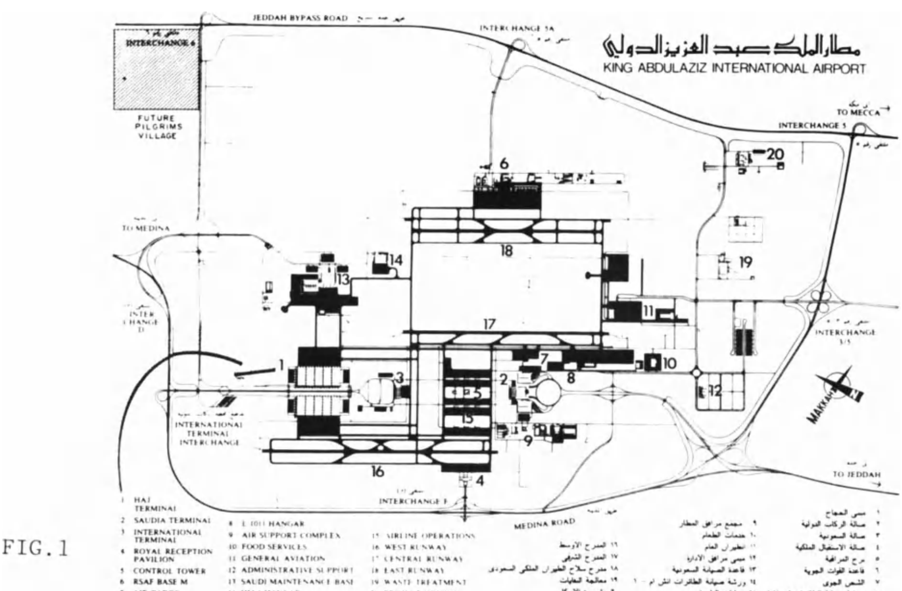


FIG. 1

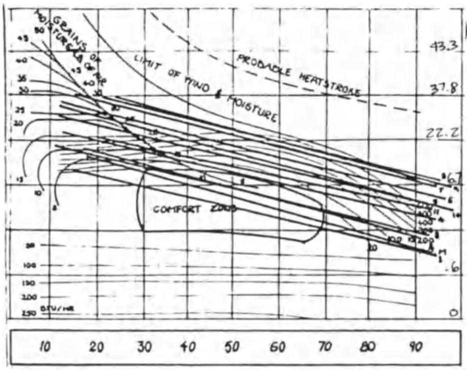
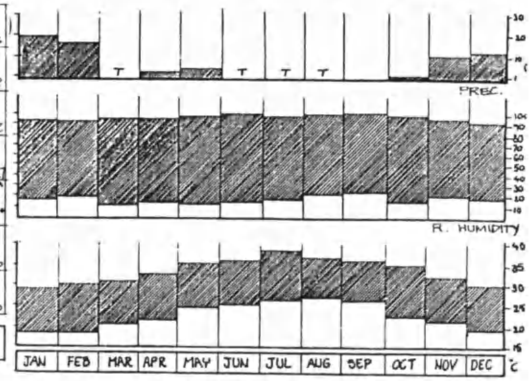


FIG.2a



KING ABDULAZIZ INTERNATIONAL AIRPORT (Fig.1 Ref.1) FIG.2b

KAIA is located 19 km north of Jeddah, the major sea-port and commercial center on the Red Sea. The airport is 105 sq km in area. It is designed to handle 10.4 million passengers by 1985 and 17 million by 2000, including the hundreds of thousands of Muslim faithfull who make the Hajj Pilgrimage to Makkah each year. The principal features of this vast airport are:-

- Three runways 3,300. 3,600. 3,800 meters long.
- North Terminal for all Foreign Flag Carriers serving Jeddah.
- South Terminal for Saudia passengers only, Domestic and International.
- A Royal Pavillion for H.M the King, visiting heads of state, ministers and other V.I.P travellers.
- Maintenance and overhaul hangars.
- Mosques in the various terminals and other buildings.
- Air Cargo Terminal with 3,600 sq.m of space, to handle 150,000 tons per year.
- Food Services Buildings, capable of serving 43 carriers.
- A.T.C center with control tower 60 meters high on 3,650 sq.m base.
- Nine Airline Operations Buildings.
- Royal Saudi Air Force Base.
- Desalination Plant to provide up to 46,500 m.m of water per day.
- Central waste-water treatment plant to recycle water for irrigation.
- Nursery facilities for the production of trees and plants.
- Maintenance and overhaul base for Saudia Airlines.
- Saudia's Flight Operations Building for briefing and debriefing flight news.

The entire KAIA Project is due for completion in 1985. However most of the above are already in operation including the Hajj Terminal Building. The enormous scale of this building coupled with the climate difficulties of Jeddah, with its small diurnal and seasonal ranges in temperature and large diurnal but small seasonal differences in relative humidity, pose a difficult comfort design condition, which the Hajj Terminal answers. (Fig 2)

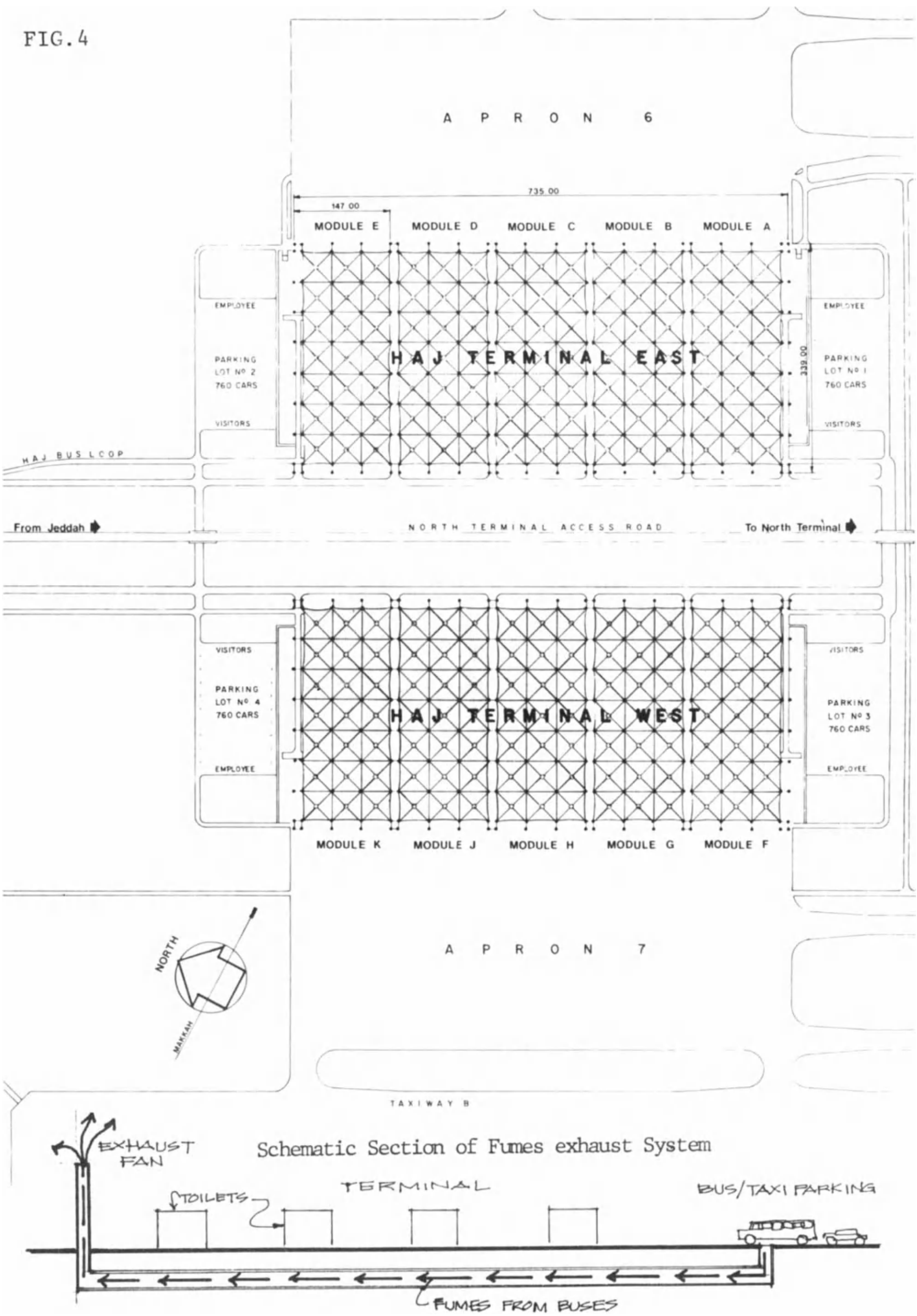
THE HAJJ TERMINAL (Figs 3,4,5)

Due to very large government investments, in the Hajj area, the number of pilgrims has risen from 1.0 m in 1970 to 1.9 m in 1982. This figure is expected to exceed 3.5 m in 2020 (Ref 2). The Hajj Terminal is designed to process 50,000 pilgrims per peak-day, as the majority of the pilgrims arrive during a 4 week period with a growing quantity continuing to arriving by air.

The Hajj Terminal Complex, occupies an area of about 1.5 square kilometers, or about 370 acres (150 hectares). It consists of two identical building complexes, each 750 by 340 meters (2,460 by 1,115 feet) flanking a central mall 160 meters (525 feet) wide. The central mall contains a complete roadway loop connecting access highways with the Haj Terminal and the North Terminal. East and West of the two Hajj structures are aircraft parking aprons which are connected to taxiway and runway systems. Each apron is designed to accommodate 10 Boeing 747 superjets at the gates and approximately 24 other aircraft in a parking position.(Fig.4). Each half of the Hajj Terminal Complex has 5 modules, each module with an enclosed, air-conditioned processing area and a covered support area. Each module has two aircraft gates and serves as an independent passenger terminal. Loading and unloading of passengers is accomplished by means of bridges between the terminals and aircraft. Each module has its own baggage claim area and customs control. Up to 50,000 travellers per day are expected to be accommodated on peak days.(Fig 5).

Two kinds of space were designed for the Hajj Terminal. One is the series of enclosed, air-conditioned terminal buildings which will be used for passport control, customs, baggage handling and other processing. The second is the much larger "support" area which will shelter the pilgrims.

FIG.4



APRON 6
735.00
147.00
MODULE E
MODULE D
MODULE C
MODULE B
MODULE A
EMPLOYEE
PARKING LOT Nº 2 760 CARS
VISITORS
HAJ TERMINAL EAST
339.00
PARKING LOT Nº 1 760 CARS
HAJ BUS LOOP
From Jeddah
NORTH TERMINAL ACCESS ROAD
To North Terminal
PARKING LOT Nº 4 760 CARS
HAJ TERMINAL WEST
PARKING LOT Nº 3 760 CARS
MODULE K
MODULE J
MODULE H
MODULE G
MODULE F
APRON 7
NORTH
MAKKAH
TAXIWAY B
EXHAUST FAN
Schematic Section of Fumes exhaust System
TOILETS
TERMINAL
BUS/TAXI PARKING
FUMES FROM BUSES

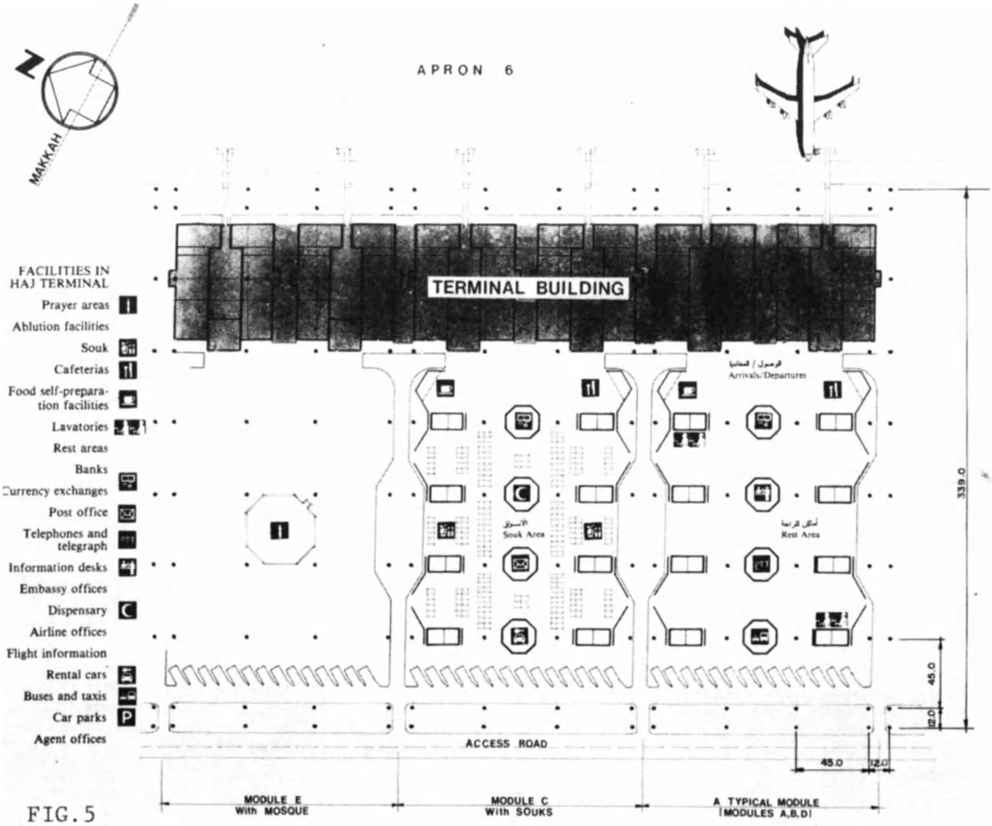


FIG.5

The Hajj Terminal is topped by the World's largest fabric roof -- 510,000 square meters of Fiberglass material coated with Teflon. The translucent fabric forms 210 tent-like units spanning 370 acres. The Fiberglass roof material was selected for its strength, weather resistance and life expectancy. Owens-Corning Saudi Contracting Services was the subcontractor for the fabric roof system.

Each of the 210 Hajj Terminal tents, or roof units, measure 45 by 45 meters (18,000 square feet) at its bottom edge and rises conically to an open support ring. This 5 meter (16-foot) ring, with the peak of the fabric attached, is held in the air by cables connected to 150-feet high steel pylons. (Fig 6). Each tent stands six stories off the terminal floor at its bottom, 10 stories high at its peak. A network of cables strengthens and shapes the fabric. Construction of the terminal roof took place one module at a time, a module being 21 tents arranged three by seven. Each module is 315 meters (1,040 feet) long and 135 meters (450 feet) wide.

The Fiberglass fabric roof permits shadowless natural light to filter through, creating a softly shaded environment that eliminates the need for artificial daytime lighting. The white fabric reflects heat off its surface and helps ensure that midday temperatures do not reach an uncomfortable level under the roof. Teflon coating helps the roof resist heat, ultraviolet rays and salt air from the nearby Red Sea. The roof's lifetime is estimated from 30 to 50 years. The prevailing wind circulates through the open sides of the structures and up through the circular openings at the peaks of the tents, thus helping to cool and ventilate the interior. (Fig 7).

Each of the 2005 sq m tent units is equipped with four novel features in specially designed ventilation columns. The 210 Hajj Terminal tents provide a total of 840 of these ventilating units (Fig 6) which are aimed at circulating the interior air for cooling, at the level of the building occupants. Each column is octagonal in plan and 1.52 m by 8.60 m high with the air propelled by an axial flow fan (Fig 9). Another unique feature is a traffic fume removing system which gathers bus and car exhaust gases at ground level in the parking area and extracts it through underground ducts by fans, to be finally discharged well above the activity area so as not to be noxious to the passengers.

At night, spotlights from below are beamed directly on the fabric roof, creating a moonlit effect underneath. From above, travelers flying in see a breathtaking view of 370 acres of fabric radiating a soft, golden glow.

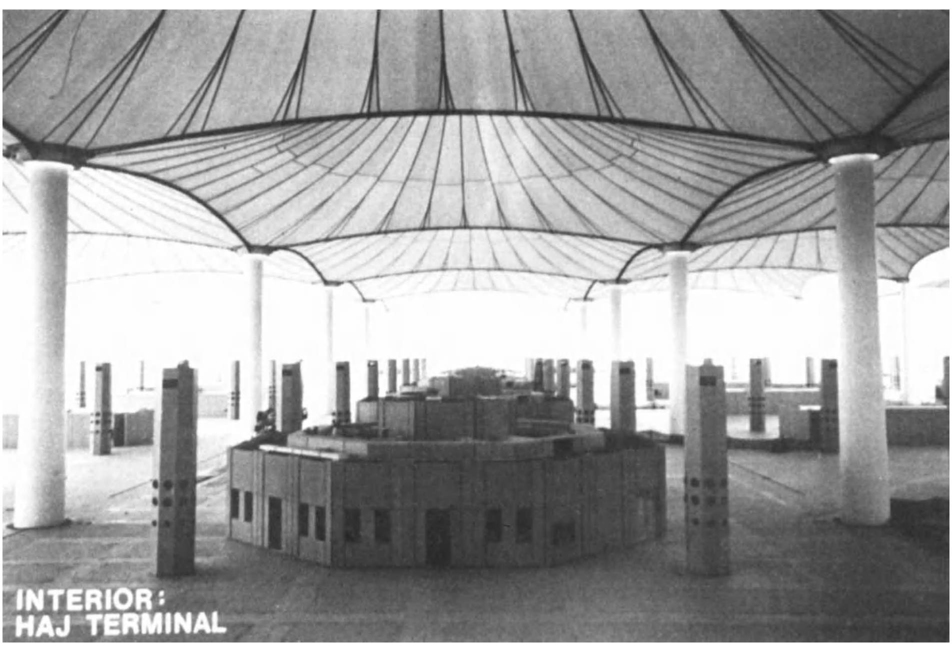
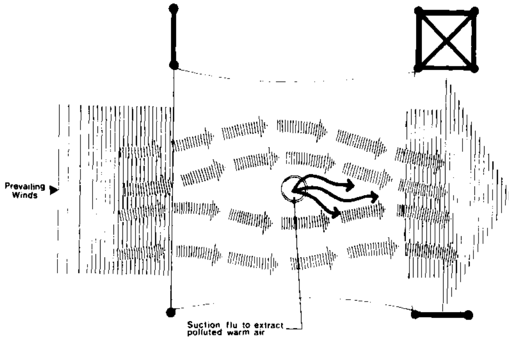


FIG.9



PLAN

FIG.7a

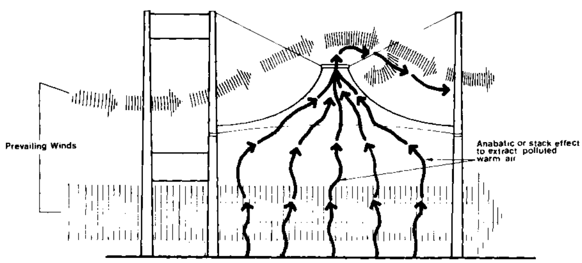


FIG.7b

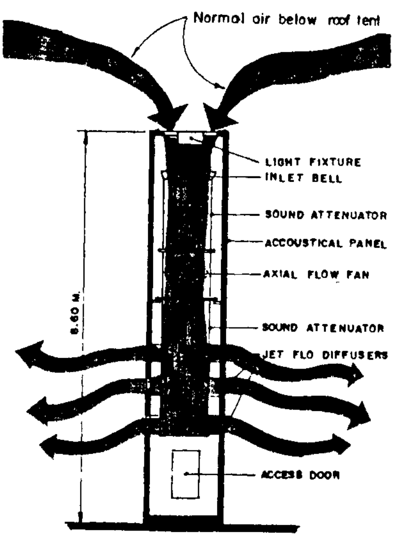
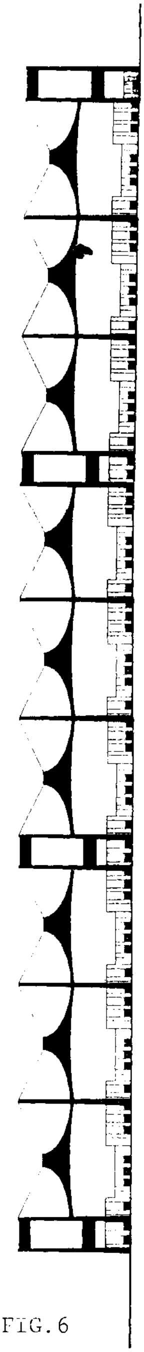


FIG.8

TYPICAL VENTILATION COLUMN



TYPICAL ELEVATION

FIG.6

ACKNOWLEDGEMENTS

Skidmore, Owings & Merrill of New York and Chicago were the architects and design engineers. Particular mention should be made of the ingenious structural design of Fazlur Rahman Khan. Hochtief AG of Essen, West Germany, was the general contractor.

CONCLUSION

The vastness of the Hajj Terminal with its one level occupancy did not permit the use of conventional air conditioning which today is normal in all new public buildings in Saudi Arabia. Furthermore, the terminal is only active for 4 months a year, peaking for one month by a very large number of passengers. Consequently, a novel ventilation system was found to ammeliorate the extreme heat of the summer. The building was first used during the August 1981 Hajj and in terms of thermal and luminous comfort, the structure was found to be a very successful and beautiful environmental machine.

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THE CONCEPTUAL PROCESS OF PASSIVE SOLAR DESIGN: BALANCING CONTEMPORARY TECHNOLOGY WITH A LOW TECHNOLOGY APPROACH

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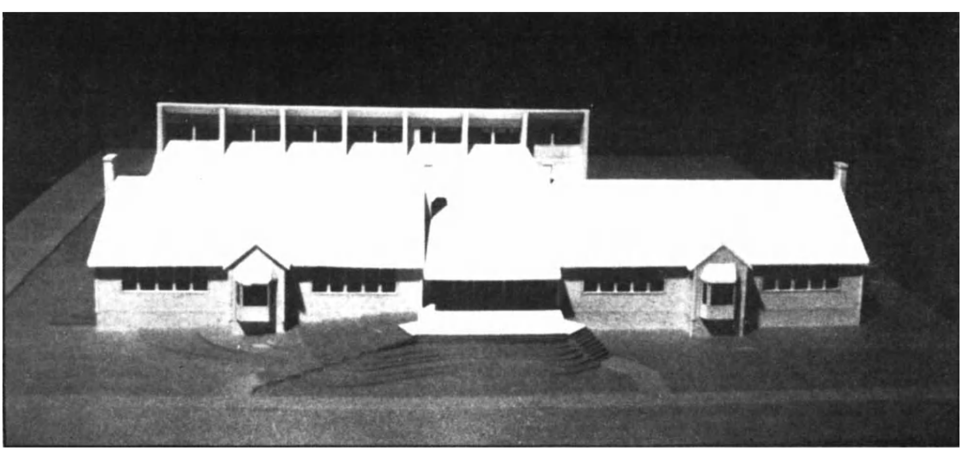
ABSTRACT

This paper focuses on the conceptual process, explaining the essential ideas which inspired the passive solar design of Essex Dorsey Senior Center in Baltimore County, Maryland, USA. It suggests why vernacular forms work so successfully on smaller buildings and specifically why Japanese and Swedish concepts provide climate responsive solutions which are at once practical, sophisticated and aesthetic. Using the completed senior center - the only known senior center in the U.S. incorporating passive solar design - as a case study, the paper discusses the issue of integration between energic, aesthetic, and functional elements of the building relating them to the special needs of the elderly. The inherent benefits of contextualism are explored, which in this project dictated a low technology, unpretentious approach.

KEYWORDS

Climate responsive design, Japanese and Swedish vernacularism, intuitive and deductive approaches, design for the elderly, Japanese architectural concepts, daylighting, shading devices, space cooling, contextualism.

Below: Model of Essex Dorsey Senior Center.



DESIGN OBJECTIVES

The objectives of the project were twofold: 1) to convert two historic schoolbuildings, each 3,000 SF to a crafts and community center for the elderly, and 2) to design a compatible addition of 7,000 SF combining the two existing structures to create a unified whole. The overall intention was to create an aesthetically pleasing, harmonious environment for the elderly. The design team used a low technology climate responsive approach applying vernacular ideas and techniques to current problems. The goal was to reduce annual energy costs 45%, emphasizing daylighting and natural ventilation in a hot humid climate - the existing Victorian schoolhouses which face southeast were originally designed for daylighting. The new addition is an L-shaped structure linking the two buildings but separated by a courtyard, a traditional plan technique for ventilation and daylighting. The large interior spaces have high volumes. The building, part of the U.S. Department of Energy's passive solar demonstration program, is now occupied by the elderly in the local community.

CONCEPTUAL FRAMEWORK

Contextual considerations. Essex, Maryland is a small community located east of Baltimore near the Atlantic Ocean, latitude 39° 11' North. The climate is essentially warm and humid with four distinct seasons.

The neighborhood is clean and neat, but somewhat rundown. Immediately surrounding the site are modest private homes built, it appears, during or immediately prior to World War II. These are simple lower middle class houses inhabited, for the most part, by the same people who moved in when the houses were originally constructed. Many of these people are now members of the Essex Dorsey Senior Center. They generally walk to the Center, although some occasionally drive.

The area is flat with very few trees, a sign perhaps that it was once farmland. Greenery is sparse. Although some families have planted bushes and a few flowers, the predominant ground cover is grass. The site itself has three mature maple trees which were saved and incorporated into the new design.

The two original schoolbuildings, set back about 50 feet from the street, are 30 feet apart. The east building is situated only 5 feet from the property line. They were originally covered with narrow clapboard siding which was subsequently covered with brown cedar shingles. Each building is about 70 feet by 40 feet, of frame construction, with a projecting front entrance facing the street and steeply pitched roofs.

The main street is only a block away and is comprised mainly of private houses with added storefronts. These, along with garage repair shops, are the primary commercial buildings along the street. Generally, the scale is low, not more than two storeys. There are beginning signs of community renewal as envisioned by a large rendering of a proposed revitalization of the street which appears in the window of a redevelopment organization. The drawing indicates trees along the median and along the sidewalks (some of which have already been repaved with decorative brick). It also suggests storefront renovations. Generally, however, the original buildings remain and, therefore, the scale of the area will not change in the forseeable future.

Approach. Keeping the two existing schoolhouses by incorporating them into the design enhanced their sentimental value to the community, since many center participants attended school there. Moreover, because of the declining birthrate in the U.S., the reuse of old schoolhouses is a practical and economically viable solution to potential abandonment.

The designers then called upon their experience with Japanese and Swedish ideas of encouraging physical, intuitive and cognitive integration of human beings with nature.

They focused on low-scale, modest, vernacular structures, since these are the type of buildings in which most people spend the better part of their lives, and their intimate qualities suited the special needs of the elderly. Utilizing analogy rather than analysis, intuition rather than deduction, enhanced articulation of certain fundamental truths of passive solar design. Vernacular buildings were often constructed by individuals who subsequently inhabited them, and their priorities, depending on where they lived, were essentially the same as those we consider important today: ventilation, lighting (or more appropriately daylighting) and heating.

Theory. The concept of simple environmental adaptation is best understood by choosing areas of the world which were for some parts of their history isolated from major outside cultural influences. At first glance Japan and Sweden appear to have very little in common, and applicability to a project for the elderly in a small community in the mid-Atlantic part of the U.S. seems very remote. But in many surprising ways Sweden and Japan represent parallel cultures which, when faced with similar environmental problems, elected to emphasize different but complementary design solutions. The Swedes designed their homes to insulate the interior space from the bitter Arctic winters, while the Japanese, also faced with rugged winters designed their farmhouses to keep the inhabitants more comfortable during the hot, humid summers. Despite the difference of emphasis, however, an important similarity should not be lost - the use of elegantly conceived solutions employing indigenous technology.

The most obvious resemblance between the two countries is perhaps the one which seems the most dissimilar: geography. It has had an enormous impact on the cultural development of both countries. Sweden runs from north to south, much like Japan, and is surrounded by water on three sides. Japan is, of course, an archipelago. Both countries are mountainous, have considerable snowfall during the winter, large forests, lakes, rapid streams which supply hydroelectric power, and finally, a lack of abundant natural resources in the form of mineral deposits. Both countries have only a small percentage of arable land - 8% in Sweden and less than 20% in Japan. Both have minority groups which were pushed to the extreme north: Sweden drove the Lapps to the Arctic circle and Japan drove the Ainu to Hokaido, the northern island of that country.

Although their climates vary, (Japan has hot, humid summers, particularly south of Tokyo), this was not always the case. Apparently Sweden was not always cold and snowy with long winters. Between 1500-500 B.C. it was considerably warmer than it is today. The Iron Age came to Sweden around 500 B.C. and with it cold weather and Teutonic people. They were basically farmers and, since there was no written law, society was established by custom much like Japan.

Far left: Swedish example of 19th century wooden structure.

Left: Typical 17th century Japanese farmhouse.

Both countries have been historically portrayed as insular societies which at the same time failed to develop truly intrinsic architecture. The actual relation between insularity and imitation is considerably more complex, however. Swedish public architecture of the 18th century does reveal strong Dutch, German and Italian Renaissance influences, yet the domestic style of the period remained characteristically Swedish, evolving from Iron Age structures and later, 13th century innovations in farmhouse design. Likewise, Japanese style reveals an admixture of Chinese, Korean and Polynesian influences, yet the foreign concepts were refined into startlingly unique and effective designs. Culturally, then, both nations were able to employ a process of innovation which enabled them to develop distinctive architectural styles.

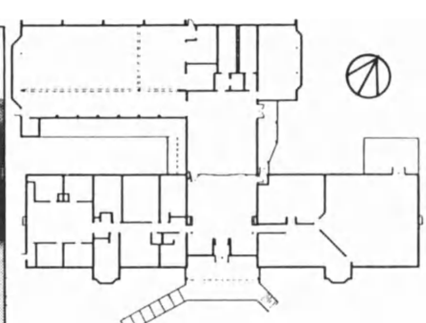
With their large forests as resources, it is not surprising that the Swedes and the Japanese have developed a sophisticated, intuitive understanding of the uses of wood as an expressive textural element of design. This appreciation spills over and is related to a love of water. The Japanese have made an art form of the bath—cypresswood lines the tub, as well as the walls and floor of the bathing room. The Swedes, of course, possess the sauna, a dry heat-retaining room generally constructed with birchwood walls and benches.

The intuitive nature of these cultures' understanding of the uses of wood extends into other areas of domestic design, notably in such areas as ventilation, insulation, and daylighting. The ability of the Swedes to design an insulated structure goes back at least 2,500 years to the Iron Age; the Japanese began to learn how to ventilate their buildings nearly 2,000 years ago.

The Swedish Iron Age house is similar to the simple rectangular structure built by the Japanese almost two thousand years ago. The Swedes call it a "Hearth house." It consisted of a single room with an open hearth in the center. The slender columns and crossbeams created a pitched, slightly curved roof generally of straw which had a louver near the top for ventilation. The difference between the two cultures is that the Swedes used horizontal notched logs which interlocked so that when the house settled the walls became tightened and, therefore, insulated and watertight. Although the winter climate in Japan demanded a similar approach, the Japanese generally used vertical strips of wood perhaps in the hope that their tropical summers would remain for the entire year.

If the Swedes could cope with their long dark winters with a fair degree of success, it is equally true that the Japanese knew how to deal with their hot, humid summers. Their concern with cooling and ventilation simultaneously led to some imaginative solutions for diffusing light and reducing glare. This integration of daylighting and ventilation is a unique aspect of Japanese architecture and represents a typically Japanese intellectual characteristic of fusing diverse conceptual trains of thought into an harmonious whole.

Below: Completed structure; back entry, the Japanese courtyard, and floor plan.



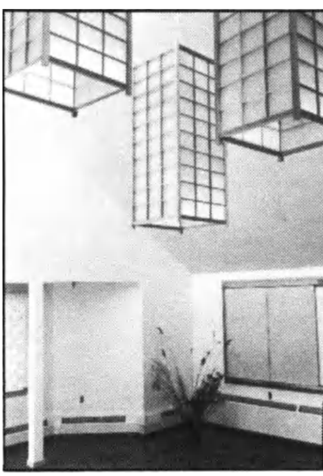
One of the most sophisticated concepts to come out of Japan incorporates the essence of light, space and time. The concept, called MA, actually extends beyond the perimeters of architecture. It is a good indication of how the Japanese perceive many things at once and how this perception influences the design of their buildings. Lines of vision can be manipulated by the use of sliding walls, light, color and circulation.

In primitive Japan it was assumed that space and time belonged together. The earliest method of defining space was to place four poles to mark the edge of a rectangle. A rope was tied around the four posts to enclose the space. A larger pole was placed in the middle for the kami or spirits to descend. This influenced future ideas of space and time which continued to be thought of as fluid and adaptable, not fixed or calculated.

Articulating the concept of MA is considerably more difficult than comprehending it. The various aspects of subtlety are often not easy to define, yet they are generally thought of as being simple. Spatial continuity between the interior and the exterior of a building, between public and private spaces, between light and shadow, and between color and texture are all part of the final image presented in a completed structure.

The Japanese sensitivity to the environment caused them to look carefully at the effects of light within a structure. Windows were covered with washi, or mulberry paper (commonly called rice paper in the United States). Although fragile, the paper allowed light to pass through and shed a soft glow on the tatami floors and smooth wall surfaces. If more light was needed, lightweight partitions called shoji screens were moved to let more light into the room. Rarely did the direct rays of the sun enter a room, due to the large roof overhang which provided shade during most hours of the day. All interior spaces had movable partitions designed to provide the maximum amount of flexibility during all hours of the day or night. Japanese architecture is characterized by the lack of fixed walls—a characteristic which has the advantage of providing ventilation and natural light into all corners of the interior space.

It is evident that the Japanese do not feel comfortable with strong bright light in their traditionally designed structures, preferring the diffused natural light from outdoors. They also understand the interplay of light and shadow and in what parts of the interior space daylight is more important. The co-mingling of interior and exterior space lessens the impact of beginning and end, light and dark. Architecturally, this was embodied in the engawa, loosely translated as veranda or porch. One is directly next to nature while at the same time protected from changes in the weather.



Left and above: Interior views showing clerestory, quilts, and sliding panels.

APPLICATION

Daylighting strategy.

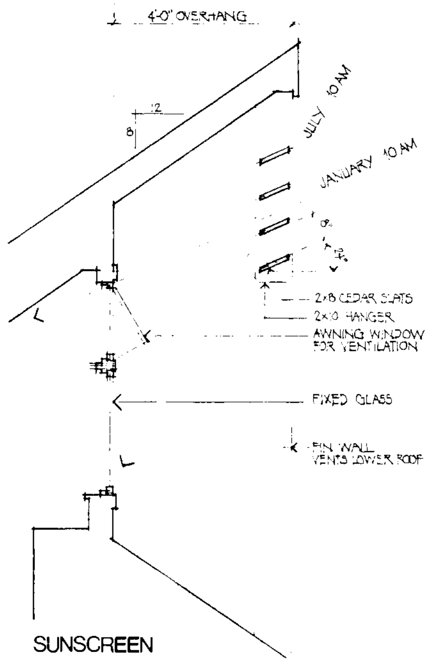
- High windows and ceilings patterned after existing buildings provide good penetration for 40 foot width.
- Form of addition to be shallow and relatively high.
- High clerestory windows allow daylight penetration to north side.
- Avoiding direct sunlight and glare, utilizing Japanese courtyard, porches, overhangs, sunscreens, landscaping and plantshelves.
- Pale, soft colors in interior spaces rather than pure white.

Cooling strategy.

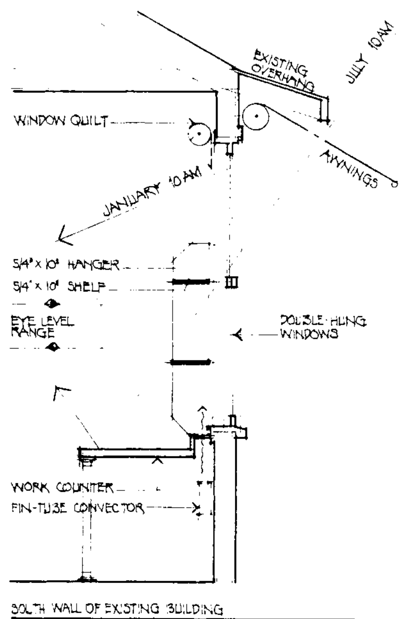
- Employing techniques complimentary to daylighting strategy, specifically shading through porches, sunscreens, landscaping and plantshelves.
- Courtyard oriented toward summer prevailing breezes.
- Wind scoops to direct prevailing breezes.
- Increased perimeter vent area.
- Interior sliding screen partition to enhance ventilation.
- Thermal chimney effect with high operable clerestory windows.

Heating Strategy.

- Well insulated low mass sun-tempered building, R-19 6" stud walls. R-38 ceiling/roof.
- Direct gain through south glazing.
- Night insulation at windows (quilts) with night setback.
- Seasonal insulation at north windows (sliding panels).
- High internal loads while in use; recirculating stratified heat.
- Domestic hot water-passive solar batch heater.



SUNSCREEN



PLANT SHELF DETAIL

SUMMARY

There are several key aesthetic and technical features which facilitate the design's effectiveness. Since passive solar priorities were daylighting and cooling, Japanese climate responsive ideas are more apparent in the completed structure. A few climate responsive features specifically responding to the needs of the elderly are:

- Adaptive scheduling. The term "adaptive scheduling" refers to the concept of scheduling activities in response to changes in daylight and temperature. For example, in the winter, the Center might be open from 11:00 a.m. to 2:30 p.m., while in the summer the hours might be adjusted a few hours earlier. Adaptive scheduling increases energy efficiency without compromising the degree of comfort within the structure.

- Intermediate spaces. Veranda areas which can function as both indoor and outdoor spaces are energy efficient in several ways. In hot weather, they can be opened for ventilation, and in cold weather they can be closed for a degree of insulation. Throughout the day, these intermediate spaces provide shade, eliminate reflective glare, and diffuse daylight, important design factors when considering the comfort of the center's participants.

- Daylighting. Older people have a great need for even lighting. The design is planned around a traditional courtyard which brings diffused daylight into a large proportion of the interior space. In addition to the role of the various intermediate spaces in achieving suitable lighting, the use of clerestories and or plants on shelves in the large south-facing windows of the existing structures will reduce the potential problems of glare and shadows.

- Traditional cooling techniques. Natural ventilation is achieved by design orientation to the prevailing winds inducing air scoops during hot, humid weather. High spaces, ventilating clerestories, solar chimneys, narrow wings and sliding screens all contribute to the free flow of air. The courtyard also serves for night air flushing. Air conditioning is limited to the operating core which is designed as a "thermos"; the activity areas are designed as "sieves" encouraging natural ventilation.

MEASUREMENTS AND MONITORING DATA

Physical monitoring of building performance began at the spring 1983 equinox as part of a year long evaluation of the building in use. Each type of space under a variety of outside sky conditions is measured. Within the larger spaces, measurements are set along a cross sectional grid using both overhead and horizontal measurements. Brightness of surrounding areas is metered to establish the effect of context on quantity of light and glare. Effects of the clerestories alone with the opaque curtains of the lower windows drawn are being noted. Measurements will be repeated at the winter solstice to examine the worst daylighting conditions. In addition, energy consumption for lighting is submetered and behavioral observations will monitor the actual use of ambient and task lights, curtains, placement of people in the space, and their activities.

CONCLUSIONS

The idea was to develop this project so that it blends harmoniously with the processes of nature, the cycles of each day, and the seasonal rotation. At every stage in the design process, we attempted to reflect this harmony by unifying design solutions with solar considerations. Finally, in drawing from the lessons offered by other cultures at other times, we learned to appreciate not only their specific designs, but their approach to those designs as well.

A PASSIVE SOLAR RESIDENCE IN PORTUGAL

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ABSTRACT

A passive solar residence under construction in Porto, Portugal, is presented. The residence is described in detail, including floor plans, construction materials used and passive systems selected for each space in the house. Predicted performance of its solar systems is also indicated.

The objectives of this research are indicated, together with some of the experimental and mathematical means that will be used to accomplish them.

KEYWORDS

Passive Solar; Modelling; Building Thermal Performance; Energy Conservation.

INTRODUCTION

Passive solar technology has been widely developed in the last few years. There have been numerous buildings designed all over the world which included passive solar systems, mostly in countries with colder climates. Yet, quantification of the thermal performance of a passive building prior to its construction still remains a difficult task due to the complexity required to describe thermal exchanges in a building in a sufficiently accurate form.

Presently, quantification of the solar contribution in a passive building is based on complex computer models such as PASOLE (McFarland, 1978) or SUNSPOT (Wray and Balcomb, 1979), or from simpler correlations using dimensional or nondimensional parameters, such as the LCR (Balcomb, 1980) and the Gordon-Zarmi (1981) methods. All these methods involve some assumptions to obtain performance predictions, namely about building characteristics and weather patterns, and, at best, the predictions can only be as accurate as the assumptions themselves.

The weather in a particular location is usually characterized by some mean parameters such as monthly degree-days, monthly total radiation on a surface, clearness factors, etc. There are other factors, however, which affect the performance of a solar building such as sequences of sunny and cloudy days and simultaneous occurrence of cold and cloudy or sunny weather. The mean parameters used in the quantification

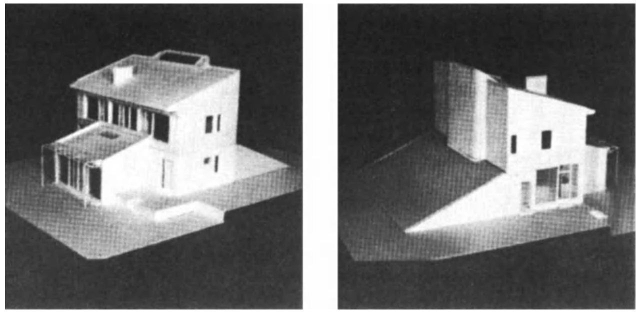

Fig. 1 Two views of the model of the passive solar residence

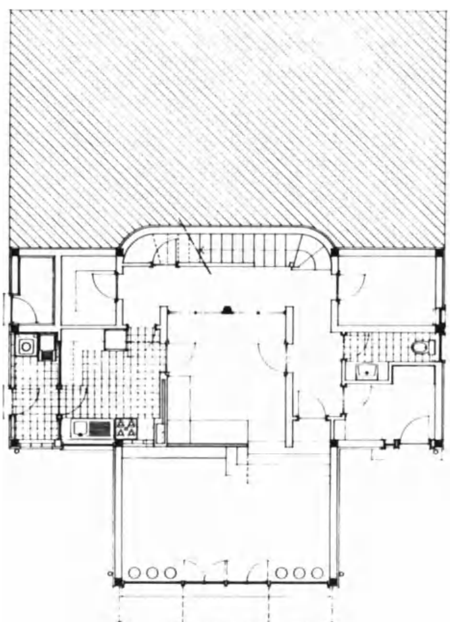

Fig. 2 Floor plan of the lower-level

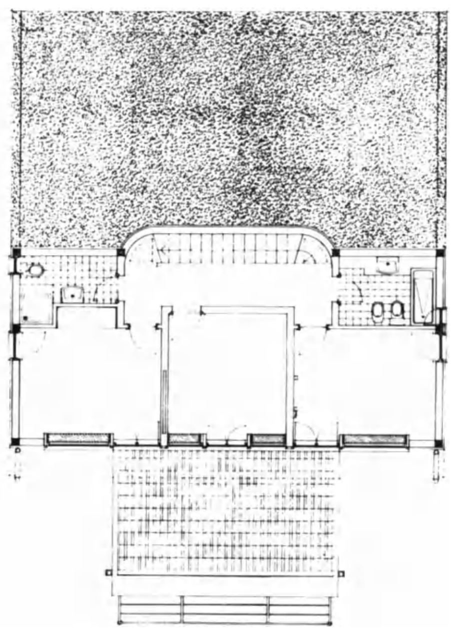

Fig. 3 Floor plan of the upper-level

procedures only take the latter weather characteristics into account in an indirect way, and some deviations between predicted and actual performance may result.

Construction techniques also play a major role in building performance. The passive design methods assume certain typical construction materials and techniques which may not be used in some regions and which may introduce some further deviations in performance predictions.

From all this, it may be concluded that it is important to experimentally verify the performance of a passive solar building and its systems whenever conditions differ from those assumed by the design methods. In Portugal, no passive building as such has yet been studied. Therefore, one was designed and is being built to help to determine how the different passive systems built with locally adapted technology and materials behave under a climate typical of the northern coastal region of Portugal (Oporto).

Furthermore, this project is intended to serve as a means of informing the general public and the building industry in particular of the effectiveness and availability of passive solar technology, thus contributing to the overall effort in energy conservation that is taking place in the country.

BUILDING DESCRIPTION

The building is a single-family, detached, two-story residence with 160 m^2 of total floor space. Figure 1 shows a model of the residence, and Figs. 2 and 3 show the floor plans of the two stories. It has a main rectangularly shaped body with the longest axis placed in an east-west direction, and an attached living-room in a lower level of the southern facade. In this way, the largest possible facade area is exposed to the south to allow solar incidence upon all major occupied spaces which are also located by the southern facade. The space by the northern facade is used for corridors, stairs, and other rooms with only occasional use, e.g., bathrooms and storage rooms.

Going from front (south) to back and left to right (see Fig. 2), the main spaces in the first floor are a living-room, a vestibule, a dining-room, a kitchen, a laundry-room and, in the north side, a study and a storage room. In the far northeast corner there is a storage space which can be accessed only from the exterior and is insulated from the main body of the house. The second floor (Fig. 3) has 3 bedrooms. There are two bathrooms in the second floor and a lavatory in the first floor.

The walls are made of solid core concrete blocks with a thickness of 0.20 m insulated on the outside with 5 cm of expanded polystyrene. The outer surface of the insulation is covered with weather-resistant plaster. There is an earth-berm covering the lower portion of the north wall such as shown in Fig. 1.

All glazings have two panes of glass with the inner space sealed to increase its R-value and avoid water vapour condensation. In addition, they are provided with a roller-shade of the type shown in Fig. 4 which can also serve as night insulation. South-facing glazed areas have horizontal overhangs over them to avoid direct exposure to the sun's rays during the summer season. In the case of the living-room, the overhang consists of a deciduous plant which will grow on the structure shown in Fig. 1. All window frames are made out of wood and are to be carefully installed to reduce leakage.

The foundation, ground-level slab, and roof structure are also insulated with 5 cm of polystyrene.

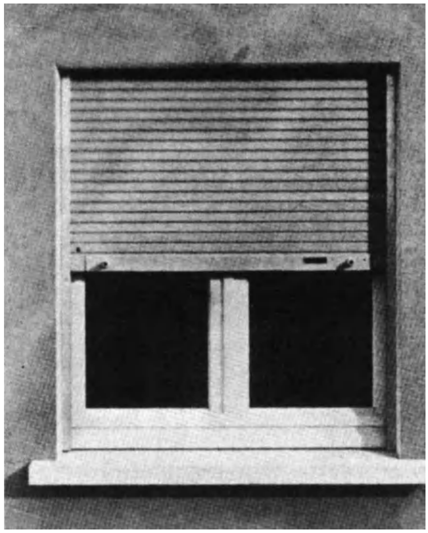

Fig. 4. Type of roller-shade used on all glazings.

The house has two major types of passive solar systems: direct-gain and Trombe wall. In the lower level, the living-room is a direct-gain system with 12 m^2 of glazed area. The floor consists of a solid 15 cm thick concrete slab topped by a layer of clay tiles. Further storage mass is provided by the interior walls, also made of 0.20 m thick concrete block, and by 6 water-filled fiberglass cylinders 0.30 m in diameter, painted in black, with a capacity of 180 Kg of water each (see Fig. 2). This combination of storage media basically combines the advantages of direct-gain and water-wall systems, allowing for daytime and early evening occupancy which usually occurs in a living-room. Due to the large area of comunication between the living-room and the adjoining dining-room, it is anticipated that this latter space will also be effectively heated by the direct-gain system.

Conversely, in the first floor, the bedrooms are essentially spaces that are occupied during the night. Therefore, a Trombe-wall is provided for each bedroom, together with a window which will provide some direct gain and visual access to the exterior of the building. The total areas of the passive systems in the first floor are 4 m^2 of direct-gain and 7.5 m^2 of Trombe-wall.

Auxiliary heating energy is provided primarily by a wood-burning fireplace located in the living-room. The stack is embedded in the concrete wall which separates the dining-room from the kitchen in the lower level and two of the bedrooms in the upper level. Thus, some heating will also be directed to these spaces. The third bedroom can be heated with a water circuit which has a heat exchanger in the stack and a radiator in that bedroom. This circuit will operate by natural convection.

Further auxiliary heating can be supplied to the spaces that may need it by portable electric units.

An active 4 m^2 solar water-heating system is provided in the domestic hot-water circuit. The collectors are architecturally integrated in the roof and the storage tank is placed in the attic between the roof and the second floor. The auxiliary energy is provided by an electric resistance placed in the storage tank. The collectors are placed with a slope of 45°.

In Summer, direct solar incidence on the glazed surfaces is prevented by the horizontal overhangs previously mentioned. Furthermore, two openings (not shown in Fig. 1) are provided in the north wall which can be opened and, together with the other window areas of the residence, allow some cooling cross-ventilation. As the ambient temperature in Summer in Oporto only seldom rises above 30°C, the cooler night air can be used to lower the temperature level of the massive walls, roof and pavements such that the indoor temperature during the day may remain within the comfort range.

In conclusion, passive solar design and energy conservation measures have been combined into the design so as to obtain a harmonic ensemble without significantly increasing building costs.

BUILDING THERMAL PERFORMANCE

This residence is currently under construction and, therefore, only estimates of its performance are available. These estimates were obtained using the LCR method for the passive solar systems and the f-chart method (Beckman, Klein and Duffie, 1977) for the domestic hot-water system.

The calculation of the solar savings fraction for this building yielded a value of 54%. The interior base-temperature for this calculation was 18°C, which corresponds to about 785 heating degree-days (°C) in Oporto. Assuming that construction will be carefully done to reduce leakage through the envelope, resulting in an average air exchange rate of about 0.6 ACH, the design heat loss coefficient for the building is 333 W/°C or 6000 W for a design-day with 0°C. Table 1 summarizes the main climatic parameters for Oporto (monthly heating degree-days (DD), daily total radiation on an horizontal surface ($\overline{G}$), and clearness factor ($\overline{K}_t$)) and the monthly solar savings fraction (SSF) for the building during a typical heating season.

TABLE 1 Thermal Performance of the Building

Month	DD (°C)	$\overline{G}$ Wh/m^2.day	$\overline{K}_t$	SSF
Nov	95	2180	0.49	0.75
Dec	202	1700	0.47	0.39
Jan	180	1800	0.45	0.42
Feb	148	2740	0.50	0.53
Mar	107	3970	0.53	0.69
Apr	53	5780	0.61	0.92
Total	785	-	-	0.54

The calculation of the performance of the active domestic hot-water system was based on a design occupancy of 4 people, each consuming 50 liters of water at 50°C per day. The f-chart method yielded that the solar system should supply 73% of the load, with a minimum of about 43% in January and December.

To determine the actual performance of the building as a whole and each system in particular, detailed monitoring will take place upon completion. A computer-controlled data acquisition system will be used to collect the following:

. climatic conditions, from a weather station to be mounted on the roof. It will measure ambient dry-bulb and wet-bulb temperatures, wind-speed and direction, and total radiation incident on the roof and on the vertical south--facing walls.

. indoor dry-bulb, wet-bulb, and black-bulb temperatures at various locations. Copper-constantan thermocouples and platinum resistance thermometers (Pt 100) will be used.

. surface and interior temperatures of walls, windows, ceilings, slabs, and other building elements. Thermocouples and Pt 100 probes have been placed inside some of these elements during construction.

. ground temperatures and temperatures of elements of the building foundation will be measured at more than 100 points at three different levels from the surface of the ground. A thermocouple was placed in each of these points during construction.

. surface heat fluxes at various locations, measured by heat-flux sensors.

. electrical energy consumption measured at 12 different circuits in the house.

In addition, individual systems such as Trombe walls, water storage containers, stack heat recuperator, and active solar energy collector, among others, will also be monitored on a continuous or periodic basis. Specific measurements will attempt to characterize air infiltration by the tracer-gas decay method, envelope leakage by the blower door method and the thermal performance of particular components such as roller-shades, for example.

The behaviour of the building can then be simulated with an unsteady model such as shown in Fig. 5 which can be solved by numerical methods (Morel, 1981). The necessary software is already prepared, awaiting only the final definition of the value of each resistance and capacitance associated with each node, which will be determined from experimental measurements. Preliminary results using best-estimate values indicate that free-floating temperatures inside the residence during average winter days are mostly within comfort range although some lower than desidered values may be observed in the lower level of the residence, as shown in Table 2[1]. Of course, this is not unexpected, as the solar contribution for heating the house is not 100% (see Table 1).

CONCLUSIONS

This residence, which is expected to be completed in late summer of 1983, will allow an in-loco verification of the performance of various passive solar systems and other building elements. Through close cooperation with the builder, it will be possible to get some information about the deviations that were required from commonly used construction technology in Portugal. Detailed cost breakdowns are also being taken during construction to make a comparison with the costs involved in a conventional building.

This information will then provide helpful hints for other builders and designers so that the quality of building construction in Portugal may be improved.

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[1] The temperatures listed in Table 2 are steady-state values calculated assuming a sequence of identical average days for each month (first column in Table 2).

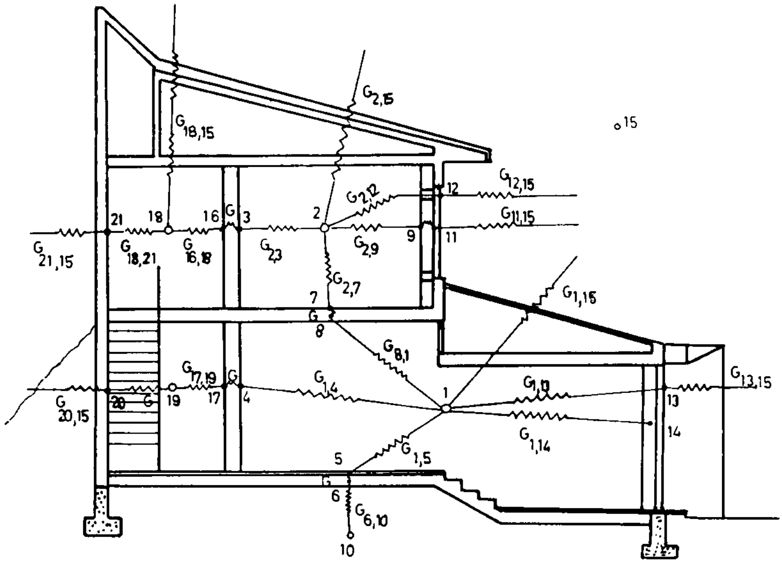

Fig. 5. Thermal resistance network used to simulate the passive solar residence.

TABLE 2 Simulated Performance of the Building

Month	Temperatures (min - max) (°C)		
	ambient	first floor	second floor
OCT.	10.5 20.5	20.0 21.5	21.0 22.0
NOV.	8.0 16.5	17.0 19.5	18.5 21.0
DEC.	5.5 14.0	14.5 16.5	16.5 18.0
JAN.	5.0 13.0	14.0 16.5	16.0 18.0
FEB.	5.2 14.0	16.0 18.5	18.5 20.5
MAR.	7.5 16.0	18.5 21.0	21.0 23.0

ACKNOWLEDGEMENT

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HUNGARIAN EXPERIMENTAL PASSIVE SOLAR HOUSE

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ABSTRACT

The aim of the passive solar R + D project in Pécs, Hungary is to yield justifications for climate- and energy-conscious building design under specific Hungarian technical-economic and climatic circumstances by designing, executing and monitoring an experimental house while evolving its system components. For the sake of this cause we propose passive systems supplemented with appropriate means of building mechanics that are relatively simple and easy to control. A more effective "high-tech" regulation alternative is to be elaborated as well. The number of solar elements applied is more than necessary in normal cases, in this way the experiment provides possibility for comparing parallel solutions in a several-year-long computer-aided monitoring. The result of the work done so far is a detailed plan of a 12o m² "flexible laboratory" with traditional load-bearing structures, passive systems as modified Trombe-Michel wall and attached sunspace, combined heat-storage of both natural and artificial control.

KEYWORDS

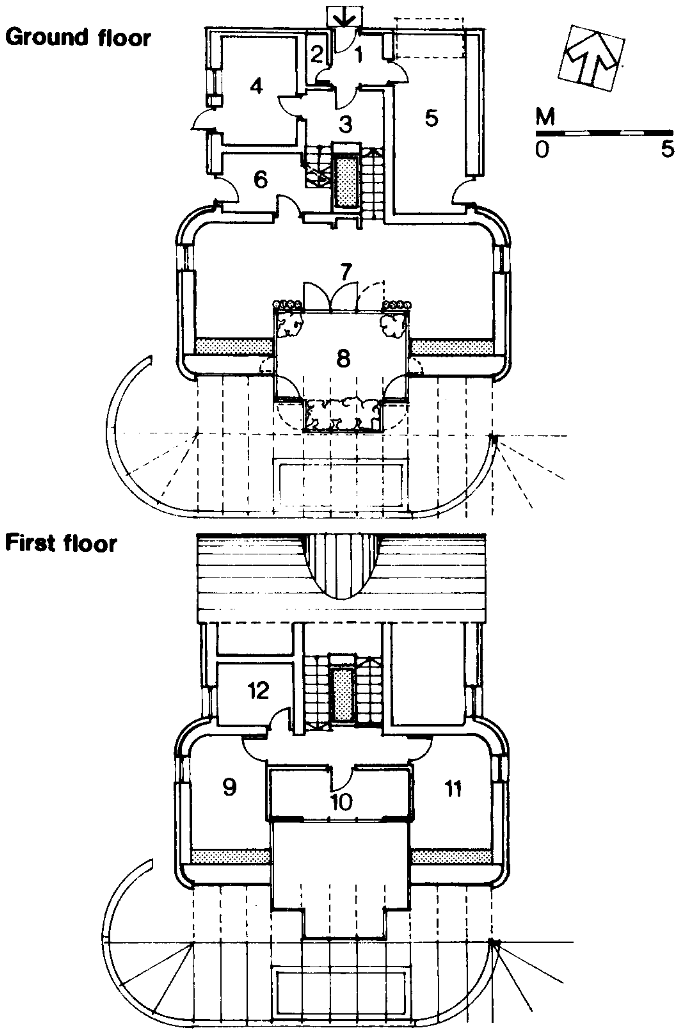
Passive solar building, climate- and energy-conscious architecture, thermosyphon mass-wall, combined heat-storage, multipurpose plant-culture, natural cooling.

INTRODUCTION

The Hungarian R + D program for low temperature utilization of solar energy is run by the Ministry of Building and Urban Development. One of the first experimental passive solar houses is to be built and monitored in Pécs, South-Hungary under contract with the Ministry according to the plans of the team headed by the authors. In spite of the fact that there is hardly any product on the home market which can be considered a passive system-component and passive design and simulation has no traditions in Hungary, not even in theory, there is a growing demand for low energy comsuming solar dwellings suitable for the increasing number of private investors.

ARCHITECTURE

The flat area of the experimental single family house, set on the south-sloping site with semi-shifted floors, is 120m². Ground and vegetation design takes into consideration either solar gain or solar radiation and wind protection or natural cooling, where appropriate. The space composition based on the buffer-zone principle is shown in Fig. 1.



1. Entrance 2. WC 3. hall 4. kitchen 5. garage
6. hobby 7. living room 8. greenhouse 9., 10.,
11. bedrooms 12. bathroom

Fig. 1. Floor plans of the experimental building

The central position of the staircase + heatstore serves proper heat distribution. The soft lines of the house are justified by aerodinamical and architectural considerations, the compact mass-formation minimizes heat-losing areas while the increased southern elevation surface maximizes solar gain /Fig. 2./. The choice of building-structures and materials is also consistent. The relatively little number of openings are well insulated, air-tight and can be shaded. The non-south-looking outer structures are provided with isolated and ventilated external surfaces /k=0,25 - 0,39 W/m² K/. The soil-covered flat roof is an excellent heat equalizer /k=0,25 W/m² K/. The south elevation being completely covered by translucant materials makes heat gain possible. In respect of future comparative investigations the floor-plan of the experimental building is symmetric, part of the structures are remountable and places of possible later vents are prepared in advance.

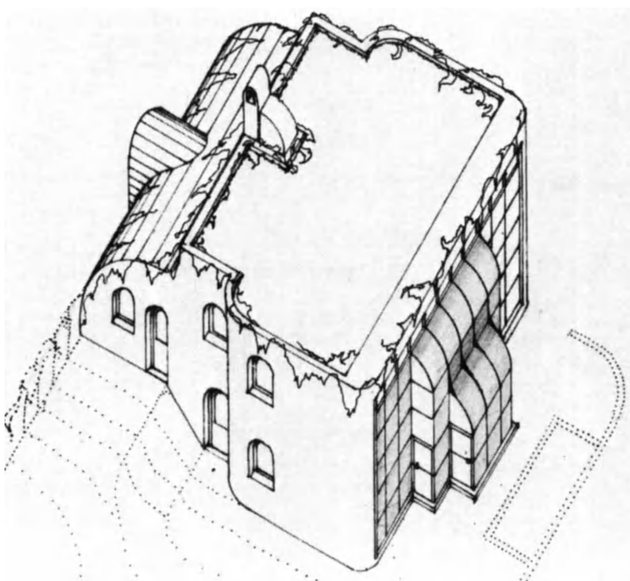


Fig. 2. Axonometric view

ATTACHED SUNSPACE

The central unit of the passive solar system - as in Balcomb house built in 1975 - is the 18 m² two level greenhouse with a vertical extension of 3o m². Only the half of it juts out of the elevation-plane - likewise in Green's Delta House from 1974 - to provide favourable surface dimensions and connection to almost all living premises. To avoid shading of nearby absorbing surfaces the protruding part is narrowed in two steps. Vertical planes of the sunspace are double glazed while arched surfaces are covered with acryl-coated U. V. - resistant, crack-proof polycarbonate sheets which had been succesfully applied for similar purposes by Farrell and Lebens. The framework is under developement by V. Sz. M. and KIPSZER Hungary.

To shun excessive massiveness of the southern elevation we planned movable glazed walls to separate the living room and combined heat-storage to eliminate the mass wall to be needed otherwise. Primer heat stores are the 4o cm rock bed on nearly the entire basic area, and the phase change material partition and parapet panels on the upper floor elaborated by Zöld and co-workers /1982/. The secondary heat-reservoir/vertical, zeolite-charged, with lower and upper vents/ - is situated in the centre of the building on the boundary of cooler and warmer zones. It is connected to the greenhouse through close-loop forced air-circulation. The heat transfer from the storage is permanently convective, but opening the vents and occasional operation of fans can accelerate hot-air heating. Shading around and in the greenhouse is mainly natural, provided by plants. A white sail-like supplementary shading can be employed till creepers grow to proper proportions. Four doors and a stripe of windows at the top can detach the sunspace from the facade in hot weather. The other way of ventilation is to pump cool air from the northern side through the house. Figure 3. makes system-function and placing of heat reservoirs perceptible. The upper scheme shows the heat up of stores on a bright winter day, the lower demonstrates the cool out period of the internal masses.

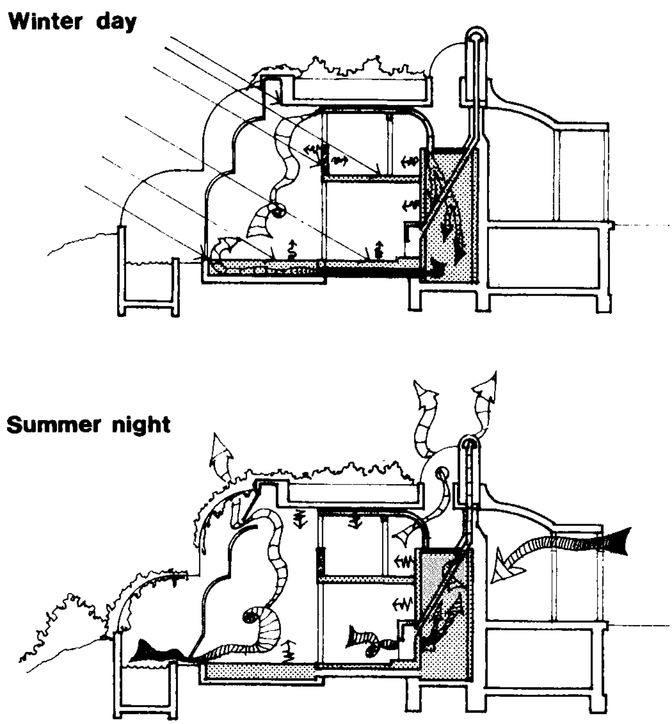


Fig. 3. Action schemes - section through sunspace.

THERMOSYPHON TROMBE - MICHEL WALL

In consequence of different climatic conditions a good number of modifications of the Trombe-Michel wall /T-M wall/ are known. The variation of ours is characterized by the following . As the necessary system components are not available at the moment, and in our continental climate cold, gloomy periods are not rare, we designed a two-level-high mass wall moderately insulated on the internal side, which heats the upper bedrooms as a gravitational air collector. This solution harmonizes with the heat distributional needs as well. The system, corresponding to the one employed by experts of CNRS Odeillo, functions self controlled. Clack-valves and control equipments are not needed to avoid cool down caused by recirculation. Disregarding the thermotechnical and aerodynamical optimum investigated among others by Utzinger, Klein, Mitchell /198o/, the air gap is 6o cm wide to make the internal cleaning of the high glass wall possible. Thus framing is simple , thin , filtration losses are eliminated and flow resistance is low, which is important in case of gravitational systems. The summer shading of the wall is provided by a reflective curtain, similar to Curtain Wall ®, applied in a townhouse in Vancouver by Mattock /198o/, Based upon function principles of large mobile partitions used in sports halls we designed a 3x6 m two layer fabric wall drown up manually or by a little automatically operated electric motor. The aluminized outer and velour inner coating has been developed by Graboplast, Hungary. On winter nights and gloomy days the curtain let down to the ground serves as a mobile heat-insulation, too. In this position it ceases harmful secondary circulation in the excessively wide gap.

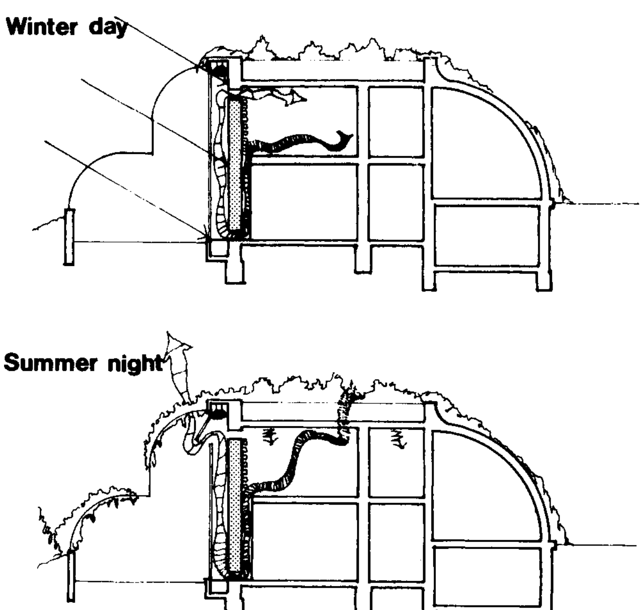


Fig. 4. Action schemes-section through T-M wall.

Choosing the material of the wall we preferred ragged stone to concrete. The 45 cm basalt wall wears a 6 cm internal heat-insulating coat of plaster, so the principle of the system is the same, as the one Chiron applied in practice in 1976. The pitch-faced external surface of the stone wall improves heat transfer. The symmetrical position of the two T-M walls provides opportunity for comparing double glass to polycarbonate skins and other alternatives. The function of the system is demonstrated on Fig. 4. The upper scheme shows the heating up period of the storage wall and air-circuit on bright winter days. The shading-insulating curtain is drawn up. The lower scheme illustrates cooling down cycle of the mass-wall on summer nights. Fresh air arrives through the opened skylight from among the plants set on the soil-covered roof. In daytime the curtain wall is let down only until the lower vents of the wall to preserve its ventilating-cooling capacity.

DIRECT GAIN

Insolation from southern direction reaches absorbing surfaces through the external and internal double glazing of the greenhouse. The heat-storage medium of the ground floor is dark ceramic floor, supplemented with vertical transparent phase change material tubes at the glass walls of the living room. In the heating season energy gain through eastern and western windows is insignificant. In summer overheating is prevented by shading trees and shutters.

MULTIPURPOSE PLANT-CULTURE

The garden-architect member of the team has provided elaborate plans for the applied plant-culture. Vegetation in and around the house is to have advantageous natural shading, wind directing, bioclimatic and psychological effects. The flat roof is replanted with evergreens /e. g. Juniperus sabina/ which need little care and are heat-tolerant. The rounded back roof is in deciduous-grown /e. g. P. quinquefolia/ having heat-insulating faculties, while the iron bars of the southern elevation hold deciduous creepers, casting shade only in summer /e. g. Vitis vinifera/. Out in the garden deciduous and non-deciduous trees vary depending on the prevailing wind, shading, etc. The west-side terrace is embowered. Vegetation in the greenhouse consists of eurythermic plants which are planted either in rolling containers or set in flower beds /e. g. Ficus carica/. Ground sculpturing guarantees keeping rainfall on spot. Vegetation decreases evaporation and provides a roughly constant humidity. A little water pool situated in front of the greenhouse helps bring about favourable microclimate.

BUILDING MECHANICS

In design besides energetic considerations environment preserving, ecological aspects have also been taken into account. The heat demand of the building, for an outer temperature of -15 °C without solar gain, is 7 KW, the characteristic heat transmission of the warm water floor heating is 5o W/m². The employed heat distributing layer is of increased thickness which also functions as a storing medium for passive direct gain. The efficiency of heat absorption is increased by dark brown ceramic tiles. A central fire-place with quick heat transmission whose smokepipe is directed through the rock-bed store provides possibility for burning household wastes as well. In summer the passive system is utilized as a natural cooling device by making use of its great storage capacities in reverse operation. Water-supply is characterized by economy and recycling, applying zeolite sewage-filter and composting toilet.

MONITORING

In the coming five years we plan to improve function-efficiency of the experimental house by developing its system-components on the basis of obtained experiences. The long-term measurement is motivated by levelling climatic extremities, and the time-consuming nature of both R + D programs and the growth of vegetation environment. Meteorological data are collected by an on-site Meteo-station while the measurement of all the other characteristic features of the house is done through temperature records. Data concerning major points /totalling 32/are microcomputer taped thus enabling direct data processing. Measured results are compared with those of simulation analyses. Conclusions are hoped to prove useful and widely applicable thus contributing to the distribution of energy and climate conscious design and building in our country.

ACKNOWLEDGEMENT

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DESIGN OF A LOW ENERGY HOUSE NEAR CHANIA, CRETE, EMPLOYING PASSIVE DESIGN PRINCIPLES

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ABSTRACT

This paper describes the design of a low energy house to be built near Chania, Crete. The employment of passive design principles to provide heating in winter and cooling in summer is described, and the thermal performance of the building at different times of the year has been assessed with the aid of a thermal network model using measured weather data for 1978. Results indicate that energy savings attributable to passive solar gain may represent 82% of the net heating load. It has also been found that daytime air temperatures in the house during the summer can be held close to ambient provided the major glazed areas are shaded.

KEYWORDS

Low energy building; passive solar design; thermal comfort; thermal network model; climate and design.

INTRODUCTION

This paper describes the design of a house to be built near Chania in Crete. The brief required that energy consumption for space heating (and cooling) be minimised and that locally available traditional building materials be the basis for construction. The thermal performance of the building has been analysed with the aid of a thermal network model developed at the Martin Centre, Cambridge, and the potential energy savings attributable to the application of passive design principles are demonstrated.

CLIMATE

The climate of north-western Crete is characterised by a small diurnal range in ambient air temperature (about 5 - 10°C) with daytime summer temperatures in the range of 25 - 30°C and night time temperatures of about 20 - 23°C. Vapour pressure is higher in summer (av. 14mm Hg) than winter (av. 8mm Hg). Wind velocity during the day is relatively low in summer (about 2 - 3m/sec) and often declines to almost calm at night. In winter, wind speeds are slightly higher, and there are occasional violent rain storms. The prevailing wind is from the north-west in summer and north-north-east in winter. Minimum daily air temperatures in winter average 8°C, and never drop below freezing.

For the reader who is more familiar with the climate of northern Europe, it may be useful to compare solar radiation and degree-day data for Kew (England) and Chania (Crete) in Table 1. It can be seen that the winter heating season in Crete lasts only 3 - 4 months compared with 7 - 8 months in the UK, and the amount of solar radiation falling on a south facing vertical surface in Crete is over twice that available in the UK from October to March. Data from Los Alamos (New Mexico) has also been included for comparative purposes. Los Alamos is at about the same latitude as Chania (35°N) but is at a much higher altitude (c. 3000m) and is influenced by the continental land mass of North America, whereas the climate of Crete is dominated by its location in the Mediterranean.

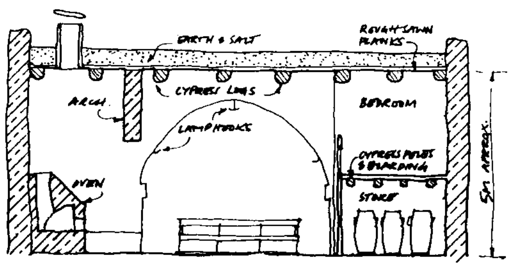
The heating season in Crete is extremely short, and the major problem in this climate appears to be the maintenance of comfortable inside temperatures in summer. Givoni (1969) suggests two approaches which may help to provide a design solution to this problem. One approach is to achieve a reduction of the inside air temperature relative to the outside air temperature by providing external walls and roof which combine high thermal resistance with high thermal capacitance, high reflectance external surfaces (eg whitewashed walls) and keeping external doors and windows closed and shaded. Another approach is to rely on ventilation as the main factor in providing comfort. In a well ventilated building the inside air temperature and vapour pressure will be about the same as outside conditions, and the inside air velocity may be assumed to be about one third of the outside air speed (c. 1m/sec). Reliance on internal air movement to achieve thermal comfort in summer is only likely to succeed if the temperature of the ceiling and inside surfaces of the external walls are not allowed to rise above the external air temperature. Clearly, solar gains to the building should be prevented, which calls for effective shading of windows, light external colouring and thermal insulation adjusted to the actual elevation of the external surface temperature due to the absorbed solar radiation. In the winter, it is likely that the thermal resistance of the building and the encouragement of passive solar gains should suffice to attain comfortable inside temperatures, without the necessity for an auxiliary heating system.

TABLE 1 Solar Radiation and Degree-Day Data for Chania, Kew & Los Alamos

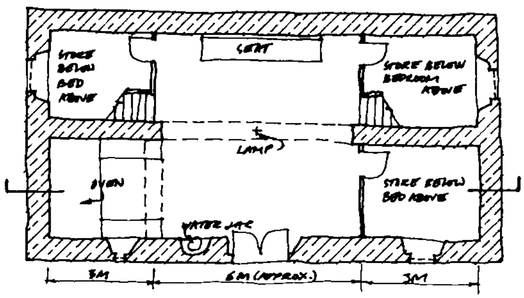
	Insolation on south facing vertical surface $kWh/m^2/month$			Degree-Days (15.5°C base)		
	CHANIA	KEW	LOS ALAMOS	CHANIA	KEW	LOS ALAMOS
JAN	79	28	146	112	346	580
FEB	81	42	123	92	304	467
MAR	88	74	109	62	282	457
APR	80	75	108	-	197	337
MAY	75	87	99	-	113	116
JUN	69	90	108	-	-	-
JUL	76	84	90	-	-	-
AUG	94	78	102	-	-	-
SEP	106	72	117	-	56	31
OCT	102	59	99	-	132	194
NOV	101	39	126	-	256	489
DEC	82	25	127	60	333	548

THE TRADITIONAL CRETAN HOUSE

The traditional Cretan house appears to be well adapted to its environment (see Fig 1). Rectangular in plan, the entrance leads directly to a large central living space dominated by a masonry arch which supports a 300mm thick earth roof. Flanking the living space are the winter kitchen and storage areas with bedrooms above. (In summer, cooking takes place in an oven outside the house.) Masonry walls are rendered externally and whitewashed, and window openings are small, thus minimising solar heat gain, and keeping the interior cool in summer. Thick timber boarding to the ceiling provides some insulation to the roof, which is 5 to 6m above floor level. The central space exploits the full height of the building providing an imposing room for gatherings of family and visitors. Casual gains from the oven and thick woollen coats probably made internal conditions tolerable on the coldest days in winter.



Section



Plan

Fig. 1. A Traditional Cretan House

HOUSE DESIGN

The client required a two bedroom house and stipulated that locally available traditional building materials be the basis for construction. Also, energy consumption for space heating (and cooling) was to be minimised through the application of passive design principles. Solar water heating was also to be included for domestic hot water. The site for the new building is in an olive grove on the south side of a hill at an elevation of 100m above sea level (see Fig. 2). It is relatively open to winds from the north-west (prevalent in the summer) and sheltered from winds from the north and north-east (prevalent in winter).

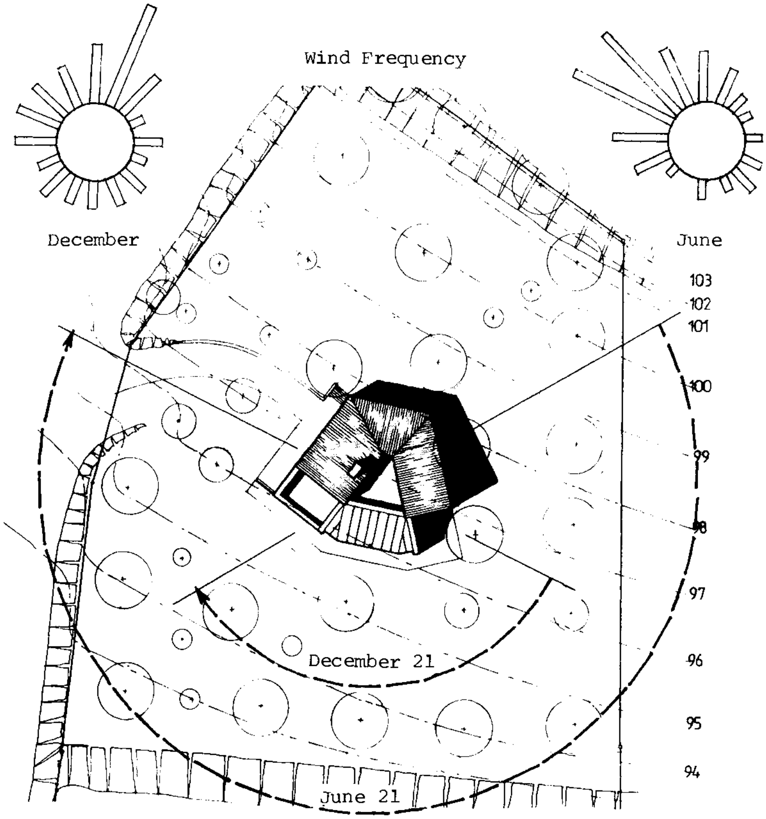


Fig. 2. Site plan showing solar azimuth angle & wind frequency for December and June

The wedge shaped plan developed from a desire to open the building to the south (to views and solar gain), and to have it closed off and bermed into the hill to the north. The highly serviced areas (bathroom and utility room), storage spaces and stairs were located to the north so that living areas could take advantage of a southerly aspect. The accommodation is grouped round a central 5m high living space, which is linked by a large opening to a conservatory. The roof of the conservatory supports solar water heating panels and an external blind to provide summer shading. (See Figs. 3 and 5.).

During the sketch scheme stage of the design, a sunpath diagram was used to determine the altitude and azimuth of the sun at different times of the year and different times of day. This enabled an initial evaluation of the extent of the penetration of solar radiation into the building through different openings. Fixed shading devices were discounted since solar radiation blocked from entering the building in October (when it was not required) would also be blocked in March (when it may be useful). During the development of the design, a model was built, and the diurnal and seasonal passage of the sun around the building was evaluated with the aid of a heliodon (Fig. 4). This study clarified a number of issues and aided decisions regarding the location and area of the clerestory opening lights.

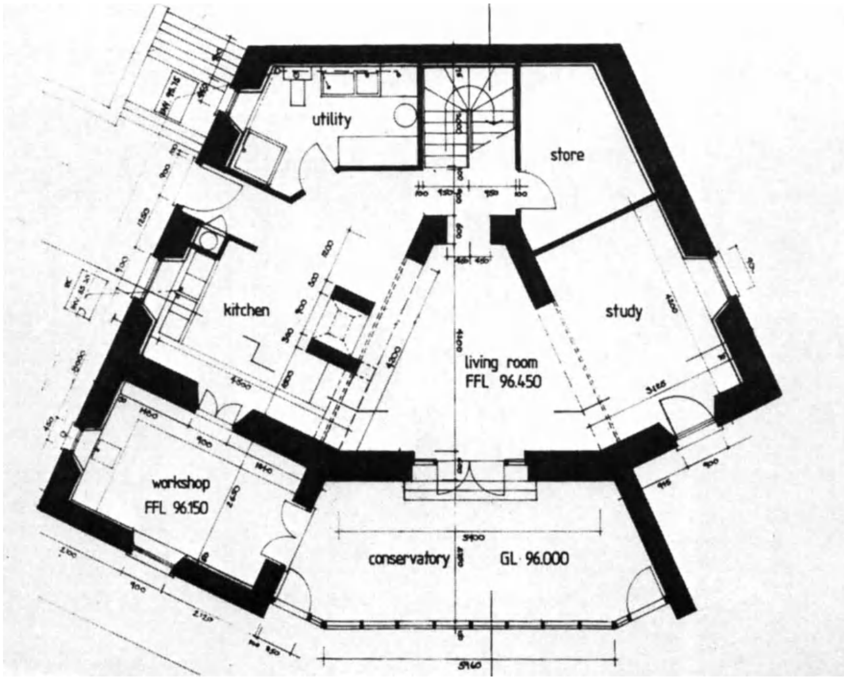


Fig. 3. Ground floor plan

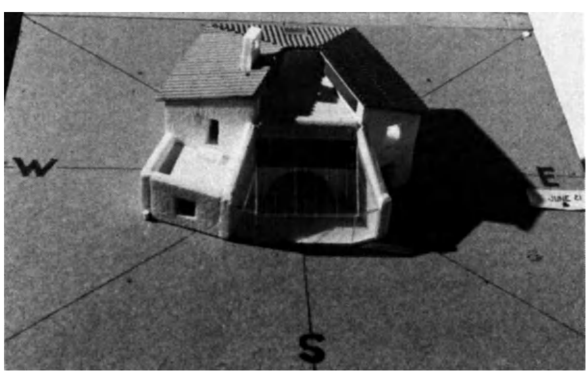


Fig. 4. Heliodon study of model - 2pm June 21st

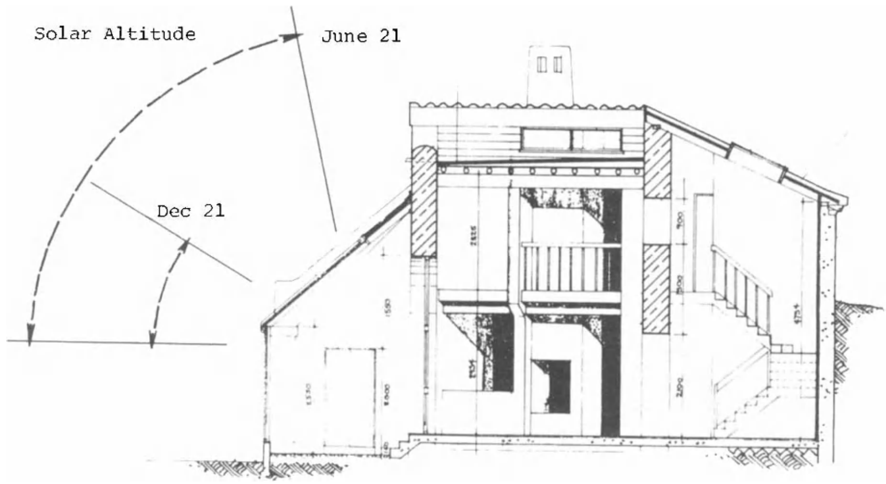


Fig. 5. Section showing variation in solar altitude during the year

THERMAL ANALYSIS

The 1979 Amendment to the Greek Building Regulations on thermal insulation, specifies maximum U-values for external walls, roof and floor (applicable to Zone B) of 0.7 $W/m^2/^oC$, 0.5 $W/m^2/^oC$ and 1.9 $W/m^2/^oC$ respectively. A maximum average U-value is also specified related to the volume of the building. In the house described here, all external structural walls (which are 600mm masonry apart from a reinforced concrete retaining wall on the north side) are lined internally with 25mm of styrofoam with plaster finish (U = 0.7 $W/m^2/^oC$). The pitched roofs contain 75mm glassfibre insulation on softwood boarding with Byzantine tiles externally (U = 0.34 $W/m^2/^oC$). The small area of flat roof is insulated with styrofoam 'Roofmate' (U = 0.5 $W/m^2/^oC$). The overall average U-value for the house is 0.71 $W/m^2/^oC$, giving a total house transmission coefficient of 230 $W/^oC$ (excluding the static conductance through the solar wall). The ventilation heat loss coefficient is 128 $W/^oC$ during the heating season, assuming an air change rate of 1 ach.

A thermal network model (Baker, Penz, & Manuel, 1982) was used to predict typical temperatures throughout the house for a series of days at different times of year. Mean monthly values of measured ambient air temperature and solar radiation for Chania 1978 (Athens National Observatory, 1979) were used as weather data input and the model was run on an hourly timestep. Ten nodes were used to describe the building in terms of two zones - the house and the conservatory. The geometry of the conservatory was represented in terms of an average solar aperture of 65^o to horizontal (total aperture area $28m^2$). Air change rates were assumed to be 1 ach for the house, and 4 ach for the conservatory, except for simulation of summer cross ventilation when values of 5 and 10 ach were used respectively.

Results indicate that in December - March the 24hr mean house air temperature is above 16^oC without any additional heating. If a thermostat set temperature of 17^oC is assumed (operating between 7 - 10hrs and 17 - 23hrs), the auxiliary heating demand would be 466kWh. The estimated net space heating load is 2530 kWh,

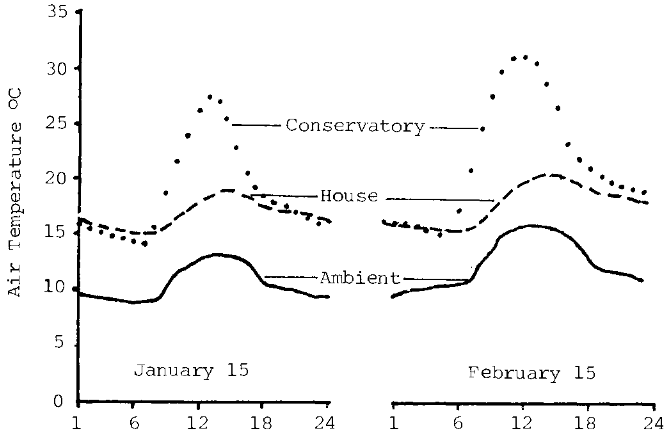


Fig. 6. Predicted winter air temperatures (free running)

and the useful solar contribution is therefore 2064 kWh (ie 82% of the net heating load). If a fuel conversion efficiency of 65% is assumed for the space heating appliance (either gas or oil), the saving in delivered energy attributable to passive solar gain is 2786 kWh. The cost of the conservatory may not be justified purely in terms of energy savings, but it is important to recognise that the conservatory also provides an attractive extension to the living space. During the winter, the conservatory air temperature is above 19oC for between 8 - 14hrs/day (see Fig. 6.), and so it can be used as an extension to the living area for most of the year.

In the summer, we are principally concerned that the house (and the conservatory) does not overheat. Different strategies to achieve comfortable inside temperatures in summer have already been discussed, and in this building it is envisaged that the principal mechanism for summer cooling will be cross-ventilation. The prevailing wind is from the north-west, which will create negative pressure over the flat roof and to leeward of the building, drawing air through the building and out through the clerestory lights each side of the flat roof. The plan arrangement and position of openings encourages circulation of ventilation air, and will hopefully minimise still air pockets. The physiological effect of air movement on comfort will be the principal parameter affecting thermal comfort, providing internal surface temperatures are close to ambient.

Clearly, solar gains must be avoided in summer, and so the whole of the pitched roof of the conservatory will be shaded for about 8 months of the year. (It is also intended that vines will be encouraged to grow over an arbour in front of the verical glazing to the conservatory.) Simulation of the thermal performance of the building in summer, both with and without shading of the conservatory, indicates that comfortable conditions may be achieved in the house with only the pitched section of the conservatory shaded (see Fig. 7.).

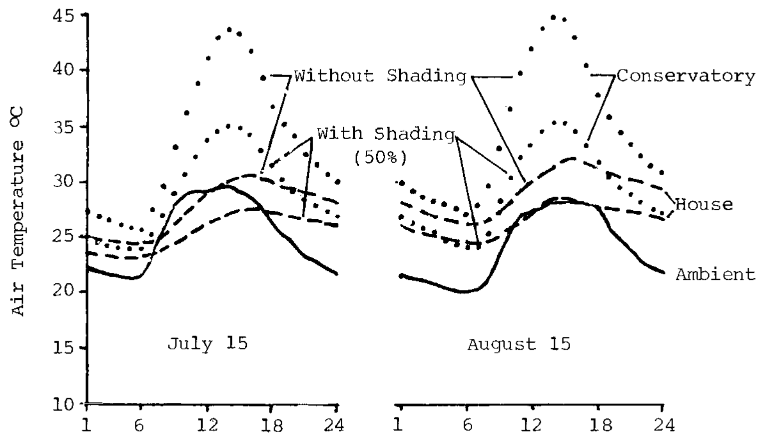


Fig. 7. Predicted summer air temperatures with & without shading

SUMMARY

Simulation of the thermal performance of the house for a series of days for both summer and winter months, indicates that over the heating season the potential saving in delivered energy attributable to passive solar gain is about 2,800 kWh. The design relies on shading and cross ventilation to maintain comfort conditions in the summer.

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A BIOCLIMATIC MULTI-STOREY BUILDING IN SICILY

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ABSTRACT

Thermal behaviour of a four storey bioclimatic building to be constructed in Messina (Sicily) has been analysed using the computer simulation model SMP.
The northern side of the building is earth protected, while a large part of the south façade is sunspaced.
Because of low thermal losses and high solar contribution, auxiliary energy demand is so low that central heating system is not necessary.
A simple methodology based on the available information on frequency distribution and persistence periods of daily solar radiation values is proposed for the evaluation of energy consumption during the heating season.
Thermal performance has been analysed also for clear day conditions in order to evaluate overheating.
Summer operation has also been evaluated.

KEYWORDS

Passive; multi-storey; sunspace; meteorological data; comfort; simulation.

INTRODUCTION

This paper is one of the products of a scientific consultancy provided by public institutions to private organizations wanting to initiate some involvement in the area of energy conscious building design and construction.
The object of the consultancy was a four storeys residential building to be built in Messina (Sicily). The building was designed following all the general rules for passive design.
In order to evaluate that both comfort and energy requirements were met, and to quantify them, SMP (Simulazione Moduli Passivi) computer model (Butera and co-workers, 1983) was used. The simulation model enables the user to analyse in detail the thermal behaviour of a room with passive devices (direct gain, Trombe wall and sunspace).

A simple methodology for the treatment of meteorological data available has been also developed.

THE BUILDING

The main features of the building (fig. 1) are :
i) south facing 60° sloping façade;
ii) all rooms sun-spaced;

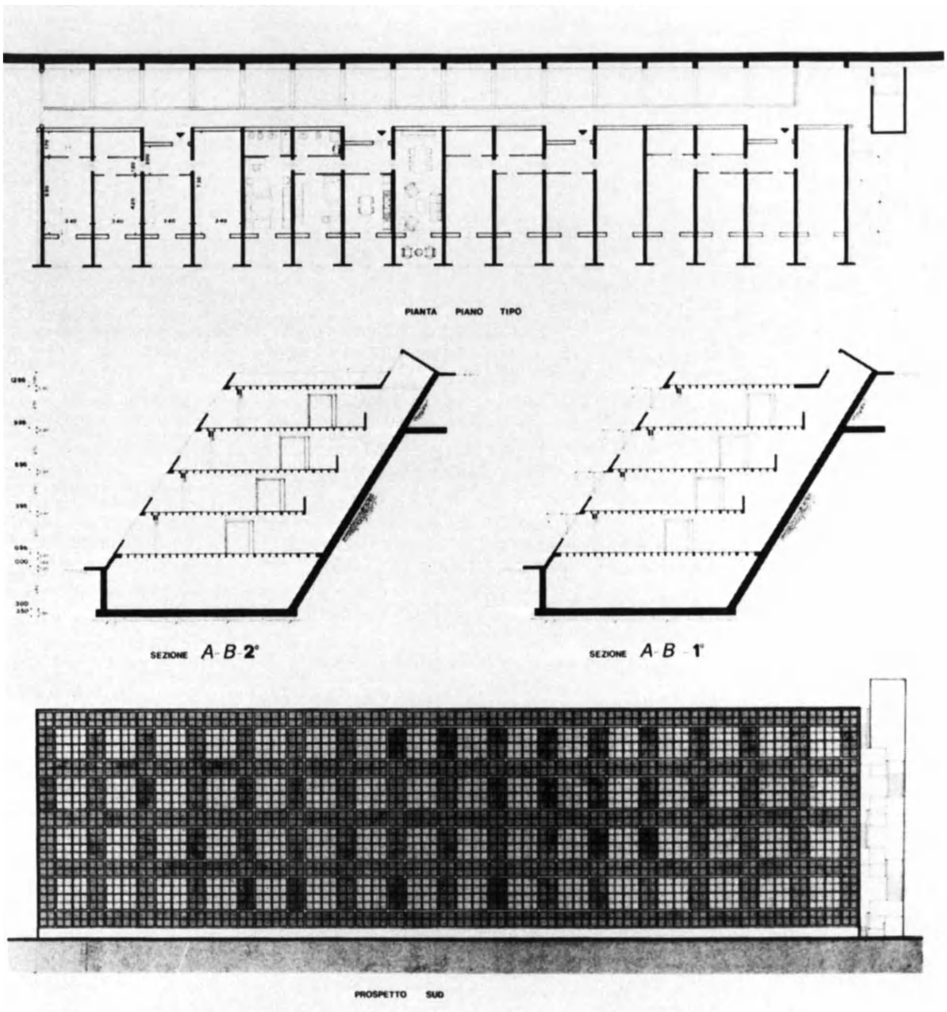

Fig. 1. Plan, sections (winter and summer operation) and south elevation of the building.

iii) the building leans on the south facing side of a hill; the entrance of each flat is from a corridor situated between the back of the building and the hill side. The corridor's space acts as a buffer zone; the north oriented part of the building is therefore very well sheltered in winter and cool in summer;
iv) the roof is well insulated;
v) high heat storage capacity (specific mass = 770 Kg/m^2 of floor area); bricks are used for south and north walls and concrete for internal partitions;
vi) ratio of the sunspace glazed area projected on a vertical surface to the floor area is 0.17.
Each apartment is also provided with a natural circulation hot water solar system.

METEOROLOGICAL DATA AVALAIBLE AND THEIR USE FOR ENERGY CONSUMPTION EVALUATION

The most suitable meteorological input for such an exercise would have been a reference year formed by hourly data. Such a reference year presently exists for Messina and for some other Italian locations, but it needs some improvement and, furthermore, it has a limited circulation.

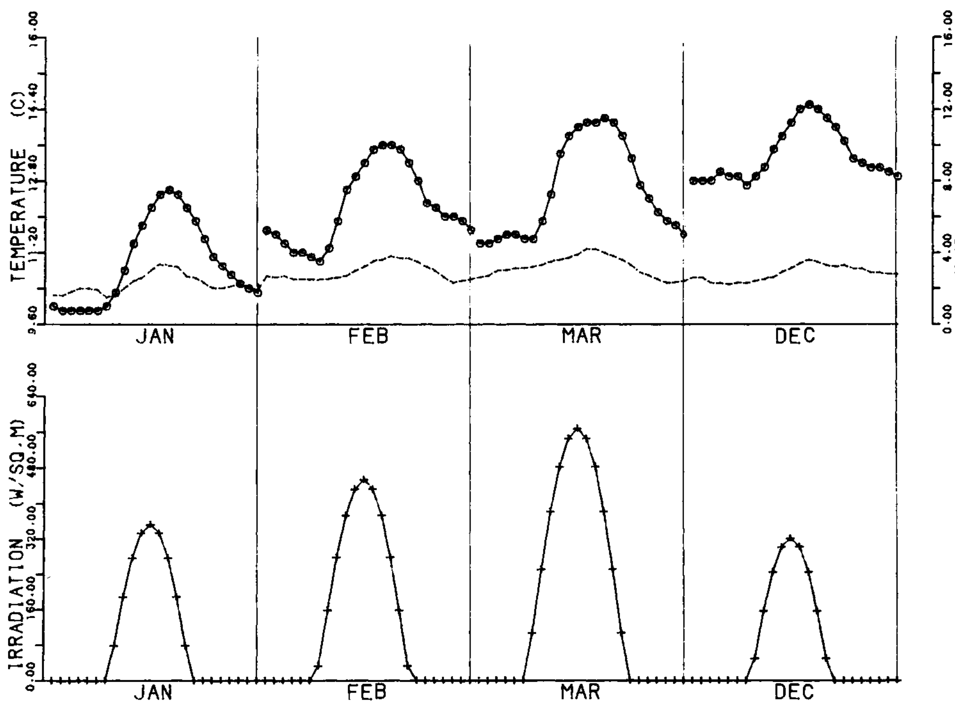

Fig. 2. Hourly values of temperature, wind velocity (dashed line) and solar radiation on winter average days in Messina.

Since our intention was not only to evaluate energy consumption and comfort for the specific case under examination, but also to establish a generic, simple and reliable methodology, it was decided to use only published meteorological data easily accessible to everybody.

Climatic monthly average days are available for 29 italian locations (C.N.R., 1982). Solar radiation on horizontal surfaces, air temperature and wind velocity hourly data on average days of january, february, march and december in Messina are plotted in fig.2. Temperature and wind velocity hourly values are the average, for each month, over a period of 20 years. Hourly values of solar radiation, instead, are derived by monthly data (average over 20 years), according to the methodology proposed by Kusuda (1977) and applied to Italian locations by Butera and co-workers (1982).

For evaluating energy consumption it was simulated a living-room located first at an intermediate floor and than at the fourth floor, both in the middle and in the eastern extreme of the building, in order to analyse three cases with three different, increasing, heat losses (14.7, 29.5 and 57.6 W/°C, respectively).

Heat gains due to people, electric appliances, etc, were evaluated according to Los and co-workers (1981) with some adjustments to allow for inhabitants behaviour in southern Italy.

Other assumptions made for the simulation were :

i) auxiliary heating schedule from 6.00 to 10.00 hours and from 17.00 to 21.00 hours; this intermittency schedule reflects a common use of heating systems in southern Italy.

ii) window shutter closed from 21.00 to 8.00 hours.

For each month, four consecutive runs, with the same input data, were made (three for initialization).

Table 1 shows monthly and total auxiliary energy consumption for all the cases examined. Results show that auxiliary energy demand is very low even in the most unfortunate room, and that solar heat gains play a very important role.

TABLE 1 Monthly and Total Auxiliary Energy Demand (MJ)

MODULE	JAN	FEB	MAR	DEC	TOT
INTERMEDIATE	7.8	0.0	0.0	0.0	7.8
UPPER	203.3	85.7	78.1	100.4	467.5
UPPER LATERAL	526.8	310.5	302.4	310.2	1449.9

A further set of runs was executed assuming an overcast day, for assessing solar energy impact on the energy balance of the room.

In fig.3 are shown sun-space and room temperatures in the intermediate module.

Climatic average days, when used as input for the simulation of passive solar buildings, may be the cause of misleading results, because solar utilizability is overestimated, expecially for high Solar Load Ratios.

In order to reduce the amount of uncertainty deriving by the use of the climatic average day, frequency distribution and persistence periods of daily solar radiation (Barra, 1981) were introduced in

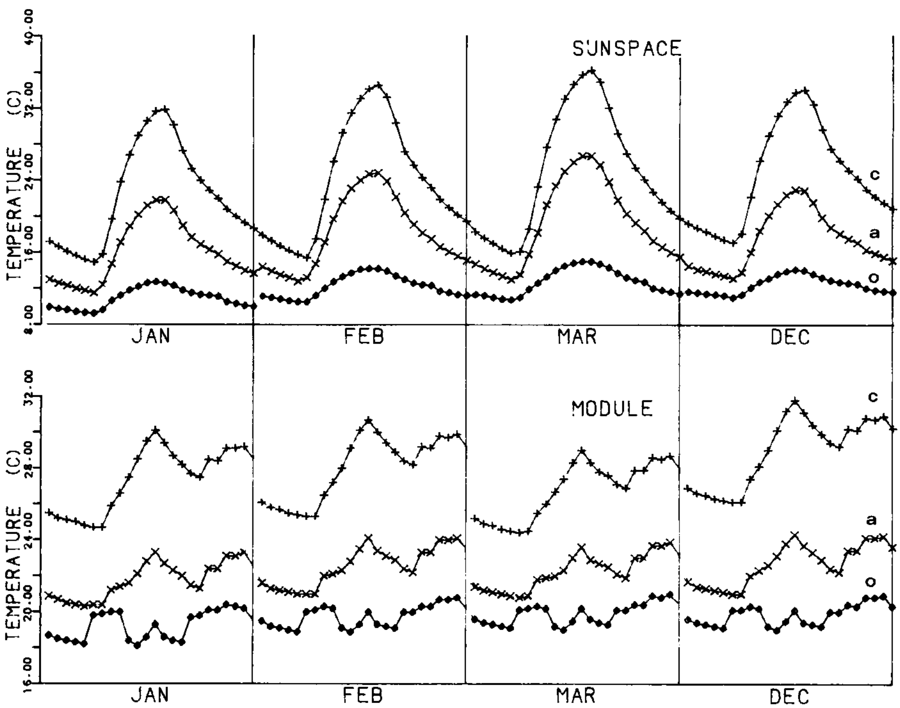

Fig. 3. Intermediate floor, center module. Air temperature in sun-space and in the room in a clear (c), average (a) and overcast (o) day.

our procedure for the calculation of auxiliary energy demand of the building (table 2 and table 3).

The methodology adopted for evaluating monthly energy consumption of each room of the building may be subdivided into the following steps:

Step 1 : hourly values of solar radiation were built-up for a daily solar radiation of 2.1 MJ/m^2day (overcast day), by using the Kusuda (1977) methodology.

Step 2 : with the new values of hourly solar radiation used as input, five consecutive runs were executed; the first run was initialized with the room thermal situation left at 24.00 hours by the run previously executed with the average day as input. The auxiliary energy demand obtained at the end of each run represents the amount expected after 1, 2, 3, 4 and 5 consecutive overcast days.

Step 3 : steps 1 and 2 are repeated with daily solar radiation of 5.2, 7.3 and 9.4 MJ/m^2 day; each of these values is the average of the ranges between 4.2 and 6.3, 6.3 and 8.3, 8.3 and 10.5 MJ/m^2day.

Step 4 : as many values of daily solar radiation above 9.4 MJ/m^2day are contained in tab. 4, as many runs were executed, after generating hourly values. Each single room was initialized with room temperature values at 24.00 hours of the average day.

TABLE 2 Cumulative Frequency of the Global Solar Radiation in Messina

MJ/m^2d	JAN	FEB	MAR	DEC
27.1	.00	.00	.00	.00
26.1	.00	.00	.00	.00
25.0	.00	.00	.00	.00
24.0	.00	.00	.02	.00
22.9	.00	.00	.05	.00
21.9	.00	.00	.10	.00
20.9	.00	.00	.15	.00
19.8	.00	.00	.21	.00
18.8	.00	.00	.28	.00
17.7	.00	.01	.35	.00
16.7	.00	.06	.42	.00
15.6	.00	.11	.49	.00
14.6	.00	.19	.53	.00
13.5	.00	.27	.60	.00
12.5	.02	.37	.68	.00
11.5	.08	.47	.72	.01
10.5	.17	.55	.78	.03
9.4	.27	.65	.83	.14
8.3	.41	.72	.86	.30
7.3	.52	.81	.88	.44
6.3	.63	.86	.90	.55
5.2	.73	.91	.93	.69
4.2	.83	.95	.98	.79
3.1	.93	.97	.99	.88
2.1	.98	.99	1.00	.96
1.0	1.00	.99	1.00	.99
0.0	1.00	1.00	1.00	1.00

TABLE 3 Solar Radiation Persistence Probability for Succession of 1,2,3,4,5 Consecutive days in Messina.*

MJ/m^2d	d	JAN	FEB	MAR	DEC
4.2	1	.17	.06	.03	.21
	2	.06	.01	.00	.11
	3	.04	.00	.00	.05
	4	.01	.00	.00	.01
	5	.00	.00	.00	.00
6.3	1	.37	.14	.10	.45
	2	.25	.04	.03	.33
	3	.15	.00	.01	.23
	4	.06	.00	.00	.16
	5	.05	.00	.00	.08
8.3	1	.00	.29	.15	.00
	2	.00	.14	.04	.00
	3	.00	.04	.02	.00
	4	.00	.02	.01	.00
	5	.00	.01	.00	.00
10.5	1	.00	.44	.23	.00
	2	.00	.32	.10	.00
	3	.00	.24	.05	.00
	4	.00	.14	.03	.00
	5	.00	.12	.01	.00

*Probability is referred to days in which solar radiation is lower or equal to threshold values of the first column.

Monthly auxiliary energy demand was then calculated by summing up the results of all runs, each weighted on the respective occurence and persistence probability of the daily solar energy value used as input.

In table 4 results of this procedure are summarized and compared with the results obtained by using only the average day. As expected, auxiliary energy requirements calculated by the average day are lower, with percentual differences that decrease as room heat losses increase.

TABLE 4 Winter Auxiliary Energy Demand (MJ)

MODULE	A.D.*	F.P.**
INTERMEDIATE	7.8	14.3
UPPER	467.5	600.3
UPPER LATERAL	1449.9	1594.8

* A.D. = Average Day

** F.P. = Frequence Persistence method

The above described methodology, even if producing more reliable results then those obtainable with the use of the average day, expecially for passive buildings, still may be criticized for the following reasons.
i) It is assumed that each succession of days or single day is preceded by a succession of average days.
ii) It is assumed that wind and temperature values do not change when solar radiation data change.
These assumption however, appeared the most sensible, in relation to the information available for the site examined.

WINTER CLEAR DAY CONDITIONS

Room air temperature has been simulated for a succession of clear days in each winter month. Results are plotted in fig. 3, and thermal discomfort conditions caused by overheating are evident. The maximum overheating is attained in december because of the concurrence of the mild temperature and the large amount of solar radiation entering the room, favoured by minimal shadowing.
Thermal comfort conditions during overheating periods, however, may be easily achieved by opening the window and the sunspace glazing.

SUMMER CONDITIONS

Summer operation of the building has been also studied.
For preventing direct solar radiation in summer months, openable sunspace glazing is used as an overhang by means of a rolling curtain added for this purpose (fig. 4).

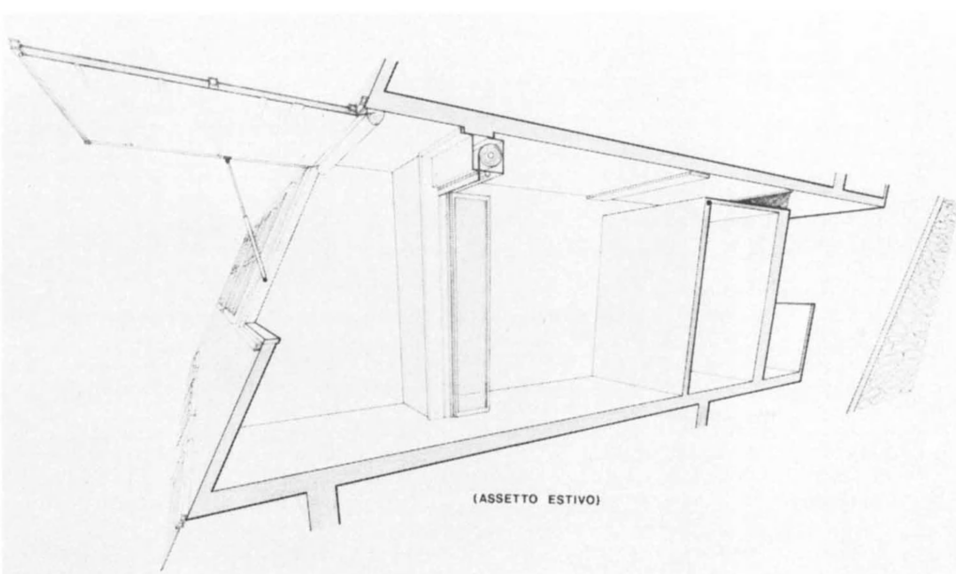

Fig. 4. Axonometric cross section of the module; summer operation

Average summer wind speed in Messina is about 3-4 m/sec; in spite of this favourable condition, the absence of opposite aperture in the rooms would allow limited air changes and low air velocity in the indoor spaces. For this reason the possibility to create cross ventilation was obtained by means of an aperture in the back of each room, communicating with the entrance corridor.
An estimate has also been made of the air flow in the rooms in absence of wind; because of the stack effect about 10 changes of cool air coming from the earth contact back space should be obtained.

CONCLUSIONS

Computer simulations show that in a mild climate, like in sicilian coastal areas, thermal comfort may be attained with very low auxiliary energy consumption in a well insulated, correctely oriented multy-storey building, with moderate solar apertures.
Energy consumption evaluations have been performed both with average day meteorological data and with a procedure that utilizes information on the frequency and persistence of days with given solar radiation values. The comparison of the two methods shows that the use of solar radiation values of the average day may be reasonable for very low or very high Solar Load Ratio values. The reason is that in the former case solar radiation contribution has little effect on the overall heat balance, while in the latter, when the contribution of solar radiation is very large, the calculated auxiliary energy demand is so low with both methods that has little meaning to prefer the more precise but more complicated one.
In all the intermediate cases, the underestimate of the energy consumption due to the use of the average day solar radiation values may be misleading. In such cases hourly solar radiation data on average days should be used with care.

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RESIDENCES USING PASSIVE SOLAR SYSTEMS AT DRAPANIAS, CRETE

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ABSTRACT

This project describes residential construction with the use of passive solar systems. Local materials and simple construction methods which function without specific demands on the occupants, were used. Effort was made so that these systems will not interfere with aesthetics or functional aspects of the house.

KEYWORDS

Heated space, cooling space, passive solar design.

INTRODUCTION

The purpose of this project is to prove that passive solar systems can be developed by local technicians and constructed by local labour. This pursuit in conjunction with the effort to minimise additional construction costs and to introduce solar architecture into the existing built environment determine the basic design criteria.

The criteria are:

a) To create comfortable conditions in the living space without the use of conventional energy sources.
b) Control of the passive systems by the users themselves.
c) Protection from direct radiation.
d) A choice of passive systems with both summer and winter operations in mind.

The building has two floors and a basement. The area of the ground floor is 92,77m^2, of the first floor 20m^2, basement 108m^2 and the building's total volume is 296m^3. The ground floor contains the living area, and master bedroom, while the first floor consists of the childrens' bedrooms. (Figs. 1 and 2).

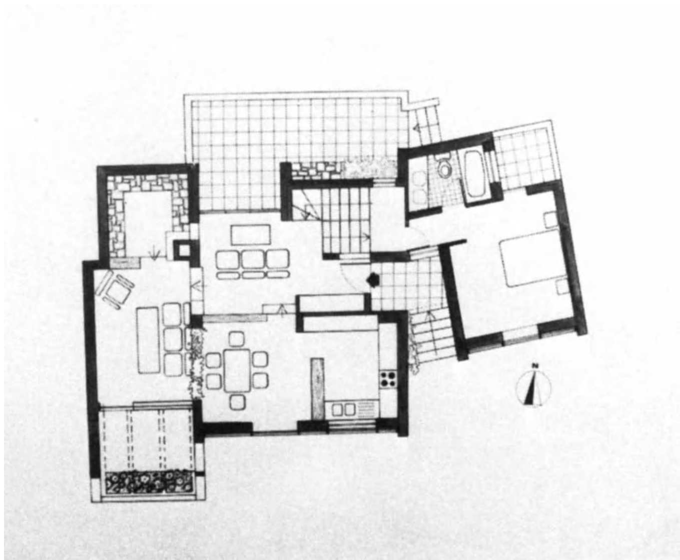

Fig. I. Ground floor plan

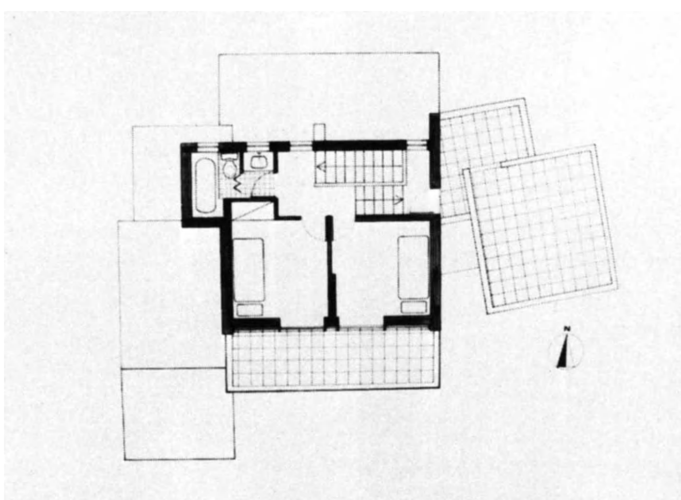

Fig. 2. First floor plan

PASSIVE SYSTEMS

Orientation. The building is divided in two main volumes with the major openings and glazing facing close to due South (Fig. 3.)
Thermal insulation. The external walls and roof are insulated and windows are fitted with night insulation. The average U-value is 0.73 W/m^2k (day) and 0.58 W/m^2k (night).
Direct solar gains. South windows occupy 10.4 sq.m. (17 per cent of the south facade) and are single glazed.
Trombe wall. This is constructed of 400mm dark coloured stones (schist) and has a surface area of 16.5 sq.m. The trombe wall is double glazed and vented. There are openings in the top part of the glazing for summer cooling. (Fig. 4).
Water wall. A metal container 300mm wide filled with water is located below the sill of the master bedroom's south window as a water wall. It is insulated at night externally with a movable panel which doubles as reflector during daytime.
Greenhouse. This is an extension of the living room separated from the space by single glazing. The greenhouse has a glazed area of 21 sq.m. tilted at 60° to the horizontal (Fig. 5). Besides the thermal mass provided by the building there are water containers in the greenhouse for heat storage. The greenhouse is vented and shaded in summer.
North windows. These were reduced to a minimum with the exception of one larger window overlooking the view and which is recessed for wind protection. All north windows are double glazed and sited so as to allow penetration of summer breezes.
Shading and cooling. Permanent shades were sized so as not to compromise winter solar gains. There are no openings on the east and west facades. Summer cooling is mainly by vigorous ventilation.
Auxiliary heating. This is provided by a fireplace situated centrally in the living room.

CALCULATIONS

Useful solar gains were calculated following a method by Franca.[1] The results are summarised in Table 1, which shows that solar energy covers a very large proportion of the heating requirements.

TABLE 1. Useful Solar Contribution

Month	Heat Load (kwh/month)	Heat Gain (kwh/month)	% of load
JAN	1.585,31	1,111,76	70,13
FEB	1.179,52	962,12	81,56
MAR	1.068,68	995,47	93,15
APR	690,74		
OCT	75,10		
NOV	554,05		
DEC	1.172,37	1,083,57	92,42
Total	6.250,67		87,55

There are excess heat gains during some months. Maximum indoor termperature in January was estimated at 23°C with minimum 15°C.

1. (Editor's note): Method 5000

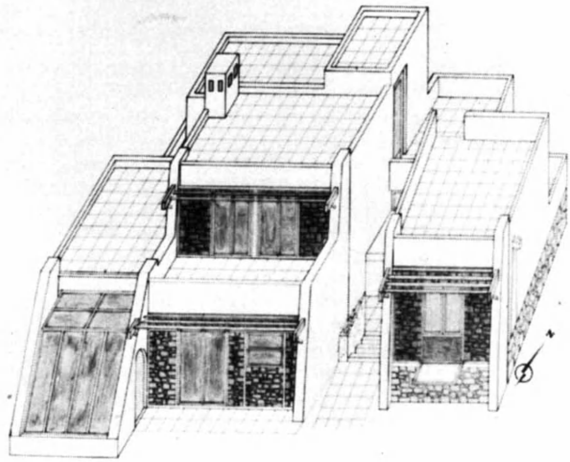

Fig. 3. Axonometric

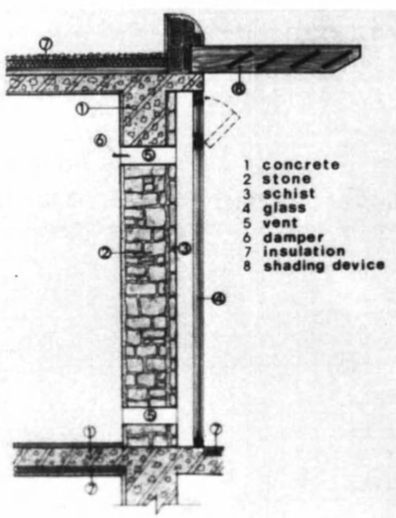

Fig. 4. Trombe Wall

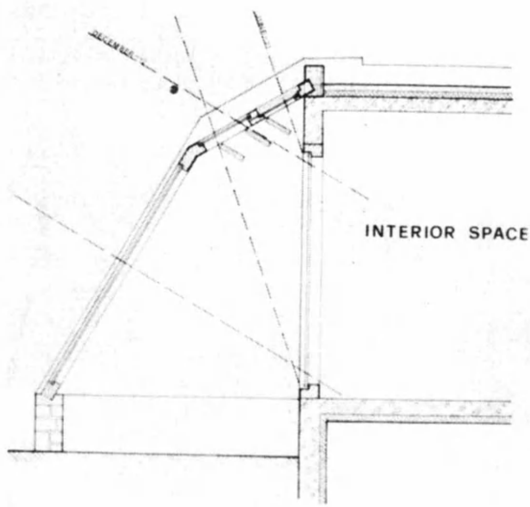

Fig. 5. Greenhouse

The extra cost for the solar systems is estimated at US $ 2,000 or 3.6 per cent of total building costs. (Shading and insulation not included in the costs).

CONCLUSION

The additional cost of the passive systems for a house in Crete is not higher than the cost of a conventional heating insulation. The function of the system demands a minimum care by the users. The aesthetic presence of the building is not contrary to the surroundings. No special high-technology equipment is required; the systems can be constructed by the existing local labour. The climate of Crete is favourable for energy conscious design.

BUILDING REHABILITATION WITH RETROFIT OF PASSIVE AND LOW ENERGY SYSTEMS

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ABSTRACT

The building rehabilitation on large scale recently became emergent for housing needs and new design tools are developing. We discuss the objective of energy saving rehabilitation of existing buildings, that may consist of energy conservation techniques and where possible of retrofit of passive and/or active solar systems. Different retrofit operations adaptable to old and new building technologies are discussed.
An example of passive and low energy systems in a rural house in Tuscany is presented here. The rehabilitation of the house - already provided with existing bioclimatic features - gave the opportunity to retrofit it with three different passive solar systems for heating and cooling, and wind, water and solar energy systems for power generation.

KEYWORDS

Retrofitting buildings; techniques; retrofit of passive solar systems; solar wind and hydro power generation systems application example.

ENERGY SAVING IN THE REHABILITATION OF EXISTING BUILDINGS

Over the last few years the investments in rehabilitation of existing buildings in Italy have overtopped 45 per cent of housing investments as a whole. This process is emphasized by the world economic crisis from which the energy aspect is emergent. It is recognized that a significant reduction of energy consumption can be achieved by operating on the existing building stock.
Essentially the energy retrofit can be realized in two different ways: by energy conservation increasing thermal insulation and/or by the use of passive or hybrid solar systems applied over the structure.

Major problems of this process are considered below. It is advisable to create a general model in order to simulate the combined effect of several strategies on conditions of internal comfort. It allows one to approach sistematically each component of the building system by considering its single and interacting role.
The method of disaggregation of thetechnological building system in those parts which have homogeneous functions is advisable; for this the classification done by National Stanards Institute may be useful (UNI/CE 0051 Dec. 1979). This reference will help to delimitate two basic classes of components: the perimetar of a building and the technical equipment. Both these classes of components require energetic retrofit operations. The first class consists of vertical external walls, windows, roofslabs, groundslabs.The second one consists of heating and airconditioning systems.
In general most rehabilitation operations whose which are intended to improve physically and functionally classes of components mentioned above, can be set up together with energetic retrofit, so the whole operation becomes more convenient.
Also in the case of energy conservation by means of thermal insulation it is relevant to evaluate a suitable cost/benefit ratio according to the specific case.
For instance if the building is overinsulated it produced exces of investment costs, but if the building is underinsulated the heating cost remains relevant.
The building technology is an other factor to be taken into account. For example a building in the medieval centre has thick masonry walls, small windows, roof wood construction, whereas a building on the modern outskirts is made of reinforced concrete with large glass surfaces and pilotis on the ground.
In the older houses the external masonry walls made of bricks and stones, for their thickness and mass, have a relevant thermal capacity that attenuates and shifts thermal flow coming from outside. Also they have a big potential thermal storage, so they can be successfully adapted to work as Trombe wall, when the incident solar radiation is high. Moreover in the case of energy conservation this type of wall works as an appropriate envelope especially in the residential building where the continuous heating is required. The thermal proprieties of the envelope also are determined by the type, amount and location of glazing. Large glazing surfaces in the recent buildings placed without consideration of aperture orientation create unwanted gains and losses from the construction, while small openings of the ancient houses determine the major thermal uniformity of the interior space. For example the retrofit operation in the building could be done by reducing the amount of glass on the north-facing surfaces and utilising south windows as a passive system elements.
Older houses have often pitch-roofs with underneath not habitable attic, that can be easily and conveniently insulated by inhabitants itself. On the contrary the flat roofslabs of most of recent buildings are built without "buffer-zone" and their insulation technique becames expensive and more difficult to realize.
In conclusion each different construction technique creates different thermal proprieties and requires appropriate energetic retrofit operations. As an example we describe the retrofit operations carried out on an old rural house.

RETROFIT OF PASSIVE AND LOW ENERGY SYSTEMS IN THE RECONSTRUCTION OF AN OLD RURAL HOUSE

Fig. 1 - Wiew of the house from SW

The house is an old rural building, sited near Monte Morello, at about 18 Km. from Florence, and built with local stone and wood. The volume is about 1700 m^3 in two floors. The house is sited on a ground sloping to SE, close to some reliefs that shelter it from North winds, with the main front facing the South. Summer sunshine is shaded by a big poplar 20 m . high, sited on the SW side of the house. The external walls have been insulated with high-density polyurethane sprayed foam, and white lime to protect it, and to keep a big thermal mass inside. The retrofit of solar passive systems for heating and cooling consists of the setting up of three different systems, that operate owing to the natural air convection and the heat radiation, chosen according to the different use of the internal room.

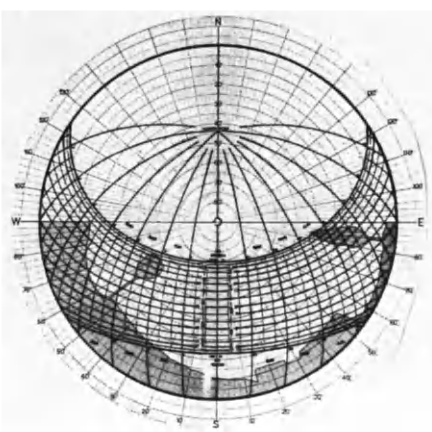

Fig.2 - Local horizon and sun paths of the site

A TROMBE SYSTEM has been set up in the left part of the house to climatize the bedrooms facing the South, to utilize properly the dayly phase difference. An AIR-

COLLECTORS SYSTEM operating by natural air convection with DIRECT INLET, has been set up in the central part of the house, to climatize two backsited rooms. The East part is climatized by a BARRA-COSTANTINI SYSTEM, with air ducts built in the floor (3).

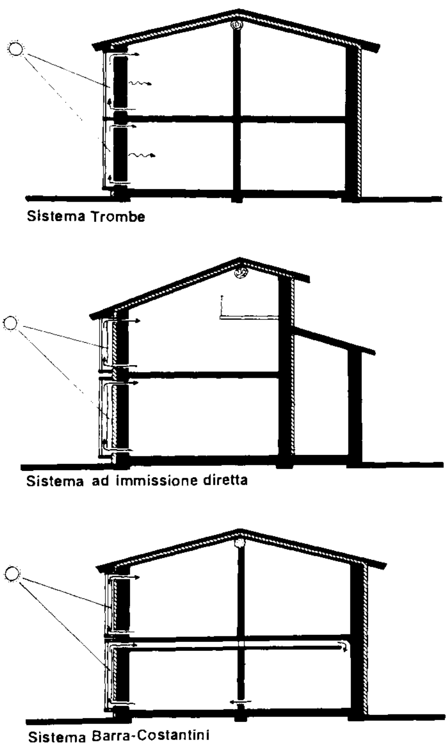

Fig. 3 - The three different systems

The ex-hay-loft now used as studio is warmed by an air collector system, that has been constructed inside the roof structure. The air is taken from the room by means of a row of holes in the lower part of the roof, and the warm air coming nut from the air-collectors is forced down with two fans thermostated. The hot water for domestic use is supplied by a parabolic solar collector 4.80 sq.m . wide, set up on the South front, with a wide angle of acceptance, and operating by free convection of water.

The local brook and frequent winds in the area suggested the setting up of an aeolian-bydroelectric system, with appropriate DC accumulators, as the main electric network is lacking there. The brook has a range variable from 4 1 per second at June to 20 1 . per second in November, so it has been necessary to realize a collection-basin with a dam, to obtain the capacity of 70 m^3 about. The forced water pipe is 40 mt. long, to get the difference of level of 6.80 mt., and it is 3" wide.

The power is supplied by a small three-phase electric generator, linked to a five-jets Pelton water turbine, manufactured by the IREM SpA at Turin. A wind power generator, with three blades horizontal rotor, produced average 400 Wh for 3 hours a day, and it has been recently substituted with a photovoltaic array of 8 panels, that supplies average 1200 Wh during a summer sunny day.

The average energy production is about 4800 Wh, and it is utilized for lighting, domestic use and craft tools.

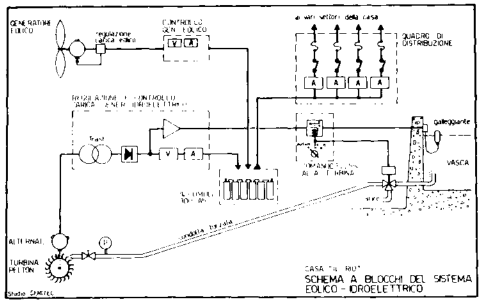

Fig. 4 - Block scheme of the aeolian-hydro-electric system with charge regula tion

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PASSIVE SOLAR HEATING FOR A HIGH ALTITUDE MULTIROOM DORMITORY

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ABSTRACT

Double glazed solid masonry wall system for two end rooms and an attached greenhouse of shalkhang type (local Sun-room) with a moveable internal shade for the ceiling for the common space have been retro-fitted for the South facade of a multiroom childrens' dormitory (SOS Tibetan Childrens' Village) in Choglamsar located at an altitude of 4000 meters (34°N, 77°E). Traditional construction techniques and materials namely mud and timber have been used except for glass carted from 400 km. away. Construction features and solar incremental costs as a fraction of the normal building costs are mentioned. Straw insulation on other walls, though planned, could not be provided because of non permissible reduction in the width of community passages.

Indoor temperature data along with ambient data are reported for the months of September to December and April to July of the years 1980-1981. Data for January to March, when passive systems are most effective, could not be taken because the place was closed on account of vacations. Thermal performance has been evaluated in terms of solar heat effectiveness and Comfort Index, which are calculated from measured temperature data. Design values of solar fraction for finite thermal capacity case have been calculated by the unutilizability method and compared with those obtained by the widely used Solar Load Ratio method.

KEYWORDS

Passive solar; space heating; solar saving; solar effectiveness; comfort index.

INTRODUCTION

Amidst snowy mountains, beyond the reach of Indian monsoons and along the Valley of the Indus river is the location of our experimental building. This site near Leh, at an altitude of 4000 m above mean sea level with a climate having 4400 annual heating degree days and annual Sunshine hours exceeding 2900 hours with mean values of normal peak solar radiation exceeding one kW/m^2, provided an ideal place for retrofitting solar systems for space heating. In view of power being available only for two hours from thermal station using diesel, shortage of fuelwood, normal practice of constructing compact heavy mass buildings and difficult logistics resulting in 200 percent premium on the price of commercial fuels, solar passive was practically the only workable option. Fig.1 gives a panaromic view of the Childrens' Village Campus.

Fig.1 SOS Tibetan Childrens' Village, Leh

Earlier work on space heating in Ladakh, using natural circulation water heating and passive air heating systems for single rooms, has been reported by Gupta (1967), Stambolis and associates (1980), Norberg (1980), Gupta (1981) and Gupta and Mohan (1981).

In all, there are eight solar systems at this high altitude site namely solar space heating, water heating, solar drying, cooking, distillation, 250 peak watt solar photovoltaic lighting system, drumless biogas digester and a multi blade horizontal axis windmill pumping unit. These constitute what might be the highest solar village in the world. Solar energy systems, however, do not meet the entire energy needs of the SOS Village complex consisting of nearly 300 children and thirty adults. Systematic conceptual integration between systems is lacking and there is hardly any monitoring except for passive solar space heating system. This is because different agencies have worked at different times to do proof of concept tests at this site. In this paper, we present the results of monitoring and evaluation of the solar dormitory, retrofitted with two glazed masonry walls (Trombe systems) and an attached greenhouse, in the SOS village at this unique location.

BUILDING SPECIFICATIONS AND SOLAR RETROFIT

The multiroom dormitory is a rectangular structure (14m x 10.5m) made with walls of Sun dried mud bricks, a wooden deck roof on joists with mud insulation on top and a wooden floor laid on raised plinth on ground. The plan and section are shown in Fig.2 and specifications of the building and retrofit solar systems in Table 1 and 2. Fig.3 shows the retrofitted dormitory's exterior (South facing view).

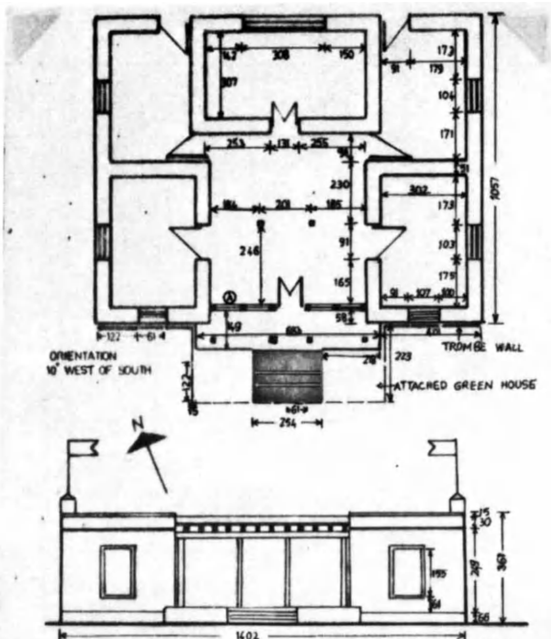

Fig.2 CHILDREN'S DORMITORY
SOS TIBETAN CHILDREN'S VILLAGE, LEH, LADAKH

Fig.3 South Facing Elevation of Solar Dormitory

TABLE 1 Building Specifications

Element	Materials	Thickness (m)	Mass ($Kg.m^{-2}$)	U-Value ($Wm^{-2}\ ^{\circ}K^{-1}$)
Walls				
External	Sun dried mud bricks	0.53	1053	1.64
Partition	Sun dried mud bricks			
	North wall	0.38	755	1.76
	East wall	0.53	1053	1.47
Roof	Mud on wooden deck	0.20+ 0.03	477	2.44
Floor	Wooden deck on ground	0.03+ 0.27	596	--

TABLE 2 Retrofit Data

Element	Trombe Room	Common Room
Floor area (m^2)	13.6	59.4
South facade (m^2)	9.5	17.3
Glass cladding (m^2)	9.5	41.3
Glass area/floor area	0.68	0.69
Frame shadow fraction	0.16	0.08

Trombe rooms on East and West sides have a mass per unit volume equal to 916 $Kg./m^3$ and a time constant of 52.3 hours. The glazed walls have been vented at one percent of glass area. Effective building storage capacitance, computed according to Davies (1973), amounts to 19.6 MJ/°K for a floor area of 13.6 m^2. The space between endrooms is a common space retrofitted with a greenhouse having an almost flat glass roof and single glazed walls on South, East and West sides. Fig.4 shows an interior view of this space through the door along with folded curtains, glass roof of the greenhouse and temperature measuring instruments. Glass roof can be shaded with this internally moveable and padded curtain and there is provision for dumping heat via roof ventilation. The double leaf door marked (A) in Fig.1 has since been removed and the common space is thus directly connected to the attached greenhouse. All internal doors are 3 cm wooden planks and external windows have double panes with a glazing in the upper half and wooden shutters in the lower half of each pane. No insulation could be provided on the exposed walls as the passages to adjoining dormitories would have been reduced too much. Trombe walls are double glazed and the outer pane is openable so that any dust, collected between two glass panes due to howling winds in the valley, can be removed. The solar retrofit systems cost nearly forty percent of the normal building cost with glass alone accounting for 16 percent out of the extra costs. Normal building costs at 1981 prices were US $ 30/m^2 of floor area.

Fig.4 Interior View of Greenhouse Attached Common Space

THERMAL PERFORMANCE - MONITORING AND INSTRUMENTATION

Mercury-in-glass thermometers with an accuracy of 0.5°C were installed in each of the two sets of rooms viz Solar Trombe wall and the common space with attached greenhouse and non-solar control rooms in similar orientation in an adjacent dormitory of identical plan and construction specifications. Eye observations were scheduled every three hours during day time and maxima and minima of DBT were recorded.
A class B weather station was set up for manual recording of corresponding shade ambient data. Solar radiation was recorded by a portable solar cell based instrument. Systematic data were obtained by a trained observer from September to December of 1980 and from April to June of 1981. Unfortunately, data for January to March, when solar passive systems are most effective, could not be taken because of vacations.

TABLE 3 Monthly Mean Measured Temperatures

MONTH	Maximum Temperature (°C)					Minimum Temperature (°C)				
	Trombe		Greenhouse		Shade	Trombe		Greenhouse		Shade
	Solar	Control	Solar	Control		Solar	Control	Solar	Control	
September (1980)	32.2	27.0	29.6	26.2	17.4	20.0	16.6	17.6	14.5	6.3
October	29.4	20.7	25.6	--	11.6	16.2	11.4	13.4	--	1.2
November	21.8	13.7	20.5	--	7.1	11.6	5.9	5.8	--	-5.6
December	21.6	10.2	17.0	--	2.8	6.8	2.4	4.6	--	-9.4
April (1981)	24.0	19.0	24.8	--	11.6	17.0	14.0	15.0	--	-1.6
May	25.8	23.6	25.2	22.2	16.6	21.0	19.0	19.0	17.0	3.2
June	27.8	26.8	29.4	25.0	19.6	21.0	20.4	21.0	20.0	7.0
July	31.1	29.2	31.8	28.6	25.0	25.4	23.6	24.0	23.0	12.8

Table 3 gives the monthly mean values of temperature maxima and minima for the solar and control rooms along with the ambient both for greenhouse and trombe systems. Significant elevation towards comfortable temperatures are noted in both solar cases for the cooler months. For the warmer months, some overheating is noted because there was not enough storage in the greenhouse system. Also the Trombe Control room showed higher maxima due to very heavy mass of the building and poor ventilation.

Fig.5 shows a typical diurnal plot of temperatures for the month of November. A steady differential of 6°C is observed between control and solar room of Trombe system whereas the greenhouse enclosed space is 13°C above the ambient.

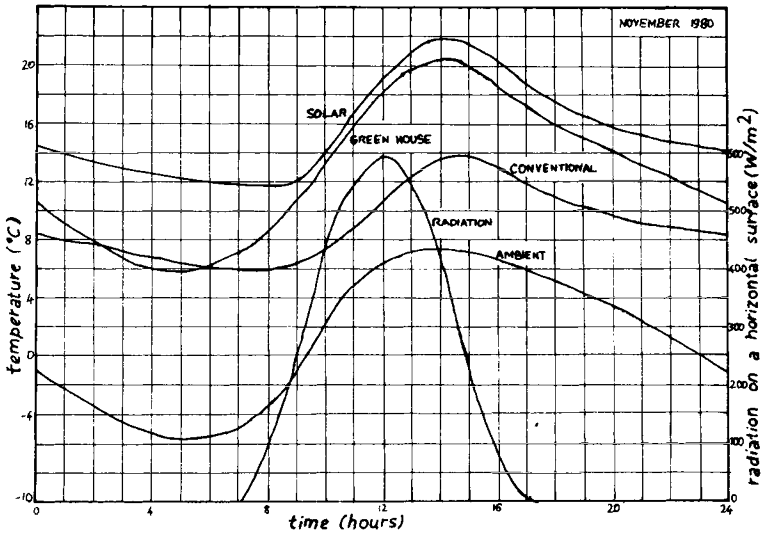

Fig 5. MONTHLY MEAN OF MEASURED TEMPERATURES SOS VILLAGE, LEH

PERFORMANCE EVALUATION CRITERIA

From the measured temperature data, we calculated solar heat effectiveness, as defined with respect to control building, by Gupta and Mohan (1981) and solar saving fraction, as defined with respect to ambient temperature, by Balcomb and associates (1981).
Main assumptions are a set temperature of 18°C, an air infilteration rate of one air change per hour and solar wall being considered as adiabatic. Multiroom effect has been taken into account by modifying the U value of North wall with a multiplier term f and by modifying Δt across the East wall dividing the two solar systems.

$f = 1/[1 + U_p A_p / \sum_2 UA]$ where p refers to partition wall and 2 refers to ajoining room walls transmittance-area product sum.
And for the present case, $f = 0.845$
Heat transfer through the open door connecting common space and trombe room was considered according to the relation given by Balcomb (1981).

$U_{open} = 63.5 \; A_D \; (H_D . \Delta T)^{.5}$ where A_D is the area (m^2) and H_D is height (m) of the door and ΔT is temperature difference between the connected spaces.

Comfort index, a measure of thermal stability of design, defined by Clausing and Drolen (1981), has also been computed from the temperatures measured. However, it was found to exceed unity in some cases and it is not yet clear if this criterion is valid for indirect solar passive systems having thermal mass of the order of 1.25 MJ m^{-2} °K^{-1} and above per unit floor area basis (present unit has a thermal mass of 1.44).

SYSTEM DESIGN METHODS

Some of the recent design methods to predict thermal performance of passive systems, namely the un-utilizability method (Monsen, Klein and Beckman, 1982) and Solar Load Ratio method (Balcomb and associates, 1980) have also been used to predict monthly solar saving fraction for the Trombe system room. However, radiation statistic curves for Indian data have been used for calculation of utilizability. In these cases, multiroom effect has been taken into account by lowering the heat balance temperature t_b (by 2.5°C in the present case) with respect to set temperature t_R in terms of internal heat generation equivalent of temperature elevation of adjoining solar room above the ambient and as before by modifying the U-value for the enclosed North wall.

Monthly values of solar saving fraction, computed from the measured temperatures and by the above design methods, along with values for comfort index and solar heat effectiveness are given in Table 4. As can be seen, the correspondence between measured data and design methods computed SSF values is not good but it is quite reasonable for solar heat effectiveness. However, the SLR method and (1- ϕ) method, for which thermal capacitance effect is explict, agree reasonably well.

TABLE 4 Thermal Performance Criteria for Trombe Wall

M O N T H	Solar Saving Fraction			Solar Heat Effectiveness	Comfort Index
	(1-ϕ) Method	SLR Method	Measured Data		
September	1.00	0.96	1.00	1.00	1.24
October	0.64	0.71	0.97	0.87	1.02
November	0.45	0.56	0.79	0.61	0.69
December	0.30	0.36	0.68	0.47	1.21
April	0.37	0.40	0.99	0.90	0.92
May	0.62	0.56	1.00	1.00	0.76
June	1.00	0.82	1.00	1.00	1.21

Effect of open door between the room and common space seems to dominate the load calculations and since it was closed as well as open at different times, we have considered it closed for all the computations listed above.

A comparison of this solar dormitory with the Odeillo house (Palz and Steemers, 1981), inspite of differences in storage characteristics of the solar wall and site altitude, is instructive because of similar number of annual degree days and Sunshine hours at Odeillo and Choglamsar. Monthly values of solar saving fraction for our solar dormitory and for Odeillo house are within 5 percent of each other except for the months of November and April to May.

CONCLUSIONS

* For better performance of passive systems, it is necessary to insulate even the heavy mass external walls and keep the connecting doors in a multiroom dormitory closed.

* There is good correspondence between solar saving fraction values predicted by finite thermal capacity procedure of design utilizing the concept of Un-utilizability and by Passive Handbook design - SLR method and also between Odeillo house and Leh dormitory.

* Values of solar saving fraction and solar heat effectiveness calculated from measured data agree reasonably well amongst themselves but not with the predicted values.

* Thermal comfort index concept needs to be re-examined in greater detail for heavy mass indirect solar passive systems.

* Solar effectiveness, even though a more realistic characteristic for no-auxiliary passive buildings, needs to be calculated from design data rather than from measured temperatures.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the enthusiastic support given by Rev.Lobsang Tensing and Mr. Thupten Dorje of SOS Village, logistic support given by Mr. Bhushan Mishri of Stakna Hydel project, Choglamsar, engineering design support given by Prof. V. Lahiri and Mr. Indrasen of Sri Aurobindo Ashram, technical assistance of Mr. D.J. Devanand and Mr. Rammohan of TERI Field Unit in the initial stages of the project and the secretarial assistance of Mrs. Shipra Gupta, Miss. Usha Rao and Mr. Felix Korus of TERI Field Research Unit. An out of budget special sanction for this project was granted by Mr. D.S. Seth, Vice-Chairman of Governing Council of Tata Energy Research Institute and we are grateful to him for making it possible for us to undertake this exciting project. To the smiling children of SOS Tibetan village, this project is dedicated.

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SAVING ENERGY IN REBUILDING AFTER THE EARTHQUAKE

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ABSTRACT

This paper presents a series of proposals on the rehabilitation of buildings, damaged during the November 1980 earthquake, with the aim of incorporating energy saving techniques while also respecting the traditional character of the buildings.

KEYWORDS

Saving energy; retrofitting technologies; thermal comfort.

THE STUDY

The need for rehabilitation of a damaged urban area after the earthquake of November 1980 was also an opportunity for incorporating energy conserving aspects into the planning process.

Since 1978, the Institute of Technology at the School of Architecture at the University of Naples has carried out research on the use of renewable energies in buildings. The plan for the rehabilitation of the town of Gesualdo produced in collaboration with the local authority can be seen as an application of this research. The plan was the first stage of a project concerned with defining the means, methods and techniques to be used in the Gesualdo area.

In this paper a classification is presented of possible techniques for improving the structure as well as the thermal characteristics of buildings in the earthquake area. The aim of this classification is to help decision-makers to choose the most appropriate techniques while also respecting the original character of the buildings.

A number of solar technologies were studied which are also applicable to other buildings in the region and to traditional buildings in general. These include the retrofitting of conservatories and of a lightweight glazed roof for solar collection. The cases studied are illustrated in Figs 1 to 6 below.

Fig. 1. Cases Studied

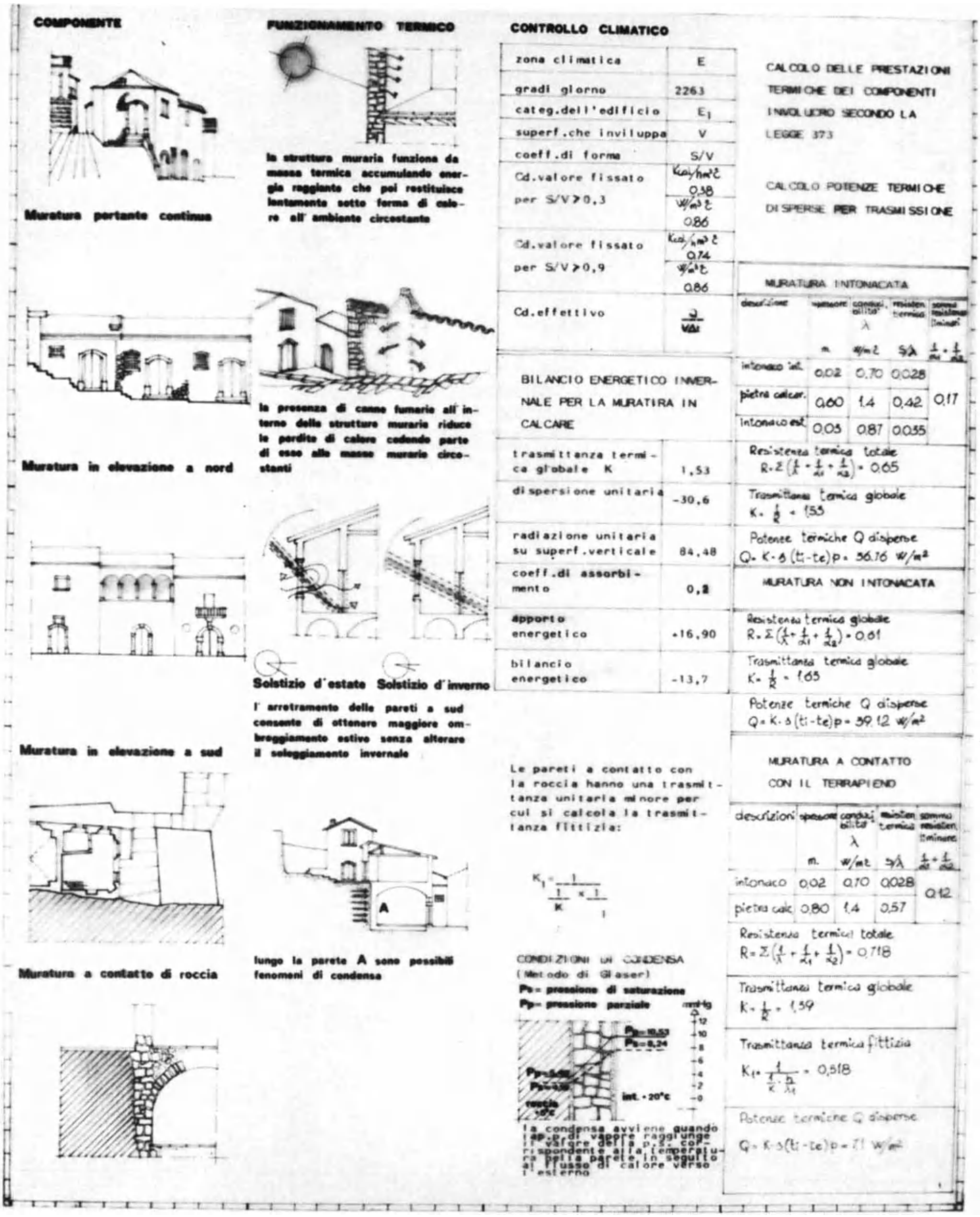


Fig. 2. Heat balance of traditional building components.

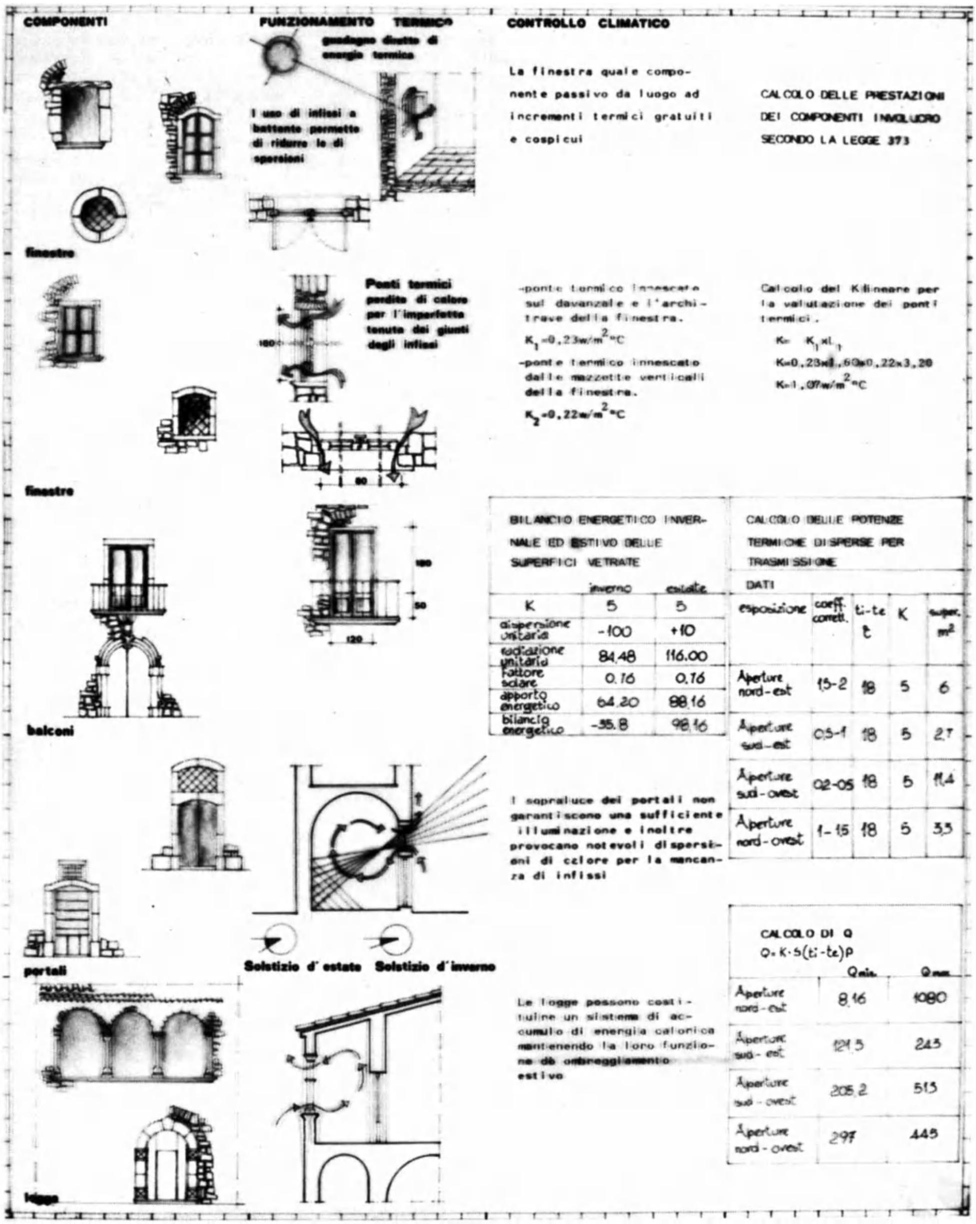


Fig. 3. Proposed energy saving techniques.

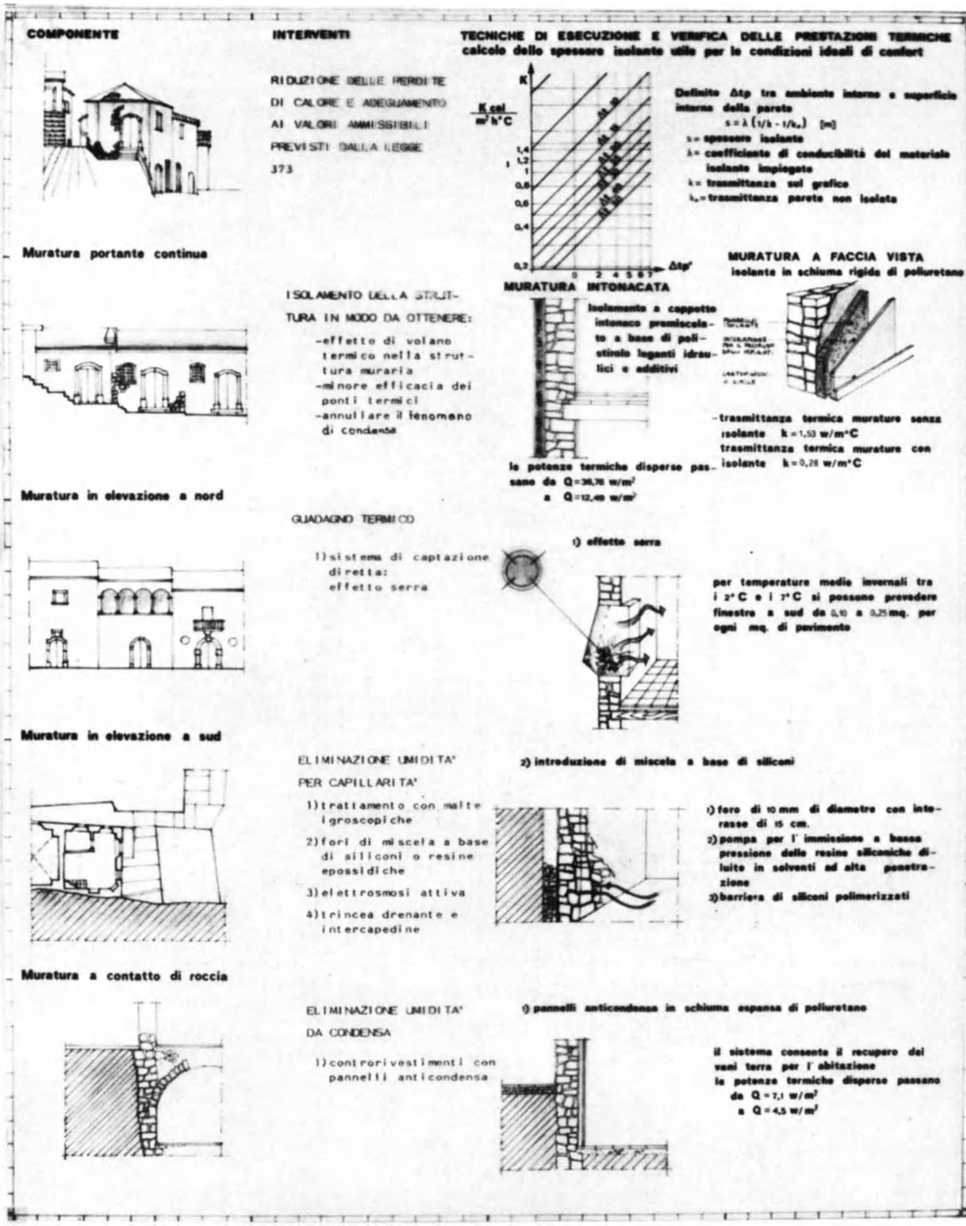


Fig. 4. Modular system of a "greenhouse wall": an application in Gesualdo.

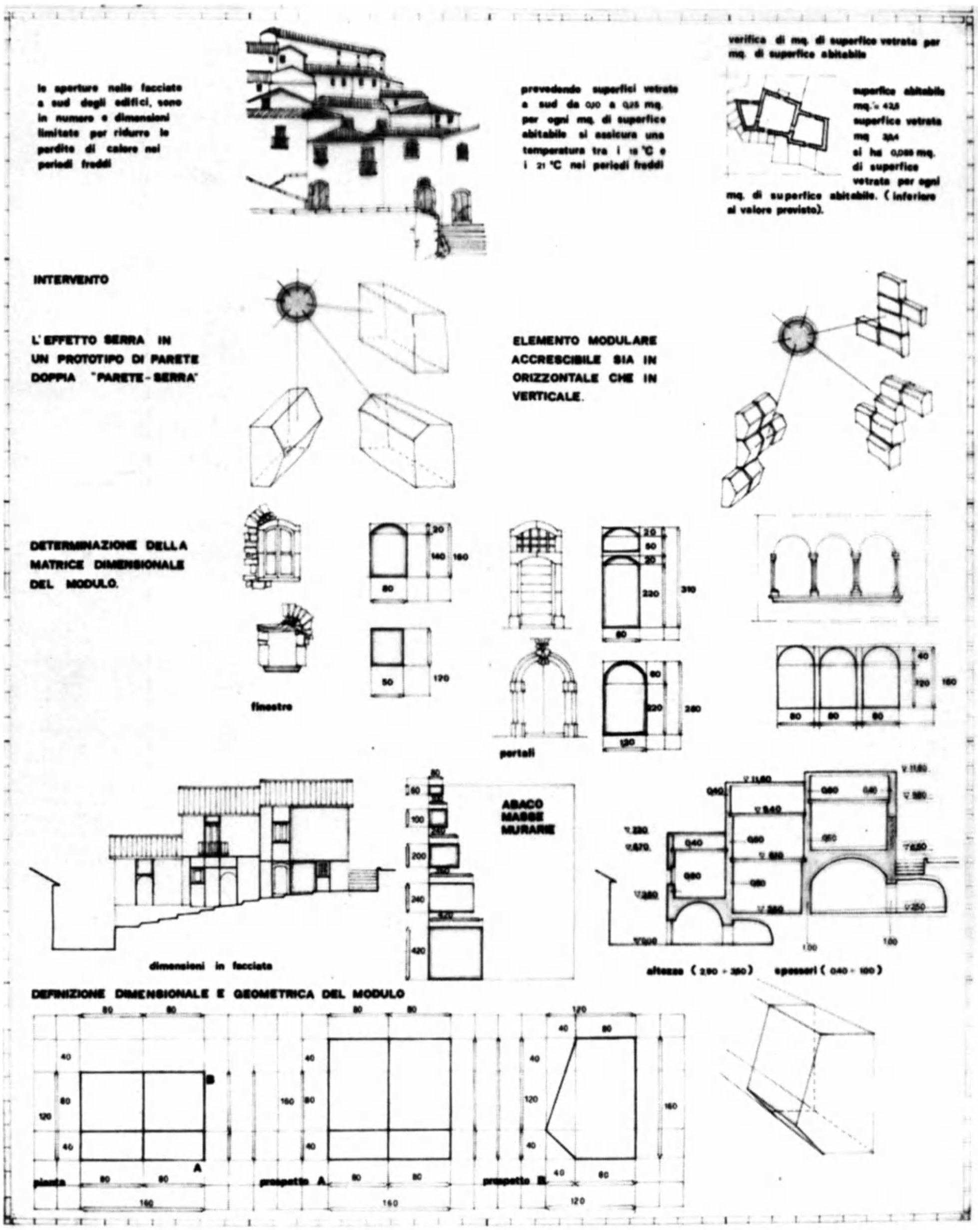


Fig. 5. Reuse of local materials and traditional techniques in the "greenhouse wall" system.

SCELTA DEI MATERIALI

REQUISITI E PRESTAZIONI RICHIESTE

Involucro:
-capacità di trasmettere le radiazioni solari
-trasparenza
Telaio:
-materiale di facile lavorazione per la produzione di pezzi in serie

RISORSE LOCALI

Involucro:
-vetro: industria del vetro ad Avellino
Telaio:
-legno di castagno
-legno di faggio

taglio del legno di castagno

CARATTERISTICHE DEI MATERIALI PRESCELTI

Il vetro oltre alla trasparenza ha la capacità di assorbire e trattenere le radiazioni solari

Il legno presenta facilità di lavorazione e possibilità di produrre pezzi in serie

Il legno di castagno oltre ad essere presente nella tradizione costruttiva locale risulta in maggiori quantità del legno di faggio

CARATTERISTICHE DEL VETRO

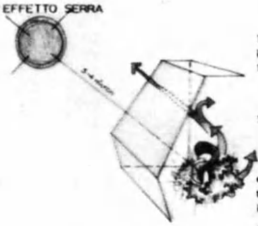
-Composizione
72% sabbia silicia e graniti
15% carbonato e solfato di calcio
13% carbonato e solfato di sodio
fusi allo stato amorfo(non cristallino)

-Dimensioni
vetri normali, spessore da 4 a 6 mm.
-Misure massime
cm300-330xcm150x180

BILANCIO ENERGETICO DEI VETRI

Mese	Quantità di calore disp Kcal/mese	SUD radiaz. Kcal/mq	SUD superf. mq.	Apporto energrtico Kcal/mese	Bilancio energetico Kcal/mese
NOV.	89631,3	57600	36	1492992	1403360,7
DIC.	238859,7	40706	36	1113552	874692,3
GEN.	311980	49300	36	1348848	1036868
FEB.	268579,5	54400	39	1612416	1343836,5
MAR.	229110	55400	39	1706874	1477764
STAG.	1138160,5	257400	37,2	7274682	6136521,5

L'EFFETTO SERRA



1/2 di é rimessa all'esterno il doppio vetro la riduce ad 1/4

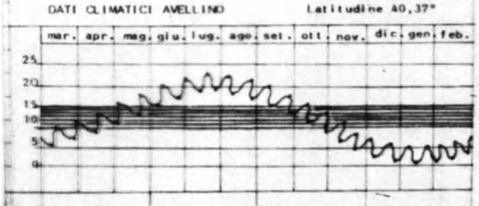
1/2 energia rimessa all'interno

energia con la lunghezza d'onda tra i 4 e 30 micron (radiazioni infrarosse)

superfici assorbenti opache(piante)

Permette di catturare l'energia solare sulla base del principio che le radiazioni termiche emesse dai corpi illuminati e riscaldati dal sole all'interno di ambienti vetrati hanno una lunghezza d'onda maggiore di quella delle radiazioni solari che non riescono a riattraversare il vetro provocando così l'innalzamento della temperatura interna.

DATI CLIMATICI AVELLINO Latitudine 40,37°

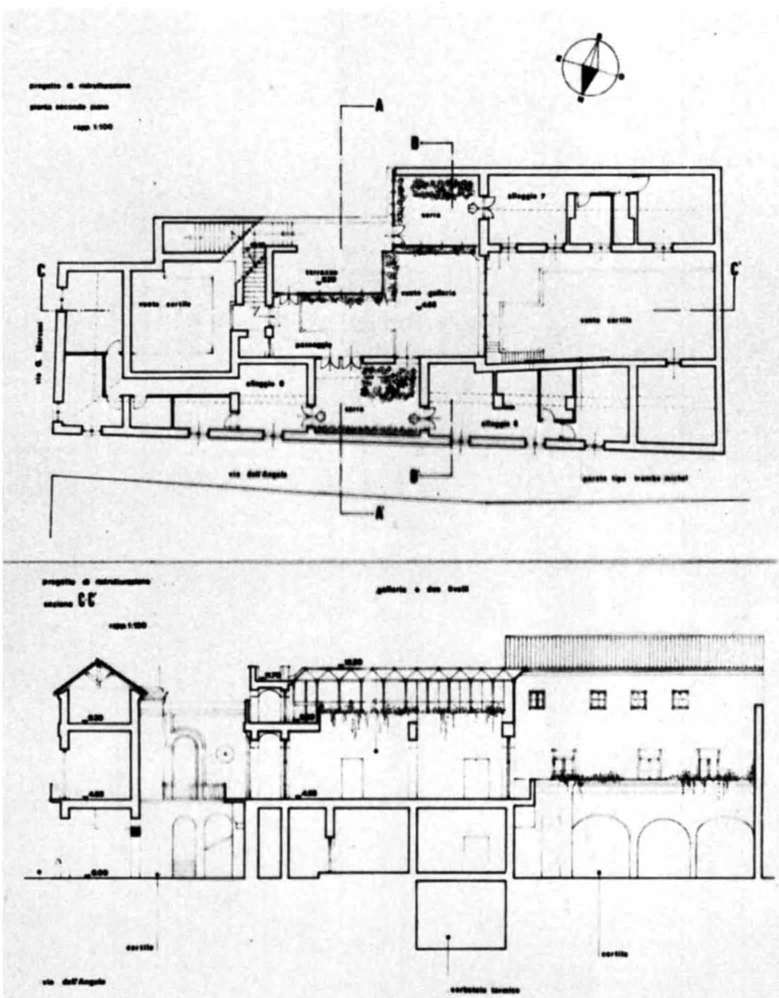


CONTROLLO TERMICO E DIMENSIONI DELLE SERRE

Temperature medie della serra nelle giornate limpide più fredde	temperatura esterna °C	serra con vetr.sempl.	serra con vetr.doppia
	4°	18°-24°	24°-29°
latitudine nord 32°-48°	7°	21°-27°	22°-32°

Dimensioni richieste per diverse condizioni climatiche per ogni mq. di superfice abitabile latitudine nord 32°-48°	temperatura esterna °C	mq. di serra per per mq. di superf. abitabile
	4,4°	0,13 - 0,21
	7,2°	0,11 - 0,17

Fig. 6. An example of building retrofitting with passive solar systems.



PASSIVE SOLAR RETROFITS IN ATHENS

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ABSTRACT

In Athens the pattern of urban development creates obstructions to winter solar access and is a major obstacle to passive solar applications on individual buildings. As an alternative to retrofitting individual buildings, this paper discusses the feasibility of intervention at the scale of the urban block by converting the atrium at the centre of the plot for solar collection and for passive cooling. The conversion is illustrated for the case of a block of commercial buildings and the results of thermal analysis are presented together with estimates of costs.

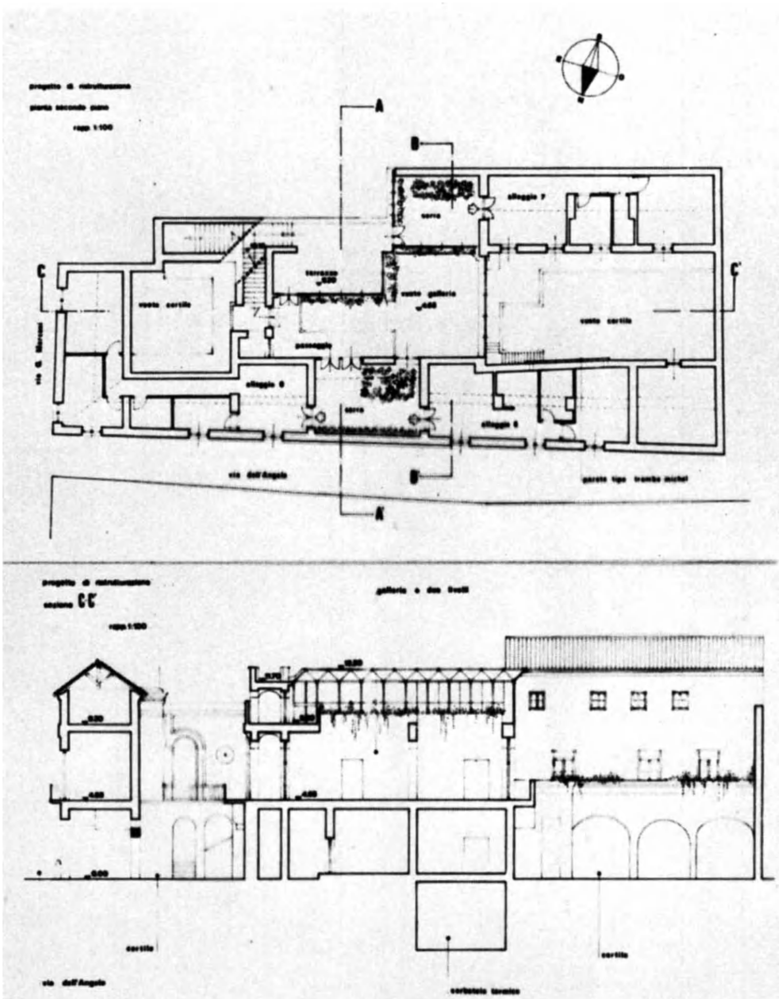
KEYWORDS

Urban blocks; Athens; solar access; passive solar retrofit; atrium; glazed roof; computer modelling.

INTRODUCTION

For the last thirty years building in Greece has followed a pattern of high-density, high-rise urban development and a construction system which is characterised by a thermally heavyweight structure and the lack of insulation. Heating is by oil-fired boilers serving individual multi-storey buildings under an intermittent schedule of operation. The length of the heating season varies from less than three months in southern parts of the country to over eight months in the north. Athens has a total of 1110 heating ^{o}C-days (base 18^{o}C). Mechanical cooling is rare because of its high capital and running cost.

In Athens the climate is mild compared to most other parts of Europe. For new buildings, passive heating and cooling can provide comfortable conditions throughout the year with little extra energy input. With existing buildings, however, comfort as well as energy demand are a function of the features described above. Their combined effect is a high fuel consumption for heating which is due to heavy heat losses from the building envelope and the conflict between intermittent heating and the slow thermal response of the heavyweight building structure. At current prices oil heating is uneconomic and is also a major contributor to the dangerous levels of air pollution in Athens. Electricity, the only other widely avail-


A
B
C
C'
vuoto cortile
via dell'Angelo
cortile

able fuel, is even less appropriate for heating purposes. In summer, buildings are at the mercy of the climate.

With the vast majority of the stock being less than twenty five years old, and a very low rate of building replacement at present, improving the use of energy in existing buildings is an obvious priority. Some possible strategies for improving existing buildings, and the priorities for research and implementation programmes have been discussed in previous papers (Yannas and Argyropoulos, 1981;Yannas 1983). In this paper some of these strategies are illustrated on the case study of a block of commercial buildings in Athens.

CASE STUDY

Existing Conditions

In Athens the unit of urban development, - the urban plot -, is delineated by the rectangular patterns of streets. The direction of streets is roughly N-S and E-W with deviations of up to 30° in either direction in some central areas. The shape of the plots ranges commonly from square 40m by 40m to rectangular 40m by 100m. These patterns are illustrated in Fig.1. The buildings, situated along the perimeter of the plots are typically five to seven storeys high with top floors set back from the street facade. An uncovered space or atrium, of varying shape and dimensions is formed at the centre of the plot.

The relationship between building heights and street width is shown in Fig. 2. Direct solar radiation does not reach into the ground floor level before March, - by which time the heating season is near its end. Only the top two or three storeys are in view of the sun throughout winter. Since these benefit already from direct gains through windows,further solar gains will depend on the feasibility of retrofitting conservatories or trombe walls on these facades. This potential is likely to be limited to less than 5 per cent of all building facades.

For those southern facades facing towards the atrium, solar access is a function of the width or length of the atrium, the orientation of its long axis and the height of surrounding buildings (Fig.2.). On average atrium widths are similar to those of streets. Therefore, with the long axis of the atrium pointing E-W, or with a square shape, the conditions of solar access of facades facing the atrium are almost identical to those facing the street. In the case of a N-S long axis the sun does penetrate into ground level throughout the winter but access is limited to the couple of hours about noon due to obstruction by buildings on the east and west. Moreover, in this configuration, the south facade is only a small proportion of the block's total area of facades.

In summary, for individual buildings access to the sun is either unfavourable due to poor orientation or obstructed to a substantial degree by neighbouring buildings. The potential for passive solar retrofits will be further limited by practical considerations such as the feasibility of altering balconies and existing facade finishings.

Proposed Modifications

An alternative to retrofitting selected parts of individual buildings is illustrated by the case study presented in this paper. This is to collect solar energy for use by the whole block by enclosing the atrium under a glazed roof attached to the roof tops of the surrounding buildings. Such a roof can collect solar radiation irrespective of the atrium orientation and is unlikely to be overshadowed by neighbouring buildings.

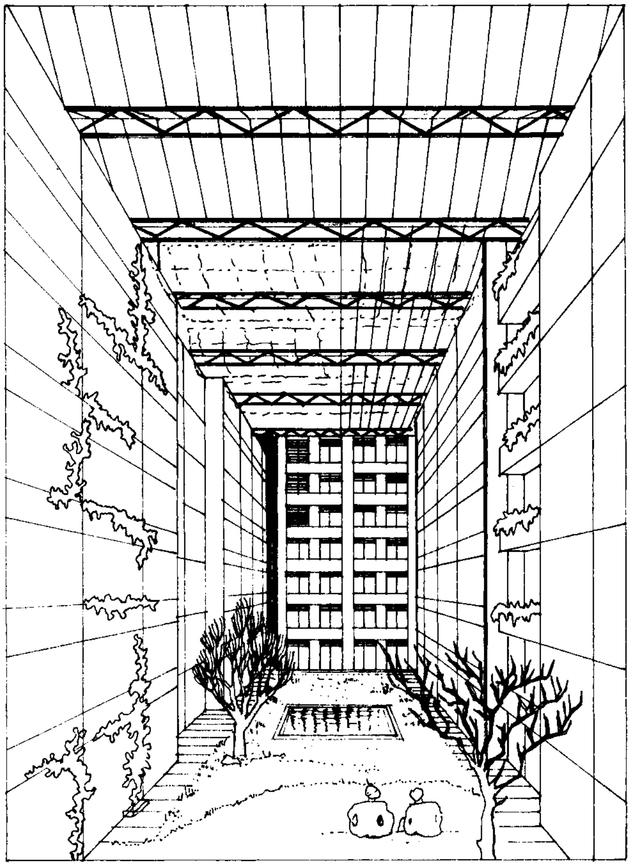


Fig. 4. Perspective view of atrium looking north

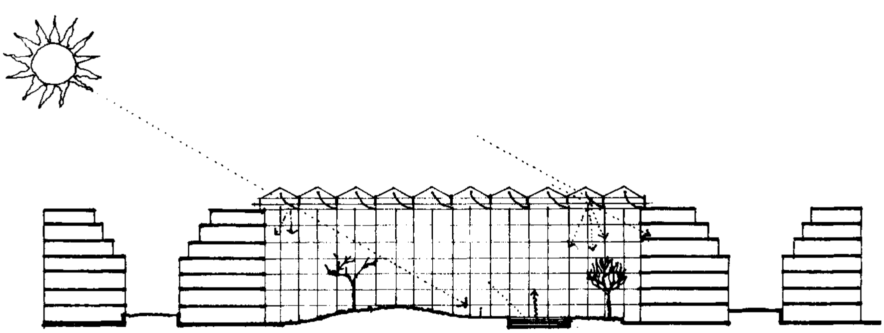


Fig. 5. Section through block

The project is for a block of commercial buildings situated in the city centre. The plot is a rectangle of 45m by 100m with a long axis direction 10° east of north. The buildings are seven storeys high including semi-basement, with top three storeys set back from the street facades. The structure is of reinforced concrete and solid brick partitions. Windows are single glazed. Each building has its own oil-fired central heating system operated intermittently during weekdays. There is no mechanical cooling. The atrium is roughly 15m by 70m, partly subdivided by low party walls along the rear building lines, and is currently unused. The ground of the atrium is not planted but includes some vegetation in its natural condition.

The design proposals for the atrium are shown in Figs 3-6. A single glazed roof of glassfibre reinforced plastic (GRP) is carried by galvanised lattice beams 1m deep at 6.7m centres supported on the existing structure and strengthened by piers tied into the structure as necessary. The double pitched glazing is tilted at 30° to the horizontal. Movable parasols of white fibreglass cloth shade the south glazing in summer and act as insulation for the north glazing in winter. The parasols are operated manually via control wires and pulleys.

The atrium ground is landscaped for communal use, deciduous trees are planted and access is provided to the atrium from the surrounding streets. A water pool is situated toward the northern end of the atrium and climbing vines are grown on the perimeter walls. All the walls facing the atrium are painted white.

THERMAL ANALYSIS

Modelling

To evaluate the effect of these proposals, thermal analysis was carried out using a microcomputer based model developed by the authors and described in detail elsewhere (Baker, 1982). The model calculates an average temperature for the glazed atrium taking account of heat flow by conduction and ventilation from the surrounding buildings and of solar gains made directly to the atrium. The average atrium temperature is then used to calculate the heat loss across the walls separating the atrium from the heated buildings. The final output of the model is a monthly auxiliary heating load for the buildings which allows for useful solar gains through south windows on the street facade, and which is given for a number of different ventilation modes. These are illustrated diagramatically in Fig. 7.

A summary of the building data used in the analysis is given in Table 1. Monthly ambient temperatures, - daily and daytime means - , and monthly solar radiation totals for horizontal and vertical south surfaces were used, as given for Athens by Pelekanos and Papachristopoulos (1980).

TABLE 1. Input Data for the Atrium Model

Atrium data (including separating wall)

	Area m^2	Glazing Ratio	U(glazing) W/m^2K	U(opaque) W/m^2K
separating wall	4284	0.3	5.5	2.0
roof	1050	1.0	6.0	-

atrium infiltration 1 ac/h
atrium volume 19950 m^3
solar gain factor (max) 0.6

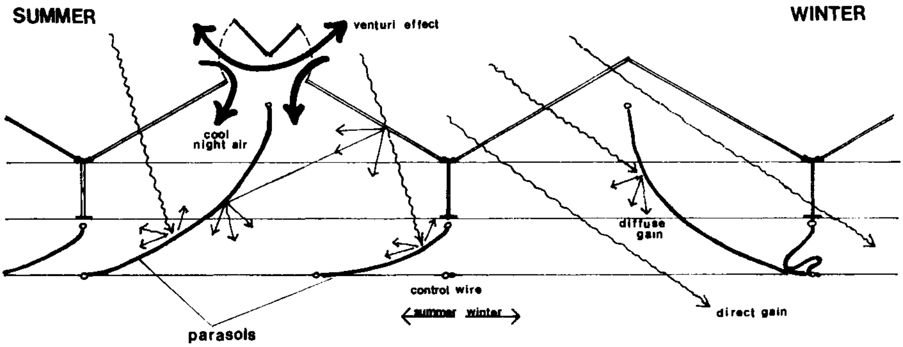


Fig.6. Section through roof

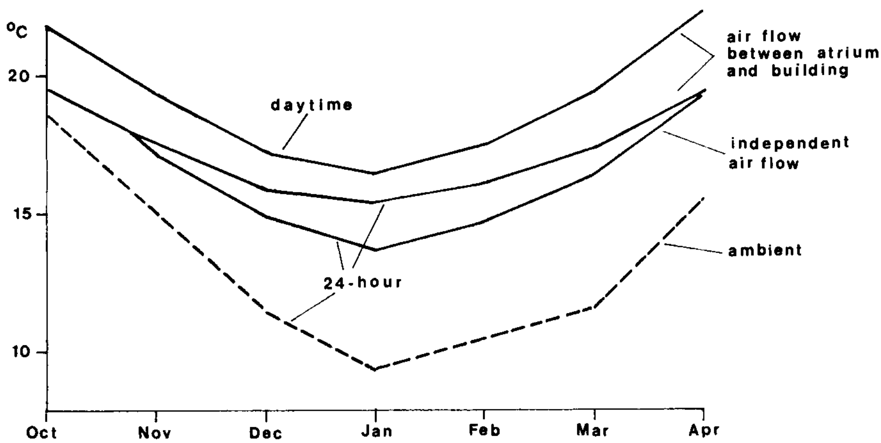
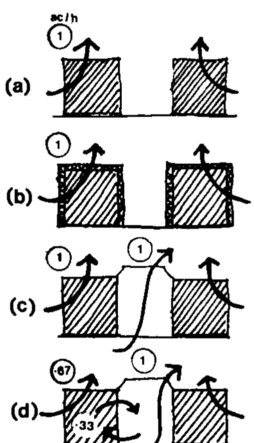


Fig.8. Atrium temperatures



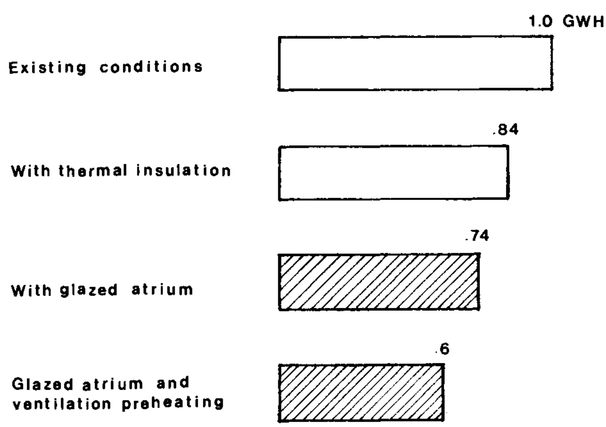


Fig.7. Outputs of model

Fig.10. Annual auxiliary heating

Building data (excluding separating wall)

	Area m^2	Glazing Ratio	U(glazing) W/m^2K	U(opaque) W/m^2K
floor	3450	-	-	1.5
walls	3344	-	-	2.0
glazing	1433	-	6.0	-
roof	3450	-	-	2.0
south facade	614	0.3	6.0	2.0

total floor area 17250
floor to ceiling height 3.0

infiltration rate .67 ac/h Ventilation from (or to) atrium .33ac/h
solar gain factor .72

mean internal temperature day 18.0 ^{o}C, 24-hour 16.1 ^{o}C

Monthly building data

	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.
casual gains KW	78	78	63	49	20	20	20	20	49	63	78	78
shading factor	.3	.4	.5	.6	.1	.1	.1	.1	.1	.5	.4	.3

Results

Reduction of total heat loss coefficient. Ignoring solar gains, the total steady state heat loss coefficient for the existing buildings is 57.9 KW/^{o}C. The addition of the atrium roof is equivalent to reducing this by 15 per cent to 49.1 KW/^{o}C. As a comparison, to obtain such reduction by thermal insulation of the building elements surrounding the atrium would have required to double glaze all the windows and to insulate walls to a U-value of 0.22 W/m^{2}K. Or, alternatively, to insulate all external walls to a U-value better than 0.5 W/m^{2}K.

Atrium temperatures. The air flow pattern between the atrium and the surrounding buildings will depend upon window opening, wind direction and other factors which cannot be predicted with certainty. To illustrate the range of possible conditions calculations of the atrium temperatures were carried out for the two ventilation modes shown in Fig. 7 (c and d). Both cases are based on the same total ventilation rate for the buildings (1 ac/h) and for the atrium (also 1 ac/h, equivalent to .4 ac/h building volumes). In the first mode (Fig. 7c) there is no mixing between the atrium and building air. In the second mode (Fig. 7d) one third of the air exchange of the buildings is attained by circulation between the buildings and the atrium and the remaining two thirds are drawn from outdoor air (ventilation preheating mode). This mode leads to higher atrium temperatures since warm air from the building is brought into the atrium instead of cold outside air. At the same time the building is receiving air from the atrium which has been already preheated by solar energy. Previous simulation studies have shown that this is likely to be an efficient way of utilising passive solar gains.

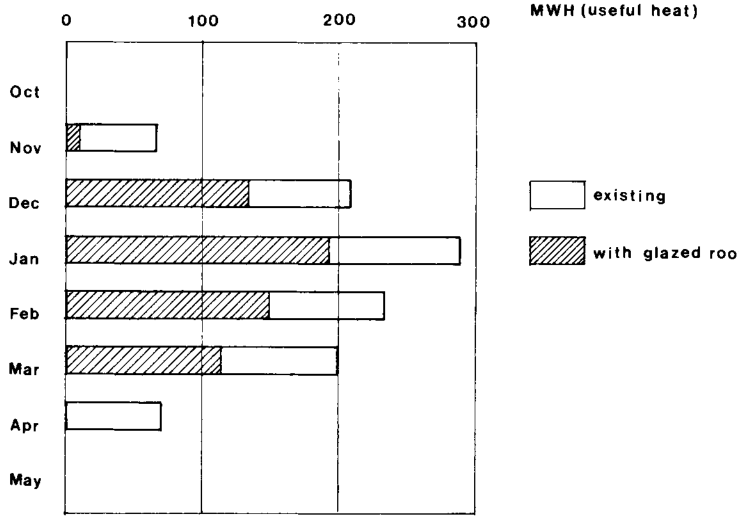


Fig.9. Monthly auxiliary heating energy

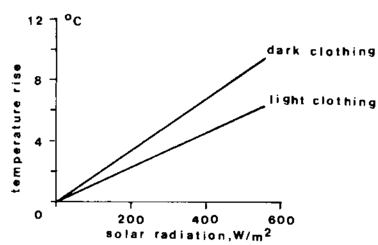


Fig.11. Rise in effective temperature as a function of radiation

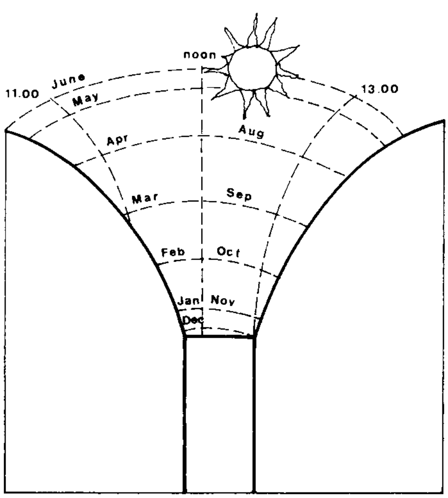


Fig.12. Hours when sun reaches at least half of atrium floor

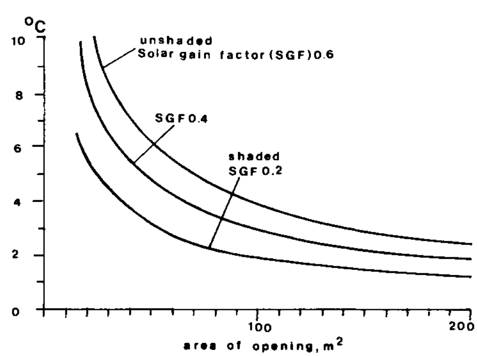


Fig.13. Openable glazing and shading to keep atrium temperature close to ambient

(Baker, 1983).

The atrium temperatures calculated for the two ventilation modes are shown in Fig. 8 (curves 2 and 3). These are average 24 hour temperatures during the heating season and are compared with ambient (bottom curve). The real situation is likely to lie somewhere between the two curves. A daytime average temperature is also plotted for the atrium (top curve) with the same assumptions as for curve 2.

Energy Savings. The reductions in monthly auxiliary heating (in useful heat) achieved by glazing the atrium are shown in Fig. 9 for the ventilation preheating mode. Annual auxiliary heating requirements are given in Fig.10. Annual savings for this case are 0.4 GWH or 40 per cent compared to existing conditions. With independent ventilation the savings drop to 26 per cent. For comparison, auxiliary heating without the atrium glazing but with walls and roof insulated to a U-value of 1 W/m^2K is also shown.

Thermal comfort. During the heating season the temperature inside the buildings is assumed to be maintained at 18^oC throughout the working day.

The temperature in the atrium is not controlled and will swing about the mean values shown in Fig.8. During sunny periods the effect of direct solar radiation can be measured as a rise in the effective temperature felt by atrium occupants sitting in the sun. This is shown in Fig.11 as a function of the absorption coefficient of clothing. The hours when direct sunshine reaches at least half of the atrium floor are shown in Fig.12 . From Fig.11 and for the range of winter radiation values in Athens during these hours the rise above the predicted atrium air temperatures is found to be between 2 and 7^oC. This means that conditions in the atrium can be within the indoor comfort zone for a large part of the heating season. The effect can be prolonged further by reflective surfaces situated so as to direct sunshine toward the atrium ground outside these hours.

Summer conditions. Provisions for shading and ventilation of the atrium are shown in Fig. 6. Ventilation is driven by the stack effect with warm air leaving via ventilators along the ridge of the glazing. The wind is predominantly from the north, but from the south in May, June and July. The ventilators are double opening to provide extract irrespective of wind direction and give enhanced suction due to the venturi effect.

Figure 13 shows that the more effective the shading, the less the heat that needs to be ventilated out. A temperature increment is required to create the buoyancy effect driving the ventilation. This increment can be kept to a minimum by producing effective shading and by giving a large area of openable vents. With 10 per cent of the glazing area openable, the atrium temperature can be kept at 1.8^oC above ambient. In calm conditions the stack effect will induce air movement through the buildings by opening windows to the atrium. Evaporation from plants and water in the atrium will provide additional cooling.

At night, the air flow continues to be upward initially as heat stored in the atrium walls is transferred to the air drawing cooler air into the buildings. After equilibrium is reached, the roof will cool by radiation and cool air will descend into the atrium through the open ventilators.

ECONOMICS

The cost of the glazed roof including valley gutters, bracing and erection costs given by manufacturers is 57 ECU (European Currency Units)[1] per square metre of area spanned. Including supporting of the structure and the shading system but excluding landscaping the total cost is estimated at 80000 ECU.

For the calculation of savings seasonal efficiency of oil heating is taken as 0.65 and the price of oil as .03 ECU/KWH (delivered). The results are summarised in Table 2.

TABLE 2. Payback Periods of the Atrium Roof.

	no ventilation preheating	with ventilation preheating
useful KWH saved	260 000	400 000
delivered KWH saved	400 000	615 000
value @.03 ECU/KWH	12 000	18 461
cost of improvements	80 000	80 000
simple payback(years)	6.7	4.3

CONCLUSION

These results are very encouraging considering especially that the costs of the roof are offset by energy savings alone and that the atrium becomes a useful space throughout the year at no additional cost.

In the next stage of the study dynamic simulation is to be undertaken with the aim of improving and optimising the design of the roof and to determine the effect of landscaping and other strategies.

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1. ECU = £0.55 = 62.78 Drahmas.

PASSIVE SOLAR HEATED HOUSE IN ARKADIA

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ABSTRACT

In this paper is described the passive solar heating of a retrofitted house. Target of this endeavour, was to cover a large percentage of energy requirements of the house with the sun. Two passive solar systems have been incorporated into the building shell and the percentage of the house requirements covered by the sun was calculated. Construction details are described for these systems and economic costs are given. Results of some measurements are discussed.

KEYWORDS

Passive solar energy; passive solar systems; passive solar heated homes; trombe-michel wall; greenhouse; shading devices; solar gains; solar heating fraction.

ENERGY REQUIREMENTS

The study concerns the upper floor of an old building at Poulithra of Arkadia (Figs 1 and 2). The calculated heat loss for the house and the cost of improvements are given in Table 1. Monthly and Annual Solar Heating Fractions were calculated by the SLR Method (Balcomb and McFarland, 1978). The calculations are summarised in Tables 2 and 3 for the trombe wall and greenhouse respectively.

Construction was only completed in mid-February 1983. Measurements taken during the last week of February and the first week of March are shown in Fig. 3 . The measurements suggest that up to 90 per cent of the heating load is covered by the passive systems.

CONCLUSIONS

1. The cost of passive systems is a very low percentage of the total cost of the house. This percentage in relation with the constructed house amounted to 4.4%.

2. Passive systems, with careful study and proper selection of materials, colours, and construction methods can improve the appearance of the building.

PLF-H*

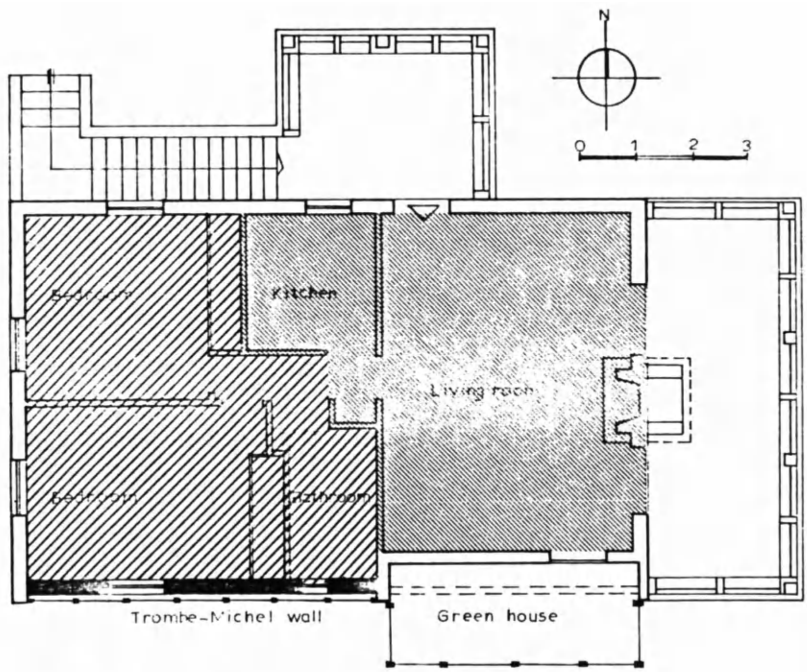

Fig. 1. Floor Plan

//// Heated by T-M wall
//////// Heated by Green house

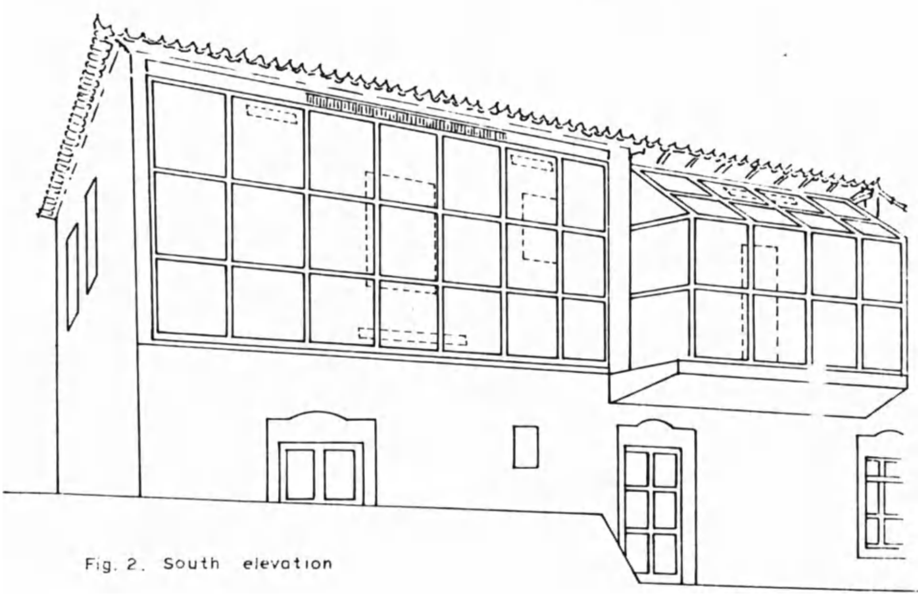

Fig. 2. South elevation

TABLE 1. Heat Losses and Insulation costs for a new house
(costs are expressed in 1983 US $)

	1	2 Doors & Windows		3 Walls		4 Roof	5 Ground	6 Uncontrolled Ventilation	Zone B / $\frac{F}{V} = 1.244 m^{-1}$
Level of insulation based at Greek's standards		T-M	others	T-M	others				
	$S (m^2)$	1.78	4.05	16.75	25.83	3675	36.75	f = 18.9	Kd $\frac{\$}{max}$ 0.791
	ΔT (°C)	20	20	20	20	20	10	20	
	Material	—	single glazed	—	expanded polystyrol	expanded polystyrol	—	a = 2.0	
	λ (w/m.k.)	—	—	—	0.041	0.041	—	H = 0.58	
	d (m)	—	—	—	0.05	0.05	—	R = 0.9	
	k $(w/m^2.k)$	3.02	5.23	0.898	0.563	0.591	2.673		Kd = 1.041
	Q (w) losses	108	424	301	291	434	982	460	Q_T = 3 000 w
	Specific cost $(Dr./m^2)$	—	—	—	170	170	—		
	Total cost (Dr.)	—	—		4400	6247		10.647 ($12[illegible])	
				Green House	others				
	$S (m^2)$	7.84		12.40	30.07	34.41	34.41	f = 26.9	Kd $\frac{\$}{max}$ 0.791
	ΔT (°C)	20		7	20	20	10	20	
	Material	single glazed		—	expanded polystyrol	expanded polystyrol		a = 2.0	
	λ (w/m.k.)	—		—	0.041	0.041	—	H = 0.58	
	d (m)	—		—	0.05	0.05	—	R = 0.9	
	k $(w/m^2.k.)$	5.23		1.205	0.563	0.591	2.673		Kd = 1.106
	Q (w) losses	820		104	339	407	920	653	Q_T = 3 243 w
	Specific cost (Dr/m^2)	—		—	170	170	—		
	Total cost (Dr)	—			5100	5850		10.950 ($130)	

TABLE 2. Calculation of Solar Load Ratio (Method Balcomb & Mc Farland).

Space Heated by Trombe-Michel Wall : S.H.F. 85 %

Month	1	2	3	4	5	6	7 (5-6)	8	9	10 (2x8x9)	11 (7-10)	12	13	14 (2x12x13)	15 (14 : 11)	16	17 (11 x 16)	18 (11-17)
	Degree days D.D.	Total radiation in south vertical surface T.R.S.V.S. (kwh/m²m.)	Specific heat loss S.H.L. (W/°C)	Modified building loss Coefficient (1) M.B.L.C. (kwh/D.D)	Gross monthly load (2) G.M.L. (kwh/m.)	Internal gains I.G. (kwh/m.)	Net monthly load N.M.L. (kwh/m.)	Gross area of windows G.A.W. (m²)	Solar gains of windows fraction S.G.W.F.	Solar gains of windows S.G.W. (kwh/m.)	Net monthly total load N.M.T.L. (kwh/m.)	Gross area of Trombe-wall G.A.T.W. (m²)	Solar gains of Trombe-wall fraction S.G.T.W.F.	Solar gains of Trombe-wall S.G.T.W. (kwh/m.)	Solar load ratio S.L.R.	Monthly solar heating fraction M.S.H.F.	Useful solar energy U.S.E. (kwh/m.)	Auxiliary energy A.E. (kwh/m.)
O	29	114	150	3.6	104	100	4	1.8	0.80 (3)	164	—	—	—	—	—	—	—	—
N	96	104	150	3.6	346	100	246	1.8	0.80	150	96	16.8	0.80	1398	14.6	1.0	96	—
D	206	89	150	3.6	742	100	642	1.8	0.80	128	514	16.8	0.80	1196	2.3	0.82	421	93
I	264	87	150	3.6	950	100	850	1.8	0.80	125	725	16.8	0.80	1169	1.6	0.67	486	239
F	224	86	150	3.6	806	100	706	1.8	0.80	124	582	16.8	0.80	1156	2.0	076	442	140
M	196	91	150	3.6	706	100	606	1.8	0.80	131	475	16.8	0.80	1223	2.6	0.84	399	76
A	85	83	150	3.6	306	100	206	1.8	0.80	120	86	16.8	0.80	1116	13.0	1.0	86	—
TOTAL	1100	—	—	—	3960	700	3.260	—	—	—	2478	—	—	7258	—	0.85	1930	548

(1) $M.B.L.C. = \frac{S.H.L. \times 24}{1000}$ (2) G.M.L. = (D.D.) (M.B.L.C.) (3) Income Solar Gain Fraction: single glazed 0.80, double glazed 0.70.

TABLE 3. Calculation of Solar Load Ratio (Method Balcomb & Mc Farland)

Space Heated by Greenhouse S.H.F. 67 %

Month	1	2	3	4	5	6	7 (5-6)	8	9	10 (2x8x9)	11 (7-10)	12	13	14 (2x12x13)	15 (14 : 11)	16	17 (11x16)	18 (11-17)
	Degree days D.D.	Total radiation on south vertical surface T.R.S.V.S. [illegible]	Specific heat loss S.H.L. (W/°C)	Modified building loss Coefficient M.B.L.C.(1) (kwh/DD)	Gross monthly load G.M.L.(2) (kwh/mo)	Internal gains I.G. (kwh/mo)	Net monthly load N.M.L. (kwh/mo)	Gross area of windows G.A.W. (m²)	Solar gains of windows fraction S.G.W.F.	Solar gains of windows S.G.W. (kwh/mo)	Net monthly total load N.M.T.L. (kwh/mo)	Gross area of Trombe wall G.A.T.W. (m²)	Solar gains of Green house S.G.T.W.F.	Solar gains of Trombe-wall S.G.T.W. (kwh/mo)	Solar load ratio S.L.R.	Monthly solar heating fraction M.S.H.F.	Useful solar energy U.S.E. (kwh/mo)	Auxiliary energy A.E. (kwh/mo)
O	29	114	162	3,888	113	113					—	—	—	—	—	—	—	—
N	96	104	162	3,888	373	200					173	12,4	0,80 (3)	1032	6,0	1,0	173	—
D	206	89	162	3,888	801	200					601	12,4	0,80	883	1,5	0,65	391	210
I	264	87	162	3,888	1026	200					826	12,4	0,80	863	10	0,50	413	413
F	224	86	162	3,888	871	200					671	12,4	0,74	789	1,2	0,57	382	289
M	196	91	162	3,888	762	200					562	12,4	0,60	677	1,2	0,57	320	242
A	85	83	162	3,888	330	200					130	12,4	0,22	226	1,7	0,70	91	39
TOTAL	1100	—	—	—	4276	1313					2963	—	4470	—	—	0,67	1770	1193

(1) $M.B.L.C. = \frac{S.H.L. \times 24}{1000}$ (2) G.M.L. = (D.D.) x (M.B.L.C.) (3) Income Solar Gain Fraction: single glazed 0,80, double glazed 0,70.

3. The measurements, during the last week of February 1983, and the first week of March proved that the percentage of heat losses covered was over 90%, - that is higher than that calculated with the SLR method.

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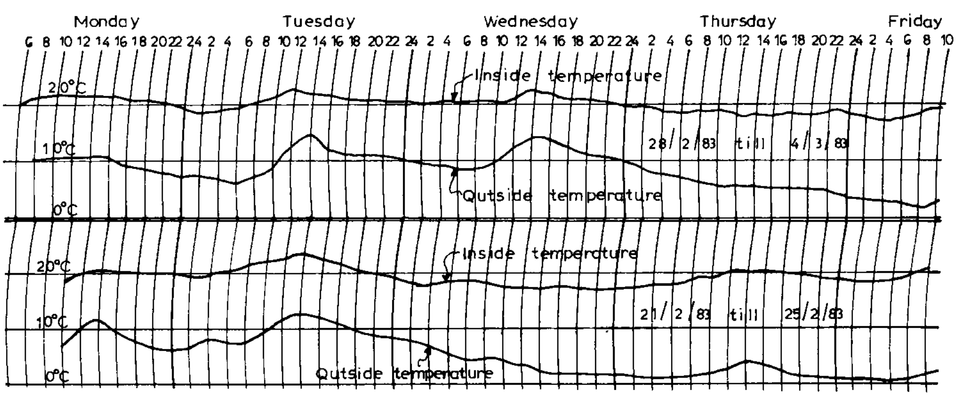
Fig. 3. Results of measurements.



ENVIRONMENTAL CHARACTERISTICS OF THE VERNACULAR UNDERGROUND DWELLING

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ABSTRACT

The potential for capturing solar energy by intelligent exploitation of the fabric of a building has been known and used in the Mediterranean region for several thousand years. This paper focuses on one such technique - the use of the earth itself as a collector and store of energy, directly utilized by positioning the building underground. Case-studies of three such dwellings are taken to illustrate typical vicissitudes encountered. Strategies for renovation and upgrading of historic cave dwellings are proposed, and attention is drawn to the stock of decaying and under-utilized rock-cut housing in the Mediterranean region - an existing source of free energy immediately available for tempering the internal environment.

KEYWORDS

Underground building; vernacular dwellings; passive heating; passive cooling; thermal mass.

INTRODUCTION

The thermal benefits enjoyed by new underground construction have been extensively studied, both by predictive modelling techniques and logging of data in completed buildings. The world's legacy of historic underground buildings, however, is of particular interest in the opportunity it affords of studying subterrannean dwellings whose thermal and humidity conditions have been established over a very much longer period of time. In southern Europe and North Africa this heritage is particularly rich: Fig.1.

Fig.1. Some troglodytic communities in the Mediterranean region.

The diversity of conditions under which these communities were founded, and have subsequently flourished or decayed, must be acknowledged in any attempted overview. Differences of climate geology, and original primary use, are marked; subterranean space may initially have been exploited as quarries, refuges or water cisterns. At Bulla Regia, for example, a Roman city in northern Tunisia, Beschaouch has recorded instances in which underground suites were contrived beneath pre-existing houses.

Nevertheless, the basic module of sub-surface living space, the rock-cut chamber, can be taken to demonstrate the most important environmental properties of these structures: the comparative thermal stability they enjoy, over both diurnal and annual cycles (Mulligan 1983). The dwelling taken to represent the archetypal cave habitat was one cave opening off a sunken courtyard in the village of Techine in south Tunisia. In predicting the thermal performance of specific dwellings, a detailed study must be made of their individual characteristics. How closely in fact do they correspond to the archetype, in physical condition and in use?

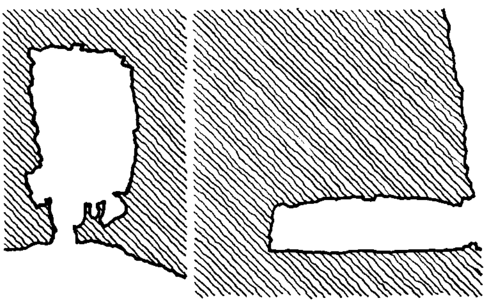


Fig.2. The cave-dwelling 'archetype'.

Plan Section

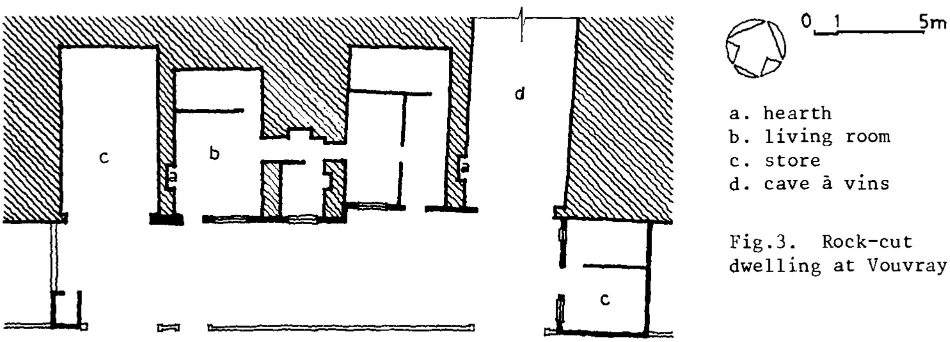
THE VERNACULAR CAVE DWELLING: PHYSICAL CONDITION

Case study 1 : Vouvray

This establishment, belonging to a vine-grower and his family, is cut back into the brow of a hill immediately beneath its owner's vine-yards: this area, just east of Tours in the Loire valley, is one of the most renowned wine-producing areas in France. The house is located on the western slope of a small valley which runs south towards the Loire: Fig.3.

In plan, it is in many ways typical of cliff-cut dwellings in the Mediterranean region. Chambers are cut parallel to one another into the rock face; each has a span of approximately 4m and may be subdivided by studwork partitions. Here, alongside the dwelling and store, a much deeper 'cave à vins' holds the wine-producer's maturing stocks. A narrow garden-court separates the dwelling from the street and is closed at either end by subsidiary outbuildings. There are mains services for water supply and drainage; non-drinking water, however, is collected from the cliff-face in a run-off gully.

The house is excavated from the tuffeau, a layer of easily-worked white limestone which has been quarried - by mining - at many locations in the Loire valley to provide the characteristic building stone of Touraine. According to the present occupants, the house is three generations old. However, the present façade, of rendered clay blockwork, is comparatively recent. Internally, the dwelling rooms have been lined with a hard cement render, giving flat ceilings and sharp internal corners. The storehouse and 'cave' have gently curving walls and ceilings of bare rock.



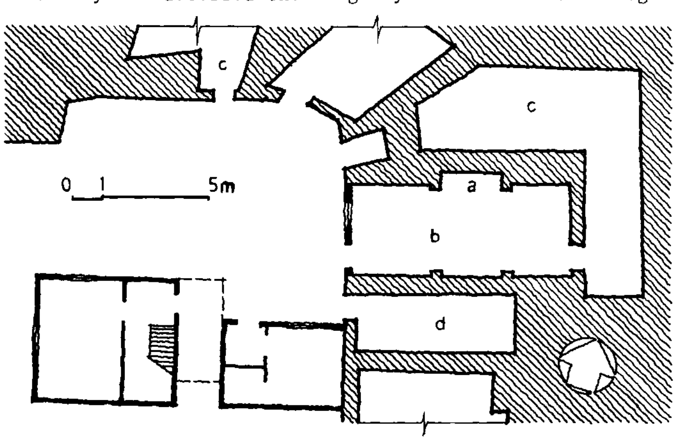
a. hearth
b. living room
c. store
d. cave à vins

Fig.3. Rock-cut dwelling at Vouvray.

The wine-grower and his family now use the house only as an adjunct to their work-place, the cave à vins. Needing more space for their home-life, they moved out three years ago. Already there is a noticeable growth of black mould on ceilings and walls, particularly in the rear bedrooms.

<u>Case study 2</u> : <u>Cumeray</u>

Cumeray lies approximately 70km downstream from Vouvray, 20km SE of Angers. It is situated on a plateau to the south of the Loire; the lack of river-cliffs here has evidently not deterred the troglodytic home-builder: Fig.4.



Key as above.

Fig.4. Dwelling at Cumeray.

The rooms which comprise the dwelling open onto a small courtyard sunk into the hill-side and reached by a gentle ramp. Only one of these chambers is now permanently used for habitation, the others serving as stores for vegetables and lumber, with a stable and a rabbit hutch. Several of the chambers interconnect by ventilation holes with a larger room, once used as a dwelling, distinguished by two large open fire-places. The present living room is heated by a closed stove, utilizing the flue of the original fireplace - now blocked off.

Most of the living accommodation is now comprised in the free-standing buildings which have been erected stage by stage on one side of the courtyard. Sanitary installations are connected to mains services; storm water draining from the court and roof gutters, however, runs to a soakaway sunk into the floor of one storage chamber.

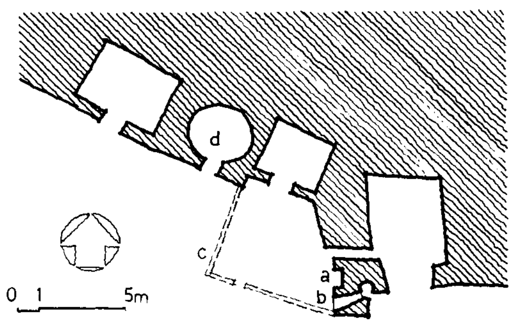
The material here is falun, a rock with similar properties to the tuffeau of Touraine. The dwelling cave has a vaulted ceiling: the exposed rock has been given successive coats of whitewash between the dressed stone supporting arches which are spaced about 3m apart. There is a small amount of mould growth. Bare rock is exposed in the walls and ceilings of the adjoining stores: in some the ceilings crumble at a touch, while in those to the right of the entrance ramp the rock is sufficiently durable to have retained original pick-marks.

Case study 3 : Avola Vecchia

The prosperous town of Avola, together with many other cities of south-eastern Sicily, was devastated by the earthquake of December 1693. Deserting their hilltop site protected by deep gorges, the citizens rebuilt Avola, on a novel hexagonal town-plan, some 6km to the south.

The new site lies on the flat coastal plain overlooked by the ruins of Avola Vecchia, which can now be reached by a modern road climbing the escarpment in a series of hairpin bends. On this mountainside are to be found 40-50 rock-cut chambers and cisterns.

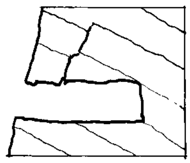
It appears that the caves were superimposed on three levels up the slope: the position of access roads has unfortunately been obscured by the building of trackways for the convenience of olive-tenders now cultivating the hillside, and of the new high road.



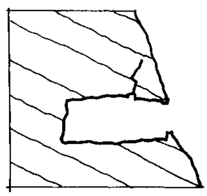
a. bake oven
b. stokehole to flue
c. demolished external wall
d. cistern

Fig.5. Abandoned rock-cut caves at Avola Vecchia.

It may be seen, however, that a typical layout [Fig.5] resembles the dwelling at Vouvray described above: parallel chambers cut back into a south-facing slope. With the exception of cisterns, these chambers are roughly rectangular in shape, with flat horizontal ceilings. A deep groove commonly separates ceiling from wall, perhaps indicating the softer stratum, first tackled by the troglodyte builder with his pick. Lower blocks could then have been prized upwards into this space and extracted: a technique of excavation particularly suited to this rock formation, where weaker more sandy layers alternate with more competent limestone strata. Particularly dependable strata have been selected to form ceilings to the caves - these can be clearly distinguished on the mountainside by their resistance to erosion. Very frequently roof ceilings are fissured parallel to the rock face at a depth of approximately 1.5m from the entrance. This cracking, due to release of stresses in the rock brought about by the excavation of underground rooms, has rarely led to collapse; the choice of this site, where bedding planes in the rock dip away from the valley rather than towards it, gives the structure an inherent stability.



Strata dip away from valley, as at Avola Vecchia.



Strata dip towards valley: movement of joints normal to bedding plane brings greater danger of roof collapse.

Fig.6. Diagram of caves excavated in dipping strata.

From the fragments of pottery found on the site, it maybe inferred that certain of the caves were used as dwellings into the eighteenth century. In the seventeen eighties, the French traveller Jean Houel remarked on the extraordinary mildness of climate experienced in this valley, and its consequent suitability for cave habitations. Some of those to which the new road gives direct access are still in use as stores.

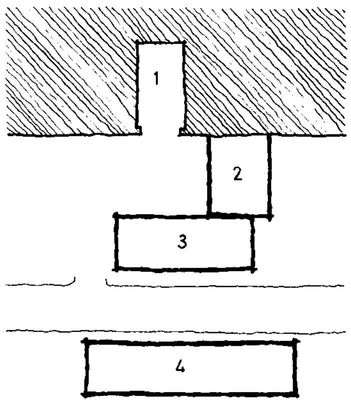
Remaining foundation walls indicate that many of the caves had facades of rubble masonry, and in some cases more extensive freestanding outbuildings. Monolithic facades are also found, with door openings rebated to receive door-jambs and horizontal bars. Former stables can be distinguished by rock-cut mangers, 700mm high by 2-3m in length, usually situated at the rear of the cave, and tethering rings worked in the roof. The presence of hearths and flues, characteristically hollowed from the rock face and completed by semi-cylindrical roofing tiles, indicate the caves used for habitation. Directly alongside these are found cisterns, conical in shape and lined with an impermeable plaster coloured pink by the addition of brick-dust. To these cisterns surface water is channelled from gulleys sloping down the rock-face.

ASSESSMENT OF AVAILABLE RESOURCES

These three examples may be taken to illustrate typical phases in the evolution of a cliff-cut dwelling, and consequent changes in its capacity to utilize passive energy gains.

The house at Vouvray exemplifies the cliff-dwelling in its most simple form. The dwelling-caves are oriented to gain the greatest degree of insolation possible for a single-aspect house: they face due south and are positioned to minimise overshadowing from above-ground structures. At Cumeray, however, the subterranean buildings have clearly been superseded in importance by the masonry additions, which deprive them of direct sunlight for a large part of the day.

This process has been documented in detail by Mouy in a study of the small town of Villaines-les-Rochers, in Touraine. The stages whereby development of the town took place are described from the stablishment in the medieval period of the troglodytic community up to the present day. A crucial point seems to have been reached in the eighteenth century, perhaps when suitable sites for cave dwellings in the locality had all been taken up. From this time onwards, progressive expansion takes place away from the cliff-face. The process is represented in diagrammatic form for a single dwelling: Fig.7.



1. original cave dwelling.
2. above ground extension parallel to cliff-face.
3. further building parallel to cliff-face enclosing private court.
4. development separated from cliff-face by street.

Fig.7. Diagram of built-form expansion at Villaines-les-Rocher.

The process of accretion, however, is far from irreversible - as shown by the case of Avola Vecchia, where the excavated caves have proved substantially more durable than their masonry additions. In this instance, the entire settlement has been abandoned.

Elsewhere, however, for example at Chinon (Touraine), a cyclic process can be observed: masonry outbuildings have been allowed to fall into disrepair, sometimes demolished, and then rebuilt in a new period of prosperity or when ownership of the property changes.

Thus the cave serves as a nucleus to the home, which expands or contracts according to the material circumstances of its present occupant. 'Improvement' may be achieved at minimal expense - for there is only a single façade to upgrade.

STRATEGIES FOR RE-USE

In assessing the energy-saving benefits of a particular form of construction, the energy costs of the building process itself must be considered side by side with the energy requirements of the completed dwelling in use.

As regards new building, a crude comparison was made of the quantities of material required to be quarried out for the construction of a cave dwelling on the one hand, and on the other a simple stone-built cottage enclosing a similar volume of space. It can be shown that the cave takes roughly twice the amount of excavation needed for its free-standing equivalent. However, the man-hours then required to dress and lay the stones, construct a weatherproof roof and carry out maintenance on all external elements throughout the latter's life, must then be taken into account.

Mao Tse-Tung's personal experience is not to be taken lightly: the lack of skilled building labour available to his People's Liberation Army at the mountain stronghold of Yenan in 1940 was a critical factor in the adoption of cave construction to house the Revolutionary forces (Penn 1964).

When considering the rehabilitation of an existing but disused cave-dwelling, however, it is clear that the necessary input in building materials and labour to restore a single damaged façade is very modest.

Moreover, from the above discussion of the three sites described, in detail, it can be seen that an abandoned or neglected underground dwelling may in fact possess a greater potential for utilizing passive energy sources than a similar dwelling which has become overshadowed by outbuildings thrown up by succeeding generations of inhabitants. Where the cliff-face facade must be entirely renewed, an opportunity exists for incorporating a structure specifically designed for passive solar gain.

Re-use : the interior

Treatment of the interior surfaces which define the underground dwelling demands careful consideration. Repair and restoration of a derelict house again offers advantages in permitting a fresh assessment of the building's potential.

Given the values of capacitance and thermal conductance of the rock surrounding the cave, two very different approaches may be taken to utilizing these properties to maintain satisfactory environment within the dwelling.

Firstly, the dwelling walls may be treated in the traditional way, as described in the case of the Cumeray house. After scraping down the walls to remove loose surface material, cracks may be repaired with a lime mortar and the surface finished with a coat of whitewash, as proposed by Charneau and Trebbi. There is no other barrier to heat exchange between the dwelling space and the mass of rock surrounding it; ground-coupling is virtually complete. Furthermore, the exposure of rock surfaces inside the home allows the inhabitant to keep a constant check on its structural condition. The movement of cracks, infiltration of ground water or, worse, penetration of the ceiling by roots could provide warning of imminent failure. Some problems of condensation, too, may be alleviated by the porosity of internal surfaces.

Secondly, a technique similar to that observed at Vouvray may be employed: the walls and ceiling being lined with a material whose properties differ considerably from those of the rock base. Such a barrier may be formed by a thick cement render perhaps with waterproofing additives, by expanded polystyrene tiles, or by an entire inner skin of hollow clay blocks: these are all materials which have been employed in cave dwellings studied in Touraine and Anjou. The variety of possible surface treatments makes generalizations as to their performance difficult. Nevertheless, the possibility of modifying the original dwelling to create a watertight, dust-proof, well-insulated envelope within the stable environment provided by the rock mass may in certain circumstances be preferred to the alternative considered above.

CONCLUSION

It has been seen that, in countries bordering the Mediterranean sea, the cave-dwelling has comprised a part of the housing stock for many centuries. Originating as a very simple basic form, cave dwellings have undergone modifications in physical fabric, in provision for environmental services and in patterns of use which must be taken into account in any assessment of their present energy requirements.

Owing to the durability of a rock-cut structure, very many cave-dwellings - which have been abandoned as a result of population shifts, government policy, or personal preference of the inhabitants - could be brought into use once more.

It seems, moreover, that a large proportion of inhabited cave-dwellings are in only intermittent use. Further studies are needed to determine what effect such a pattern of use will have on the thermal performance of inherently slow-response structures.

Within the Mediterranean region, however, a considerable variety of climatic zones are encountered, from cool temperate to arid. Theoretical analysis may provide an indication of the low-energy potential of underground dwellings, given regional climatic data. A complementary investigation of the area's existing cave dwellings will provide immediate evidence of what utilization strategies have been found to provide comfortable homes underground.

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THE EARTH-SHELTERED DWELLINGS OF SANTORINI, GREECE

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ABSTRACT

This paper reports the thermal performance of the earth-sheltered dwellings in the island of Santorini in Greece. Temperature and relative humidity, both external and inside four different houses have been measured during the months of July and August. A numerical simulation model has been developed and compared with experimental data. The results are presented in the paper.

KEYWORDS

Earth-sheltered dwellings; traditional Greek architecture; thermal network model; simulation vs. experimental data.

INTRODUCTION

Even though climate is not the most important determining factor in traditional architecture, in Greece, as in most other countries, it can be noticed how building practices have developed in a close relationship with climatic factors. The study of this relationship could be of great importance and practical value for today's architecture.

Among the many interesting examples of climate influenced Greek traditional architecture, one of the most important are the still inhabited earth-sheltered dwellings in the island of Santorini.

CLIMATE AND GEOGRAPHIC DATA

Santorini is a volcanic island, the remaining of a volcanic mass, halfsubmerged in prehistoric times. It is the southernmost island of the Cyclades (see Fig. 1), at 36° 25' N latitude.

The climate is mild, with small temperature variations: the mean temperature is 11°C in January, and 25°C in July. The humidity is high, ranging from 62% in summer, to 76% in winter (mean values). Solar radiation data are not available for Santorini. Prevailing winds, both in summer and in winter, are North-North-East.

Fig. 1. Position of Santorini

THE ARCHITECTURE OF SANTORINI

The compact form of the fortified settlements of the island, built for defence reasons, provide buildings with shading and protection from prevailing winds. In other settlements, such protection is either provided through proper orientation, or is given by high white-washed walls, built on the three sides of the front-yards (see Fig. 2).

Many houses are at least partially earth-sheltered, being carved in the sloping cliffs of canyon-like valleys. The massive constructions and the contact with the earth provide very efficient summer cooling. (see Fig. 3).
The facades of the houses have a door, with a window over it and one on each side(Fig. 4). The typical house is composed of two rooms, divided by a partition wall, which repeats the pattern of the external openings(Fig. 5). The inner rooms are only occupied at night and are not directly illuminated by the sunlight. Other chimney-like openings provide natural ventilation to these excavated rooms (Fig. 6).

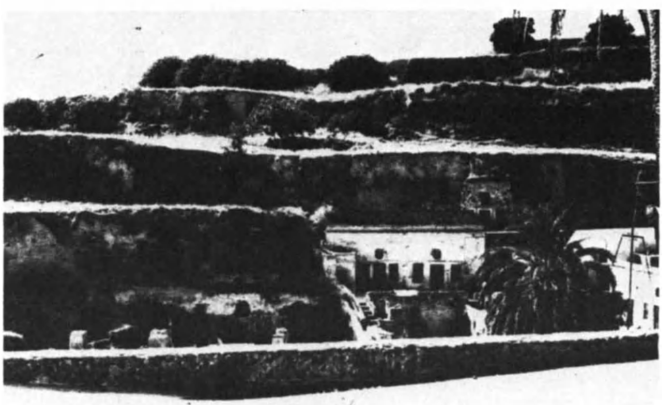

Fig. 2, 3 and 4.

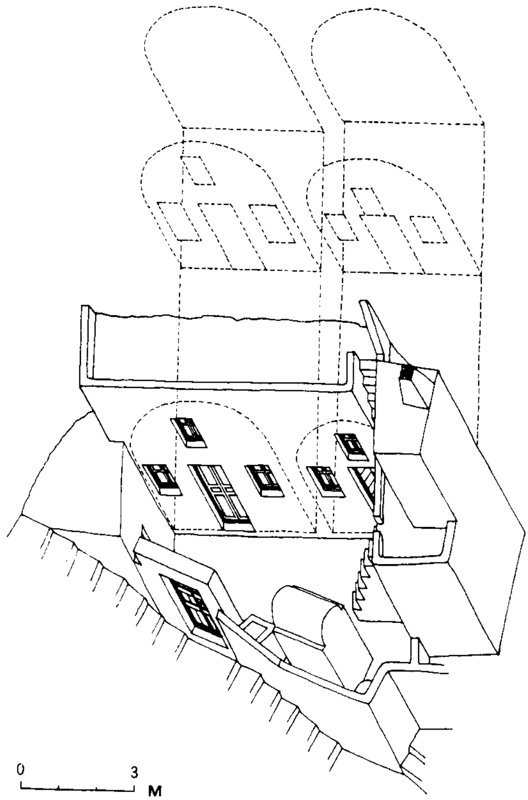

Fig. 5. Axonometric view of a typical earth-sheltered dwelling

The dwellings are covered by vaulted roofs, usually barrel vaults. Larger dwellings are composed of the same vaulted elements repeated two or more times.

The construction techniques are determined by the local materials and based on the properties of the volcanic earth of the island, which mixed with lime produces a very solid and homogeneous cement.

The origin of the vaulted roofs must be seeked in the evolution of the houses of Santorini (underground dwellings, partly underground-partly above ground, constructed). In some villages the vaulted roofs bear flat terraces, probably for agricultural activities.

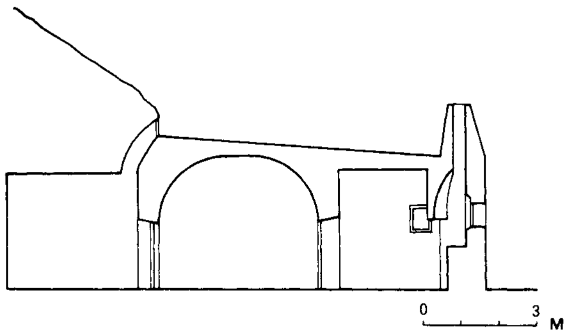

Fig. 6. Vertical section with ventilation opening

The yard acts as an external room of the house used for many family activities. Since water is very scarce, rainwater is collected in underground cisterns.

White-washing, the traditional external finishing, reflects the sun and minimizes solar gain. The openings are not big, so light colors, usually white, compensate for loss of light.

Shutters, internal or external, act as climatic controls for avoiding heat losses in winter and excess solar gain in summer. Curtains act as shading controls in summer when the doors are left open for ventilation.

The climbing vine, the favourite plant of Greeks, is not so common in Santorini, because it may cause damage to the houses excavated below and to the cisterns.

MEASUREMENTS

The thermal performance of a typical partly earth-sheltered and partly above ground dwelling is analysed here. Four houses were monitored during the past months of July and August. Internal and external air temperature and relative humidity have been measured and recorded on paper by thermo-hygrographs.

Indoor temperature was very constant, 22-22.5°C, while the outdoor temperature swing was around 11°C with maximum temperature 32°C and minimum 21°C. The humidity of the houses resulted very high, about 90%. Theodore Bent, an English traveller, who visited the island in 1883, wrote: "The houses are cool in summer and warm in winter, but they are very damp; and curiously enough, the inhabitants of Santorini suffer

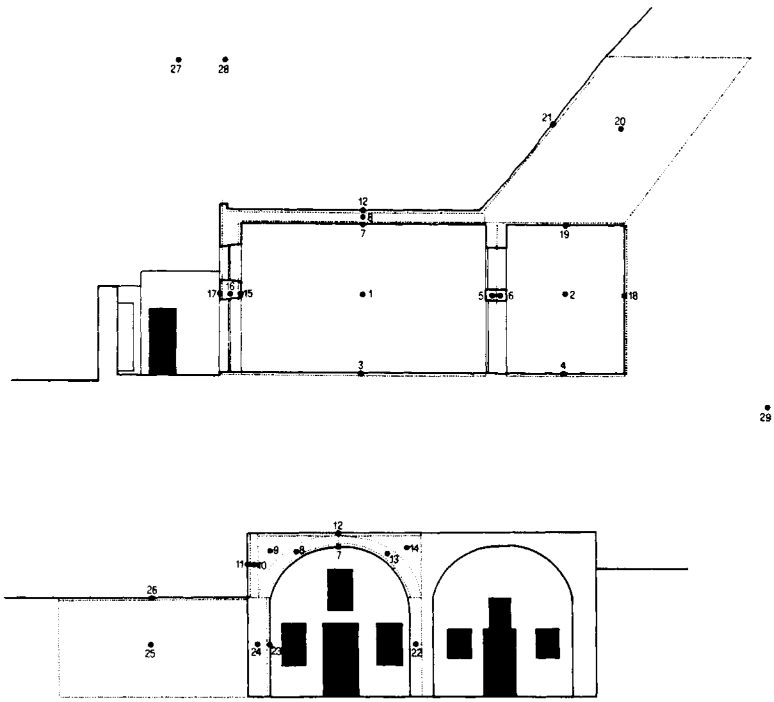

Fig. 7 and 8. Section and elevation showing position of nodes

more from damp than anything else".

NUMERICAL SIMULATION

A thermal network model has been used for simulating the behaviour of the dwelling shown in Fig. 6. Position and significance of the nodes are shown in Fig. 7 and 8., while the resulting thermal network is shown in Fig. 8. The energy balance equations, relative to all nodes, have been solved simultaneously, hour by hour, by a computer code derived from PASYDY,a passive solar systems code, developed by our group.

Due to the lack of data, solar radiation data have been derived from the well known expression $\bar{H} = H_o(a+b\ n/N)$, assuming a=0.20 and b=0.51 (see Flocas, 1979), and monthly values of n/N have been taken from the near island of Naxos (36°06' N latitude). Deep ground temperature has been taken equal to the mean annual air temperature, i.e., 17.5°C.

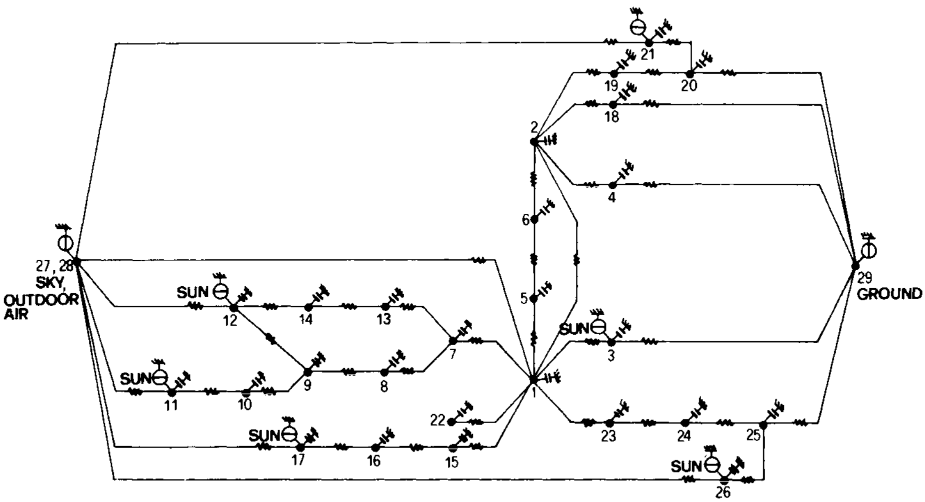

Fig. 9. Thermal network

The convective heat exchange between the two rooms is given by:

$$\frac{1}{3}\,\varrho c_p c_d A(gH\,|\Delta T|\,/T_m)^{\frac{1}{2}}$$

where A is the door area, H its height, and c_d=0.9 - 1.0. Absorption coefficients for solar radiation are as follows: facade, 0.15; roof, 0.15; room floor, 0.80; ground, 0.80. Internal heat gains are assumed equal to 300 W, but only during nocturnal hours.

MODEL VALIDATION

Firstly a summer day - July 25 - has been simulated, and resulting data have been compared with experimental ones, showing a very good agreement (see Fig. 10.). In fact, while the measured outdoor temperature fluctuates between 21 and 32°C, and indoor temperature between 22.0 and 22.5°C, simulated data, obtained using as inputs the same mean outdoor temperature and daily swing, show that the internal temperature varies between 22.1 and 22.8°C, in the first room, and between 21.8 and 22.4°C, in the second room.

Based on such a good agreement, the same model has been used to simulate a winter day, using mean values of external air temperature and temperature swing taken from climatic average data. The results are also shown in Fig. 10.: indoor temperature varies between 14.5 and

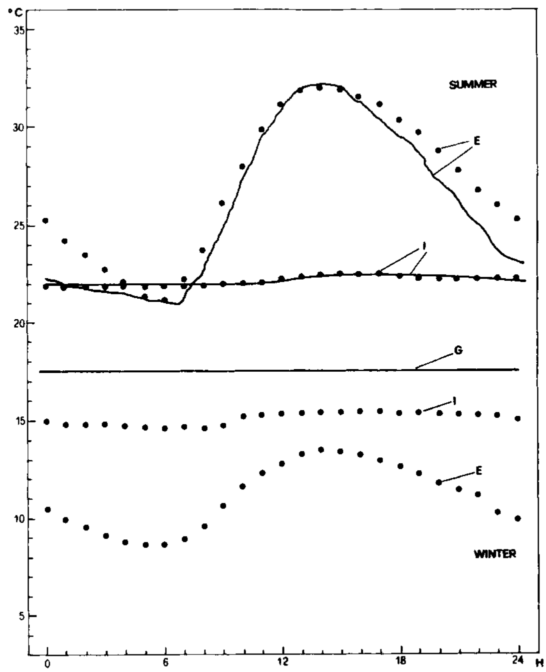

Fig. 10. Simulated (dotted lines) and measured (solid lines) temperatures: E, external, I, internal(second room); G, ground.

15.7°C, in the second room, and 14.7 to 15.5°C in the first one, with no heating, while the external temperature varies between 8.6 and 13.4°.

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REVIEW OF CLIMATIC DESIGN CONCEPTS AND DETAILS IN TRADITIONAL ARCHITECTURE IN VARIOUS CLIMATIC ZONES -SAUDI ARABIA

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ABSTRACT

Review of climatic design concepts and details in traditional architecture in various climatic zones -Saudi Arabia

KEYWORDS

climate - traditional architecture - concepts and details - Saudi Arabia

INTRODUCTION

The traditional architectural design concepts, forms and details show phenomenal climatic response in the vast desert environment of Saudi Arabia. The traditional design methodology and passive control systems are analyzed in the hot-dry, hot-humid, composite and upland climates. Various scientific climatic concepts and details such as "the Liwan, Hawi or Finna, Khalwa, Satieh, Rowshans/Mashrabiya, Badgirs" show passive cooling design methods useful in design of contemporary buildings. Comfort conditions during varying climatic conditions and diurnal changes are discussed.

In hot-humid Jeddah the houses are upto six stories high, do not have courtyards and "Rowshans" (projected decorative bay windows) for maximum ventilation. Framed structure using coral stones pilasters and "Mashrabiya" as infill provides light airy structure for hot-humid climate.

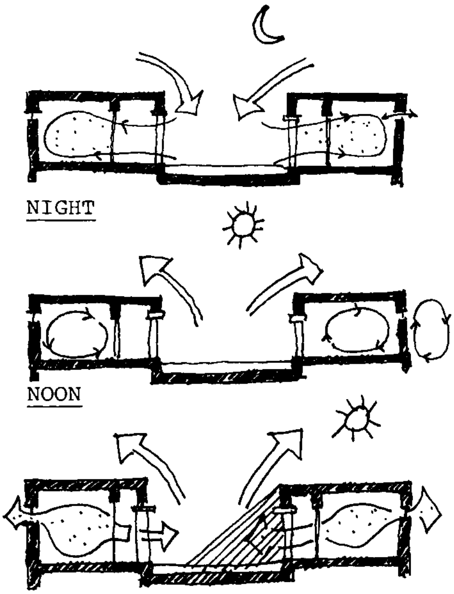
In hot-dry Riyadh the courtyard becomes the centre of focus in a thick walled house with very little external fenestration. Maximum number of doors and windows open under protection of collonaded passages on to the courtyard. The courtyard provides coolness from the cool night air which is filled in the rooms to keep them cool during the day. Thick walls provide the required time-lag. Poor air-change and lighting conditions are observed in some of these vernacular dwellings.

Similarly, entirely different forms of tall mud and stone structures tapering to the top are to be found in uplands of Asir province while conical mud-plastered thatched roof structures with African influence are observed in the hot-humid regions of Nejran. Several of such typical buildings and their climatic concepts are discussed below.

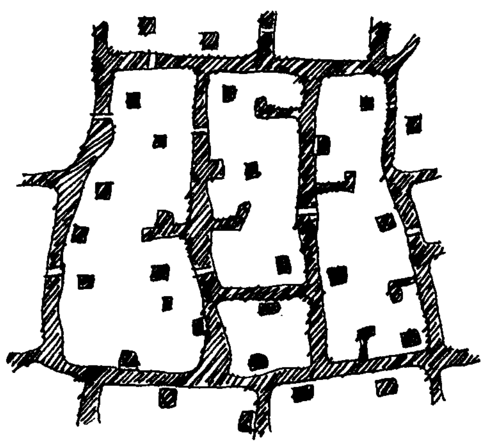
The traditional concepts of planning and urban forms show similarities found in comparable climatic regions in other parts of the world. It is recognized here that the dominance of religion created certain type of organization and the need for privacy resulted in special details in the micro-environment of the rural or semi-urban layout. The Islamic-Arab city or town also developed with centrality of mosque, the market-place ("souq"), "khans" and "hammams" surrounded by housing and other services. However, in the organization of these basic elements of the Arab towns, the climatic aspects of design seem to dominate the overall fabric of any small or large development. The Islamic-Arab town development was not based purely on religious requirements but effectively took into consideration the climatic and geographic elements of the region. Special details such as narrow dead end streets with irregular layout provided protection against dust storms. Very narrow streets with hardly any passage from outside allowed the dust storms to pass over a development rather than through it. Narrow streets and overpasses also provided protection against the sun in hot-dry areas. In Riyadh or Qatif one finds mud-houses built close together sharing two or even three walls in large continuous lumps. Thus, most of the houses remain protected along the narrow streets from the sun. The sun penetration was only limited to courtyards during the afternoons. On the other hand, in Jeddah the houses are set far apart, free-standing where possible and taller rather than of low spread with more regular and wider streets allowing the air-passage for through ventilation in the hot-humid region. In uplands of Asir the houses are set on the sunny side of the hilly terrain to gain maximum insolation, set close to each other, and built of thick stone or mud wall to retain sun's energy during colder periods. These characteristics are comparable to hill towns of Italy or the first stone dwellings built by American Indians at Mesa-Verde. Some of these climatic characteristics of individual buildings and urban layouts are discussed in this paper.

In recent times concern has been expressed by various individuals and government agencies not only about learning from the past experiences and achievements of man as builder of his own environment but also about preservation and restoration of historic/traditional architecture from which there is a lot to learn. The traditional architecture with its climatic and cultural/communal solution also poses questions of how they could be utilized or transplanted in the new urban context.

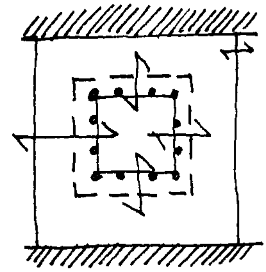
This paper is a brief review of a more detailed field and theoretical survey carried out by the author in his efforts to understand the role of climate in formation of the traditional environment in Saudi Arabia. The examples are only representative of the main aspects of the climatic response in traditional architecture in the four dominant climatic regions, 1. Hot Dry, 2. Hot Humid, 3. Composite, 4. Upland. The nearby areas in the Eastern Province as well as the far away places in the Southern Provinces are described from author's personal experiences. Most of the climatic design elements are discussed with illustrations. The presentation of this paper will be



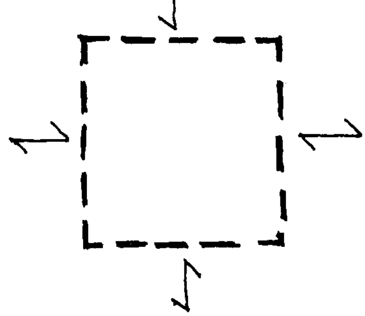
1. Courtyard system - 3 cycles



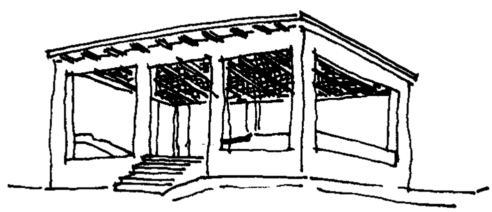
3. Narrow winding streets and courtyards of arid settlements



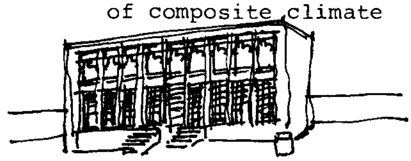
2a. Introvert traditional house



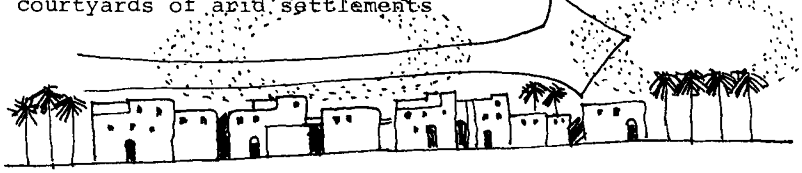
2b. Extrovert modern villa



4a,b. Pavilion like structures of composite climate



4b.



5. Narrow streets and courtyards do not permit the sand storms to penetrate

accompanied with colour slides (from which some of the diagrams are prepared) not included in the publication of this paper.

I. HOT DRY (Examples: Riyadh, Gassim, Mecca, Medina).

I. a. CLIMATE (Riyadh, Location : N 23° 34' E 46° 43')

Average Daily Maximum - May to September approximately 40°C reaching maximum average highest of 43°C in July. Average Daily Minimum - November to January approximately 10°C reaching lowest minimum 7°C in January. Average Relative Humidity - Average Relative Humidity around 40% to 50% during November to February reaching highest average to 50% in December and January. Thus, indicating higher humidity during colder and rainfall periods. Otherwise low average humidity of approximately 15% to 16% during June to August indicating low humidity during hot dry period. Rainfall - Annual average rainfall of 50 mms falling mostly during December to May leaving June to November completely hot-dry. Highest average rain fall of approximately 21 mms each during March and April.

(Climatological Data Summary period 1966 - 1975).

I. b. TRADITIONAL CLIMATIC DESIGN RESPONSE

The traditional (adobe and stone rubble) architecture of the hot dry region is similar to other comparable climatic regions such as adobe architecture of Mexico, Northern Nigeria, Rajasthan (India) and other such areas throughout the world. In the central provinces and elsewhere in the hot-dry regions of Saudi Arabia courtyard houses with thick external mud and stone rubble walls provide appropriate environmental solution. The external environment in the hot-dry desert is harsh and thus internal private life around the courtyard is emphasized.

COURTYARD

Courtyard houses create internal micro-climatic conditions providing comfort, security, privacy and protection from glare and sand storms. The external exposure is minimized with as many as three party walls in which group of houses are lumped together. The external openings are minimized avoiding direct solar gain while most of the windows and doors open on to the courtyard. Diagramatically the house functions as shown in figure (1) during various periods of the day as explained in a series of diagrams. Courtyard acts as light well as well as ventilation shaft bringing in cooler air at night. Temperature in the courtyard also drops due to irradiation to the clear desert sky. The diurnal changes in the central desert region amount to 10-15°C during summer months. The courtyard house takes advantage of this diurnal range by allowing cool air to descend into the courtyard which in turn fills up the room all around. The sun rays reach the floor of the courtyard during the high noon when the heated air rises and the convection currents set up by this action keeps the house cool until late afternoon. In larger houses several courtyards of different sizes were integrated to set up air movement in different rooms to maintain comfort conditions. The thick walls with very small external openings possess timelag long enough (over 8-10 hours) to avoid penetration of heat during day from direct or reflected radiation. During colder periods the walls maintain temperature balance by accumulated heat during the day which is reradiated slowly during the night.

The courtyard houses with small external openings (that can be easily closed during sand storms) are also ideal for the required privacy because of minimal exposure towards the outside streets. Several household activities by the women take place in the courtyard. The large internal openings (towards the courtyard) are further protected by collonades either on two, three or all four sides. These collonades act as a corridor and as a place to work or sit under the cover adjacent to the rooms such as a kitchen or family areas.

The groups of houses are lumped together and have two or three shared walls reducing external exposure and shading each other. Streets are narrow, winding and dead ends streets with overpasses and underpasses (similar to composite climate layout in Qatif) further provide shade and cast protective shadows on adjacent buildings. Penetration of sun except during highnoon is minimized. The streets are laid out in form of zigzags and are so narrow that the sandstorms blow over and across the development without much of it entering the streets, buildings or courtyards. In richer houses a water fountain may further provide evaporative cooling and increase the level of humidity to the desired comfort conditions. Where water is available individuals may sprinkle or throw water on the courtyard floor which evaporates and cools the air, sets up air convection currents and adds to the humidity.

II. <u>HOT HUMID</u> (Example : Jeddah, Gizan, Yanbo).

II. a. <u>CLIMATE</u> (jeddah, Location : N 21 29' E 39 12')

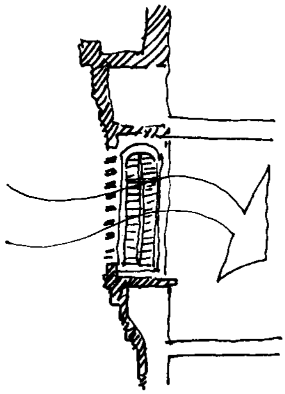
<u>Average Daily Maximum</u> - Hot humid climate with maximum temperature rising to 42°C average during summer months of May, June, July, August.

<u>Average Daily Minimum</u> - Temperature is relatively mild during winter months of December and January - average 15°C. <u>Rainfall</u> - Irregular rainfall of 12 cms average during October and April. <u>Average Relative Humidity</u> - High humidity throughout the year of 75% to 80%.

II. b. <u>TRADITIONAL CLIMATIC DESIGN RESPONSE</u>

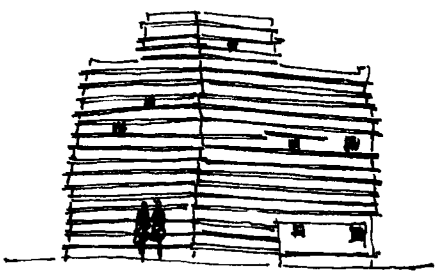
The traditional or vernacular architecture responds to the hot-humid climate of the region basically by building 1. Tall airy structures allowing maximum through ventilation, 2. "Rowshans/Mashrabiya "(decorative projected wooden bay windows with grill work (Fig. 11-13), 3. Use of thick coral stone walls tapering towards upper floors as frame structure, 4. Wood framed roof and floor construction, 5. Less thickly laid out urban plan, 6. Wider and more regular streets, 7. Placing sleeping spaces at the top for advantageous ventilation.

Jeddah is selected for study since it has been an important port on the West coast. It was involved in extensive trading and thus building materials as well as technologies of that period were imported here first from the Far East, Southern Europe and North African countries. The buildings in Jeddah built of several stories represent higher technological achievements of a trading and business community as compared with those of the Eastern or Asir provinces farming communities. It was possible to import material such as timber from Indonesia, Burma, Zanzibar, India and several other countries along which came superior craftsmanship and building skills. The architecture in Jeddah influenced the building art and technology of the nearby areas such as Mecca and Medina. Courtyard a definite feature of the hot dry region is non-existant in Jeddah except in some very

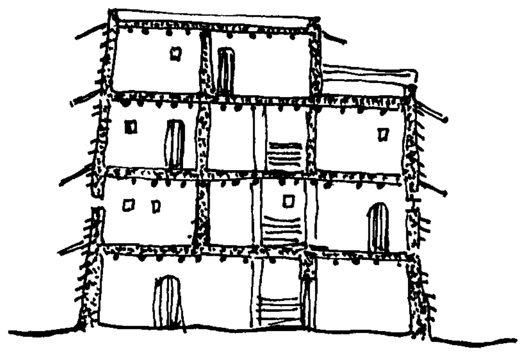


8a."Rowshans"- projected
bay windows of Jeddah

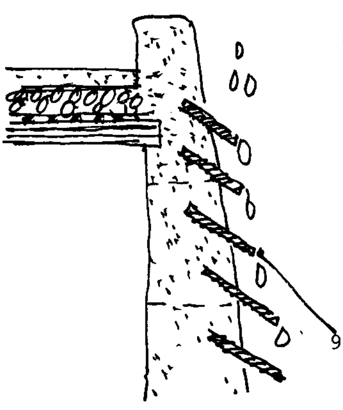
8b.Tall airy structures of Jeddah
-Humid climate



9a.Mud and slate house in
Asir- Temperate climate



9b.Section through mud house
in Asir



10. Mud and thatch roof houses of south-
western humid coast

9c.Slate inserted between the layers of mud
protects wall surfaces from erosion by rain

large houses to achieve through ventilation and to create large interior open space. The buildings were built taller thus allowing wind penetration in thickly populated areas and taking advantage of off-shore and on-shore breeze during the diurnal cycle.

Rowshans - The "Rowshans" form a dominant external element of design in multi-storey houses of Jeddah providing several functions; most important of which is through ventilation. The "Rowshans" in some respect resemble and act as projected bay windows. Besides ventilation they provide required privacy for the women or family (who can look out without being seen by the strangers on the road). The "Rowshan" is basically a projected bay window which is an added element to the openings in the building often continuing through several floors. It is wood framed and enclosed with decorative screens which permit free flow of air and do not collect heat as compared with a glazed bay window (which may produce a green-house) effect when located on the sunny side). Small clay jars filled with water placed on inside sill provide evaporative cooling (the wood itself acts as a filter). The perforated decorative screen also acts as a filter for dust. The "Rowshan" may have internal wooden shutters or louvers that can be closed during the sand storms. In recent times the incorporation of highly decorative "Rowshans" has become uneconomical and impractical (because of unavailability of sufficient number of craftsmen) but "Rowshans" are being used once again in some buildings affectively.

II. c. NEJRAN, AL-DERB, ASGAIG (SOUTHERN PROVINCES)

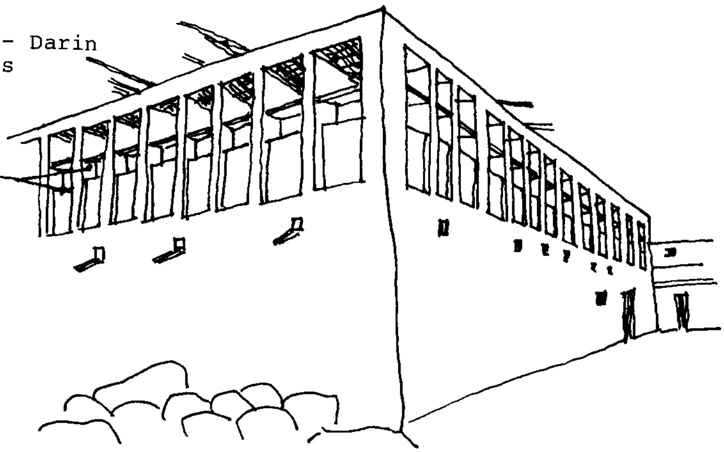
It was uniquely different experience to visit hot humid areas of Southern provinces. Traditional buildings of conical shape similar to those found in hot-humid regions of Africa are built from dried river-reeds and mud plastered walls internally. Roofs are covered with dried thatch. The African influence in use of construction and architectural forms is evident because of large number of people of Ethiopian, Southern Sudanese and other African origins live here. The construction of light conical shaped building using mud plaster and dried reeds prevents accumulation of heat. The hut when entered provided simulated comfort conditions of sitting in shade under a tree. The mud and reed construction breaths very well and thus air change was continuous without any openings other than the door. The apex of the conical hut was lightly plastered with mud thus allowing hot-air and smoke to escape through the "semi-transparent" roof construction. Each mud hut or groups of two to three formed an average household with an adjacent yard enclosed by split bamboos and dried reed low walls. Some of the activities related to farming and outdoor sleeping took place in this yard. The unorganized nature of the villages visited may be attributed to the non-permanence of such structures of limited life spans.

III. COMPOSITE (Examples : Qatif, Dhahran, Al-Khobar)

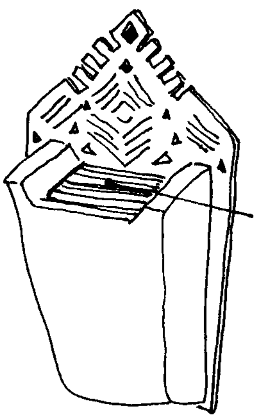
III.a. CLIMATE (Dhahran, Location : N 26° 19' E 50° 08')

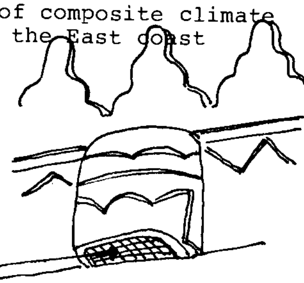
Average Daily Maximum - High temperature range of 35°C to 42°C during May to October. June to September approximately 40°C and above with highest average of 40°C in July and August; cooling off towards November (29°C to 31°C during November to April). An average temperature of about 22°C during the pleasant months of December, January and February. Average Daily Minimum - Highest minimum of 29°C during

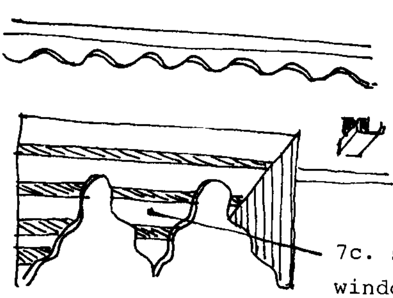
6a.Tarut island - Darin village houses



6b."Badgirs" of composite climate in a house on the East coast







7a,b,c. Vents in the hot-dry and composite climate

January and February. Average Daily Minimum - Highest minimum of 29°C during January to February and the lowest of around 12.5°C average during December to February. Average Relative Humidity - Relative humidity all throughout the year about 41%, the lowest of 41% average in June. Low humidity during hot-periods and highest of 67% to 68% during December and January (during the rainfall period). Rainfall - Annual average of 79 mms. Most of the rain falling in flash rains during November to April. Half of the total rainfall during December and January (total average of 34 mms during the two months).
(Climatological Data Summary Period 1950-76).

III.b. TRADITIONAL CLIMATIC DESIGN RESPONSE

Composite climate represents greater challenge for the design of proper building environment since it fluctuates between hot-dry and hot-humid conditions. In Dhahran it is represented by the harshness of July and August temperature of 42°C average (with lower humidity) and pleasant months of December and January when the temperature averages 22°C (with increased humidity). The design response in such a climate cannot be unidirectional. The architecture arcund Qatif which is considered traditionally representative of the area seem to have responded to some basic climatic and cultural needs as well as the technology available to the farming community of the oasis.

The mud and stone rubble houses use: 1. Courtyards, 2. Thick rubble walls for increased time-lag, 3. "Badgirs", 4. "Satieh" (terrace for sleeping), 5. Party walls (houses are lumped together), 6. Narrow winding streets, 7. Overpasses and underpasses, 8. Ventilation grills in windows and walls (decorative perforated plaster panels), 9. Collonaded passage around courtyards, 10. Largest number of openings towards courtyard, 11. Wood framed mud roof and floor construction, 12. Small external windows protected by wooden shutters and tinted fan-lights plus "Rowshan" type windows on lower floors, 13. Some pavilion type rooms for sleeping on roof, 14. Activity cycle in use of spaces according to varying climatic conditions.

STREET LAYOUT (URBAN FORM) FOR CLIMATIC PROTECTION

Most of the hot-dry or arid traditional development have narrow winding street layouts. In Saudi Arabia, hotdry and composite climatic regions have climatically suitable urban or rural group forms which are closely knit together with narrow winding streets. The streets are partially or wholly shaded throughout the day except for the penetration of sun during the high noon. The underpasses and overpasses also help pedestrians move under shaded comfort conditions. The streets have public spaces called "Barahas" where children play and some of the community activities take place here. The streets are shaped differently in different places. Some of the streets are narrow and curved, some are narrow and bent while the others may be dead end streets. All of which are carefully laid out to discourage blowing of sand, provide shade and privacy.

IV. UPLAND (Examples: Abha, Khamis Mushait, Ahad Rafidah, Taif)

IV.a.1. CLIMATE - (Abha, Location : N 18°50' E 42°58', Altitude 2000 m above sea level - average height). Average Daily Maximum - Highest average temperature of 21°C in July. Average Daily Minimum - Moderate temperature of 10°C to 12°C during January. Diurnal changes are considerable averaging 10°C to 12° during September. Rainfall -

Considerable rainfall of 30 cms per year, most of which falls during the month of August flooding the "Wadis". Its situation near the escarpment creates continuing cloud cover specially during the rainy season. Relative Humidity - Throughout the year Relative Humidity is moderate but it rains a little most of the year around with maximum rainfall during August. Highest cf 80% around rainfall period with low of about 40% around November to February.

IV.a.2. CLIMATE - (Khamis Mushait, Location : N 18° 81' E 42° 43', Altitude 2000 m above sea level, average height). Average Daily Maximum - Maximum average temperature of 33°C during summer. Average Daily Minimum - Average daily minimum of moderate 10°C to 15°C dropping to lowest average of 4°C during cold periods. An average of 15°C to 20°C during the sunny days. Rainfall - Certain amount of rainfall throughout the year but most of the total rainfall of 30 cms per year falls in the month of August flooding the lower "Wadis". Relative Humidity - Highest average of 80% during some days in April to June and the lowest of 25% during October to January. Continuing cloud cover specially during the rainy season.

IV.b. TRADITIONAL CLIMATIC DESIGN RESPONSE

It was a joy to visit simple but magnificent architecture of the Asir province farming communities which is either built with mud or rubble stone found locally and wood framed floors and roofing (wood used is partly found locally and partly imported). Historically the differences between the different tribes in the region required the design of housing, granaries, fortresses, "Qasaba" (watch towers) and other public buildings so that they were defensible during the tribal wars. The "Qasaba" for example were located in the advantageous positions so that the movement of grain or enemies could be watched carefully. The houses which form the main area of observation for this study could be separated in two distinct categories: 1. Mud Houses, 2. Stone (rubble) houses. The combination of the mud and stone in which the "stone apron" is used at the lower level to form a strong base on which the mud house is erected. They are magnificently tall three to five storey structure tapering upwards with small square windows. The windows and the surfaces around it are painted internally as well as externally in bright bold patterns of colors. The most highly developed of these houses are to be found in Wadi Tindaha where the vernacular character is preserved to a great extent in traditional small farming villages laid out in a string along the valley ("Wadi"). The farming community of approximately 10,000 lives in close relationship with fertile land terraced to suit natural contours of the land where houses and other buildings are pleasantly integrated to become one with the natural environment. In this scenic area one discovers the preserved values of traditional architecture developed over a period of few thousand years and handed over from one generation to another, from father to son. The building crafts were similarly developed over a long period of time with the members of community participating in building each other's houses (sometime in exchange of farm products). The craft and technology of building was handed down from father to son which is rapidly diminishing with young men finding alternative employment in the nearby cities.

Some of the villages are built against the southern slope thus each house accumulating heat in the thick stone or mud walls which is essential during the colder periods at night. (Some of these hill towns remind one of the hill towns of Italy or Spain.) The defence and security besides the climate is one of the main criteria of design and thus the streets are narrow with possibility of blocking them with heavy wooden gates at different points. Open trench for rainwater and sometimes sewer runs in the back of the houses, which is being changed with the introduction of new infrastructure.Narrow winding streets specially in the back of the houses also formed a kind of communication channel between the residents. The markets in most villages (or one weekly market among several villages) was mostly located outside the village once again because of security reasons. Some of these villages (because of the defence as one of the main criteria for design) resemble also the border towns between Pakistan and Afghanistan. Some of the public buildings such as schools visited by us had large courtyard used for outdoor teaching and physical training. The outdoor activities are emphasized here as permitted by the climate. It is common to find women working in the farms, sewing or doing other house chores in the backyards. The climate once again and the farming need may have generated this change in life style distinct from the indoor life of hot dry, hot humid and composite climatic regions of the vast desert Kingdom. Unlike the other areas of Saudi Arabia the mosques among these farming villages are located on the fringes of the development rather than centrally.

MUD AND STONE HOUSES - Mud and stone (rubble) houses form the two main categories of traditional architecture in this area. Some areas have dominantly mud houses mainly in the "Wadis" as compared with houses on the hilly terrain with availability of crumbling rocks in abundance from which stone houses are built. The large houses among these are called "Qas" or "Hisa" which means fort or castle in Arabic and they portray such physical architectural images. While the houses in the "Wadi" are independently laid out near the farm land. The houses in the hilly terrain are grouped together on the slope (the buildings in most cases are independent of each other and do not share party walls as found in lumps of houses in Hot Dry or Composite climate) presenting once again a fortress like character on the sunny side of the slope when possible. The traditional architecture in Asir is among one of the finest examples in the world of "Architecture without Architects". The almost complete use of local materials (except for some timber for beams and framing which was imported) itself must be emphasized as a conservator of energy and environment. The sensitivity and requirements of satisfying climatic as well as security and culture in design are unmatched anywhere else in the Kingdom (except may be in Jeddah).

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"EL RAWASHIN" OF JEDDAH
SAUDI ARABIA

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ABSTRACT

El Rawashin as a native solution of an opening in the vernacular architecture of Jeddah, played an important socio-cultural role in the traditional buildings. They give Jeddah's architecture its own distinctive character, but as an opening treatment, El Rushaan (singular) was also designed to play an important role in controlling the oppressive climate of Jeddah.

KEYWORDS

Hot humid; cross ventilation; glare; comfort; socialising, El Rawashin (plural), El Rushaan (singular).

INTRODUCTION

In such a hot climate as Jeddah's the compact urban fabric caused by the grouping of Jeddah's tower houses, resulted in narrow, shaded pathways and small open spaces between buildings (Fig. 1). This was a step forward for comfort attainment. A further step was to provide continuous air movement to overcome high humidity levels. The spread fabric that resulted (Fig. 2) had most of the pathways going with the wind movement from north to south. As a result of this the needed protection from the very intense solar radiation and high humidity levels was initially achieved in the outdoor spaces.

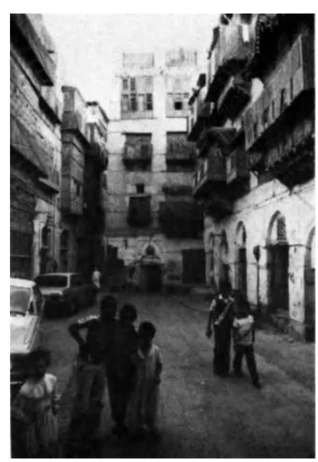


Fig. 1

Fig. 2. Jeddah's Historic Area

CLIMATE OF JEDDAH

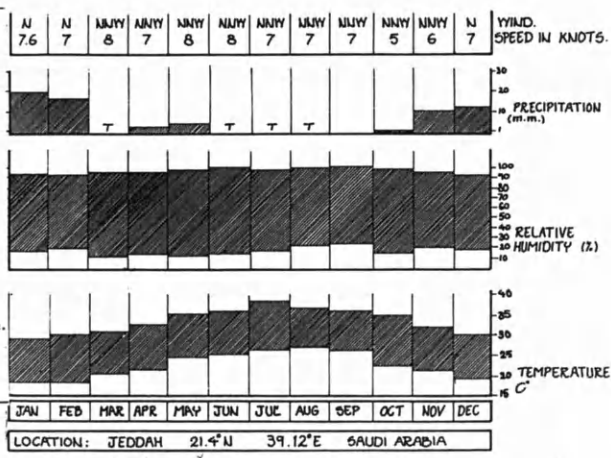
3 CLIMATIC ZONES:

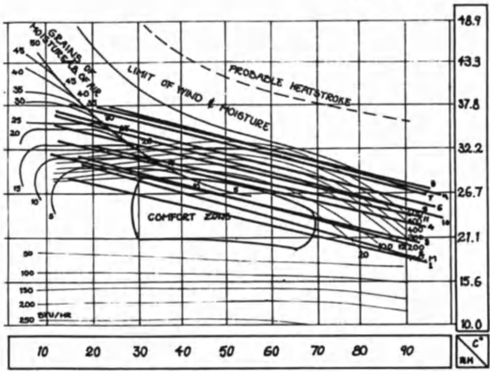
1. 4 MONTHS: 1,2,3,12
   DAYS Warm 29.7°C Arid 15.3% R.H.
   NIGHTS Cool 19.3°C Humid 92% R.H.

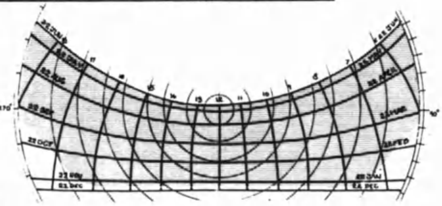
2. 3 MONTHS: 4,5,11
   DAYS Hot 33.9°C Arid 11.3% R.H.
   NIGHTS Temperate 22.7°C Humid 93.6% R.H.

3. 5 MONTHS: 6,7,8,9,10
   DAYS Hot 36.5°C Arid 17.28% R.H.
   NIGHTS Warm 25.6°C Humid 95% R.H.

- o Small diurnal variation in temperature.
- o Very big diurnal variation in relative humidity, due to very high radiation & surface reflection levels during daytime & a drop in temperature during night time.
- o Wind direction is mainly from north to north-west with average speed of 7.05 Knots.







Over heated period, Jeddah.
Source: Metrological Department, Western Region, Saudi Arabia.
10 Years Historical data 1970-1979

El Rushaan[1]: El Rushaan was the answer for the protection from the high solar intensites, glare and was the source of the needed ventilation within the interior spaces. El Rushaan was more than an opening. It was an extension of the inner space to the exterior, where the residents used the area as a sitting and sleeping space, where cross ventilation was maximum within the Rushaan area because of the big openings that helped the air penetration into the house. This was easily distributed into different spaces within the house by the clearstories over the doors and cabinets that were built into the walls which divided the space within the house (Fig. 3 & 4).

Fig. 3. Typical Rushaan with the wooden screen surrounding the openings for privacy.

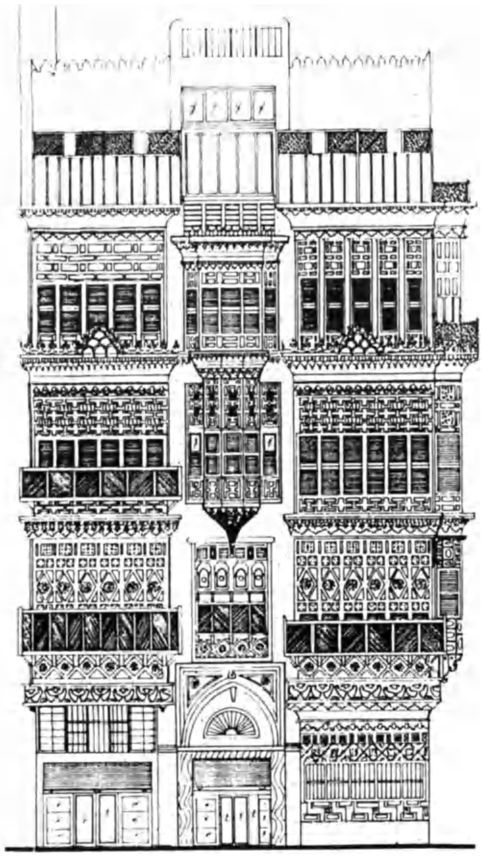
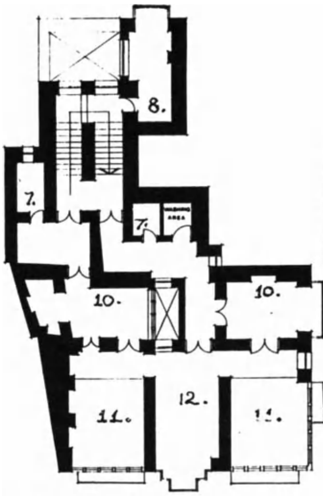


Fig. 5. Nour Wali House front elevation facing 320° Az from north.

Fig. 4. Interior view of a typical Rushaan. Note the use of space within the Rushaan.

1. A word of Indian origin; "Rushaandan" means the source of light or the clerestory windows near the ceiling; "Rushaandan" is derived from "Roshani" meaning "light" and "Dan" meaning "giver".



THIRD FLOOR PLAN

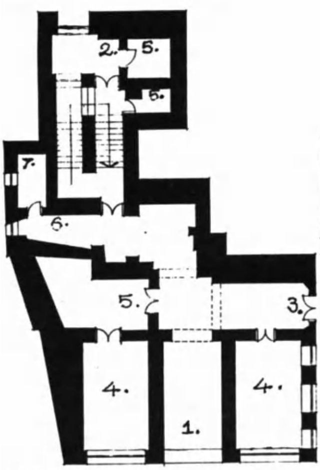
Fig. 9

FOURTH FLOOR PLAN

Fig. 10

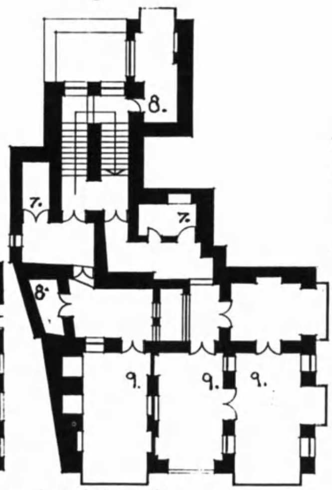
FIFTH FLOOR PLAN

Fig. 11



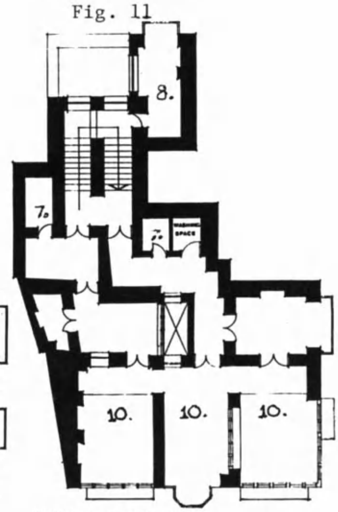
GROUND FLOOR PLAN

Fig. 6



FIRST FLOOR PLAN

Fig. 7



SECOND FLOOR PLAN

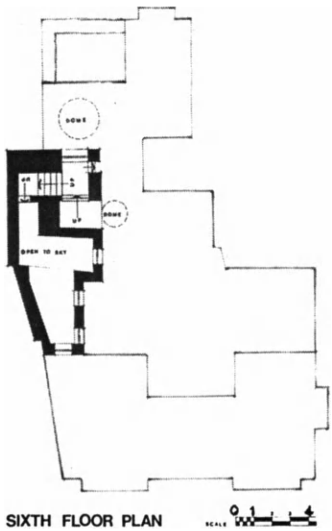
Fig. 8

Legend

1. Main Entrance
2. Back Entrance
3. Women Entrance
4. Dewan (visitors room)
5. Khazannah
6. Wudu Place
7. W.C.
8. Kitchen
9. Family living room
10. Majlis
11. Mabit
12. Majlis or Mabit open to sky

Nour Wali House[2]: In all houses; staircases, kitchens, bathrooms and W.C.s are located in the opposite direction of the wind, & the rest of the rooms (which are for multi-use) are facing the wind with a facade of Rawashin.

2. Nour Wali House street facade is 320^{o}Az.



SIXTH FLOOR PLAN

Fig. 12

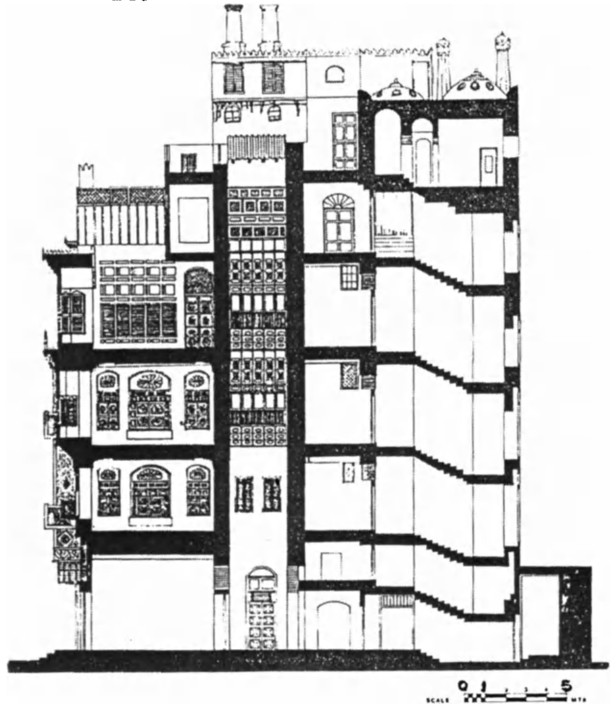


Fig. 13. Nour Wali House, Section.

El Rushaan was built out of teak wood panels were restricted to 30 cm in width, because of the boards from which they were carved. The usual dimensions of the single Rushaan were 3 m. in height, 2.3 m. in width, and 1.1 m.-1.9 m. in depth, to allow sufficient space for a sleeping adult. Some of the Rawashin were built with a depth of 1.9 m. to accommodate a man & his wife. The Rushaan had either a screen that surrounded the wide openings of the Rushaan, or movable wooden venetian blinds which played a major role in conserving the level of privacy needed within the interior space. This privacy requirement placed severe design demands which hampered bio-climatic requirements. The solution was adequately met by the design of the Rushaan.

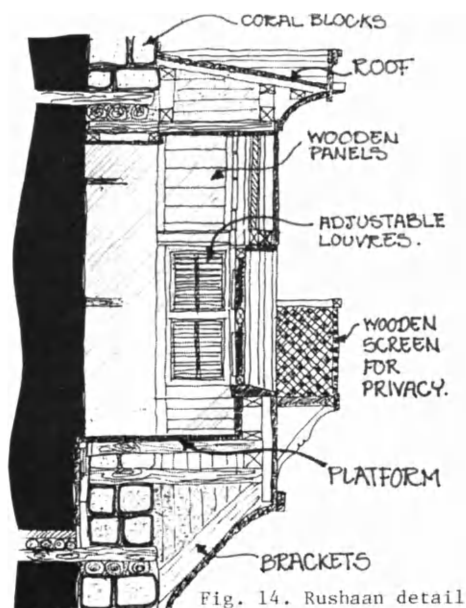


Fig. 14. Rushaan detail.

The woodwork of the screen belt is made up of wooden mesh, that is built up of semi-rounded strips of wood 1 cm in width, with spaces of 1 sq.cm. in between. The rounding of the wood strips help to reduce the glare where as the light distribution on the rounded parts is much smoother than strips with sharp corners. Note that the screen composed of 1 cm strips of wood and 1 sq.cm. voids gives 50% of the total opening (1.92 sqm) free from breeze obstructions, glare and solar intensity. The actual working area of the opening in the Rushaan is much more than 1.92 sqm. because the screen was always placed away from the opening and at 20 cm less in height. This gives more area for ventilation needs than modern windows offer (1.2 sqm). Added to this the glare and solar radiation factors and the merits of El Rushaan are obvious.

Fig.15. Rushaan on the ground floor did not have screens around them as this floor is to be used by men.

Fig.16.
.Typical simple window
.Cantilevering Rushaan
.& A Mabit on the top

Fig.17. Rawashin were either connected vertically or horizontally for decorative purposes

The Rawashin in concept, were the same. The difference lies only in the taste and ability of the client and the craftsman. But within the same concept of design the role of the Rushaan varied according to the size of it. It developed from: 1) Simple windows having the screen built around its openings, to 2) the cantilevering Rushaan as an extension of the interior spaces with all the different shapes and decorations, to 3) a full room size on the top of the building named "El Mabit", where the residents slept during hot days,as air velocity increases it is cooler with height and freedom from neighbouring structures.

Today, there are some attempts to revive the Rawashin as an architectural element, but unfortunately there is very little understanding of the Rushaan. Most of the applications are just ornamental, placed on existing buildings with relatively small areas of windows for ventilation. Add to this the employment of new Rawashin (actually the Mashrabiah concept) screens on the outer surface of the elevations, where it loses its role as an extension of the interior space, beside reducing the area of the openings, i.e. already too small for sufficient ventilation.

Fig. 18. Old Nasif House in the background & new Rushaan work in the foreground used as an office. Note the glass panels behind the new Rushaan

Fig. 19. Note the large openings after the removal of the screen.

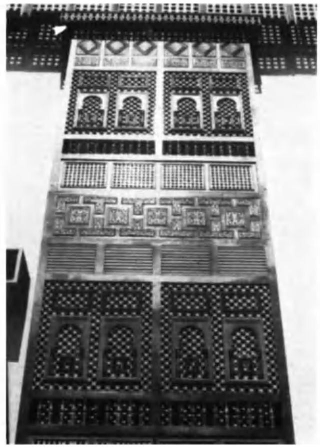


Fig. 20. Ornamental application of a new Rushaan on an existing building.

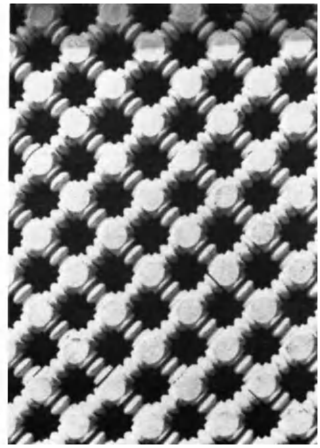


Fig. 21. The relatively wide voids in the screen destroyed the demand for privacy.

Unfortunately, new Rawashin of today are employed in a cosmetic manner where the only benefit is for shading. The earlier benefits of glare and radiation control, ventilation enhancement & privacy, fundamental to Muslim social behaviour are now lost.

Fig. 22. The Jeddah Municipal Building. It is very similar to the old extensive use of Rawashin, but is fake ornamental work.

Rushaan & Mashrabiah:

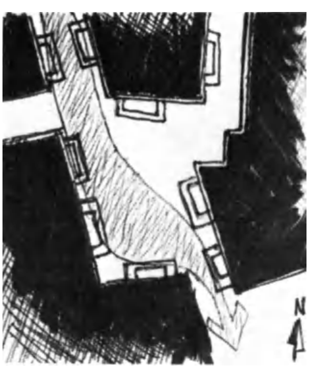


Fig. 23. Air penetration through the Rushaan which is used as a functioning space.

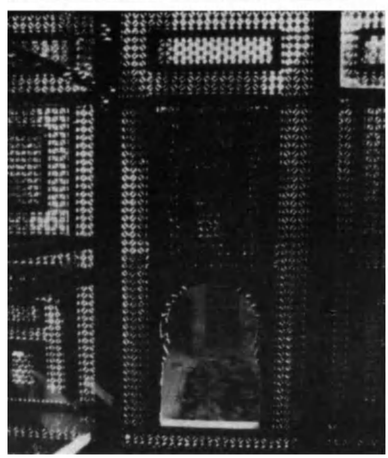


Fig.24. Mashrabiah.El Sehami House,Cairo, Egypt. Looking into the courtyard. Note the use of glass behind the screen work.

The relationship between the Mashrabiah and Rushaan is not understood and the following table attempts to identify similarities and differences.

TABLE 1 Rushaan and Mashrabiah

Rushaan	Mashrabiah
o Mainly for enhancing cross ventilation through its space and the interior of the house	o Allows convective cooling by penetrating cool air from the courtyards into the interior space,where the warm air is ventilated outward either through other Mashrabiahs opening into the walkways or through El Shokshekah on the top of the room
o Constructed from wood which is of high conductive values.	o Have less conductive resistance as the amount of wood used is much less.
o Light intensity is mainly controlled by the very narrow outdoor spaces but glare is reduced by the screen work.	o Light is very well controlled by the rounding of the constructive elements & the degredation of the opening sizes.
o The extensive use of wood may lead to the reduction of the humidity levels as the wood fabric will absorb large amounts of moisture from the air.	o Mainly used in hot arid regions.
o Space within the two is used for sitting or sleeping.	
o Both provide an adequate level of privacy demanded by Muslim's social behaviour.	

CONCLUSION

In several of the overheated areas of the world such as Turkey, Iraq, Syria, Egypt, Pakistan, Afganistan, India etc., screening devices have been historically employed for climate control and privacy. The origins are lost in history and the recent use evidences a mixture of cultural influences modified to local needs. This paper has attempted to define the Rushaan of the Hejaz of Saudi Arabia, comparing it with its well known sister the Mashrabiah.

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Fig.25 & 26. El Rawashin of Jeddah

LESSONS TO BE LEARNED FROM A COMPARATIVE EVALUATION OF THE TRADITIONAL TOWNS OF RIYADH & JEDDAH IN SAUDI ARABIA.

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ABSTRACT

A detailed critical discussion of traditional patterns of architecture and urban design in Jeddah and Riyadh will be discussed in relation to the modern international style communities which have emerged in both cities over the last decade. An examination of some consequences of current trends in both cities, for urban development along modern western lines follows. Recommendations for future design and planning from this comparative study of traditional and modern development are given for Riyadh and Jeddah.

KEY WORDS

Islam, tradition, modern, climate, shade, airflow, courtyard, stair-well, P.U.D.

INTRODUCTION

Interaction between man and his environment marks the beginning of civilization. Relevance of the ancient world for contemporary urban designers is that it established distinguishable patterns for human settlements. These patterns are founded on three bases.

1. Climate as a determing factor in key design elements such as openings, walls, roofs, yards/courtyards and the choice of materials for individual buildings. Also in the arrangement of clusters of buildings for ammelioration to a desired micro-climate in both interior and exterior spaces.
2. The socio-cultural base which in our context is rooted in Islam, manifesting itself in the built environment through traditions and values of community and individual.
3. Resources, in which technology and economy play a major role.

Riyadh and Jeddah have experienced intensive development arising from two decades of economic expansion. There is growing evidence of problems associated with recent international style sections of both cities alien to local conditions. This awareness has led to renewed interest in traditional towns with particular reference to the way in which their design and construction harmonise with climatic and social needs.

HISTORICAL BACKGROUND

Riyadh; which means 'gardens' resulted from the merging of several villages along the green belt of Wadi Hanifa (Hanifa Valley). Its location at the crossroads of old trade routes afforded it the chance of exposure to 'outside' elements, but being in the interior, a certain degree of privacy was also maintained. With the unification of the land under King Abdulaziz, Riyadh was chosen as the capital city. Recent revenue from oil in the Eastern Region transformed the Kingdom's economy. Modern communications, well paved roads, airports and a comprehensive system of highways link Riyadh to all parts of Saudi Arabia. Within a quarter century, Riyadh has changed from a mud walled city to a cosmopolitan capital.

Jeddah; on the Red Sea, takes its name from the belief that Eve's tomb is located just outside its old walls. Settlements are believed to be 2500 yrs old. With the advent of Islam the importance of Jeddah was clearly marked. It is the first port of call via air or sea for annual pilgrimage each year, to perform the Hajj in Makkah. Increase in oil prices has had a great impact on the development of the city during the past ten years, significantly adding to Jeddah's importance as a trading, banking, commercial, administrative, and communications centre.

CLIMATE CHARACTERISTICS

The desert environment results in hot dry air, arid ground and minimal cloud cover, resulting in very little relief from solar radiation. However clear skies facilitate rapid re-radiation of heat and a fall in night temperatures in Riyadh. While in Jeddah temperatures are high and the diurnal humidity range is extreme. The cooling effects of on-shore winds maintains a comfortable range for much of the day. (Fig. 1a, 1b, Tab 1).

COMMON SOCIAL & TRADITIONAL CHARACTERISTICS

The Arabian Peninsula is the birth place and cradle of Islam. Islam means submission to the will of God (Allah)and to the faith in God. The fundamental principle of Islam is the belief that there is only one God and that Mohammad is His messenger to mankind. The Quran (revelation to the Prophet (P.U.H.) and Hadith (the sayings and practices of the Prophet) together constitute a practical guide for daily living. Behaviour of Muslims is a reflection of religious belief. Customs and traditions are religious in origin.

The teaching and practice of Islam is reflected in house design and community planning. In house design, priority is given to providing the needs of the extended family and within this unit, for the needs of individual privacy. In Islam, women must be guaranteed privacy within and outside the home. Preservation of family privacy increases the importance of the domain principle in house design.

Riyadh and Jeddah embody the functional spatial hierarchy which has its origins in classical Islamic teachings. Different levels of urban function require a distinctive design structure and arrangement of public spaces. Neighborhoods provide for daily needs and services of the community through a commercial centre. As urban size increases, roads converging at the centre define larger districts which subdivide into their own system of movement. Each centre includes a mosque proportional in size to the centre (Ref 1).

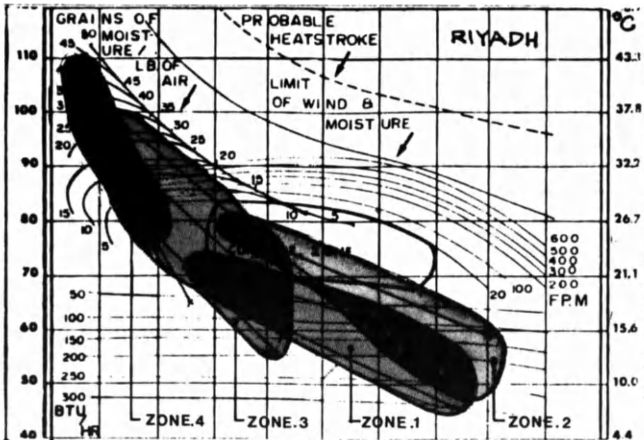
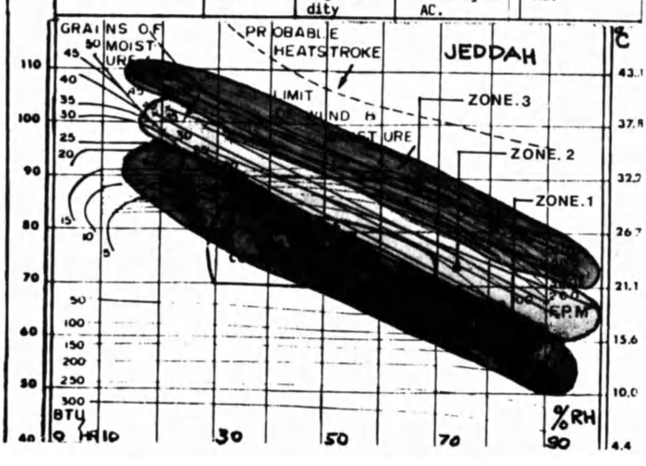


Fig. 1A

		Diagnoses		Prescription	
		Day	Night	Day	Night
RIYADH	ZONE 1	Cool and moderately humid	Cool and semi humid	Direct solar heat	Indirect solar heat
	ZONE 2	Temprate moderate humidity	Cool and semi humid	Comfort	Indirect solar heat
	ZONE 3	Hot and semi arid	Temperate moderate humidity	Evaporative cooling add 10-30g./lb.	Indirect solar heat
	ZONE 4	Very hot and arid	Temperate and semi arid	Evaporative cooling,add 35-45 g./lb.	Evaporative cooling 5g./lb.
JEDDAH	ZONE 1	Hot and semi arid	Cool with high humid	Air-flow to 600 f.p.m. or 5-15g/lb.	Add indirect solar heat
	ZONE 2	Hot and semi arid	Temperate and humid	Evaporative cooling	Airflow 100-200 f.p.m.
	ZONE 3	Very hot and arid	Warm and high humidity	Evaporative cooling or AC.	Dehumidify or AC.

Table 1



Bioclimatic Charts

Figure 1B

PHYSICAL FACTORS & TRADITIONAL COMMUNITY AND HOUSE DESIGN

Riyadh: (Fig. 2) Traditional pattern of desert architecture is evidenced in the 'old' section of the city. The solid mass of courtyard houses separated by very narrow shaded alleys shaped the old city. One or two storied structures of mud and wood are characteristic. This particular style moderated the effects of climate which is characterised by sandstorms, large amounts of solar heat and strong winds. The width of main roads was usually 6-12 metres and secondary 2-6 metres. House height averaged 8-10 meters (Ref.2). The tunnel effect of thick high walls running along narrow streets created draughts of air circulating all the time. This and the shade provided by high walls moderated the discomfort of hot summers. Courtyards of traditional houses were built to receive cool breezes, with shade in summer and sun in winter. The main building material was sun dried clay bricks. Sand or limestone was used as a foundation under mud brick walls,widths of 50 cm at ground level & 20 cm at the parapet. Mud bricks are ideal to withstand the extremes of the Riyadh climate. Being light in color, they reflected some of the sun's rays into the atmosphere and since they are low conductors of heat and cold they insulated the interior walls against the high summer and low winter temperatures. The result is a constant temperature, within the walls, which approximates the average range of the exterior wall surfaces.

During the day temperature within a structure tends to be generally lower than that outside and the reverse is true at night. This tendency was utilised by builders through clever use of courtyards,stairwells and carefully placed windows. Courtyards were used as open space for ventilation and functioned as well as regulators of temperature within the house. Protection from direct sunlight was ensured by high surrounding walls. The cool night air which is denser than the air in the courtyard and interior spaces tends to sink into and replace warmer lighter air of the courtyard. The movement of air creates and maintains circulation of cooling air through the building. Courtyards acted as tunnels through which draughts of air followed. Windows were small and the numbers in a building were kept to a minimum. They face the courtyard or the north or south walls since the midday sun in summer is perpendicular to the roof tops.

Jeddah: (Fig. 3) 'Old' Jeddah exhibits recognisable street hierarchy. There are five main roads including the north-south spine. These are connected by a network of lanes of varying widths. The narrowest may be as narrow as two meters while the other wider streets may be 16 meters across. Average street widths in 'old' Jeddah was between 4 & 7 meters (Ref.3). Many 'old' Jeddah houses were built 3 to 5 stories high & the tunnels created as a result of the narrow spaces separating them channelled cool draughts of air from one street to another. The height of the buildings shielded the streets from the glare of the sun. This and the constant flow of air made the streets and alleyways more comfortable than the wider modern roads.

Most of the houses were oriented to catch the cool breezes from the sea in summer. A central stairwell leading to the roof acted as an air shaft into which air was continuously being pulled. During the days cool air was sucked into it from the cooler streets outside. All rooms were arranged around the stairwell to make maximum use of the air flowing through it. Courtyards were rarely used. 'Windows' were much larger and more numerous than in Riyadh houses. Constructed of hard East Indian wood which absorbed the moisture from the air, these windows extended from the face of the building in order to catch the air. Intricate lattice work characterise these "Rawshin" which functioned as a screen against the glare and dust but which also regulated the flow of air from outside to the air shaft. They afforded the members

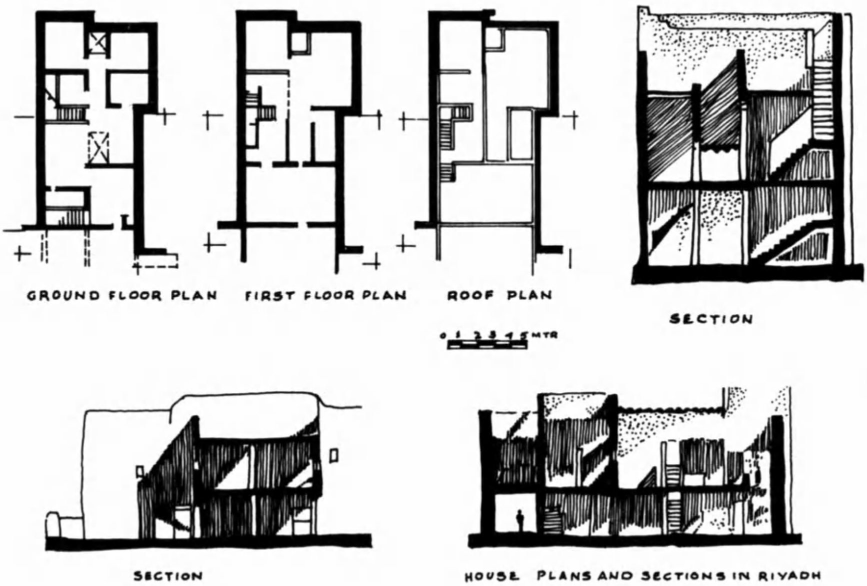
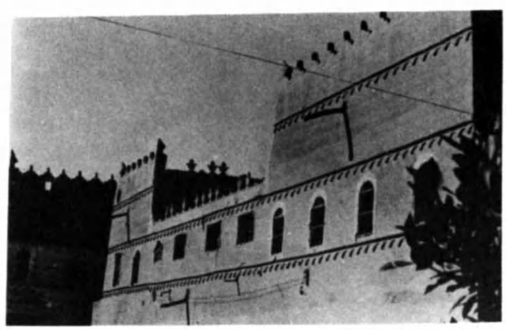


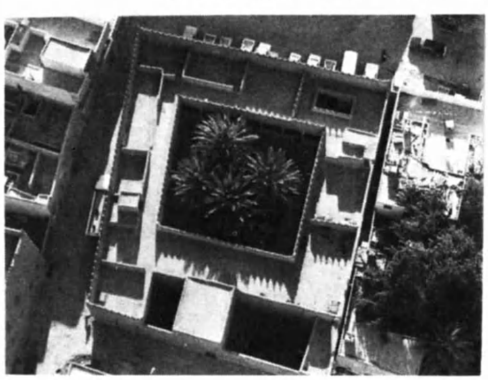
Figure 2A

Typical traditional house - Riyadh, S.A.

Figure 2B

Traditional Houses in Riyadh





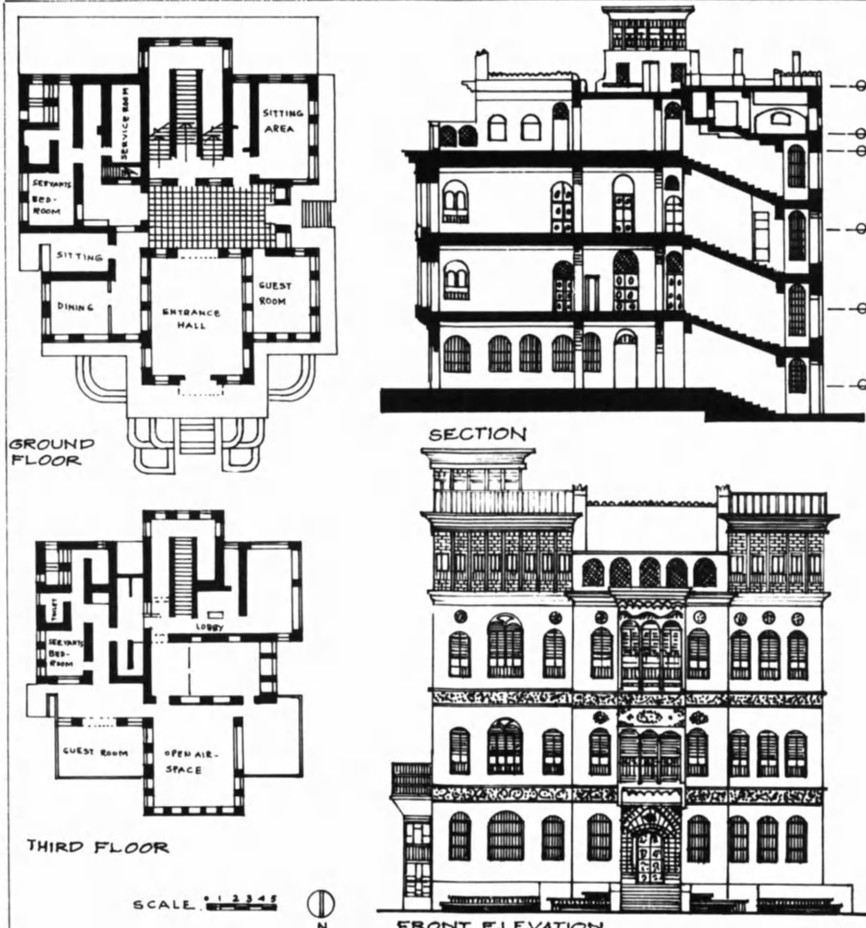


Figure 3.

Typical traditional house - Jeddah, S.A. (Nasseif House)

CURRENT URBAN PROBLEMS

Population living outside both city centres is increasing. In Riyadh, new settlements extend 20 kms beyond the 1970 limits and in Jeddah extension is almost 35 kms. This type of leap-frog development continues. (5) There is a parallel infilling towards the city centre with commercial establishments, massive concrete and glass structures in the gaps resulting from suburban migration. Centralisation of services is concentrating in the 'old' city.

From action master plans of both cities, planners were unprepared to deal with the urban explosion. Consequent development around structuring elements provided by the planners has been haphazard, resulting in a feeling that a coherent image of the city has never been achieved. Massive migration into both cities forced municipal planners to face the immediate problem of providing social services, so preventing decisions that make desirable images.

To summarise, major problems facing Riyadh and Jeddah are:
1. Rapid growth of shopping centres, high-rise apartments and office blocks. Development pressures prevent land use planning.
2. Massive and much needed residential development within zones results in rows of monotonous single family houses or apartment buildings.
3. Community services have low priority as land is expensive and densely built in city centres.
4. Newly developed areas face the opposite problem. Low population density and low demand for the same services inhibit their development.
5. New style housing depends on mechanical air conditioner. Huge amounts of energy are consumed daily to get the desired results. Vast extension of cities means that motor transport is absolutely necessary. While there were less than 20000 private cars in Jeddah in 1971,260,000 vehicles are anticipated in the peak hours of 1991. Problems of heavy energy consumption and resulting pollution have arrived in Saudi Arabia.

The rapid growth of both cities has been achieved at great cost. Riyadh action city master plans estimate the cost of current growth is SR.1.8 million per hectare. If the rate of development continues at 10 sq.km. per annum then the cost will be SR.1.8 billion (Ref5). When the cost of building and maintaining primary infrastructure is added and the life of each infrastructure is taken into consideration, the maintenance of the project might become as costly as the construction. (NOTE - S.R. 3.44 = US$ 1.00).

RECOMMENDATIONS

Planning and Urban design require multi-problem solving including climatic, social, functional & operational problem. Planners must not lose sight of the problem of communication & concerns of the framework in which solutions to problems occur. Consideration therefore, should be given to the use of appropriate technology and lessons learnt from traditional buildings and communities. A careful blend of modern technology and traditional techniques can produce greater satisfaction.

Planners should work towards greater control of energy used by the population by minimizing use of air-conditioners or through encouraging passive cooling techniques in buildings. Planners should also look more closely at planned unit development which optimises movement, landuse and energy.

Some benefits of P.U.D. can be:
1. There is greater flexibility of design. The introduction of traditional design methods become more possible.

of the family a private view of the exterior. Internal walls of these houses have grills which allows air to penetrate right into the centre of the house. Houses were constructed of coral limestone blocks, roughly cubical in shape from 250 to 400 mm on an edge. They were laid with mud joints. Horizontal wood members spaced vertically, at about 1 meter internal, reinforced the exterior walls. Timber lintels or masonry arches framed the openings. Foundation excavations, generally 1.5 meters (Ref 3) deep were filled with large coral limestone blocks.

THE URBAN IMAGE AND THE NEW METROPOLIS

Rapid economic growth in Saudi Arabia in the last decade brought with it massive urban development in both cities. From 1968 to 1977 the built up area of Riyadh increased to four times the size it was. The population doubled. In 1971 the Jeddah Municipal budget was SR.5 million while the population was 380,000. In the wake of the 1973 oil boom the population has more than doubled and the budget increased to SR.1,350 million today. (Ref 4).

'Old' sections of both cities still display the traditional forms of architecture and street patterns. Growing outwards from these sections are the more recently built modern structures. Neither city, however, has a distinctive urban pattern. Each consists of a number of districts or localities which vary in character and which developed without previous planning. These new suburbs contrast sharply, both in style and materials used, with the 'Arab' houses of the city centre. New concrete and marble villas and apartment blocks, though well built and comfortable - because of compression A/C - have little in common with the traditional houses that once distinguished both places from other urban centres of the world.

Present trends have been towards pre-planning of suburbs or localities which fringe the city's orthogonal grid plan and uniform lot size of between one hectare and 350 sqm, giving the areas a regularity which is prevented from becoming dull by the individual style of each structure. These areas are characterised by an excellent network of roads which facilitate maximum use of automobiles. Pedestrian traffic is kept to a minimum as a result of lack of shade along the roads and an absence of services (shops etc.). General density level is 40-60 persons per hectare. (Ref 5).

Located somewhere in the middle of each individual site is the modern 'imported' villa style home. This is closer to the traditional house than apartment blocks. However, whereas old Arab houses were built to create shade these new villas leave exposed large areas of surface. Side yards, unless used for gardens or planted with trees, radiate heat into the atmosphere and add to general discomfort of summer temperatures. Windows are very large and unprotected; open balconies & terraces do not provide the privacy needed by families. Traditional houses started to decline with the introduction of A/C and reinforced concrete into the building trade, stronger and longer lasting, it maximised land use because it could be used to build taller buildings. These new structures unlike traditional homes are less cool since they are not built with any natural mechanism for cooling. As a result the use of air-conditioners increased considerably in both cities, even in smaller one room homes as people came to depend less on natural cooling. The effect was an urban spread into wider streets,since narrow shaded streets were no longer seen as necessary. This trend was made necessary by the influx of automobiles into the Kingdom,and they in turn made possible the move towards a low density pattern. Within traditional towns there is no place for wheeled vehicles and as each year passes more of the coral block and mud brick houses are bulldozed or converted to museums where they exist as relics of the past.

2. Less expensive to service. Shorter roads, power and sewer lines are easier to construct and cheaper to maintain.
3. Eliminates long distance travelling.
4. Guides the expansion of cities.
5. Highway network for easier access can be built around instead of through them.
6. Housing costs are kept within reasonable limits.

BIOCLIMATIC NEEDS AND RESPONSES

Riyadh city	Jeddah city
• High day temperatures and low night temperatures, low humidity, low rate of rainfall large diurnal temperature variation, distinct variations between hot summers and cool winters, little air movement and sandstorms. Very high intensity of direct solar radiation.	• High temperature, low rainfall, small diurnal and annual variations in temperature, large range in diurnal humidity, extreme at night, light wind with long periods of still air. High intensity of direct solar radiation.
• High intensity of radiation builds up heat in urban areas and inside houses. Arid conditions.	• High humidity causes the subjective feeling of skin wetness, and moderately high temp. and radiation.
• Reduced solar radiation. Glare avoidance techniques. Use of non-absorbing heat materials. Promotion of night cooling.	• Promote continuous through ventilation to ensure a sufficient rate of evaporation, and the prevention of solar heat gain.
• Design enclosed and inward looking plans with courtyards.	• Design single rows of rooms, allow through ventilation.
• Orient and shape buildings to north south direction to gain minimum radiation.	• Orient/shape buildings to north for prevailing breezes, and minimise the sun effects.
• Build thick wall buildings, and discourage high rise buildings, narrow streets for shading and coolness.	• Raise buildings on stilts and encourage high rise buildings. Spread buildings and streets for easy air flow.
• Landscape for shade, and water fountains within spaces to cool the air by evaporation, and reduce dust.	• Landscape for shade and allow free passage of air through spaces to increase evaporative cooling.
• Locate large openings towards courtyards, and small openings towards the outside with heavy shutters of high thermal resistance.	• Make openings as large as possible, openable, and placed to allow air flow to living areas.
• Use high thermal capacity materials, Roofs of heavy materials with outside insulation, paint light colors in outside surfaces. Promote air-cooling of building structure. Extract undesirable interior heat year around except winter time.	• Use low thermal capacity materials with outside reflective surfaces. Build double roof construction, paint light colors on outside surfaces. Promote air cooling of building structure . Extract undesirable interior heat year around
• Promote evaporative cooling of interior & exterior spaces except in winter.	• Promote ventilative cooling of interior spaces except for a few days in the winter.

Below (Fig.4) are guidelines to accommodate design requirements for houses and neighbourhoods in Riyadh and a design of a proposed prototype housing

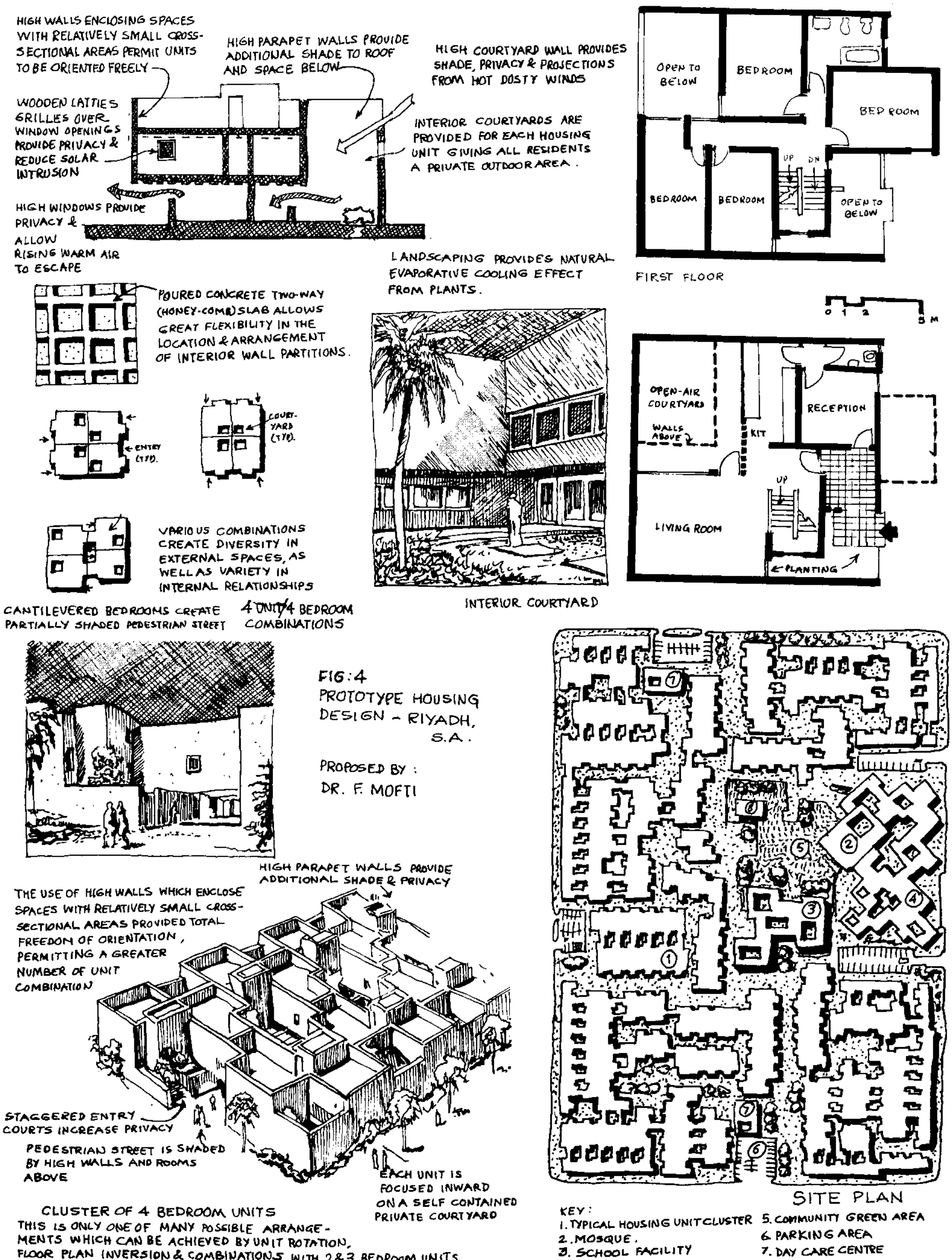


FIG:4
PROTOTYPE HOUSING DESIGN - RIYADH, S.A.

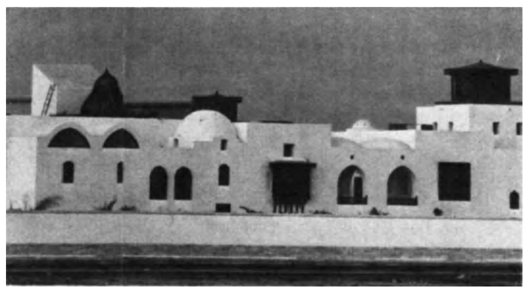
PROPOSED BY: DR. F MOFTI

scheme. Consideration was given how the use of suitable traditional techniques along with modern technology, to respond to climate & cultural constraints.

GUIDELINES

A. Cultural Factors: (1) The dwelling should be designed in two separate sections: a) family and b) guests. (2) - Family privacy assurance a) traditional space between public & private property respecting guest & family domain, b) protection of openings by means of lattice work, shutters and deep high windows; (3) - Spaces for functions must be large enough for rearrangement when changes in life-style, income or family growth demand it.
B. Climatic Factors:(1) Layout-compact courtyard, (2) Air movement-double banked rooms, temporary provision for movement of air, (3) Openings-small 10-20% of wall space, ideal position along north and south faces of structure, internal openings or grill work, (4) Protection of openings-exclusion of direct sun light, (5) Walls & Floors-heavy, poor heat conductors, heavy internal walls for thermal storage, (6) Roofs-heavy, eight hour time lag.

NOTE:
Specific Guidelines for housing design pertaining to the local conditions of Jeddah have not been worked out yet. However, some effort along the lines of Riyadh proposal has been attempted by several designers. (Fig 5 is Al Sulaiman House - Jeddah, S.A.).



CONCLUSION

While it is easy to understand why the break with tradition occured, efforts must be made towards a satisfactory balance between contemporary needs and the elements in the local ecology and cultural heritage, as demonstrated in the above proposal, which will give our cities the distinctiveness they presently lack, while considering the great demands these cities make on our financial and energy resources. Traditional towns contributed to clean environments, climate adaptation, energy efficiency and cultural satisfaction with a feeling of well-being and delight for the inhabitants. While traditional buildings and communities are not the topic of this paper, they provide an excellent resource, historically known from which lessons are learned in the development of appropriate technology for the needs of the built environment of Saudi Arabia.

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ENERGY RESPONSES TO VERNACULAR SHELTER AND SETTLEMENT IN CONTINENTAL MOROCCO, NORTH AFRICA

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ABSTRACT

Continuous pressure throughout the world for increased energy sources cause a re-evaluation of thermally adaptive structures. This study examines vernacular approaches to the needs for passive cooling in the hot dry zones of the Middle East, with special emphasis on the courtyard houses and urban fabric of Morocco, North Africa.

KEYWORDS

Courtyards; fountain, tiles; tradition; privacy; roofs; arcades; enclosure.

INTRODUCTION

Morocco is situated between latitude 28-36°N and longitude 8-12°W and possesses three principal geographical features 1) long coastline, 2) plain, and 3) mountain range. The principal cities are identified, including Marrakesh (Fig. 1).

In hot dry zones of Morocco traditional urban fabric (Fig. 2) and buildings have succeeded in achieving successful responses to passive cooling systems.

They have done this through clusters to reduce heat gain, through proper orientation, proper use of material, through manipulating the number and size of openings and through such devices as courtyards.

The following pages will make a descriptive analysis of the above, as well as exploration of potentials. The discussion is limited to the continental area of Morocco with special emphasis on Marrakesh as a typical example of the hot dry region.

THE NATURE OF CLIMATE

The climate of Morocco may be divided into three subtypes: marine, continental and mountainous. Summer temperatures vary with location, but mean monthly values of 20-25°C are usual (30°C and over in continental areas, lower in marine locations). Winter average tends to be between 7-13°C, night temperature may fall to near, and occasionally below freezing. (Ref. 1).

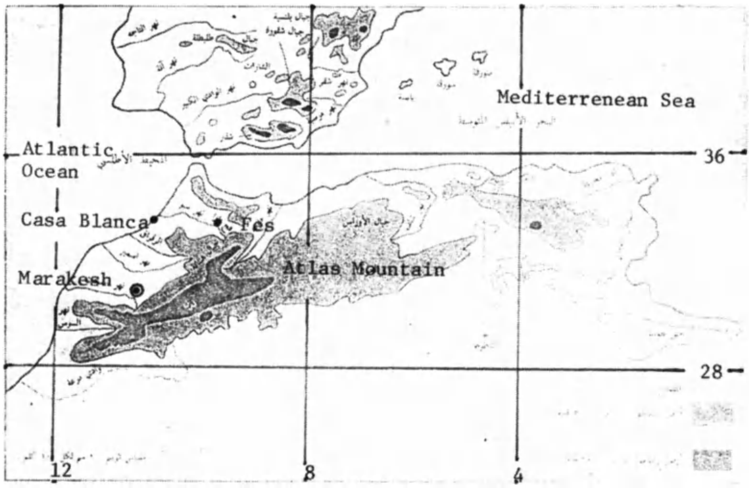


Fig. 1 - Map of Morocco

Fig. 2 - Aerial View of Hot Dry Region Settlement, Marrakesh

BIO-CLIMATE ANALYSIS OF MARRAKESH

A state of bio-climatic comfort and the different zones are established (Fig. 3) then the conditions that determine the comfort situation are determined. Finally, the facts established in the diagnostic section are examined and alternative remedies that should be considered are recorded. Consideration is year-round both day and night. (Tab. 1, Ref. 2)

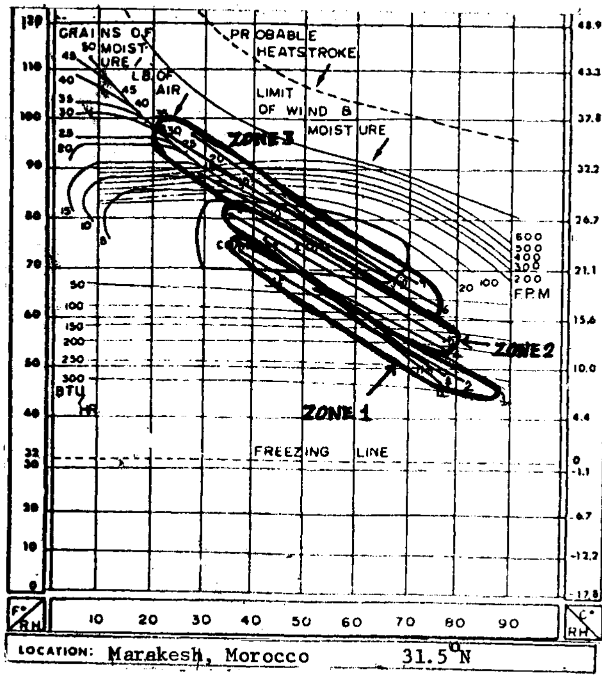


Fig. 3

Zone	Months	Diagnosis: Day	Diagnosis: Night	Prescription: Day	Prescription: Night
1	1,2,3,12	Cool, Av. 68°F. Moderate Humidity Av. 55% R.H.	Cold -Av. 48°F High Humidity - Av. 50% R.H.	Mild Exposure to direct solar gain approx. 50 BTU/HR Indirect solar store for night	Indirect stores solar or artificial heat approx. 300 BTU/HR. Insulate for heat 1055
2	4,5,10,11	Comfort zone for both temp. & humidity	Cool-Av. 55°F High humidity Av. 80% R.H.	Prevent direct heat gain or indirect solar store for night use	Indirect stored solar or artificial heat approx. 100-250 BTU/HH. Insulate for heat loss
3	6,7,8,9	Overheated Av. 95°F Semi-arid Av. 30% R.H.	Slight cool- Av. 68°F. Humid- Av. 90% R.H.	Evaporative cooling and shade. Air cool building envelope. Insulate for heat gain	Metabolic and indoor heat adequate

Table 1

FEATURES OF THE BUILT ENVIRONMENT IN MOROCCO

1. Al-Dar (the House) Moroccan houses are introverted, they open upon a patio with arcades. The typical Marrakesh home is organized around the Wust Al Dar (center of the house) which is a square courtyard paved with Zalijs (marble), generally with a marble fountain and orange or lemon trees for climatic ammelioration as well as to

add aesthetic values (Fig. 4, Ref. 3).

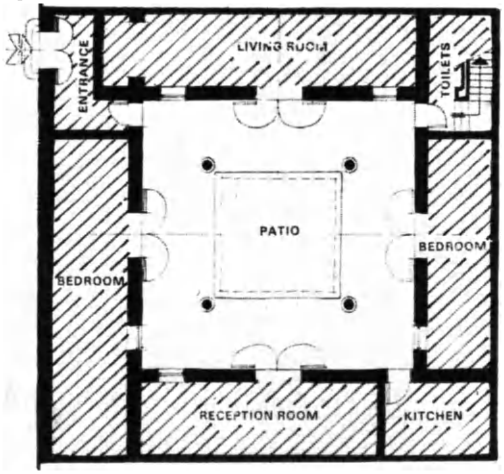


Fig. 4 - Plan of a Typical Courtyard House of the Plains Region

Rooms are constructed on two, sometimes three storeys around three or even four sides of the courtyard. Pillars support the roof of a long open, but covered arcade around the patio. The rooms are wide but not very deep, they get plenty of light and air, and usually have a double door and two low windows. The ground floors invariably consist of the living room and one or two bed rooms, bathroom and kitchen. There is also a space around a fountain used for ceremonial purposes. The next floor is reserved for the master bedroom. A large hall is arranged for formal dinners and reception. This is reached by a staircase at the entrance. The arrangement indicates the importance of privacy, where the family quarters are separated from the guests section (Fig. 5).

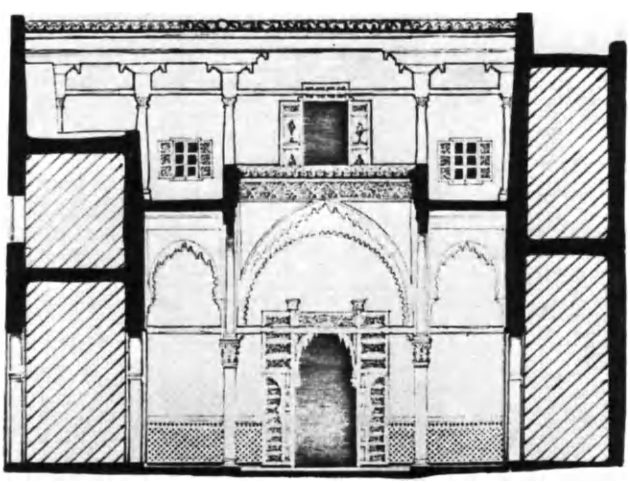


Fig. 5 - Section of a Typical House in the Plains Region

2. Al-Madina (The City) In the city of Marrakesh, all government and public buildings are centralized. Religious buildings, great mosques, neighbourhood and medrasa (school) occupy a place of prime importance. The public baths are founded within the neighbourhood. The souks (markets) are close by the great mosque, they consist of covered small streets. These streets are filled with stores, workshops, grocers, car painters and metalsmith.

3. Nomad Tents: This shelter, made out of stretcher fabric, best meets the needs of people travelling by camel. The tent is woven by the women,in strips 60 cm wide which are joined together for the length of the tent. Men fasten these bands together with clamps. They are then raised on poles and attached to the ground. Pillars divide the interior into two equal parts. The first is reserved for men and for visitors, the second for women and domestic activities.

METHODS OF CLIMATE AMMELIORATION

1. Interior Space Organization and Air Flow: The traditional houses of Morocco are compact, inward looking buildings with an interior courtyard. This minimizes the solar radiation impact on the outside walls and provides a cool area within the building. The courtyard is a dominant element in the house design, spatially, it is the focal point and acts as an extension to surrounding covered terraces and the rooms beyond. These terraces which are usually on two or three sides of the courtyard, and the covered gallery on the first floor, help to reduce the quantity of heat gain during the day and provide shaded areas.

As the height of the court is usually greater than any of its dimensions on plan there is always adequate shading, even when the summer sun is almost directly overhead. When the courtyard is provided with water and plants it acts as a cooling well and modifies the micro-climate. The use of these elements also helps to raise the very low humidity of the air to a more comfortable level, and is often supplemented by spraying water on to the courtyard floor several times a day. (Fig. 6).

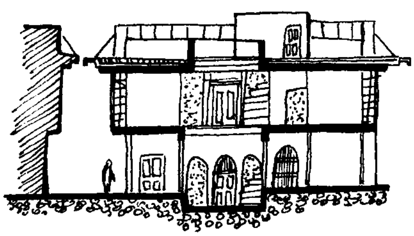
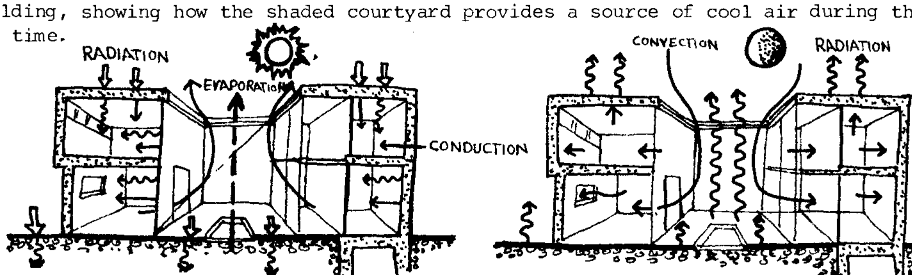


Fig. 6 - A Typical Courtyard House Section

The diagramatic sections (Fig. 7) illustrate the thermal system of this type of building, showing how the shaded courtyard provides a source of cool air during the day time.



(a) Day Time (Heat Phase) (b) Night (Cool Phase)

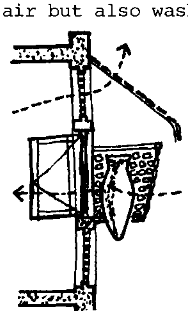
Fig. 7 - Diagramatic Sections to Show Thermal System

2. Building Materials and Methods of Construction: Two basic elements are considered in the selection of building materials, availability and performance. The environmental factors are a major influence and have a great effect on the durability and behaviour of materials. Not only must the materials used be suitable for the specific climatic conditions involved, but the design and detailing must be appropriate to both the materials and the climatic conditions. Traditional houses of Morocco are constructed from stone and mud with massive walls to conserve heat in winter and resist solar and thermal radiation in summer. Small openings and domed or vaulted roofs assist cooling.

The amount of heat penetrating a building depends largely on the nature of the walls and roof. In Morocco, to insulate the interior from the exterior heat, buildings are traditionally constructed with thick walls and roofs and with very small openings. These are built of materials with a high heat capacity such as clay and stone. The wall mass is often reduced with the outside surfaces painted white, or some other light colours to reflect a maximum of the radiant heat. As roofs are domed or vaulted, a hemispherical vault has a larger surface area than its base. Consequently, solar radiation is diluted due to deflection and re-radiation during the night, is also greatly facilitated.

3. Urban and Socio-Cultural Features: It is recognized that the dominance of religion creates a certain type of organization and that the need for privacy resulted in special details of the urban layout. The Arab city or town also developed around centrally located mosques, suks (markets), khans (rest for trading) and hammams (public bath houses), medrasa (school) surrounded by houses and other services. In the organization of these basic elements of the Arab cities, climate influence seems to dominate the overall fabric of any development. The Arab architecture or town development was not based purely on religious requirements but effectively took into consideration the climatic and geographic elements of the region. Special details such as narrow dead-end streets with irregular layout provided protection against dust storms. Very narrow streets with hardly any passage from outside allowed the dust storms to pass over a development rather than through it. Narrow streets also provide protection against the sun in hot areas. In Morocco one finds mud houses built close together, sharing two or even three walls. Thus more of the houses remained protected from the sun with the help of the narrow streets. Orientation is controlled to minimize solar gain on all vertical and horizontal surfaces.

4. Use of Water: When water is available, ingenious evaporative cooling techniques are employed. These coolers are based on the evaporation of a thin film of water on a carrier over or through which air is passed. The simplest system is porous pots, filled with water, which seeps through the walls of the pot moistening the outside and cooling the passing air as it evaporates (Fig. 8). A spray pond is more effective than a still pool of the same size and has the additional advantage that it not only cools the air but also washes it. (Fig. 9).



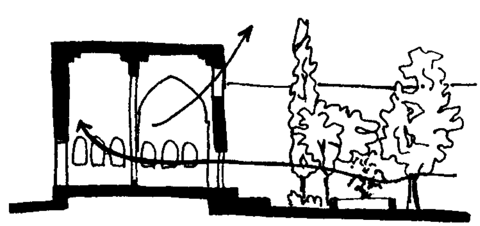
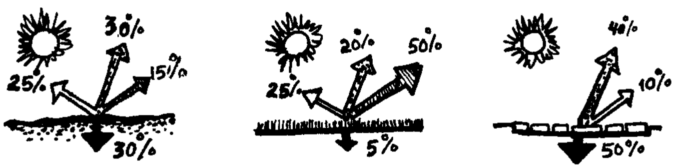


Fig. 8 - Use of Porous Pot for Cooling. Fig.9-Use of Spray Pond & Plants for Cooling

5. Landscape: The beneficial effect of landscape elements is quite considerable. They provide protection against glare and dust. These elements will include trees, ground cover and lawns, when they will effect the cooling requirements of a building. Trees are more effective than other landscape plant types for shading large areas of walls and windows through which most heat gain occurs. The natural cover of soil tends to moderate extreme temperatures and stabilizes conditions. Plant and grassy cover reduces temperatures and while they may be still further reduced by other vegetation. Cities and man-made surfaces tend to elevate temperatures and reduce humidity (Fig. 10, Ref. 4)



(a) Bare Ground (b) Grass (c) Paving

Fig. 10 - Effect of Landscape Elements

EXPLORATION OF POTENTIALS

1. Landscape: Various landscape elements may be used to reduce the energy consumed in air conditioning a residence. They significantly reduce the temperature of the exterior walls of a house during hot periods. The table below shows the average reduction in surface temperatures for east and west facing light-coloured walls with various types of landscape plants providing shade or cover. Data was recorded on warm summer days in Miami, Florida. (Table 2, Ref. 5)

Landscape Elements	Ave. Temp. Reduction at Daytime, No direct Sunlight (°F)	Ave. Temp. Reduction at Daytime, Direct Sunlight (°F)
Large tree size	6.4	24.5
Moderate size shrub	7.6	24.3
Tree/Hedge combination	10	2.8
Thin vine	8	13.8
Thick vine	7.5	10

Table 2 - Average Reduction in Surface Temperature through Landscape

2. Roof Cooling: Cooling loads may be reduced with a minimum investment of electricity. It is a design approach where roof ponds and/or roof sprays can cut incident heat load on flat roofs with small capital investment. These sprays or ponds can also serve as cooling towers for a conventional air conditioning system.

A roof pond is simply a standing layer of water commonly one to six inches deep. A roof spray applies water to the roof through a network of spray heads. Some systems are designed so that water evaporates completely and the roof is kept damp. In other applications, a spray or sprinkler is used in conjunction with a pond.

The shortage of water in hot dry climate is main disadvantage of these solutions. To overcome this, a system was developed known as Skytherm Roof Pond, consisting of water filled polythene bags placed on the roof and a movable covering of 50 mm.(Ref.4)

3. Wall Design: Clay, stone and brick have been traditionally used, but have been replaced by poured concrete or concrete blocks. Although cavity wall construction can be effective if properly designed. A composite wall will be satisfactory, if it consists of heavy weight internal layer externally insulated by rockwool, which is protected by an outer waterroof skin. This type of construction would restrict the rate of heat flow and reduce the amount of heat absorbed by the inner wall during the daytime. Good ventilation is needed to ensure that buildings of this construction do not become much warmer at night then those with a simple solid wall.

CONCLUSION

In this study an attempt was made to understand the architectural features as well as urban fabric that particularly effects the passive climate responses. In new housing development these factors of designing for passive cooling seem to be forgotten. It is common today to see people in the Moroccan cities use balconies of the tall apartment complexes, for sleeping in summer. The intention is not to reassess vernacular solutions in a formal sense, but to understand the principles behind it for possible use in modern development. For this purpose the following recommendations are given, aiming at developing design guidelines responsive to the demands of hot dry zones.

- Use of water element (sheet and spray) for evaporative cooling.
- Use courtyards where applicable. The width must be smaller than the height.
- Apply passive cooling elements throughout the building itself.
- Make compact plans.
- Window openings should be small.
- Utilize party walls to reduce heat gain.
- Utilize building materials with high heat holding capacity.
- Utilize ventilated attic-roof concept.
- Utilize whole-house night ventilation for cooling in summer.
- Provide private space for potential summer night sleeping.
- Roof could be domed or vaulted to minimize heat transfer.
- Surface to volume ratio should be employed to reduce radiative gain.
- Orientation and building shape should be decided in favour of cooling in most circumstances.

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THE ECOLOGY OF THE VERNACULAR HOUSING IN TURKEY
TOWARD DESIGNING FOR 'LOCUS'

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ABSTRACT

The present study examines the morphology of vernacular houses in Turkey in terms of their micro-climatic properties. Human aspects of these forms are also analyzed briefly especially in hor-arid regions of the country which has four distinct climatic and ecological conditions. The vernacular house forms developed for centries within these varying ecosystems reflect highly sensitive micro-climatic solutions.

KEYWORDS

Ecology, micro-climate, passive cooling, hot-arid climate, vernacular architecture, courtyard house, Turkey.

INTRODUCTION

For centuries man's experience with the natural environmental factors has led him to diverse settlement forms in different settings. Apparently emergence of various types of habitation occur largely within the parameters of interacting socio-cultural, economic, technological and physical environmental factors. This is a human ecological phenomenon. That is, while man is adapting to the limitations of natural factors--i.e. climate, topography, available resources to generate his living environment, 'meso-environment' (Fitch, 1972), or architecture; he acts actively upon nature through his cultural forces--his technology, tools, beliefs, ideologies, economic systems--and imprints his norms upon the resulting forms. There is a whole range of examples which reflects how and why people organize their environment in various forms (Rapaport, 1969) and scales from house, city or region to an entire landscape shaped by symbolic attitudes toward nature (Tuan, 1974) namely harmony with nature.

In vernacular architecture this harmonious relationship with nature reflected itself in the proper use of building materials found available within the ecosystem in which it is developed, in the division of living spaces, the orientation of the individual housing units and the entire settlement as a response to seasonal and daily changes in climatic factors. The resultant forms however in turn require daily and seasonal adaptation in user activity patterns in and around the house unit in particularly adverse environments like hot and arid climates. This reciprocal relationship established between nature, the built environment and man's activity patterns is in this study called as the ecology of the built environment; denoting the criticality of choice within a given ecosystem for generating living spaces and man's cultural adaptation to it.

For the purpose of this study ecosystem is defined as a unit of human community--as biological organism as well as maker of culture through symbols--in a locality or region interacting together with its functionally related such environmental factors as climate, available resources, site characteristics constituting a given in forming the built environment.

THE ECOLOGY OF VERNACULAR HOUSING IN TURKEY

Topography and the Building Materials in Use:

Central plateau region: It is a high plateau with average altitude of 1000 m. and is enclosed by mountain ranges on the east, northwest and southwest. The geographical events in this region once rich in lakes have left in a distinct quantity of such building materials as clay and mud suitable for brick in the regions of Sivas, Kayseri. In Konya and in northern and western plateau travertine and tufa are common materials found.

Western plateau and Marmara region: They are the home of classical marble used as facing for brick. Southeastern region from north to south is a zone of mountains where stone is the only building material. The white Midiat marble of Mardin and dark basalt of Diyarbakir are much used in this district.

Climate:

The Mediterranean: It includes the south and west coast. The summers are hot and humid; the temperatures in winter are moderate. The western coast enjoys a Mediterranean climate as well. The summers are hot and dry; the winters near the coast are mild but colder toward inland. Rainfall is moderate on the coasts and decreases inland. The average rainfall is about 700 to 2500 kg/m^2/year.

Semi-arid region: Includes central Anatolia and eastern Anatolia. It has a low annual precipitation. The temperature changes between day and night are high. Winters are longer and cold, while summers are not as hot as in southeastern parts. The central plateau of Thrace reflects similar conditions with central Anatolia, except its southern coast is similar to Mediterranean type of climate.

Hot-arid region: Includes the southeastern region and some eastern parts of the central Anatolia. This climate is characterized as having large diurnal temperature changes in summer and winter; very low rainfall not exceeding 500 mm; low humidity 24%; high solar radiation both summer and winter. The day time temperature in summers may range between 27°C and 49°C which exceeds the 31°C and 34°C skin temperature which is very stressful. The winter temperatures are around 5°C, and cold seasons do not last long. All these discourage plant life, and dry dusty ground reflects the sun's rays producing an uncomfortable living condition, putting limitations on man's daily activities in the city life (Karaman, Egli, 1981).

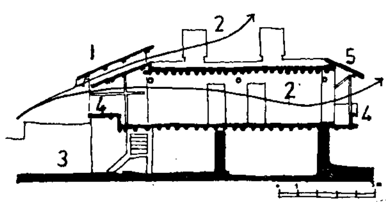
The Moderate climate: Includes the Black Sea coasts of the north, enjoys warm summers, mild winters and fair amount of precipitation at all seasons. It is characterized by dense forests and a scarcity of flat lands.

House and Settlement Types:

An examination of the general characteristics of habitations developed within the ecosystem described above shows highly responsive micro-climatic solutions. Fig. 1.

Fig. 1. Vernacular house and settlement typology in Turkey

Pools, fountains, terraces and double roofs, eyvans, serdaps, and gardens are the common elements of micro-climate. Most of these elements are found in all regions. However they are more critical in environmental design in hot-arid zones. The attention given to the cross ventilation in houses and settlement formation is common practice in hot humid or moderate climate.Fig.s 2 and 3.As a result the settlement type is dispersed in character.Timber becomes the dominant building material in use.



1. Double roof
2. Prevailing wind: cross ventilation
3. Garden, patio
4. Balcony, gallery, lattice windows
5. Sun shade

Fig. 2. A House in Bucak, Mediterranean, micro-climatic elements

The use of water as cooling element increases dramatically in hot arid zones. The settlement form is compact in character and buildings are inward-looking with courtyards, patios, living spaces facing mainly toward the south. Fig. 4.

The available material stone is used widely in arid zones (Kayseri, Diyarbakir, Mardin, Urfa) as structural reasons--arches, vaults, and domes--as well as its thermic values, heat retaining capacity.

Man's activity patterns: People's activity patterns during long summer months have tremendously been affected by this type of climate. The daily life cycle is

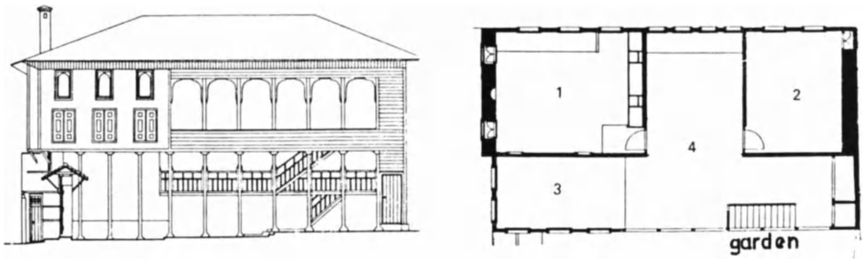


Fig. 3. Bursa House, Elevation from the garden side and plan of the upper floor, 1 Winter salon; 2 bedchamber; 3 summer salon; 4 gallery.

Fig. 4. A hot-arid settlement, Kayseri Turkey

dictated by the sun. The daily activities are divided into three parts at odd hours. Work and school are concentrated in the morning hours from six o'clock until one o'clock in the afternoon. Afternoons are devoted to lunch, rest at home, while the evening is a time to shop, visit or outdoor recreational activities. These restrictions present crucial implications to planning new settlements. At night outdoor sleeping is observed during the hottest period of summer for a few weeks in all regions. However this peculiar activity pattern becomes more crucial in hot-arid zones during long stressful summer months. For this dialectical relationship between man and nature is more critical for human adaptation in hot-arid zones, a detailed examination of the vernacular housing in this region will shade more light to the question of passive cooling in architecture. The city of Diyarbakir is chosen for analysis for it has most arid and significant architectural characteristics.

DIYARBAKIR: A CASE STUDY

The city is surrounded by the historical wall on a flat land. It is typically a compact hot-arid settlement. Fig. 5.

Fig. 5. Diyarbakir, southeastern Turkey
(After A. Gabriel)

House Form: The house type reflects an inward looking character. That is, the openings and the direct relations to such public places as street is kept to a minimum. This socio-fugal (privacy seeking) character of the house apparently is a result of the climatic restrictions, socio-cultural factors, technological constraints, that is the totality of all these ecological phenomena interacting together. However, an examination of the micro-climatic factors will suffice for the purpose of this study. Fig. 6.

Orientation: The division of living spaces as summer and winter section is a major concern to overcome discomfort. Summer quarters are oriented to the north and winter quarters to the south.

Rooms: are designed open-ended. Due to seasonal division of the house the rooms are also divided into summer rooms with northern orientation which have much shading and night breezes and into the winter rooms with a southern orientation which have direct exposure to sun, warm daylight and protection against the winter winds. The arched window units oriented toward the courtyard serve for ventilation purposes as well. The function of these windows is not clearly seen without an examination of the climatic performance of the whole house. Since the walls of the house are particularly thick (50-130 cm.) and have good thermal capacity, the temperatures of the wall's internal surfaces remain relatively constant throughout the day. The outdoor temperature fluctuates throughout the day and afternoon exceed wall temperatures, the windows are opened to let the warm air out and cooler air in indoor spaces evenings. Fig. 7.

Courtyards: Contains usually a small garden, a pool to aid summer comfort where the most family life takes place during summer. The shading trees also help to prevent penetration of excess radiation. A second courtyard seen in Mardin houses helps retain the night coolness for a longer period of time. Fig. 8.

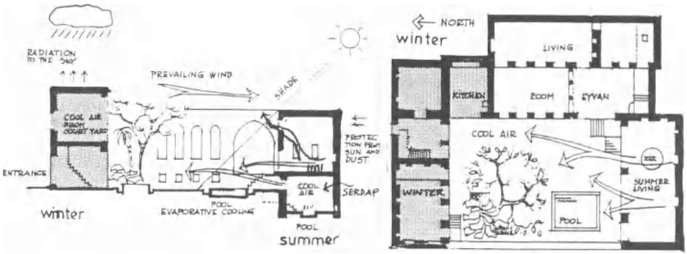


Fig. 6. A socio-fugal (privacy seeking) Diyarbakir house

Eyvan: Eyvans, closed spaces in three sides and open toward the courtyards, are important elements in the house. This shady space used day and night mostly contains a small pool or selsebil makes the favorable part of the house.

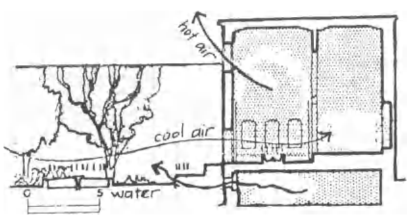


Fig. 7. Windows as ventilator

Serdap: Are usually on the lower levels, basement, designed for cooling purposes. Fig. 9.

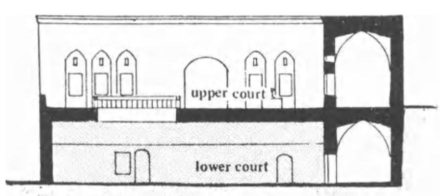


Fig. 8. Double yard in Mardin house
(After: M. Turan et al.)

It usually contains either a small pool or a system called selsebil, both of which utilize the latent heat transfer to lower room temperature. Selsebil is a kind of ornate fountain with water running down a sloping ceramic surface terminating in a small pool underneath. While water is sliding down it evaporates and helps the room to cool down (Erginbas, 1953). "A measurement taken on a July afternoon in the cool room of Serdap of the house of Diyarbakir indicated a 5°C lower dry bulb temperature and 10% relative humidity compared to that of outside" (Imamoglu, 1980).

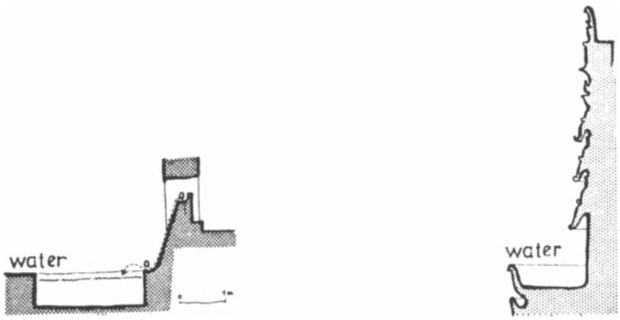


Fig. 9. Selsebils, Diyarbakir
(See Fig.6 for the detail)

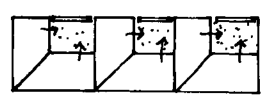
SUMMARY AND CONCLUSIONS

The new developments in hot-arid zones are being challenged for they have failed in responding to the ecosystem they were designed for, while vernacular solutions reflect highly sensitive solutions not only in the micro-climatic considerations, but also in their visual, experiential quality as well. It has been widely accepted today that designing for 'locus' (Rossi, 1982) through typological transformation in design process is an important variable that has escaped the attention of the international style for a long time. The courtyard house as a type has abstract value to be taken as a frame of reference for designing 'tout emsembles' today in terms of, (i.e.):

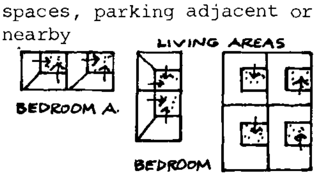
LOCUS:
Climate: Hot-arid
·The direction of breezes prevailing in hot seasons
People:
·People's daily activity Patterns during summer and winter in terms of work, school, home, recreation, outdoor activities

SPECIAL CHARACTERISTICS:
Type: Courtyard House
·Flat roofs
·South-north orientation
·Shady, cool spaces: Evyan
·Courtyards, patio
·Trees
·Cross ventilation
·Double windows, ventilation
·Symbolic connotations (To be defined during the research)

TYPOLOGICAL TRANSFORMATION:
·Potential high density type: Adaptation to patio unit



A prototype for street-oriented with private indoor spaces, parking adjacent or nearby



·Larger units with more privacy

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HARAT AL-AQAWAT AL-MADINAH AL-MUNAWARAH
AN ENERGY CONSERVING ISLAMIC TOWN IN SAUDI ARABIA

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ABSTRACT

The space concept was the fundamental principle in traditional Islamic architecture. The dominant principle had always been form follows space and space is adapted to function. Space also adapted to the environment where it effects the indoor and outdoor spaces. Harat Al-Aqawat is a case study composing solutions responding in terms of efficient utilization of energy in hot arid zones, with an emphasis on outdoor and indoor spaces.

KEYWORDS

Zuqak - Dahliz - Diwan - Qaah - Rushan - Muslim - Jilah - Saqefah.

INTRODUCTION

Traditional muslim space was based on some variables and constants where they attempted to satisfy their physical and spiritual needs.

		Humans			
	Physical env. (climate)		Economics		Pleasant
Constants	Sharia law	+ Variables	Technology	=	living
	Arch. determinizm (spaces)		Materials		environment

The following pages will illustrate a descriptive analysis of a traditional building environment, responding to passive cooling systems in urban design and house design, where they developed various environmental devices such as a courtyard and a unique treatment by applying the Qaah and Diwan in houses.

BIOCLIMATIC CONSIDERATIONS

An examination of the bioclimatic condition for Al-Madinah Al-Munawarah serves as a basic for evaluation of the discussion in this paper. The meteorological information (Table 1) is transferred to the bioclimatic chart (fig. 1) to provide a basis for evaluation in the matrix of comfort needs. (Table 2).

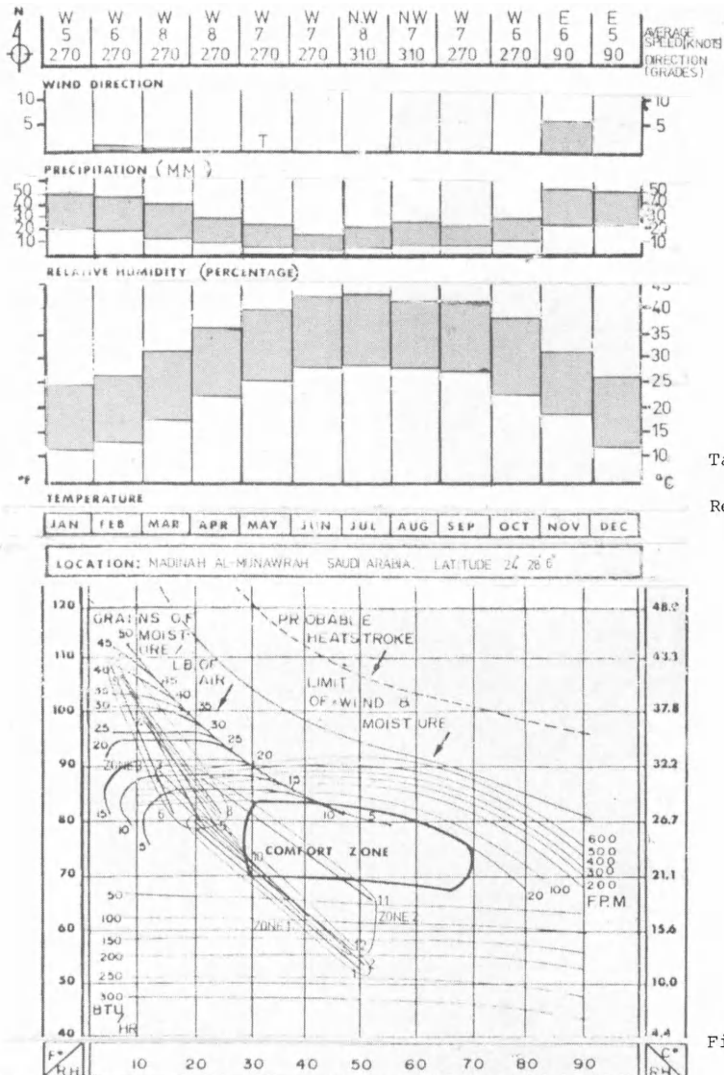


Table 1

Ref: General Meteorological Dept. 1980

Fig. 1

AL-AQAWAT DISTRICT

The holy city of Al-Madinah Al-Munawarah (the Enlightened City) is located in the west of Saudi Arabia, 150 km east of the Red Sea. It was the first city in Islam where the Prophet Mohammed (peace be upon him) travelled from Makkah to Yathrib and there established the first city in Islam (Al-Madinah), as the capital of the new Muslim State. Al-Aqawat district is located to the east and south of the Prophet's mosque (Al-Haram) where it is the only remaining part of the old city, shown in the aerial photograph (fig. 2). A closer look clearly reveals the fabric of buildings, streets, open spaces, and courtyards (fig. 3).

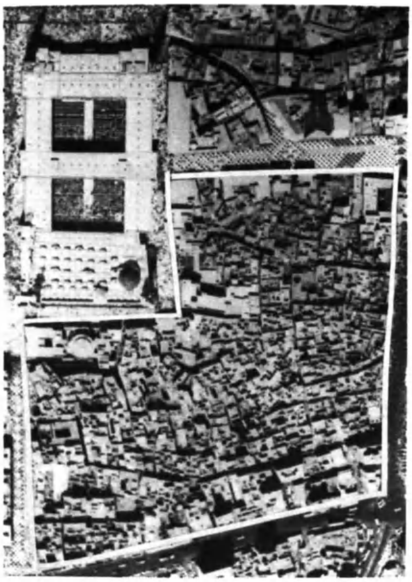


Fig. 2

Ref. 1

Fig. 3

LEGEND

Libraries

1. Public
2. Arif Hekmat (1853)
3. Mazhar Al-Farouqy (1875)

Schools

4. Alam Al-Dien(1883)
5. Qura Bash (1780)
6. Hussein Aga (1856)
7. Al-Rustumiah

8. Public bath(Hammam Tibah Fig.14(1838)
9. Rubat Al-Mimany

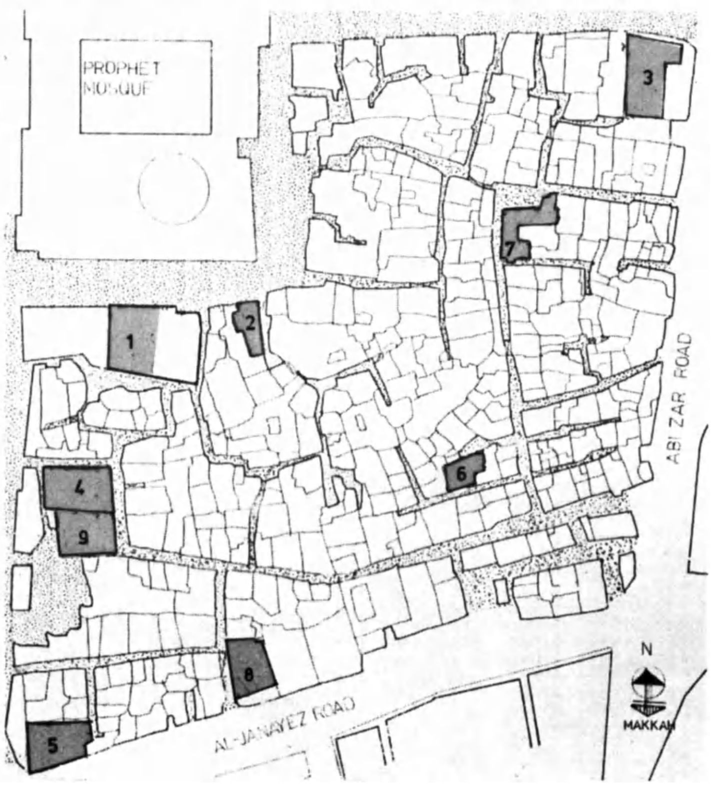


Fig. 4

Zone	Month	Diagnosis		Prescription	
		Day	Night	Day	Night
1	Dec/Jan/Feb	Temperate 25 C Av. Semi-arid 22% RH Av.	Cool 12 C Av. Moderate humi-dity 50% RH Av.	Add not more than 5gms/lb. of air for evaporative cooling and moisture	Add 200-250BTU/Hr. may be ac-quired by in-direct solar & indoor heat generation.
2	Mar/Nov	Temperate 31 C Av. Arid 18% RH Av.	Cool 17 C Av. Moderate humi-dity 40% RH Av.	Add 5 to 15 gms/lb. of air moist. -ditto-	Add 50/100 BTU/Hr. -ditto-
3	Aug/Sep/Oct Jul/Jun/May Apr	High Temp. 40 C Av. Arid 8% RH Av.	Temperate 26 C Av. Semi-arid 20% RH Av.	Add 40gms/lb. of air moist./lb. of air -ditto-	Add not more than 5gms/lb. air moisture -ditto-

Table 2

SITE DESCRIPTION

Harat Al-Aqawat is a homogeneous community of approx. 57,693 sq. m., composed of residential buildings, four schools (Madrassah), two libraries (Maktabah), a public bath (Hammam), a small local market (Suweqah), residences for old and poor people (Rubat) (fig. 4). The district plan shows the compact urban form where close spacing is recommended to provide sheltering from hot winds and to provide mutual shading and cooling through shared walls, thus avoiding solar exposure.

The orientation of narrow streets (zuqak) are mostly toward the east-west and north-south, and this is a proper layout as seen from the bioclimatic information, where the wind direction most of the year is from the west, east and north-west. (Tab. 1). The narrow and bent streets are advantageous for the breakdown of dust storms. Relatively high buildings (three stories) reduce the high intensity of direct solar radiation and affords the opportunity for large openings toward the street, where the Rawashin reduce the glare without reducing the air movement inside as well as to achieve good privacy (fig. 7). Narrow streets stop the sun from striking the exterior walls of the house in summer except for a short time each day. This reduces the heat gained by direct solar radiation, and also minimizes the amount of direct solar radiation striking the ground between houses. In the evenings street surfaces are wetted to create evaporative cooling and reduce the mean radiant temperature of pavings. (figs. 5 & 6).

Fig.5

Fig.6

Saqefah, are the extension of the houses to allow an under-pass, which have defensive reasons, and for shading a street. They also breakdown the long alleys into areas with closed vistas, to provide a satisfactory cooling comfort by convection,where they have the same thermal functions as a courtyard. (fig. 8).

Fig. 7

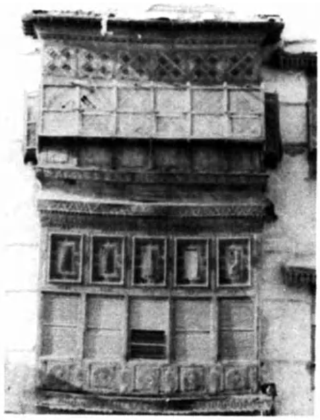
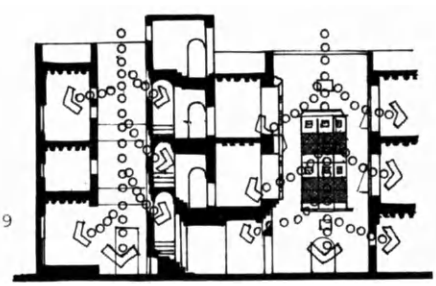


Fig. 8

THERMAL BEHAVIOR OF AL-AQAWAT HOUSES

The heat exchange processes of these courtyard residences is closely integrated with the street pattern and morphology, also within the house through the courtyards, Qaah, Rawashin, etc. The comparison is made below (Tab. 3) to provide a clearer understanding of the illustrations (figs. 9 & 10).

Fig.9



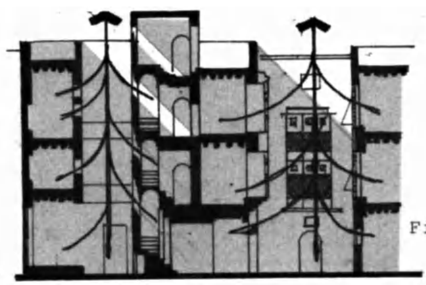


Fig.10

NIGHT	DAY
• As surfaces lose heat, the temperature of the adjacent layer of air gradually decreases. • Cool air being denser than the relatively warm air in the street collects inside. • Exchange between this cold air and the warmer indoor air takes place through the openings in the surrounding walls.	• Exposure to the sun varies from wall to wall. • Exposure of each wall changes the movement of the sun. Part is reflected and the rest is absorbed causing an increase in the surface temperature. • The flow of heat through a wall depends on its thickness and on the thermal capacity and resistivity of its material. • The hot surfaces lose heat to the adjacent cold air layer. The rising heated air is replaced by relatively colder air until the temperature of the air inside the courtyard reaches that of the outside.

Ref. 2

Table 3

HOUSE DESIGN FEATURES

Public buildings such as schools, libraries and rubat have a courtyard system. (figs. 11,12,13). Typically private houses were designed to accommodate an extended family use a Qaah and Diwan system in which passive cooling is achieved. (fig.16A.3 & 4). Ground floor (fig. 16A.4) where the Qaah and Diwan functions as a living area during the summer. The thick walls (60-100 cm) have a high absorption heat capacity. So they absorb the daily solar heat load rather than immediately transmitting it to the interior of the building. This heat is gradually stored in the walls and later released to the interior of the building and into the cool night air. The guests room is located in the Maqad (fig. 16A.1).

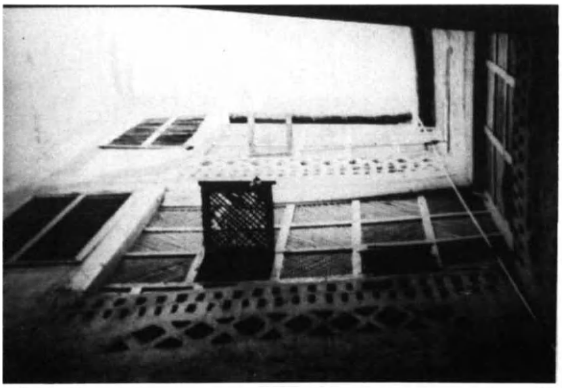


Fig. 11

Fig. 12

Fig. 13

Fig.14

Upper floors were used during the winter. The living area occurs in Majlis (fig.16B.5) and Moakhar (fig.16B.6) with guests in al-Majlis. These walls and roofs radiate heat which was absorbed into the interior, thus making the inside warmer than the outside at night. Small openings in walls were used to minimize the ventilation at night, especially in the rear rooms.

The Dahliz (fig.16A.2) with its bent entrance having a function of privacy, breakdown of dusty winds and to allow cross ventilation through the house and Zuqak. The Dahliz, Diwan and Qaah were washed every afternoon to assist the anabatic cooling system.

BUILDING MATERIALS

The walls and pillars possess a very low thermal conductivity. The ground floor and first floor were constructed of lava "Al-Harawy Stone" where they carried more load, the second and third floor constructed by burnt clay brick where the load is lighter and they are supported by wooden poles(Duvon). The roof is a compact mixture of mud and gravel laid on woven, palm frond rats,which are laid over in a diamond pattern of stiffening sticks,which is finally laid on a(Merwad & Felqah). The roof with this Combination of materials forms a very low thermal conductive surface which minimizes heat gain during the hot summer days,and works as protective surfaces to the lower level.

fig.15

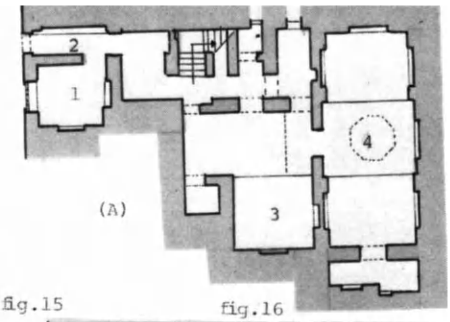
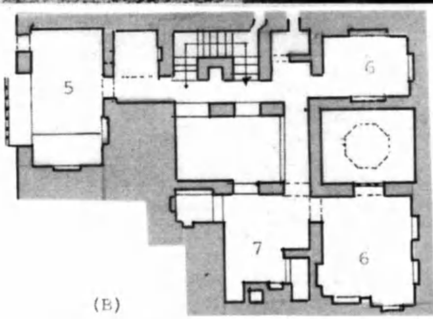
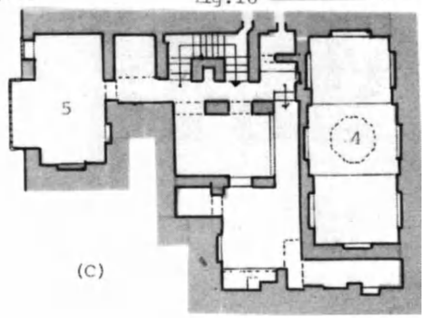


fig.16





INTEGRATED COOLING COMPONENTS

Due to the small quantity of rainfall, it is not practical to use evaporative cooling methods in traditional Madinah residences. Consequently, other cooling techniques were developed which were well integrated in the vernacular building:-

The Qaah is a living area on the ground floor located at the rear of the house. In proportion the width is approximately one-third the length. It is subdivided into three areas, these being defined vertically, the central part,which is lower,serves as the entrance. The Qaah is reached through the Diwan (fig.16A.4). The Qaah has no opening on the sides but instead has one opening on the roof called the Jilah(fig.19). The Jilah has flaps which can be opened or closed depending on the position of the sun(fig.23). It is opened and closed by using ropes that are pulled from below. The areas which are flanked and over looked by rooms on the first floor known as Muakhar.

The Diwan is a central court having a covered sitting area on one side.(fig.18).It is overlooked by a number of rooms and openings in the stair-case. The Diwan is approached from the Dahliz through a bent axis. The stair case opening to the Diwan (Minwar) is stepped inwards from the top to facilitate the flow of air into the interior. (fig. 24).

Rushan is another cooling component which covered the large opening toward the street by a wooden screen. It is intended to reduce the glare of the sun without reducing the cross ventilation through the living spaces as well as to provide the total privacy needed in Muslim society. (fig. 7).

The Dahliz is the bent entrance of the street which offered privacy and uninterrupted flow of cool air into the building interior through an anabatic action and the expulsion of air in a Katabatic action.

The roofs are used by occupants for security and privacy. They are used for summer night time sleeping and social activities. The roof plan is subdivided into allocated spaces for separation and privacy, such as male and female quarters and guest sleeping. (fig. 15)

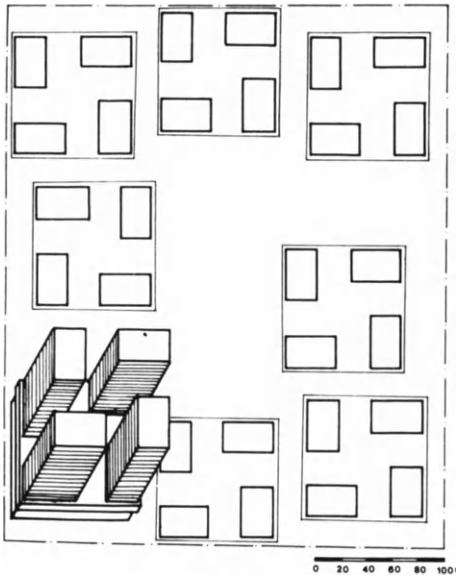
Fig.18

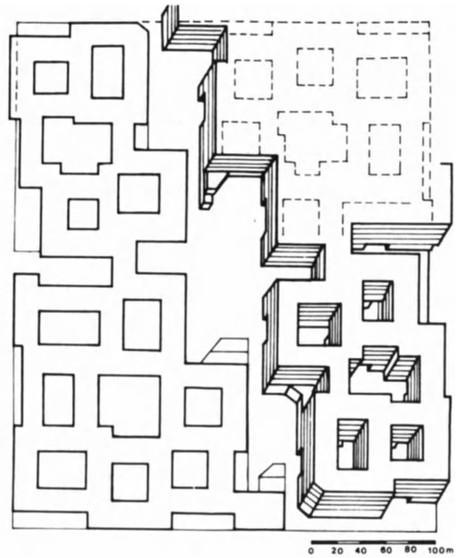
Fig.17

Fig.19

HOUSE COOLING SYSTEM

The system employed in Al-Aqawat is for a whole house cooling system in three stages.
1) The Night Katabatic Cooling (fig. 20): At this time all the openings are secure in the open position including the Jilah and all windows and doors. This permits the cool dense night air to flush out the interior heat and the heat stored in the thermal mass of the structure to assume pre-dawn temperatures.
2) Day Conservation (fig. 21): When the above identified low temperatures have been attained, all the openings including the Jilah and exterior doors and windows are closed to preserve the coolness attained at night.
3) Evening Anabatic Cooling (fig. 22): When interior temperatures rise to acceptable levels in the late afternoon all openings including the Jilah, windows and doors, are opened to allow the warm air to be released in a vertical upward motion so as to flush out the interior heat and to commence cooling of the building structure.
The cycle then again commences with the following Night's Katabatic air flow. In this way the separate components combine to provide a whole house cooling system.





The Kingdom of Saudi Arabia is undergoing rapid development in all fields and as a result many traditional approaches to architecture and urban design issues have been overlooked and neglected. This brief study is meant to provide a measure of understanding regarding the morphology of compact urban form and house design treatment in relation to the extreme thermal conditions of a hot zone,and to achieve highly responsive and historically proven passive cooling systems. This study does not intend to apply or emphasize vernacular solutions,but to understand the idea behind them for possible use in modern developments. Important lessons that may apply are:

- Compact urban form, oriented as possible to East and West.
- Courtyard design, with Qaah and Diwan concept.
- Water system for evaporative cooling.
- Rawashin will allow ventilation and privacy.
- Shared walls to reduce heat gain.
- Use building materials (lava stone) which has high heat capacity.
- Roof for summer night and evening and recreation.

CONCLUSION

The art of architecture is a manifestation of a civilization. It is a physical record of the achievements of particular people extended through centuries, with each successive generation adding to or subtracting from it. But, nevertheless,remaining a continuous link through the centuries. The physical proof is as important as history itself and furthermore, it can be more readily understood than written words. Cities are for both present and further generations, so it is appropriate that they should be preserved as a cherished legacy and a record of their development through time.

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CONVENTIONAL PRACTICE WITH SOME GUIDELINES FOR ENERGY OPTIMIZATION THROUGH PLANNING AND URBAN DESIGN FOR ARID REGIONS

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ABSTRACT

The first part of this paper criticizes conventional practice in planning and urban design in arid areas, in terms of efficient utilization of energy. Basic criticisms are related to: negligence of rural areas and overemphasis and overgrowth of urban areas; overdependence on imports, especially food; exclusive zoning of land-uses; overdependence on the automobile in the circulation pattern; underutilization or overutilization of urban land in terms of density and building height; following the pavilion pattern, in terms of buildings and open spaces instead of the traditional courtyard pattern which is superior in several ways. The aim of the critique is to clarify the most common mistakes and it implies the direction for efficient utilization of energy.

The second part of the paper proposes guidelines for the efficient utilization of energy in planning and urban design in arid areas, which includes: basic strategies; self-reliance at various scales; agriculture within the city; more emphasis on developing the rural economy; mixing urban functions at various scales; efficient circulation pattern and transportation modes; and pedestrianization and rehabilitation of old and historic areas.

KEYWORDS

Energy conservation; planning; urban design; arid areas.

I. INTRODUCTION

Naturally, energy conversion is a universal phenomenon that underlies all processes of life, including those processes that shape the man-made environment -- e.g., site treatment, transportation, construction, etc. Energy unconscious decisions in planning and urban design usually results in inefficient utilization of energy in these processes. The overall outcome of such unconscious decisions, at local, regional, national, international and global scales, can be considerable waste of irretrievable energy as well as a low quality environment. Conscious decisions on the other hand, can reverse the situation -- producing an energy efficient and high quality environment.

Rapid urban development in several arid areas of the world, e.g. the Middle East and North Africa, necessitates the above mentioned consciousness. While some attempts have begun in energy conscious architectural design in arid areas, very little is known about similar attempts in planning and urban design. Energy conscious decisions in planning and urban design can facilitate further energy conscious decisions at the smaller scales of architectural design and design of exterior spaces.

II. CRITIQUE OF CONVENTIONAL PRACTICE IN PLANNING AND URBAN DESIGN IN ARID AREAS

The critique of conventional practice in planning and urban design is not intended for its own sake. This critique is intended to clarify some of the common mistakes to be avoided, which also implies the desired direction towards recommended solutions; in terms of efficient utilization of energy. Basic criticisms are discussed in the following.

II.1. Negligence of Rural Areas and Over-emphasis of Urban Areas

The dual processes of rural emmigration and overgrowth of urbanized areas are usually accompanied by the disruption of localized, relatively self-reliant, economies in rural areas, with their supporting technologies and logistic arrangements. Small scale dispersed economic activities in rural areas are gradually replaced by large scale centralized economic activities in urban areas, which are predominantly dependent upon foreign imports. In other words, the rural economy (which is labor-intensive and energy efficient) deteriorates while the urban economy (which is machine intensive and energy wasteful)expands.[1]

In most developing countries, including those of the Middle East, investment in the agricultural sector brings higher returns -- as much as three times higher -- than investment in other parts of the economy does. Yet the urban economy usually gets the lions' share of both private and public investment. Typically, 20 to 30 percent of the population may live in rural areas. The price of this misdirection of resources is borne by the nation in the form of rural stagnation, urban overcrowding and inefficiencies in terms of energy and economy for both areas. [2]

In most developing countries, including those of the Middle East, the imbalance in living conditions favoring the city over rural areas is usually increased by planning actions concentrated on the needs of the city and neglecting those of the country. [3] The resulting migration from rural areas, which deteriorate, to urban areas, which expand, has a strong influence on energy consumption and production. Urban expansion implies an increase in secondary and tertiary economic activities, which means an increase in energy consumption. Rural deterioration implies a decrease in primary economic activities (especially food production), which means a decrease in the production of some energy resources.

Urban size has historically been constrained by the city's ability to draw on a surrounding area for its basic provisions, especially food. But in modern times, motorized transportation has offset the effect of distance, and as a result the whole globe acts as a hinterland for the world's cities. The trouble is that while the list of countries unable to feed themselves grows, the number of countries that produce exportable surpluses has dwindled. While scores of new importers of grain have emerged over the past two decades, not a single new exporter has been added to the important global exporters who can be numbered on the fingers of one hand. Viewing the globe on a regional basis, only North America, Australia and New Zealand export grain; Africa, Asia, Latin America and Europe are net importers. The time could come when the combined demand for food from the more than 100 importing nations will exceed available supplies from the handful of exporters. If exporting countries experience a series of bad harvests, or if they decide to shift much of their agricultural crop from grain to other crops from which alcohol fuel can be produced, in order to solve their problem of dependence on imported oil, the victims would be the cities of the world that are sustained with imported food especially in the poorer countries. [4]

The problem of importing food for expanding cities over large distances is still severe, even if this food is imported within the same nation. The larger the city, the longer will be the distances between areas of supply and the city. The longer such distances are, the more energy is consumed in transportation. In addition, the growth of cities is usually accompanied by more centralization in the food-supply system, which means more machine and energy intensive activities. A city like New York imports much of its food-supply from California. Accordingly, in the USA food system, only one fourth of the energy used actually goes into food production. The other three fourths is used to transport, process, and distribute the food after it leaves the farm. Unfortunately, most major Middle Eastern Cities seem to be following the same model of New York. [5]

II.2. Over-dependence on Imports

Decisions taken at different levels of urban and regional planning, including national or city policies and programs, affect directly and indirectly the nature of architectural, landscape and urban design projects. Sometimes such decisions are geared towards dependence on imports in order to accomplish certain goals of a policy, or a program, that can include massive projects within a very limited period. Overdependence on imports implies waste of energy due to needed transportation and also due to characteristics of architectural and landscape architecture imports that are frequently inappropriate to the local environment. Overdependence on imports also implies inefficient energy utilization, since it leads to underutilization, or even nonuse, of local natural and human resources.

II.3. Uncontrolled Urban Growth and the Natural Environment

In addition to the negative effect on the distribution of economic activities, uncontrolled urban growth has other negative effects on the physical environment that inevitably lead to energy waste. It usually leads to depletion of natural resources, through an increase in resource utilization to satisfy urban needs and through encroachment upon productive lands. Productive lands include agricultural areas, pasture areas and areas with underground potable water. Such resources can be partially replaced through far more use of fossil fuels. It is also very apparent that with the expanse in urban area, energy consumption increases due to enlongated transportation distances.

II.4. Exclusive Zoning of Land-Uses

Since the advent of functionalism, whose beginnings were in the 1929 Athens Charter of the CIAM group, segregation of land uses in separate zones has been considered to be a primary objective in planning to satisfy hygenic requirements in the urban environment. This segregation was a reaction to the chaos of the urban environment during the Industrial Revolution of the 19th Century. [6] In practice, the segregation of land uses proved to result in a dull environment visually as well as socially. [7] Almost at any scale, the segregation of uses in separate zones results in more need for mobility and consequently more energy consumption in the different ways of transportation. [8]

II.5. Over-dependence on the Private Automobile

In urban transportation, overdependence on one mode of transportation, especially the private automobile, leads to transportation inefficiency as well as a considerable increase in energy consumption. Studies have shown that the private automobile, especially when the driver is the only passenger, is the most inefficient mode of transportation in energy terms. [9] In addition to its polluting effects, the nature of the private automobile requires considerable areas of the city to be exclusively devoted to its use, streets, parking lots, etc. [10]

Unfortunately, trends in most Middle Eastern cities favor the private automobile, providing wide streets and parking lots in the process of urban growth. These considerable asphalt areas absorb and retain solar heat, and consequently contribute unfavorable heat to the city micro-climate. In addition, unlike traditional alleys, wide streets and parking lots are completely vulnerable to sand storms and hot dusty winds. [11] The more efficient modes of transportation, specifically mass transit and bicycle transit, receive unfortunately far less attention.

II.6. Under-utilization or Over-utilization of Urban Land

Under-utilization or over-utilization of urban land, in terms of density, has a direct negative effect on energy consumption in transportation and infrastructure (horizontally and vertically). The new suburbs made of single family detached houses produce a very low density that necessitates a considerable spread of the infrastructure. Consequently, this spread leads to higher initial and running costs as well as more expenditure of energy in initial construction and in the running operation. The freestanding high-rise buildings, on the other hand, contribute more floors than overall density increase due to spacing requirements and provision of parking lots and wide streets. Cost and energy expenditure,both initial and running, increase significantly in the case of high-rise buildings due to special structural and mechanical operation requirements, and also due to the generally concentrated load on the horizontal infrastructure.

II.7. The Pavilion Pattern Versus the Courtyard Pattern

It should be noted that both detached villas and freestanding high-rise buildings follow what is called the "pavilion pattern". The opposite pattern that has been traditionally followed in most of the Middle East, being predominantly in the hot-arid zone, is the courtyard pattern. In their book "Urban Space and Structures", Leslie Martin and Lionel March (1972) have made a quantitative comparison between these two basic building patterns in terms of efficiency in utilizing the site. They found the courtyard pattern to be three times higher than the pavilion in terms of efficiency in space utilization of the site. [12]

Other quantitative studies have also shown that the courtyard pattern is generally more favorable than the pavilion pattern in terms of floor areas to site area ratio, surface to volume ratio and estimated circulation time to volume ratio. It should be noted that efficiency in the above mentioned three ratios positively affects economic efficiency and energy utilization efficiency in the built environment. [13] Efficiency is due to the courtyard pattern's compactness and common walls.

In addition, the pavilion pattern which is being predominantly followed has other climatic disadvantages in comparison with the courtyard pattern. As indicated above, the pavilion pattern has greater surface to volume ratio which means more exposure of buildings to sun and wind. Moreover, unlike the courtyard pattern, in the pavilion pattern open spaces are not contained. So, air cooled at night, by irradiation to sky from horizontal surfaces and by convection, is swept away soon in the morning to be replaced by the general mass of hot air, which is a considerable disadvantage especially in hot-arid climates. [14]

II.8. An Illustrative Example

Most of the above criticism is clearly manifested in a recent housing project in Jeddah, Saudi Arabia, called "Jeddah Rush Housing Project", composed of 32 towers each 15-stories, totalling 1936 apartments (fig. 1). In response to the good intention of housing the maximum number of people in the shortest period of time, the project was constructed in an impressively short period of around 2 years. Such speed demanded the importation of almost everything -- building materials, labor and construction equipment -- in order to utilize advanced construction technology. [15]

A research analyzing and evaluating the project has indicated that it is theoretically possible to build the same number of apartments in low-rise buildings on the same site and utilizing mostly local labor and materials. That theoretical alternative would demand a longer period of construction of around 4 years but would result in a faster overall rate of occupancy. To explain this last point, it should be noted that in the "Jeddah Rush Housing Project" occupancy starts after finishing the construction of the whole project, while in the theoretical alternative new residents can move in every few months as soon as a package of low-rise buildings is finished. [16]

In addition, it was found that the same floor areas of the project, which follows the pavilion pattern, could be built in about only one-third the present height (5-6 floors) if the courtyard pattern is followed (fig. 2). The same research indicated that the theoretical alternative could provide more privacy for residents and a better design of open spaces. The above comparisons imply the waste of energy in building and operating massive projects such as "Jeddah Rush Housing", which are unfortunately being mostly followed in the Middle East. [17]

III. GUIDELINES FOR THE EFFICIENT UTILIZATION OF ENERGY IN PLANNING AND URBAN DESIGN IN ARID AREAS

III.1. Basic Strategies

Three basic strategies are proposed here for overcoming the universal problem of dwindling reserves of fossil fuels, which are : 1) to save oil as much as possible through energy conservation measures in order to raise the efficiency of energy utilization; 2) to utilize renewable energy resources replacing fossil fuels as much as possible; and 3) to gradually restructure the economy and the man-made environment in a way that allows the first two to happen more efficiently. These three strategies underlie the guidelines mentioned in the following.

III.2. Self-reliance at Various Scales

In order to realize the third strategy of restructuring the economy for energy efficiency and in order to overcome the negative effects of over-dependence on imports as mentioned earlier, self-reliance should become a main objective of different levels of planning for economic development. Self-reliance should be achieved not only at the national scale, but also at the regional, subregional and possibly settlement (town or village) scales. Self-reliance at these smaller scales is especially needed in many desert countries in the Middle East where human settlements are concentrated at relatively few locations in the vast desert area,

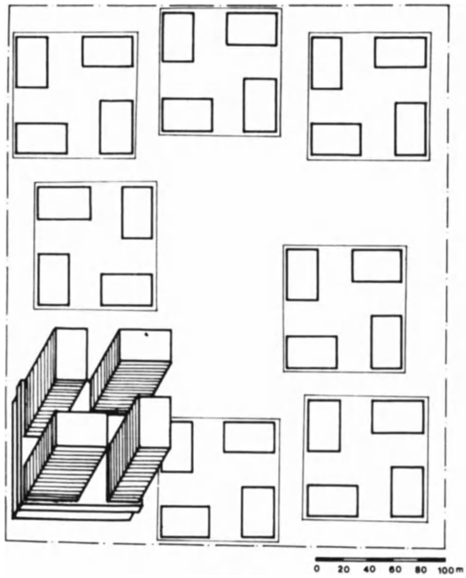


Fig. 1. Jeddah Rush Housing Project illustrating the separated pavilion pattern. [15]

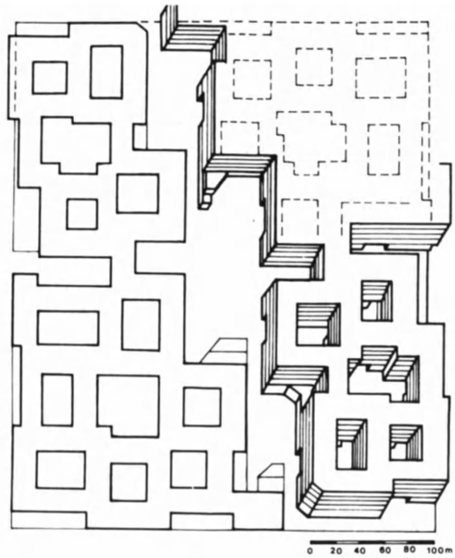


Fig. 2. A conceptual alternative to Jeddah Rush Housing Project (courtyard buildings with common walls) accommodating the same number of apartments. [17]

Fig. 3. A proposal for the central village of Togan. [29]

Fig. 4. A proposed pattern for the zone where city and countryside meet. [30]

necessitating long transportation routes for the delivery and exchange of goods and services. The difference between self-reliance and self-sufficiency, which is not advocated here, is that most basic needs are met locally in self-reliance while all basic needs are supposed to be met locally in self-sufficiency. Generally speaking, basic needs are considered in this research to mean energy resources, water, food and primary economic activities in agriculture and in industry.

Peter van Dresser in his book entitled "A Landscape for Humans" dealt with the main objective of self-reliance at several scales as it can be achieved in the uplands region of Northern New Mexico, USA. [18] Some of his ideas which were found to be appropriate for developing countries in general and especially desert areas are mentioned in the following:

A. There should occur a redistribution of population, means of production and patterns of trade in a manner that facilitates greater local and regional self-reliance in the production of goods and services. As part of this redistribution, the smaller range of "urban places" (villages, towns and provincial cities) should undergo a renaissance as vital functional elements in the economic and cultural order. [19]

B. In agriculture, monocultural cash crops (export oriented) are ecologically and economically vulnerable, e.g. "Potato Blight" in 1848 Ireland. Accordingly, they should be avoided, and the same applies on over-specialization in primary industries. Instead, the aim should be a diversified economy based on and symbiotic to available natural resources. In addition to diversity in agriculture, and partially based on this diversity, a "vertically integrated" complex of biotic resource industries should be developed. For example, a localized spinning and textile industry can increase many times the value of wool taken from sheep, instead of limiting the economy to raising sheep and selling their wool very cheaply as a raw material. Such integrated economic diversity can increase economic security and stability for towns, regions and nations. [20]

C. A type of production technology should be encouraged which is adapted to the utilization of renewable resources (vegetative growth, climatic cycles and energies, ...etc.) and based on science, skill and manpower in small and medium scale intensive activities, rather than on large scale, extensive mechanization and mechanical energy activities. [21]

D. Small and medium scale economic activities as outlined above can be efficient. Inefficiencies, due to lack of economy of scale in individual productive operations, can be more than compensated for by simplified logistical relationships (including "site economies") and by freedom from parasitical costs of financing, over-transportation, over-handling of commodities and over-administration of services. [22]

E. Small and medium scale economic activities based upon and symbiotic to available natural resources, as mentioned above, have many different applications. As an example, for the encouragement of localized production and exchange of basic commodities and services, there is needed an effective and relatively dense intra-regional network of roads. These highways should be as inexpensive as possible and engineered for relatively light traffic and moderate speeds. If such roads are sensitively planned especially in terms of location and runoff arrangements they can help in stabilizing the landscape rather than in aggravating erosion. Another example is the resort and recreational facilities which are recommended to be small-scale, dispersed, and integrated with the economic and civic life of the organic communities. This kind of facility is contrary to conventional practice where large recreational complexes can monopolize the best sites for non-productive use. [23]

F. Communication and education institutions and techniques should be developed in a way that facilitates the above mentioned transformations, while maintaining a high level of social and ecological awareness and a reasonable degree of scientific and intellectual competence. Especially, education institutions should be practically oriented. [24]

Another important author who also advocates self-reliance, energy efficiency and a healthy physical and social environment for small urban communities is Michael N. Corbett. In his book entitled "A Better Place to Live, New Designs for Tomorrow's Communities", [25] he emphasized the importance of location, size and density, which are discussed in the following.

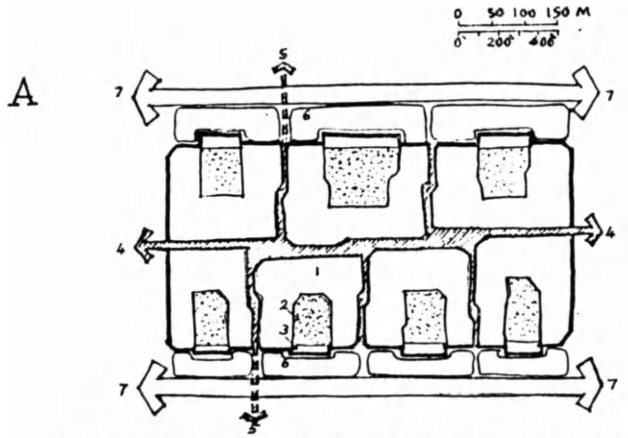
In terms of location, the following characteristics were found to be most important in achieving self-reliance: [26]
- Availability of water without non-sustainable demands on groundwater.
- Potential for local production of a variety of wholesome food.
- Potential for meeting energy needs locally.

Having the above location characteristics, energy consumption in the transportation of water, food and energy would be minimized. To explain further how energy transportation is wasteful, it should be noted that the longer the distance electricity must travel the more electricity is lost due to resistance in the transmission lines. In addition to the above main location characteristics, there are other location characteristics that can help in achieving both self-reliance and a high environmental quality, which are:
- Potential for development of an economic base, especially if based upon some natural resources such as agriculture, forestry, fishing or mining.
- Absence of environmental hazards and environmental contamination.
- Proximity to transportation corridors and proximity to a cultural center.
- Desirable climate and scenic beauty.

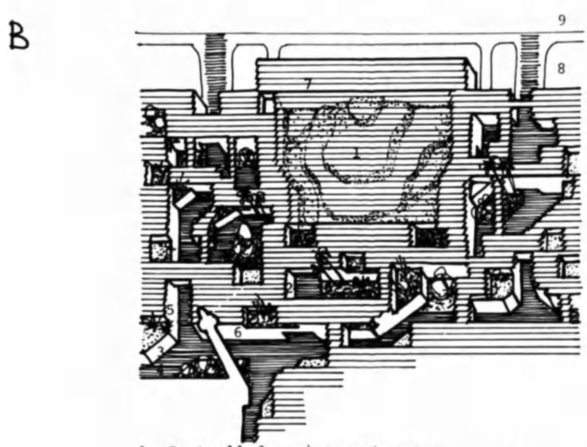
In terms of size and density, the urban pattern advocated by Corbett is one of small, relatively moderate-density towns with enough distance between them to give a lower density overall. Moderate density within the town would provide stimulating social contact and would eliminate most of the need for automobiles by encouraging pedestrian and bicycle circulation. Low regional density would reduce air pollution, allow local agricultural production (in areas between towns and even inside towns) for each town's needs and permit easier waste management and recycling. [27]

III.3. Agriculture Within the City

The basic concept of mixing agricultural and urban land uses at various scales has been dealt with before, by several authors, for the same objectives of self-reliance through local food-production, environmental quality and lately for energy efficiency. In 1898, Ebenezer Howard promulgated a scheme to build new towns rather than adding population to the already large cities. The new towns, called garden cities, were supposed to be small in scale, having a strong relationship with the surrounding country-side, and to a great extent self-sufficient in food and employment in diverse urban functions. [28] M. Tewfik made a proposal for planning the central village of Togan area in Eastern Sudan, in which he employed the basic concept of mixing agricultural and urban land uses [29] (fig. 3). The Center for Environmental Structure, Berkeley, California, USA, also employed the same concept in their proposed solution for the zone where city and countryside meet, instead of the conventional suburbia [30] (fig. 4). The author also used the same basic concept of mixing agricultural and urban land uses in a prior work, "A Proposal for a Self-reliant Desert Community in the Middle East" [31] (fig. 5).



1. Neighborhood, with a mixture of residential, commercial and other public functions along the community main street.
2. Controlled Environment Space
3. Administrative, Storage, Mechanical & Industrial Functions
4. Community Main Street (Pedestrian, bicycles & electric tractor train).
5. Secondary Streets.
6. Parking.
7. Vehicular Traffic, which includes public transportation.



1. Controlled environment space
2. Residential courtyard (small neighborhood)
3. Urban plaza
4. Community main street (pedestrian & bi-cycles)
5. Secondary street (pedestrian & bicycles)
6. Commercial, and other public functions, mixed with housing
7. Administrative,storage,mechanical and Ind-ustrial functions
8. Parking
9. Vehicular traffic

Fig. 5. Mixture of urban and agricultural land-uses at the scales of a community(A) and a neighborhood (B)[31]

The pattern of mixing agricultural and urban land uses has been practiced before in the Middle East and still exists in some cities, but unfortunately it is disappearing at an alarming rate. Unayzah, a rural Saudi city with a population of 35,000 in 1977, demonstrates this pattern very clearly. In this city, urban and rural land uses once existed side by side. Next to the city's center used to stand some of the best palm trees and most intensively cultivated fields in the Qasim region. [32] Al-madina Al-munawara is even a stronger example. The whole city was sunken in and surrounded by orchards of palm trees. Both cities and more in Saudi Arabia and the whole Middle East can consciously utilize urban growth patterns in the direction outlined before, in order to conserve such precious natural resources and achieve a reasonable degree of self-reliance.

III.4. More Emphasis on Developing the Rural Economy

In addition to encouraging agricultural production near and inside cities, in order to achieve a degree of self-reliance at the local level, the agricultural sector at the national level should receive adequate attention especially in terms of investment in order to achieve self-reliance at the national level and decrease migration from deteriorating rural areas to overcrowded urban areas. Thus, the gap between city and countryside would be minimized, the quality of life in both would be improved and country's natural and human resources would be more optimally utilized. As mentioned earlier, investment in most developing countries in the agricultural sector brings higher returns -- as much as three times higher -- than investment in other parts of the economy. In addition, investment in the agricultural sector enables the absorption of the labor force growth (human energy growth) faster and more economically, than investment in capital intensive industry does. Thus, unemployment or underemployment in urban areas could be overcome.[33]

The solution to the problems of food shortage and dependence on imports, rapid depletion of energy resources, unemployment or under-employment, and quality of life in both overcrowded urban areas and deteriorating rural areas cannot be found inside cities alone. A major part of the solution can be a flourishing agricultural base that can support a network of decentralized small scale labor intensive industries. As agricultural profits generate new indigenous markets for industrial goods, the people employed in these industries will generate a new market for agricultural products [34] "Vertical Integration" of these industries, along the lines suggested earlier by Van Dresser can strengthen and stabilize this rural economy.

III.5. Mixing Urban Functions at Various Scales

In order to realize the strategy of restructuring the man-made environment for energy efficiency, and in order to overcome the negative effects of segregating land uses in the city, mentioned earlier in Critique of Conventional Practice in Planning..., mixing of functions should become an important objective in urban planning and urban design. Almost at any scale, from a whole city to a building, the mixing of functions decreases the need for mobility. At the scales of a city to a neighborhood, the mixing of functions can minimize the use of vehicular transportation and accordingly can save considerable amounts of fossil fuels. In addition, such mixing can encourage pedestrian and bicycle transportation which would save further amounts of fossil fuels, beside decreasing air pollution and enhancing the urban environment. [35]

The mixing of urban functions, however, should not be implemented arbitrarily. One of the most important guidelines here is to decentralize places of work and mix them with housing as much as possible. This guideline applies even to most light industries that do not generate pollution nor necessitate continuous long operations. To explain this last point further, it should be noted that it is always more efficient, in terms of energy and consequently cost, to transport materials than to transport people. If the industrial plant is concentrated, the bulk of workers must live away and commute. If the plant were scattered, the workers could live near their jobs, and it is the processed materials that would have to be collected for assembly from their several places of manufacture. The working men must be transported twice daily; the material and mechanical parts at much longer intervals. [36]

Another important guideline for mixing urban functions is to decentralize commercial, recreational and other service activities. Such activities should be distributed between small scale numerous "town centers" and neighborhoods, instead of the conventional huge Central Business District on the one hand and large shopping centers at the city periphery. M. Corbett recommends keeping the small scale "town center" within 0.5 to 1.25 miles from residential areas to facilitate bicycle and pedestrian circulation in a town or an urban module (7,000 to 30,000 in population) within a city.

III.6. Efficient Circulation Patterns and Efficient Transportation Modes

The above mixture of urban functions in small scale neighborhoods and "towns" or "urban modules" should minimize the use of the automobile. A schematic circulation diagram of such a "town" is shown in fig. 6 in which all streets feed outwards to a peripheral ring road, rather than inward. Bicycle and pedestrian paths, on the other hand, would run inward from each neighborhood to the geographic center of town, where the commercial and civic facilities people visit most often would be located. Vehicle access to the town center could be provided by a single service road bisecting the town, either on grade or below grade, and connecting at both ends to the ring road. With such a circulation system, one could reach any point in the town by auto, or travel between any two points, if necessary, by driving out to the ring road and around to the appropriate street entrance. The route would be fairly indirect, however. The direct routes would be reserved for the bicyclists and pedestrians for whom distance is more crucial than it is for car drivers. [37]

Maximization of the use of pedestrian and bicycle circulation and minimization of the use of vehicular traffic can also be implemented in existing cities in urban rehabilitation projects. Figure 7 shows how this can be achieved in a segment of downtown streets through different treatments including: converting a street from vehicular into pedestrian with parking lots, which are necessary for this auto free area, at the periphery; limiting the width of the vehicular road to the central lane only and expanding the width of the side-walks for pedestrians; including a bike route beside the vehicular lane or in the middle of a completely pedestrianized street. [38] Figure 8 shows other possibilities.

Cycling and walking are certainly two of the most energy efficient modes of transportation, as can be seen in the chart in fig. 9, while the automobile (especially when driven by 1 person) is the least efficient. [39] Generally speaking, public modes of transportation are also considerably more efficient than the automobile, and should be encouraged as much as possible. However, public modes of transportation cannot operate successfully, in terms of economics and convenience, unless the overall density is relatively high and the intervals for stopping are long enough depending on the specific mode. In any case, it should be noted that no single mode of transportation is capable of serving all urban needs. While the automobile (the dominant transportation mode) has caused considerable harm in energy terms and in environmental terms, it cannot be omitted completely and it cannot be replaced by one or two modes of transportation. A successful circulation

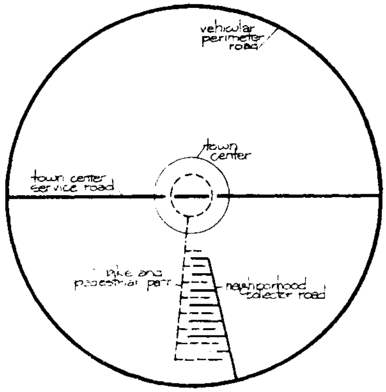


Fig. 6. A schematic diagram of the circulation pattern in a town, maximizing pedestrian and bike circulation and minimizing vehicular traffic. [37]

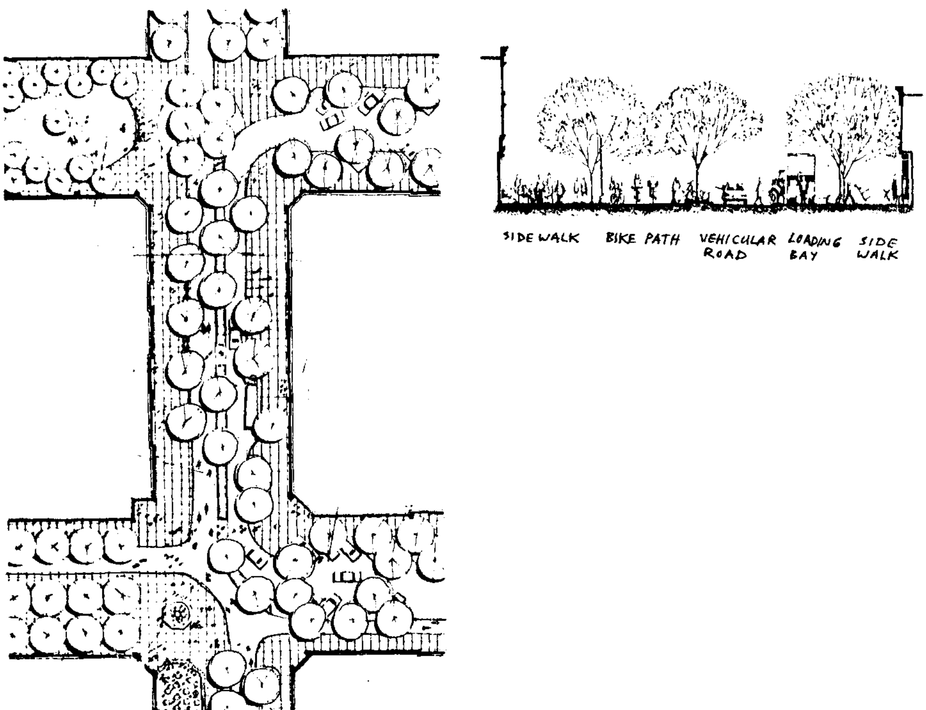


Fig. 7. How conventional downtown streets can be converted into predominantly pedestrian and bike environment [38]

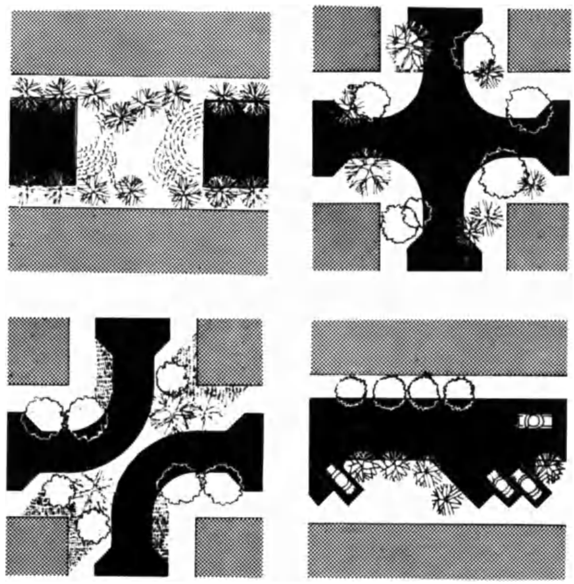


Fig. 8. Possibilities for converting conventional urban streets into a pedestrian oriented environment. [42]

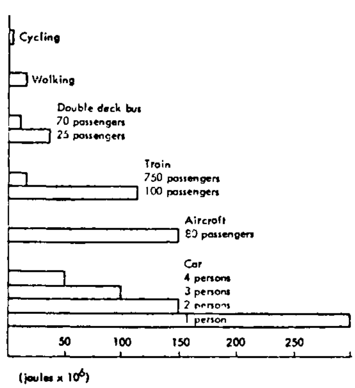


Fig. 9. Energy efficiency of different travel modes, units in joules/person/100 km. [39]

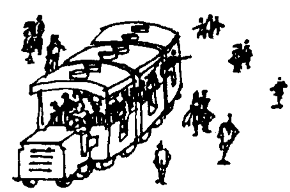


Fig. 10. Battery operated tractor train which can mix with pedestrians. [10]

pattern would be multi-mode. The larger the scale, the more complex would be the needs and accordingly the need for more modes of transportation. The planner should attempt to achieve an appropriate combination of such modes, while attempting to minimize the use of the automobile.

Battery-operated vehicles deserve more attention from planners and urban designers for their advantages of not generating direct air pollution nor noise pollution. Battery-operated vehicles include the private car, the mini-bus and the tractor train (fig. 10). The last two can be designed to operate at low speeds of 10 to 15 miles per hour, which can allow them to mix safely with pedestrians. Such mixing would result in the additional advantages of flexibility in the choice of the transportation mode and would enable the expansion of the pedestrianized zone. [40]

Finally, it should be noted that communication can replace transportation, with considerable savings in time, cost and energy. Telephones, closed circuit televisions and wireless communication can considerably decrease the need for mobility. Furthermore, advanced communication systems facilitate the possibility of decentralization of several urban functions that were conventionally centralized in exclusive large zones for the sake of assumed efficiency, e.g. offices and most industrial plants. Accordingly, the type of mixed urban functions at the small scale can be efficiently achieved. [41]

III.7. Pedestrianization and Rehabilitation of Old and Historic Areas

The pedestrianization of downtown streets is particularly more justified in the old and historic parts of the city for environmental, cultural, social and aesthetic reasons. In addition, streets in such old areas do not easily accommodate automobiles. Middle Eastern cities are very rich in historic areas that need pedestrianization for the above reasons; and furthermore because pedestrianization would literally save such areas which are presently deteriorating at an alarming rate. Pedestrianization of historic areas would stimulate the redesign of the whole environment, not just the circulation pattern, and hence the revival and rehabilitation of the whole area. Energy would be saved not only through decreasing gasoline consumption in automobiles, but also through making more efficient use of these old areas -- with all their buildings and open spaces -- and accordingly eliminating the need to spend considerable amounts of energy to build new facilities.

The pedestrianization of historic areas can provide an opportunity to improve the efficiency of the overall circulation patterns of such areas and the city at large. This is especially true when the pedestrianized area is extensive, not just a small mall. One of the best examples in this direction is the historic central area in Munich, West Germany (fig. 11). In this excellent example, the extensive pedestrian network is supported by even a more extensive network of public transportation, including buses and a rapid transit system organized in different layers underneath the pedestrianized area and linking it to the rest of the city including its residential suburbs. [42]

IV. CONCLUSION

From the above discussion the main points emphasized in this paper are:

- Achievement of self-reliance at various scales, especially through more support of rural areas and local resources while minimizing dependence on foreign imports.

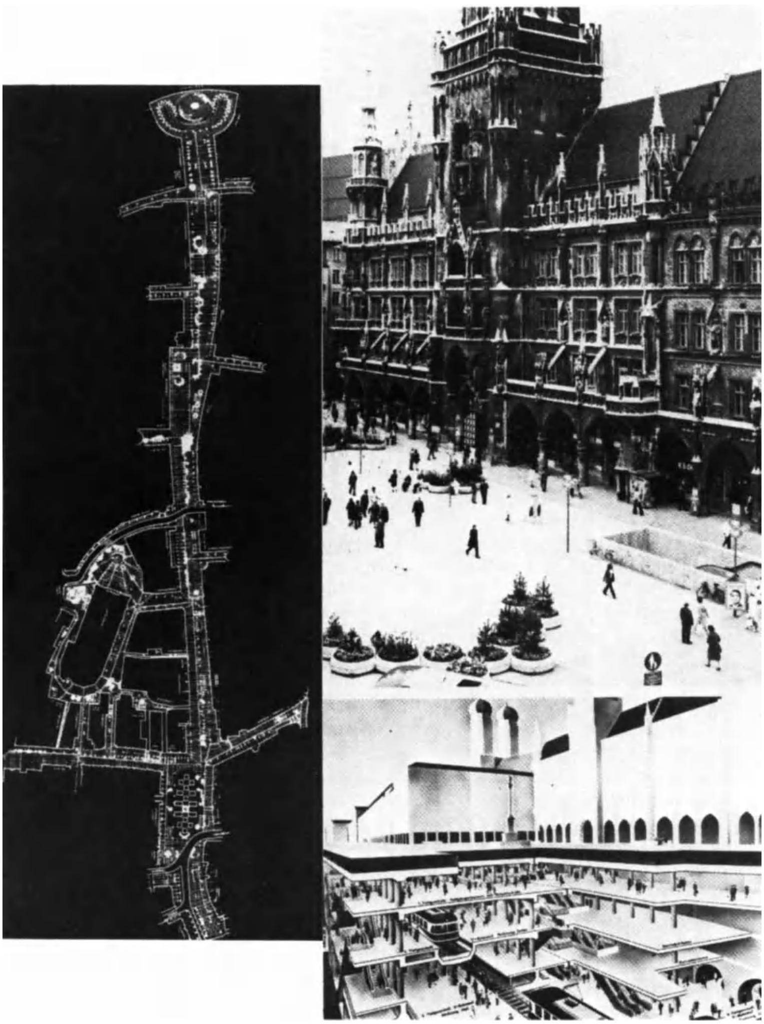


Fig. 11. The extensive pedestrianized network in the Central Historic Area of Munich, W. Germany and the multi levels of public transportation supporting it.[42]

. Protection of sensitive areas of the natural environment from urban encroachment, and appropriate management of the local natural resources.

. Appropriate choice of location, size and density of urban areas.

. Practice of agriculture within urban areas at various scales.

. Mixing urban functions appropriately rather than segregating them.

. Developing a multi-mode circulation pattern, minimizing the dependence on the private automobile and maximizing the accommodation of pedestrians, bicycles and battery operated vehicles.

. Pedestrianization of urban, especially old and historic, areas should attempt at rehabilitation of the area, upgrading the efficiency of different facilities, and upgrading the overall circulation pattern of the city.

. Maximization of the use of the courtyard pattern and minimization of the use of the pavilion pattern, in terms of the basic pattern of buildings and open spaces.

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SOME BIOCLIMATIC ISSUES IN THE DESIGN OF OCEAN FRONT COMMUNITIES: THE EXAMPLE OF "OLD" MIAMI BEACH, FLORIDA, USA

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ABSTRACT

This paper examines the bioclimatic impact of site planning and platting decisions made during the early development of the seaside City of (South) Miami Beach, Fla. USA at the turn of the century which has since evolved to become 1) an international tourist resort destination, 2) a large permanent residential community for a predominantly elderly retired population, and 3) the recently designated and first twentieth century historic district. This community fronts the Atlantic Ocean and is situated in a sub tropical, hot and humid zone. The evolutionary adaptation of selected building typologies to the original land platting patterns are presented from a ventilative, daylighting and shading standpoint. The social utilization of the outdoors is very pronounced. These structures represent local vernacular examples which were created in the pre-air conditioning era of USA construction prior to World War II. The architecture which evolved beyond original platting intentions addressed climatic issues. The potential exists to maximize passive energy benefits from a more thoughtful and comprehensive approach to land organization (platting) in relation to desired building typologies in the planning of seaside communities. Current applications and impacts from ocean front developments generally offer completely opposite and negative results.

KEY WORDS

Platting; typology; courtyard; breezeway; shade; socialization

METHODS

A variety of data has been collected from a continuum of sponsored and non sponsored research in the area from 1977-82, regarding the history, architecture and social issues. These methods combined physical with behavioral evaluation techniques and include field surveys and measurements of buildings, lot and climate data, photography and visual analysis, public records analysis, literature review, structured interviews, participant observation, and graphic mapping.

Fig. 1. South Beach, view South

Fig. 2. View North, 1940

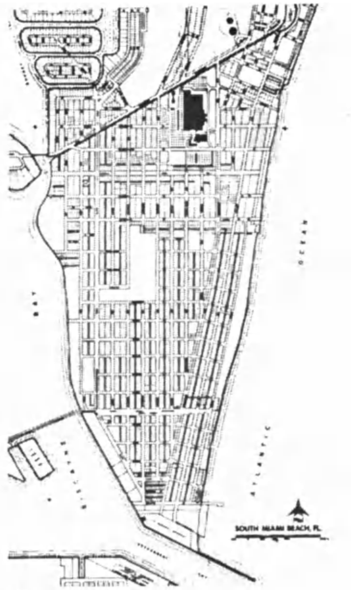


Fig. 3.

SOUTH MIAMI BEACH: LOCATION AND EVOLUTION

The City of Miami Beach today, is a developed barrier island approximately seven miles long with a number of smaller, natural and manmade islands, bounded on the west by Biscayne Bay, on the east by the Atlantic Ocean, on the north by the City of Surfside, and on the south and west by Government Cut and Biscayne Bay. The legal City limits include approximately seven square miles of land, and nine square miles of water. Miami Beach water frontage includes 7.4 miles of ocean, 10.5 miles along the Bay and 18.9 miles rimming inland waterways. 'South' Miami Beach has a very strongly defined urban form with the area almost completely surrounded by water, with the Collins canal on the North, and the Government cut in the South (Fig.1). The land area is approximately 1046 acres or 1.63 square miles with approximately 44,000 persons living there representing 48% of the City's population on approximately 24% of the land area; 62% of the residents are over age 65. South Miami Beach is linked to the mainland (Miami) by two automobile Causeways.

The climate of Miami Beach area is classified as subtropical marine, the only such climate in the United States. Miami Beach is influenced by it's proximity to the equator, the Gulfstream, and by the prevailing winds from the Southeast, Miami Beach's location on the ocean has a local moderating influence on it's climate. Miami Beach has less fluctuation in its daily temperature than does the City of Miami across the Bay. Fluctuation on the Beach averages 10 degrees Fahrenheit compared to 18 degrees Fahrenheit at the Miami Airport, 10 miles inland. In addition, the City has an average of 46 inches of precipitation each year, with 75% of that occurring between May and October, compared with the airport which gets nearly 60 inches. September is the wettest month of the year, while March is the driest. The average humidity is 70%, and the average wind speed approximately ten miles per hour from the southeasterly trade winds. On Miami Beach, the yearly average temperature is 76 degrees, the surf temperature is 79.8 degrees, and the city averages 240 days of sunshine annually.

Fig. 4. View South on Ocean Drive

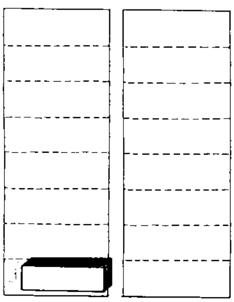


Fig. 5. Single Lot

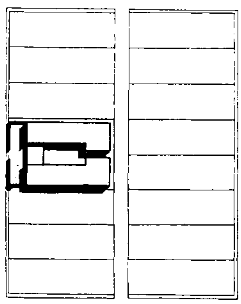


Fig. 6. Double Lot

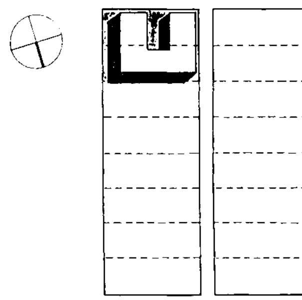
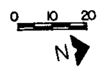


Fig. 7. Double Lot

The first inhabitants of Miami Beach were believed to be the Tequesta Indian tribe, the aborigines of the lower east coast of the Florida peninsula who might have settled there around 1400. The Tequesta flourished in the Mangrove swamps and sandy dunes that formed most of the island. The area was almost inaccessible and visited only by the most adventurous hunters and explorers. An unsuccessfull attempt was made to form a coconut plantation on the island in 1870 (H. B. Lums). In 1896 when the City of Miami was founded (Flagler and Tuttle), another fruit and vegetable plantation was begun by J. S. Collins when he discovered fresh water aquifer. At this time the Lummus brothers, who were Miami business men, began acquiring land holdings south of the Collins plantation in the area of present day 'South Beach', for the purpose of creating a '<u>City fronting the Ocean</u>'.

The 'Barrier Beach' as this area was then called was a popular recreation area for Miami's mainland residents. A bathing pavilion was located on the ocean and a ferry line operated between Miami and the Beach. On July 9, 1912, the first subdivision plat was recorded through the Ocean Beach Realty Company by the pioneer founder Mr. J. N. Lummus. This subdivision was located at the

Fig. 8. Century Hotel



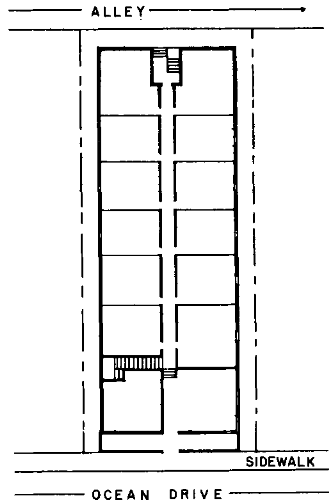


Fig. 9. Plan

southernmost tip of the island adjacent to the bathing pavilion. The following years saw the creation of two more land sales companies, one by Collins-Pancoast and the other by Carl G. Fisher who envisioned luxurious residential estate and recreational development in the areas north of South Beach. By 1915, the infrastructure was established and the three companies merged their efforts to incorporate the 'Town' of Miami Beach. Mr. Lummus was the first Mayor who donated land for a public park fronting the Ocean in his name which is the focal point for South Beach today (Fig.4). In 1913-14, many modest homes were built in this area including the first hotel.

1920-29 saw the famous Florida land and development 'boom' years. Many hotels, apartment houses and private residences were constructed in the prevailing 'Mediterranean' eclectic style of the period. The severe hurricane of 1926 and the subsequent national economic 'crash' of 1929 brought an end to this period of rapid growth and speculation. The post depression 'boom' years occurred from 1930 to 1941. The permanent residential population quadrupled during this period and the newly arriving middle class introduced 'tourism' as the major attraction of the area. The new wave of tourists sought to forget the gloomy, depression ridden northern cities and a small group or architects responded by introducing a whimsical, playful streamlined-moderne brand of 'Art Deco' style to the hotels and apartments houses. By 1940 the South Beach area was fully developed (Fig. 2).

The importance of the architecture within the South Beach of Miami Beach is well summarized in the "statement of significance" in the historic district nomination submitted to the State Historic Preservation Office in 1978: The area became officially an historic district on the National Register of Historic Places in May 1979; the first 20th century district...."'Old' Miami Beach is significant because this 1.0 square mile area contains the largest concentration of early twentieth century resort architecture in the United States. There are approximately 1,200 buildings remaining which are presently used for residences, commercial enterprises, and as hotels. Their construction dates between 1923-1945. Resulting from a combination of historical and economic forces, the area developed relatively rapidly, netting an extraordinary architectural consistency. Surveyors have identified over four hundred noteworthy buildings in the district."

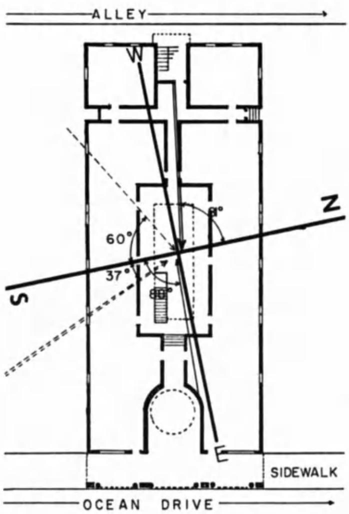


Fig. 10. Plan Solar Orientation

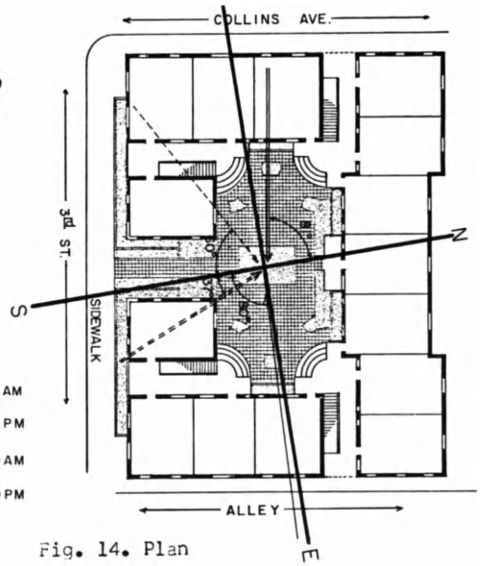


Fig. 14. Plan

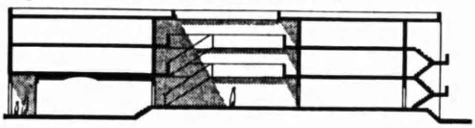


Fig. 11. Section

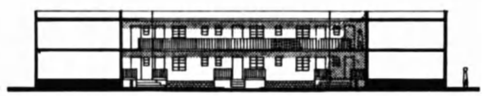


Fig. 15. Section

Fig. 12. Elevation

Fig. 16. Elevation

Fig. 13. Street View

Fig. 17. Courtyard

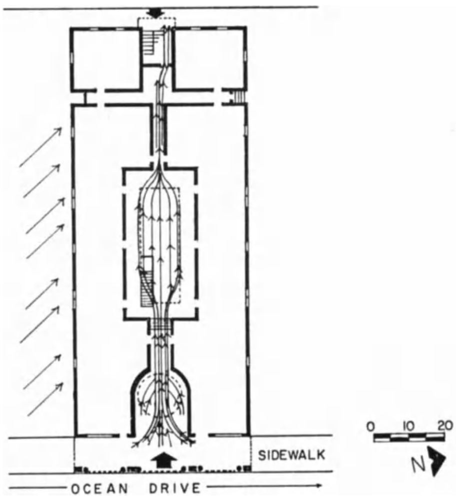


Fig. 18. Wind Pattern

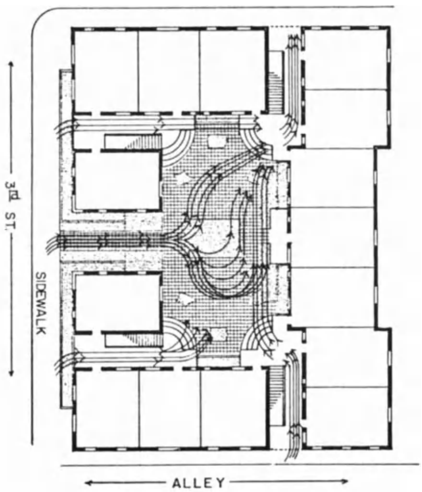


Fig. 19. Wind Pattern

PLATTING AND BUILDING TYPOLOGIES

The first subdivisions ran in a northeasterly direction, 12 and 1/2 degrees east of true north with the long dimension of the blocks oriented directly to the prevailing southeast breezes. Subsequent platting in the area followed a true north-south grid in the area (Fig. 3). This contrasts with the City of Miami across the Bay and other inland developments in which the long dimension of the blocks ran in an east-west direction with the short side of the blocks facing east. The typical South Beach block measures 300 by 400 feet and is bisected in the north-south direction by a 20 foot wide service alley. The block totals 2.57 acres and is divided into 16 - 50 by 140 foot lots with 8 of the 50 foot lots facing east in each block.

The area is characterized by many individual property ownerships which has led to developments on mostly one and two, and sometimes three adjacent lots. From hundreds of buildings surveyed, ten typological variations have been found adapted to various lot combinations. The basic type is the central corridor linear building on a fifty foot lot. Other variations on mid block and end block conditions form open spaces and courtyards with channel shape, U shape, H shape and Split and L shape buildings (Fig. 5-7). For the most part, these apartment and hotel buildings have very good ventilative orientation fronting the Gulfstream breezes.

The basic building typology is linear with the central corridor running east-west the length of the building. The first hotel (1914) was constructed in this manner and still exists. Illustrated is the Century Hotel (1939) with ornamental 'Art Deco' details of the period including 'eye brows' over the windows for token sun protection (Figs- 8-9). At the front of the building is usually found a wide lobby, porch or both collecting the breezes. The corridor then acts as a breezeway intensifying the breezes as they pass through the building to an opening at the end. Each door to the apartments contains a transom overhead as well as a screen door. The side yards of 10 feet between buildings also act to intensify the breezes. The original windows were vertical casements which when open, would direct breezes into the rooms. Doors and windows are almost always open here.

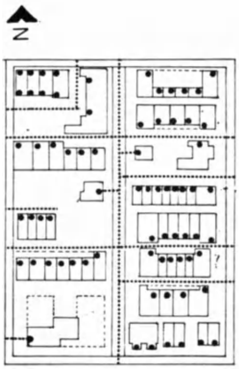


Fig. 20. Res. Block

Fig. 21. Mid Block Walkway

Illustrated in Figs. 10-13 is the most interesting variation on the 50 foot lot, the Hotel Leonard (1925). This building begins to split the central corridor and form a small interior courtyard. The courtyard represents 13% of the building area, is 20 by 40 feet and three stories high. The narrow opening leading into the space creates a 'Venturi' effect for the incoming breezes (Fig. 18). Solar shading for the space has been documented for winter during January 10 AM and 4 PM, and summer during July at 10 AM and 4 PM. This courtyard is almost always in shade with the deepest penetration of sunlight occuring in late morning July (Fig. 11). This building also overhangs the public sidewalk right of way forming a covered arcade for additional sun protection. As a result of these devices, the building enjoys extensive utilization by residents and visitors of the outdoor spaces with a high degree of comfort and activity.

Figs. 14-17 document an interesting courtyard building constructed on 2 lots on an end block condition and facing south in the longest dimension. This building is the Ocean Terrace Co-op Apartments and was constructed in the 1930's. The large courtyard (35 by 70 feet) comprises 22% of the building area. There are five penetrations into the space from the east, south and west taking full advantage of wind currents (Fig. 19). The sun always penetrates some of the space, therefore, the area is heavily landscaped with fruit trees to provide additional shade. The deepest penetration is illustrated for July (Figs. 15-16). This courtyard enjoys extensive use by the residents.

As one moves back from the Ocean front blocks to predominantly residential (apartment) blocks with a few small homes, another interesting phenomenon takes place which may be attributed to the breezeway effect of air currents between buildings. Fig. 20 illustrates a typical block with 'mid block walkways' indicated with a dotted line and entrances to the various apartments and buildings indicated by dots along the pathways. There are very few entrances located on the streets. Socialization areas can be found primarily on the southeastern face of the blocks as well as on the mid block pathways consistant with the path of prevailing breezes and entrances. These arrangements surely evolved over a period of time, could not have been envisioned in the original intent, and provide clues to future platting and building arrangements to take maximum advantage of climatic benefits.

CONCLUSION

The platting intent indicated envisioned a modest 'City fronting the Ocean' composed of single family residences. The evolution of building (courtyard) typologies and building arrangements within the blocks at higher densities (60 to 100 dwelling units per acre) and at a small building (human) scale, illustrates the importance of maximizing climatic benefits in ocean front settings. This area is comprised of a predominantly elderly retired population who are primarily concerned with sun protection with maximum benefits from healthy breezes. The illustrations included are but a few from hundreds of examples within the area which provide design and planning clues for subdivision platting consistent with well planned building arrangements. Later examples (not located within the historic district) and erected during the post World War II years to the present day, offer completely opposite and negative results. The buildings are usually larger and completely internalized being completely dependant on air conditioning. Open spaces are usually left over and not wéll conceived for climatic benefits or social purpose. The residents are forced to adapt to 'found places' in order to enjoy the climate (Fig. 22).

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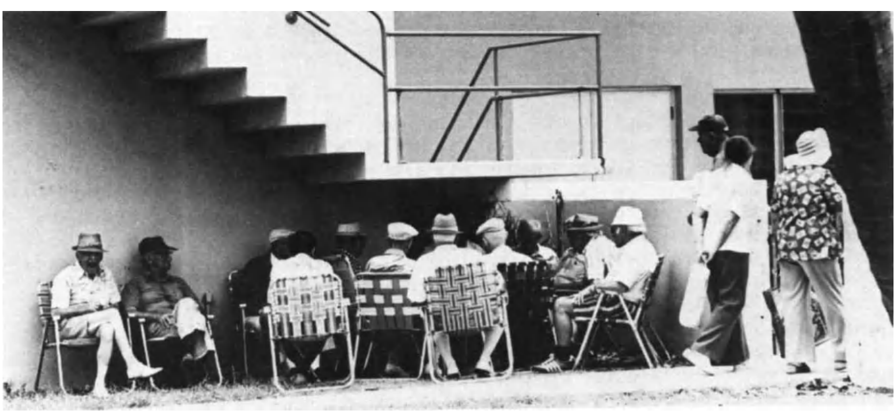

Fig. 22. Seeking the shade in modern buildings

TLALPUENTE: PLANNING FOR ENERGY EFFICIENT COMMUNITIES IN MEXICO

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ABSTRACT

Tlalpuente is a pilot community on the southern rim of the Valley of Mexico experimenting with an alternative to urban sprawl. Located in a green belt which serves as the principle source of subsoil water for recharging the Valley aquifer, Tlalpuente is a model for a form of residential land-use which conserves a non-urban environment and creates a "green barrier" to the physical expansion of Mexico City urban space. At present illegal settlements threaten the green belt areas and can not be contained simply by legislating "ecological conservation." These areas must be occupied by a new kind of settlement based on low-energy architecture, passive energy systems and rational use of scarce resources, especially water.

KEYWORDS

Tlalpuente; Mexico City; greenbelt legislation; low energy residence; lifestyle.

INTRODUCTION

The purpose of this paper is to describe a pilot project for experimenting with low energy alternatives to traditional urban residence patterns. The site of this experiment is a rapidly shrinking green belt which spans the southwest edge of the world's largest city in the Valley of Mexico. From the viewpoint of city planning, the idea behind the community is to occupy green belt space to create a barrier to the physical expansion of urbanized area. Tlalpuente is a residential community planned for a maximum of about 150 families in an area of about 2,000,000 m^2, in a highly dispersed settlement pattern which attempts to maintain the basic ecological nature of the zone: woodlands and agriculture. The mild climate of the Valley of Mexico makes passive heating and cooling of dwellings an easy matter and residents have experimented with a variety of solutions. Tlalpuente's most severe ecological problem, however, is shared by many communities in the region: water supply and water conservation.

In this paper I present an introduction to some of the planning considerations for the development of this model and some of the problems we have yet to solve.

ECOLOGICAL SITUATION OF TLALPUENTE

Tlalpuente is situated on the lava flows of Mount Xitle in the Ajusco volcano complex on the southern rim of the Valley of Mexico. This area, known as the Sierra de Ajusco, has a predominant land-use pattern of agriculture and heavily modified low forest of oak, madron, juniper and pines. This pattern has been present for centuries, but the essentially rural character of the area is now being threatened by rapid population growth (mostly immigrants from Mexico's provinces) and the economic distortion caused by housing shortages and Mexico City's expansive urbanism.

Given the city's tremendous growth rate, it is tempting to be resigned to the inevitable urbanization of large parts of the green belt, were it not for the crucial ecological importance of the area for the entire Valley ecosystem. The green belt, which extends from the Sierra de Ajusco around the southwest rim of the Valley to Toluca, is the principle area from which the Valley of Mexico aquifer is recharged by rainwater infiltrating the subsoil. Urban expansion threatens to cover these areas, reducing the rate of renewal of the city's major water supply.

Human settlement in the Valley of Mexico has always been faced with water as a primary limitation. The Valley presents a curious paradox of water scarcity (rainfall concentrated in four months from June to september) and over-abundance (the Valley floor is lakebottom with severe flooding and drainage problems).

Indian civilizations located in the Valley solved these problems by respecting the basic lacustrine nature of the region and by implementing region-wide hydraulic control systems maintained by inter-community cooperation to reduce flooding. An offshoot of this sophisticated hydraulic engineering was the chinampa agricultural system, based on fields raised from the bottom of shallow lakes, one of the most productive and energy efficient agroecosystems in human history.

When the Spaniards invaded Mexico the complex Indain hydraulic system fell apart. Within a few years the newly constructed colonial city flooded severely and it was decided to drain the lakes. This process has taken over three centuries and has not been totally acheived even today. Nonetheless the area of chinampas and other types of agriculture which supplied the city's food have been drastically reduced.

The growth of the city during the past decades has put a tremendous strain on the water supply of the Valley. The aquifer, which supplies most of the city's needs, is currently being pumped at the rate of 50 m^3/s, whereas hydrologists estimate that the rate of recharge is only about 20 to 25 m^3/s. This deficit has caused problems of accelerated subsidence in the historic center of the city, which is now 9 metres below the level of the canal system built to drain the Valley.

Urbanization of the southern green belt would exacerbate these problems considerably. Apart from the increase in demand for drinkable water, deforestation which accompanies normal urbanization would undoubtedly affect rainfall, which has already shown a tendency to decrease over the past years. Many soils would be covered with constructions and pavement and would no longer be permeable to rainwater. Thus, not only would the rate of subsoil infiltration be reduced, but water would run on the surface to the Valley floor where is would create further drainage problems.

The problem of water supply alone is sufficient motivation for a serious effort to preserve the green belt, but other motivations exist as well: the unique floral and faunal associations in danger of extinction, the diverse food production activities (including grains, fruits, vegetables, flowers and forage for livestock) and the rich cultural heritage of the Nahua Indian communites with their ancient traditions of caring for the earth in this region.

TLALPUENTE AS AN ALTERNATIVE RESIDENCE PATTERN

An important step in conservation of the green belt was taken in a Municipal Department decree, effective in February of 1983, defining permitted land use and constructions within the area designated for "ecological conservation". In particular, residential land-use patterns are restricted to two types: 1) "forestry with dwelling" and 2) "agriculture and livestock with dwelling." (Diario Oficial of the Mexican Government, Primer Seccion, pages 117 to 126, 29 November 1982). Urban-style housing developments, office buildings, shopping centers, parking lots and similar constructions are prohibited. Roads which enter the area must be for local access only. These areas are to be of restricted access to maintain low population density at all times. So that development of the areas do not put further burden on overtaxed city services population density is restricted to not more than 2 families per 10,000 m^2. Residents are required to be self-sufficient in water, through rainwater collection.

The importance of this new law cannot be underestimated but legislation alone is insufficent to ensure conservation of this area. To understand why it is necessary to occupy green belt space with an alternative residence type we must examine the socioecomic context in which Tlalpuente exists.

Before the new law there were three types of settlement patterns expanding in the green belt area outside of Tlalpuente which we can call 1) traditional, 2) low income immigrant and 3) high-income immigrant. The traditional type is the nucleated town typical of much of rural Mexico in which live many agriculturalists with land in the green belt area.

Low-income immigrants form new colonies (often overnight) by illegally invading an area and constructing whatever minimal shelter can be made with whatever refuse is at hand. At worst, these illegal colonies continue to grow in the same manner. At best, the residents are able to find jobs, pool resources, get legal recognition for their settlement and solicit city services. In this way the area becomes incorporated into urban space.

The third type of dwelling constructed before the new law is in some ways the most troublesome from the standpoint of green belt conservation. The high-income immigrant buys or otherwise adquires a large piece of forest and/or agricultural land in the area. He first erects a tall wall around the property, often topped with broken glass and barbed wire. Inside he constructs a shack for armed caretakers who guard his property. He then proceeds to build a mansion, usually ugly, always wasteful of energy and water and requiring a live-in staff to maintain the house and grounds. The natural landscape is destroyed and paved over for parking the several family cars or lawns and gardens are planted requiring constant watering and intensive care. Even swimming pools and fish ponds may be constructed. To support this waste, the high-income immigrant uses his influence to get preferential services from the city and builds a large pipeline to monopolize whatever water supply available. Obviously the carrying-capacity of the green belt zone for this type of residence in extremely limited.

Illegal invasions by squatters of whatever income level is one of the reasons that enforcement of the new law is difficult. Simply declaring areas "biological reserves" will not stop such invasions. Rather the green belt areas must be occupied by an alternative land-use which serves as a barrier to invasion and preserves the ecological conditions of the zone.

In Tlalpuente the worst abuses of the types described above have been avoided and a few residents have begun experimenting with low energy architecture, small single family dwellings integrated into the habitat, effcient in the use of construction materials, energy and water and oriented towards the land as a woodland and food production ecosystem.

Fewer than 20% of the property owners have constructed houses and are living in the community at the present time. These houses were constructed before the new law but most of them (though not all) reflect the spirit of that law. Any visitor to Tlalpuente will note the results of the efforts of the property owner's Association to preserve the area -- the ecological conditions within the community constrast greatly with the surrounding area towards the city. The Association has approved recently a new Regulation which conditions future constructions within the new law and adds other restrictions for environmental, safety or æsthetic reasons. Among many other aspects, the new regulations suggest or require the use of certain low-energy, resource efficient technologies particularly relating to rainwater collection and water conservation.

TLALPUENTE: THE NEXT PHASE

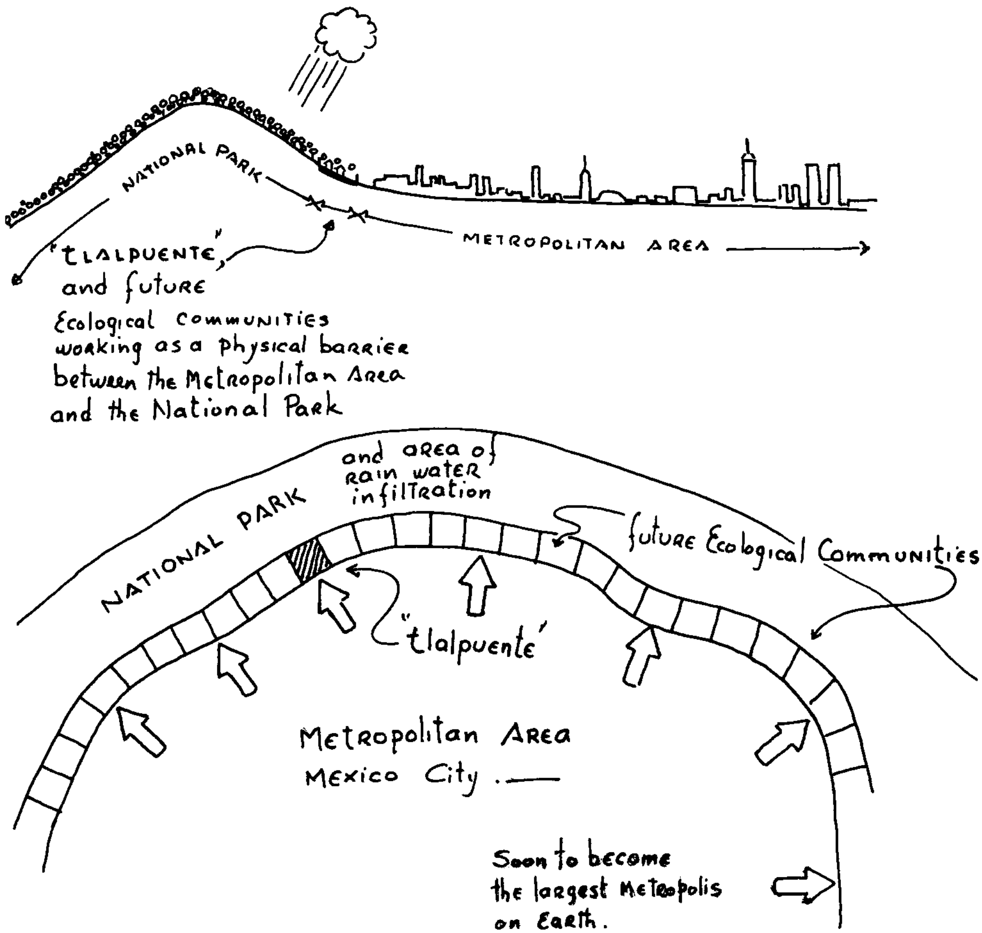
The regulations conditioning construction in Tlalpuente and the new green belt law (and other forthcoming laws) represent the end of a long phase (over 15 years) of struggle by many people to gain official acceptance for the idea of environmental conservation through low energy, habitat-responsive living patterns. Tlalpuente and similar communities now face a new problem of enforcing and adapting the new legislative measures so the development of these areas is an orderly process that actually preserves green belt habitat conditions.

Although one problem is presented by recalcitrant property owners who believe that the new laws should not apply to them, this is a small, if troublesome, minority. A more serious problem which must be faced is the practical one of development of working versions of appropriate technologies to make the alternative lifestyle feasible and attractive.

For example, the Tlalpuente regulations require dwellings to provide for the separation of grey water for recycling. However, the first complete recycling systems installed have not been entirely successful. Problems arise from variations in local materials etc. and are fairly easy to identify but they indicate that a good deal of serious experimentation is necessary to develop satisfactory systems. Unfortunately, for the moment, the Association does not have funds to support this experimentation and it must be left to the residents at present. Considerable support comes, however, from what we might call the "low energy alternative" community in Mexico, a small but dedicated band of architects and experimenters who have taken an interest in the goals of Tlalpuente. We sincerely hope to widen this support community to include international groups as well since such support helps us deal with local authorities and advance the cause.

CONCLUSION

Tlalpuente has as its principal goal the creation of a model residential community appropriate for the preservation of the green belt and which can serve as a physical barrier to the expansion of destructive urbanism. The legal basis for such communities has been established. We now face the tremendous political and technical task of making them a reality.


NATIONAL PARK
METROPOLITAN AREA
"tlalpuente", and future Ecological communities working as a physical barrier between the Metropolitan Area and the National Park
NATIONAL PARK
and area of rain water infiltration
future Ecological Communities
"tlalpuente"
Metropolitan Area
Mexico City.
Soon to become the largest Metropolis on Earth.

MARIN SOLAR VILLAGE

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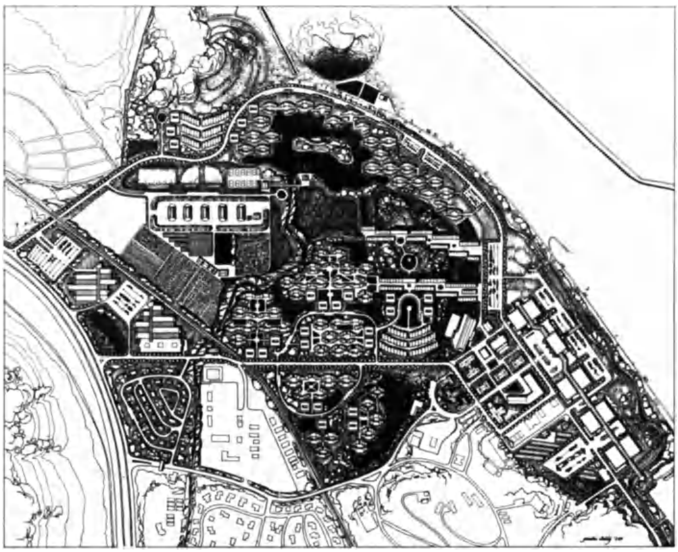
Marin Solar Village was planned in an effort to integrate workable solutions and new models addressing the issues faced by most communities in the eighties: the rapidly escalating costs of housing, energy, and basic services; the need to strengthen local economies with new jobs, the reduction of transportation congestion, the enhancement of the natural environment and quality of life. The plan involved converting about one-third of the 1271 acre Hamilton Air Force Base, located twenty miles north of San Francisco, California and abandoned as surplus federal property.

The key concept of the plan is sustainability. This concept is an ideal that is modified by particular local conditions, the characteristics of site, economics, and technical feasibility. However, its basic implication is balance and permanence: balance between the availability of local renewable resources and local consumption patterns; balance between people living in the community and the availability of jobs within the community; balance between maintaining the natural environment in good health and the needs of the people who live within it.

The design strategies adopted for Marin Solar Village to achieve a sustainable, balanced community are not experimental. All have been tried before and have been proven to be feasible. The innovative characteristic of the proposed development is that these ideas have been combined in a general comprehensive plan that is buildable and economical today. The aggregation of these strategies reveals a fortuitous coincidence: not only do they increase energy efficiency, but they also serve as ecological stabilizers; not only do they allow reduction in housing cost, but they also increase the quality of the environment and allow for social diversity and integration.

Therefore, the 1500 units of new townhouse and apartment dwellings reduce energy and land consumption because of their compact form as well as solar application. As a result of the reduced land construction and infrastructure costs, almost all of these dwellings will be priced below market rate housing. The rehabilitated Village center with community facilities, retail, and recreation gives purpose to a pedestrian network and electric transit system. The on site biological sewage treatment plan recycles wastes into biomass and energy, while recovering water for the commercial farm. The mixed-use components, new and rehab office, and light industrial space will generate local employment, economic strength, and community identity, as well as decreasing energy consumption in transportation by reducing commute time.

The energy analysis of the prototype plan shows that the overall energy use in building, transportation, services and food system could be reduced without any major changes in lifestyles or any significant cost premium at least 45% from today's levels of comparable communities in California. By selecting alternative technologies and conservation measures in order to replace depletable fuels, primarily petroleum and natural gas, we have been conservative and we have chosen only those that are proven cost effective today.



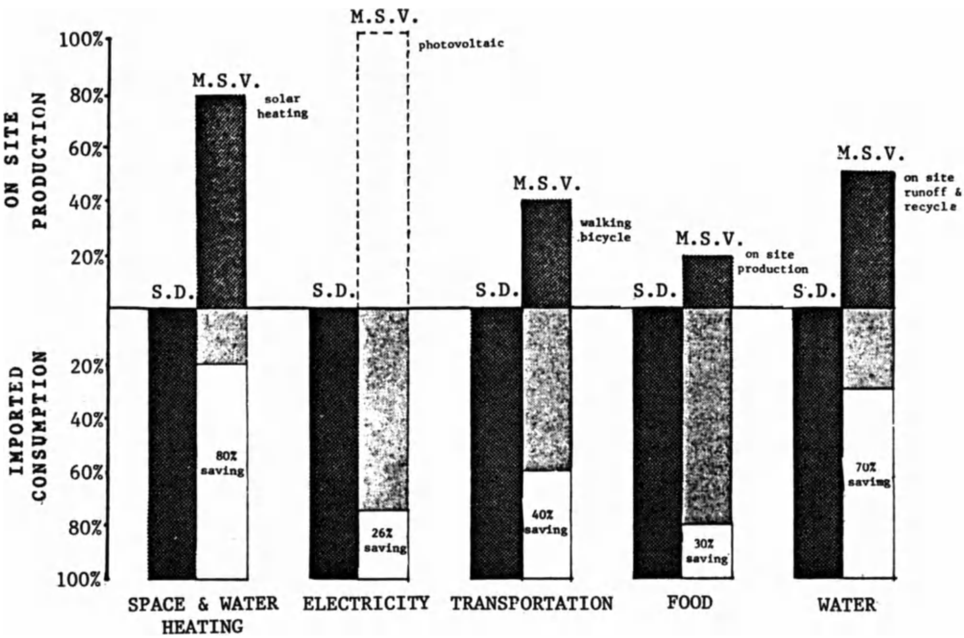
-MARIN SOLAR VILLAGE PLAN-

On Site Energy Production

The outlook for generating on site electrical energy is not favorable because of lack of wind, the still high costs of solar thermal-electric technologies, and insufficient organic material and space on-site to justify the cost of a facility converting wastes to electricity. However, provisions for on-site electrical cogeneration using conventional fuels to reduce peak demand may be feasible. An energy reduction of 40% through cogeneration or 25% just by adopting state of the art conservation measures has been calculated.

Approximately 40 acres of the Solar Village are given over to agricultural production of vegetables and soft fruits, and to related facilities. It is estimated that in commercial production, this area can supply approximately 30% of the Village population's requirements for fresh fruits and vegetables. In addition to commercial agriculture, space has been provided within each neighborhood for community gardens, backyard gardens, and terrace planting.

The entire water needs of 95 acre feet annually can be supplied by recycled wastewater held in a reservoir. The Village is designed for water conservation through the use of draught resistant plantings and low water devices in all residences, and through the reuse of purified waste water for agricultural use.



-Energy and Resources Comparison Between
Marin Solar Village (M.S.V) and Standard Development (S.D.)-

Transportation

The main strategy is to reduce auto use and commuting to jobs and services by linking jobs, homes, and services within the Village and by providing accessible alternatives to using the car for short trips which themselves account for the majority of private auto use. An energy reduction of 40% will be possible by reducing the commuting population by at least 25%. By using a more compact housing form, the auto is eliminated from circulation within the neighborhood while still remaining accessible. The centralized parking under the atrium apartments located at no more than 400 feet from one's dwelling vastly reduces the amount of paved surfaces and their inherent construction costs and storm drainage. The pedestrian quality of the neighborhoods should enhance social integration and discourage use of the auto within the village. Minibus service loops each neighborhood at short intervals, connecting homes, business, shopping, schools, and a transit center with connecting buses to other locations.

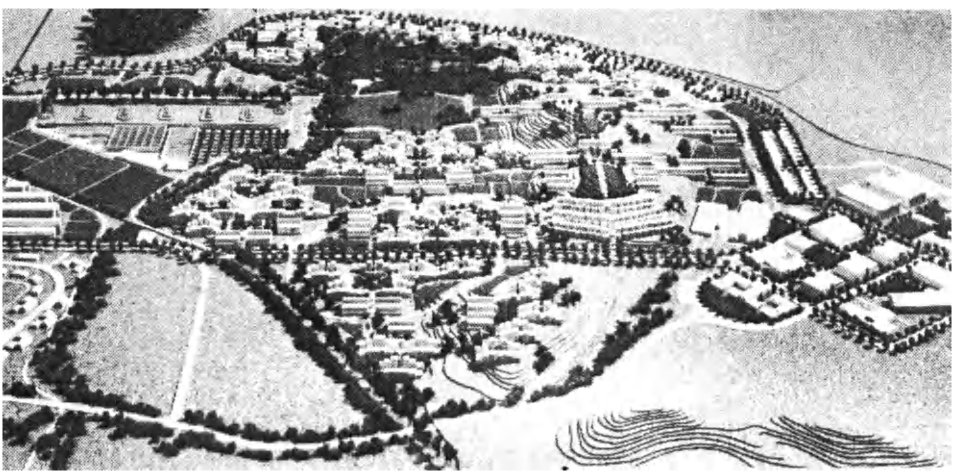
Building Rehabilitation and Commercial Center

At least 770,000 square feet of existing space will be rehabilitated for light industrial and commercial use. Another 800,000 square feet of new office and light industrial space will be built, including two three-story buildings designed for extensive natural daylighting and passive solar heating and cooling. The plan calls for reserving 24 acres for the office center and 40 for light industry.

The existing stock of building provides the best resource to reduce the cost of space for business and housing, and therefore, possibly attracting a mix of large and small business in research, distribution, and light manufacturing. This fact, in addition to the provision of a variety of housing prices and retaining more earned income within the area through both job creation and exporting less money for energy, will possibly enhance the economic diversity identified as a major goal of the proposal.

Housing Plan

The plan calls for building 1500 new dwellings in five neighborhoods over a ten year period, plus rehabilitating some existing housing. The housing development is in a sense the principal aspect of the Marin Solar Village plan. All points of the community design are interdependent with the housing: economics, quantity and type of commercial scale, transportation strategies, landuse and recreation.

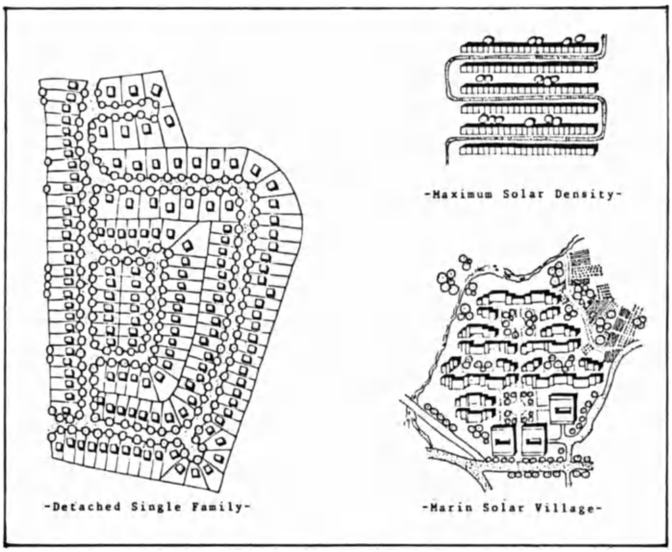


-Marin Solar Village-

The economic guidelines indicate that the total project would need a minimum of 1,000 units. The need to create a balanced community with differing employment types and lifestyles require a great variety of flexibility of housing units, from single family townhouses to small studios; from shared living clusters to apartment residences. All new buildings are oriented south and spaced for 100% solar access, with solar heat collected by windows, greenhouses, and trombe walls, and stored in the building mass.

The principal design guideline was to adopt attached dwellings rather than single family dwellings. Several studies have demonstrated reductions in heating and cooling demands of 50% as a result of townhouse-type party wall construction. The townhouse building type reduces construction and site development costs as well. Reduced roadways, shorter utility lines and smaller land areas all contribute to the overall reduction in costs, and, indirectly result also in energy and resource savings.

In terms of land areas, the Solar Village Housing pattern consumes 66% less than a typical neighborhood of detached houses, while providing a rich variety of open spaces, private yards, and cluster courtyards. The community gardens, square and greens provide identity for the neighborhoods and social gathering points.



-LAND USE COMPARISON-

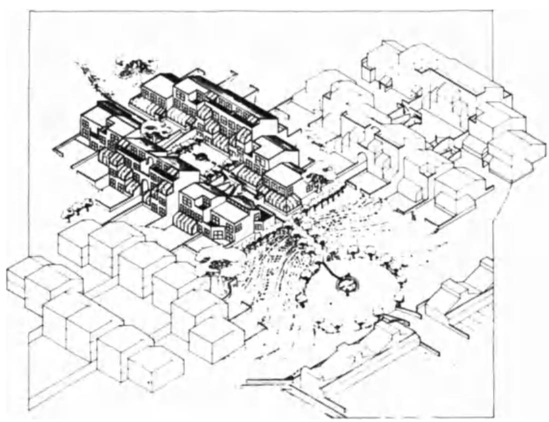
Housing Prototypes

Four basic housing types were developed to provide variety in the plan, structure for the neighborhoods, and a response to unique topographic situations. The four types--cluster townhouses, small homes, south terrace, and atrium apartments--were designed with several floor plans, generic massing for solar access, and schematic passive solar systems.

Cluster Townhouse

This prototype is a collection of townhouses surrounding a courtyard or plaza. The cluster is a social grouping of up to 14 units (two potential stacked units) which is smaller than the neighborhood but larger than the individual dwelling or building. All access is off the court creating north and south entries. Each unit has a private yard away from the court. The three-story building heights are at the center of the cluster where the courtyard is broadest. The two-story units at the ends close the courtyard, and have a shorter spacing for solar access.

The cluster is quite flexible, changing throughout the plan to create neighborhood greens, square, or opening to the lake. Although this is a fairly dense pattern,

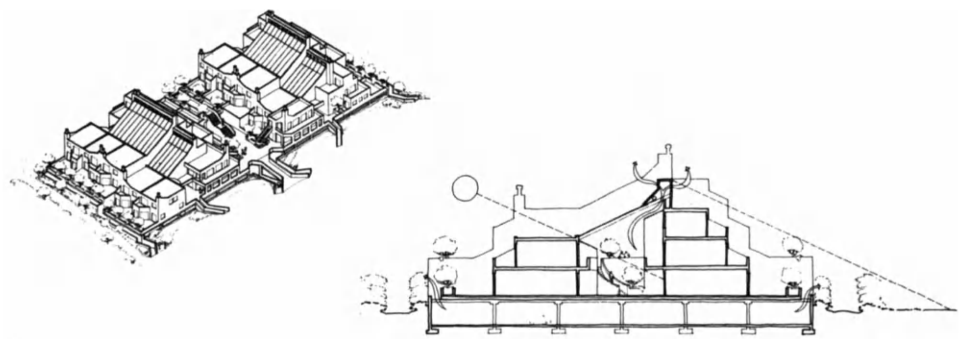


each unit has a private entrance and yard. The clusters "mesh" together in a diamond fashion according to the solar access guidelines for spacing. The broad center of one cluster fits with the thinner end dimension of the adjacent cluster. The spaces between clusters are private yards, when close to the housing, and community garden or recreation space when housing is separated beyond the solar access minimums.

Atrium Apartments

This prototype organizes ten smaller units around a solar atrium. The atrium is glazed with sloping south facing skylight roof. This space is the central entry point for all the units and therefore acts as an entry vestibule. As a passive solar greenhouse, the space acts as both a buffer zone, shading the space while it is ventilated through the Belvedere Ridge. This combination of shade and ventilation will keep the space comfortable through summer periods.

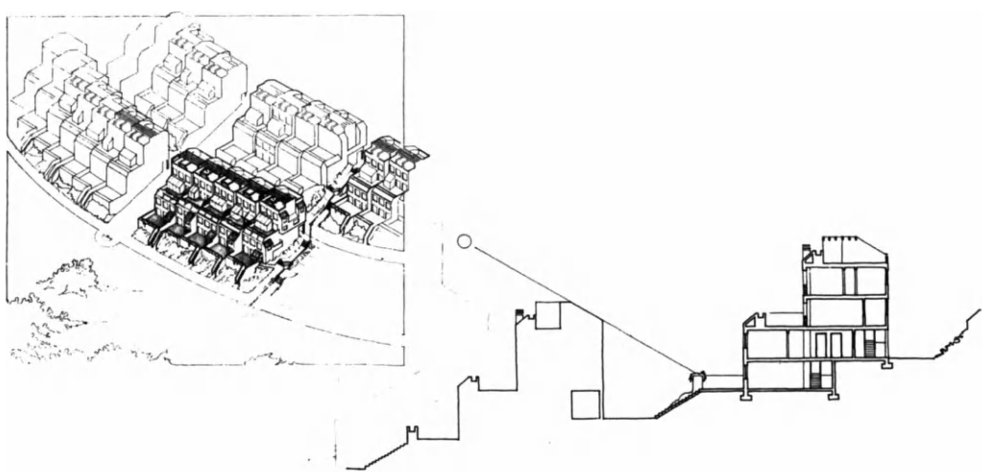
The winter sun will heat the buffer space, and small fans will draw warm air from the atrium and store its heat in the concrete floor structure. This floor structure, made of "spancrete" panels, has integral air passages to allow charging of the mass. The stored heat will passively discharge into the apartment via floor radiation and convection. As there are no stacked units, each apartment has approximately 400 square feet of radiant floor. The heat will naturally migrate to the upper floors at a sufficient rate to maintain comfort levels throughout the house.



Below the apartment, one half level below grade, 87 parking spaces are provided. These serve both the apartments above and the adjacent neighborhood of cluster townhouses or south terrace housing.

South Terrace Housing

This housing prototype generates the highest densities on site in response to its favorable south slope location. This slope allows solar access to closely spaced buildings as they step up the hill.



The stepping provides terraces and south walls with excellent views and an open feeling in a dense configuration. In plan, the townhouses step to form a large crescent, forming the lower edge of a hilltop park above and a kind of gateway to the Village Center below. The crescents have pedestrian paths running across to the hillside for individual entries and paths runing down the hill to connect the main boulevard and the park. The location and scale of the crescent will provide a symbol and focus for the village; following the sun, wrapping the hillside and ceremoniously framing the park.

Two plan types are stacked to form a four-story building. The lower unit is entered from the south via a large terrace. This two-bedroom unit employs a simple masonry south wall and direct gain for heating. Cross-ventilation for the lower floor is aided by a stack effect up the stair well. The upper floor plan has both a south terrace off the main living space and a rooftop deck. The stairway to the roof deck doubles as a belvedere to aid summer ventilation. The plan is set back employing the lower unit's masonry fireplace. This upper unit is entered from the north via an exterior stairway.

FRIENDLY HOMES: A SUSTAINABLE COMMUNITY

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ABSTRACT

Friendly Homes is a cooperative community in a rural Kentucky setting which is to be food and energy self sufficient. It is located on 115 acres of rolling Madison County farmland (36° N) and consists of 116 dwelling units with supporting community facilities to be built over a ten year period. Started by a group of retired people, it is a utopian model for a sustainable future. The "Seniors" live on fixed incomes, and over the years have built up savings and equity in their present homes. From these resources, they are able to provide the capital for the construction of the community. Younger community members will do the construction, grow the food and provide the services required by the community, receiving wages and building equity in their homes and in the community. Because of this internal economy, the quality of life will remain uncompromised even though the community is to be built at low cost.

To complement this unusual economic and social structure, it was necessary to design an architectural counterform which was generated from the same sorts of values. During the process of designing Friendly Homes, it was discovered that a number of low energy approaches become possible as well as economical at the integrative community scale which are not possible at smaller scales. Such concepts as the Hillside annual cycle passive solar heating system, the conditioned Village Walk, and the methane digester/sewage disposal system are all very cost effective at Friendly Homes, but would be in appropriate in a smaller project. Indeed it appears that many widely scattered approaches in alternate energy integrate very naturally within the framework of a cooperative community. This seems to be just the right scale and structure for appropriate technology to provide the dwelling counterform for the sustainable towns of the future.

KEYWORDS

Sustainability; Community; Integrative Systems; Design; Passive; Architecture; Appropriate Technology; Annual Cycle System; Internal Economy

INTRODUCTION

Over the past ten years we have become very proficient in designing and building energy efficient dwellings using alternate technologies. This background will be very valuable in the next phase of our work. The problem of designing an integrative community to sustainable standards is a good deal more complex than the problem of designing even a 100% solar energized dwelling. The scale of community is the smallest scale at which the question of sustainability can be properly formulated and at which there is the possibility of an efficient and economical response.

The modern city seems to need to grow ever larger even as parts of it decay and collapse. It is never able to find a "right size" at which it works best. This is perhaps a function of the artificial support systems necessary to maintain its essentially unsustainable structure. In contrast, the sustainable community, because of the interrelationships and balance among all of its systems has a fairly specific size at which it works best and beyond which it should not permit itself to grow. Its goal cannot be to maximize production with no upper limit, but rather to balance its systems. The premium is on maximizing the quality and quantity of internal energy flows rather than on maximizing exports from the community.

Because the concept of community extends to societal and institutional relationships the design problem is seen as a whole; that is, the design of community; rather than the design of housing plus school plus commercial, etc., which so typifies the reductionist approach of modern architecture as the counterform of modern society.

HOUSE SCALE VS.COMMUNITY SCALE

We in the Appropriate Technology movement may also be accused of having reductionist tendencies. As long as we focused our attention on the individual dwelling there was the likelihood that we would be interested in optimizing its performance as a system yet in overall net energy terms, this has often been done at the cost of increasing the ecological burden on the surrounding environment. As systems they have often been energy efficient, but because the isolated single family residence is an inherently inefficient building type with greater heat loss surface and greater transportation and infrastructure costs than in more aggregated settlements, they often increase overall energy consumption rather than decreasing it.

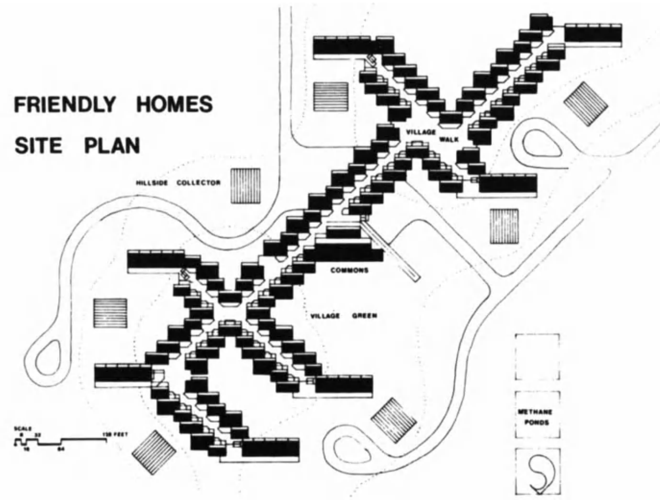
When attention turns from housing to community as the essential scale of the problem, a whole new range of linkages present themselves. The single family residence can very adequately address itself to issues of energy performance and even to energy autonomy, but even if it may be possible, total autonomy at the scale of an isolated individual dwelling hardly seems to be a useful model for society at large. If we look to housing complexes in whatever form, they are both architecturally and socially little more then dense aggregates of isolated single family dwellings and as such seem to be poor candidates for sustainability. It appears that the one model which is large enough and integrative enough to contain many synergistic possibilities yet small enough to be feasible in terms of local resources is the intentional community.

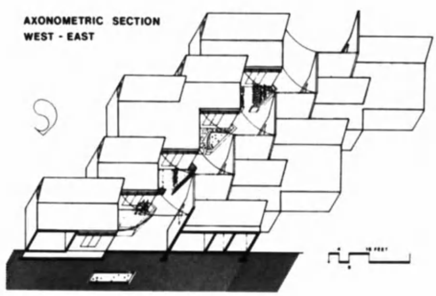
ALTERNATE ENERGY SYSTEMS

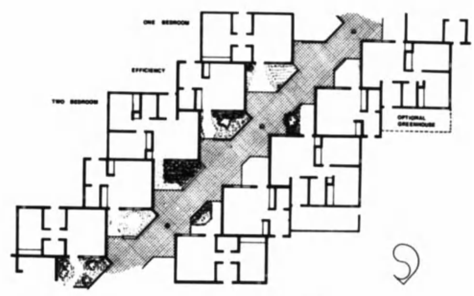
There are five major alternate energy systems at Friendly Homes, each designed to integrate with the other systems yet maximize its own performance as well:

1- Sunside insulated solar skylights bring direct gain into each unit along its entire north reinforced concrete fire wall. As a single long piece of 4 mil teflon stretched between curb and wall it is simple and inexpensive. An interior sunshade of multiple layers of reflective film also runs the length of the skylight and is a simple solution to the night and summer insulation problem. A "U-tube" distribution system removes excess heat from the skylight and blows it through a simple heatexchanger in the earth below the slab. The same U-tube passively distributes heat from the annual cycle system. Additional direct gain is available through south facing windows and optional greenhouses on the southern (se, sw) units.

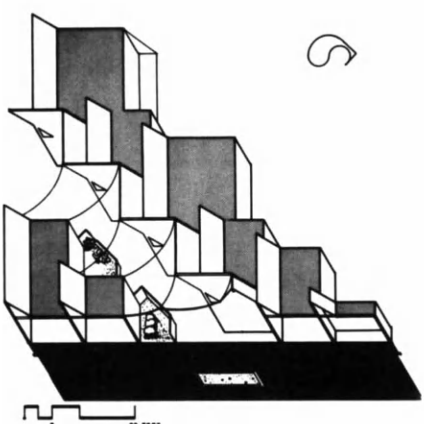
2- Village Walk Canopy has a teflon tensile surface facing south for direct gain and a multi-layer reinforced fabric tent structure sloping north for heat retention during the winter. This north facing tent is rolled back and opened during the summer. Additional heat from the annual cycle system whose storage is located below the walk creates a temperate climate with year round gardens for each unit.



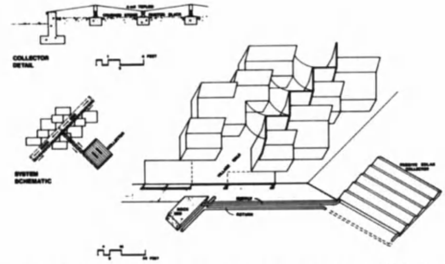




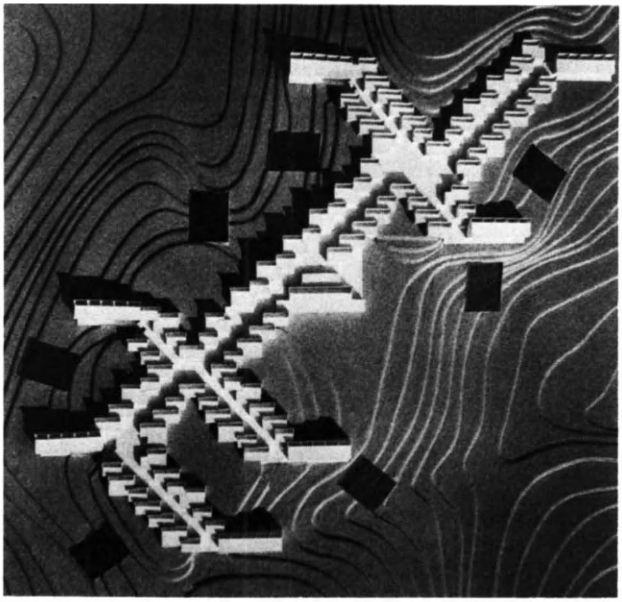
BUILDING PLANS

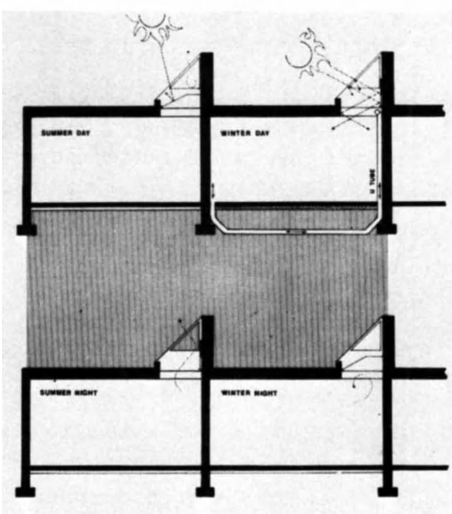


AXONOMETRIC SECTION NORTH - SOUTH

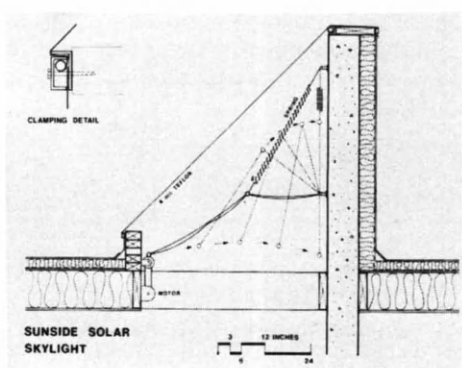


HILLSIDE PASSIVE ANNUAL CYCLE COMMUNITY SOLAR HEATING SYSTEM





SUNSIDE SOLAR SKYLIGHT SYSTEM



SUNSIDE SOLAR SKYLIGHT

3- Hillside passive annual cycle community solar heating system is among the largest and least expensive of passive heating systems. Heated air convects upward from the huge (40'x 60') simple collectors to a long rock bed located under the length of the village walk, which is then covered with six feet of earth. Controlled heat loss from this enormous partially insulated mass together with the direct gain systems, account for 100% of the community's heating requirements by passive means alone. As heat collection is only in the summer, the sloped collectors may face in any direction and still meet design criteria.

4- Solar hot water is collected by unglazed fin tubes within the conditioned village walk where freezing is not a problem.

5- Methane digestion of human and agricultural wastes provides fuel for central food preparation as well as an engine-generator providing electricity and waste heat reclaimed for hot water.

6- In addition the cooperative community framework and its architectural counterform provide many other energy savings in the areas of agriculture, transportation and services.

INTEGRATION

We now have a sufficient number of varied systems in our appropriate technology catalog, so that for a large project like a community, it could be a simple matter to make a selection of various systems to satisfy the different end uses, but this approach would merely be mirroring the overspecialized, additive methods of the larger society. It would not be possible to generate a whole integrated system in this way. Instead, the village needs to be designed as if it were an organism with an interrelated, interdependent network of systems. The goal is neither to maximize the efficiency nor to minimize the cost of individual systems. Rather it is to assemble reasonably efficient, reasonably inexpensive systems which are also capable of interaction with and support of other systems. The operational aim is to have relatively few interacting systems do many different things, perhaps even some what redundantly; to have a few elements interact with each other in synergistic, mutually supportive ways, creating new economies and efficiencies at the scale of the whole which do not exist at the scale of the parts.

Example: There is a necessity for concrete fire walls between dwelling units. These walls are extended four feet above the units permitting a simple inexpensive solar skylight to be stretched between wall and flat roof; the massive wall also serving as heat storage.

Example: Human wastes which must be processed and disposed of in any case are combined with agricultural wastes in a digester producing valuable methane and compost.
Example: The village walk becomes both circulation as well as conditioned space as well as garden/greenhouse as well as insulation for the dwellings as well as a part of the annual cycle heat storage and distribution system.

In a community system as organism, there is a dynamic relationship between parts and whole which increases the performance of both, in an integrative rather than an additive way. As efficient as individual units may be, their performance is enhanced by their relationship to other units and to the village walk. The performance of the village walk is enhanced by its relationship to the underground annual cycle heat storage, and the heat storage is enhanced by its relationship to the groupings of individual units. There is a degree of redundancy here to be sure, but the cost of each individual system is low compared to any system which could stand by itself and the redundancy adds a level of insurance and dependability to the overall system.

The community scale of this project offers a number of possibilities that would not be present at the scale of an individual dwelling. For example, the large area of ground covered by building offers the possibility of large earth heat storage mass where edge losses are minimized and where heat migration through the earth is slow enough that an annual cycle system may be used (collection of heat in summer when there is more sun, high in the sky, with high air temperatures and efficient, inexpensive, passive collection, for storage under the community for use in winter).
The village walk system also contains many features which would make little sense in a single dwelling. It is perhaps easier to understand that efficiencies of food production, waste disposal/methane production, transportation, and community services are not only highest at the community scale, but also that the interaction of these systems raises the combined efficiency still higher.

INTERNAL ECONOMY

We are starting to be able to formulate the basic framework of characteristics by which sustainable communities may be structured. It seems clear that an essential characteristic is the presence of an internal economy. In today's global economy, people or groups of people who choose to live in a sustainable way appear to put themselves at a distinct economic disadvantage to those in the larger society who mortgage the future in order to maintain their unsustainable life styles. The solution to this dilemma is to form new, intentional communities with internal economies. The internal economy both obviates the need to obtain many goods and services in the larger economy, as well as generating value which is limited to the community and to its members. The structure may be considered to be similar to that of the modern institution (university, hospital) or corporation or to the medieval Italian commune, except that instead of the essentially hierarchical and autocratic nature of these organizations, the sustainable community would have to have an essentially democratic structure like the Israeli Kibbutz or Moshav. It might be similar to the American corporation except that the shareholders would also be the workers.

The internal economy would include such sectors as energy, food, services and transportation. There would not necessarily be a strict requirement that all such services be generated within the community, but it would be necessary to establish a very rigorous accounting system which would track the economic interactions outside the community and would be used to make certain that the net balance was a sustainable one. This process would be more painless than it might at first appear to be. It would be administered by a system of incentives rather than by restrictions. For example,community members would be entitled to receive at little or no cost, their essential food, energy, transportation and services. Additional needs purchased outside the community would of course be a good deal more costly to members. By the system of internal economy, members would have a good deal more control, not only of their individual life styles, but of their collective lifestyle as well, then they could have living in the larger society.

CONCLUSION

Economists claim that sustainability of our culture and way of life is too broad an issue and too long range an issue to be able to be dealt with by economics. They claim that sustainability is a political question. Politicians also claim that sustainability is too broad and long range an issue to be dealt with politically. They claim that sustainability must prove itself economically. It becomes increasingly likely that before sustainability can work globally it must first work locally. We have had numerous successes that have convincingly demonstrated both the practicality as well as the economy of small scale, appropriate technologies which neither consume nor pollute. We have essentially mastered the parts. It still remains for us to construct wholes. The smallest scale wholes which are now starting to emerge are sustainable communities. Within the next few years they will gently begin to change mans patterns of settlement, and his prospects for the future.

REVIEW OF PASSIVE HEATING AND COOLING RESEARCH

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ABSTRACT

This paper summarizes recent research works of the author on passive solar heating and cooling of buildings. The studies summarized are : Experimental validation of the LASL predictive formulae for Direct Gain; Extention of the LASL correlational formulae into a generalized model; Nocturnal Radiant Cooling; Convective Cooling; Roof-pond cooling; Earth Cooling. The paper presents the methodologies and summarizes the results of these studies.

INTRODUCTION

This paper summarizes the recent research of the author at the Unit of Solar Building and Energy Conservation of the Institute for Desert Research, on various subjects dealing with heating and/or cooling of buildings by utilizing natural energies.

In the area of passive solar heating the work included an experimental validation of the predictive equations which were developed by the Passive Solar Group of the Los Alamos Scientific Laboratory (LASL) in the USA for Direct Gain.

Satisfactory agreement has been found between measured auxiliary heating and the values predicted by the LASL formula, given the real climatic input data. The research then continued with expansion of the original LASL model, which deals only with specified "reference" designs, into a generalized model. The new model does not include "Constants" but instead computes the Solar Saving Fraction (SSF) and Auxiliary heating (Aux) for Direct Gain on the basis of the thermophysical properties of the building and the energy system.

In the area of passive cooling of buildings the research has covered the following systems:

- Nocturnal radiant cooling
- Convective Cooling
- Indirect evaporative cooling by roof ponds
- sub-surface earth cooling

The paper presents a summary of the methodology and finding of these various studies.

2. EXPERIMENTAL VALIDATION OF THE LASL PREDICTIVE FORMULA FOR DIRECT GAIN HEATING

In an experimental validation study (1) of the LASL model for direct gain, measurements of the auxiliary energy consumption were taken in 3 large test cells (about $12m^2$ each) built of materials with different heat capacities while having similar overall heat loss coefficient. The experimental period lasted 3 months (Jan - March 1982). Computations of the "predicted" auxiliary energy consumption were carried out according to the LASL formula.

Table 1 gives the comparison between the measured and computed auxiliary energy consumption during the 3 months of the study. When the DD is computed either on the basis of a fixed T_{set}(18.3^oC) or on the basis of the actual average indoor night temperature.

As can be seen from Table 1[1] fairly good agreement exists between the measured and predicted auxiliary energy, when the DD is calculated on the basis of the average indoor night temperature. When the DD was calculated with fixed T_{base}(18.3^oC) the discrepancy between the measured and the predicted values was larger, due to the deviations of the actual indoor night temperatures from the basis assumed by the model (18.3^oC).

3. A GENERALIZED PREDICTIVE MODEL FOR DIRECT GAIN

The procedure by which the LASL correlational formula were developed involved regression analysis of simulation results from "reference" buildings, under discrete conditions of the design details of the systems, such as the amount of thermal storage, night insulation, etc. As a result of this procedure the constants of the correlational formula were also generated in discrete form for the different reference designs.

However, on close inspection of the relationship between the specific values of the constants and the various design conditions for which they are applicable it becomes clear that these constants actually express the parametric effects of specific features of the system, such as the amount of the thermal storage, thermal resistance of the glazing etc.

In addition, the structure of the input data was modified, to facilitate the use of the model as a design tool.

Consequently, the correlation formula which were developed by the LASL group for Direct Gain were extended into a generalized model (2). The Constants which appear in the original model are computable from the thermophysical properties of the building and the energy system.

a. The Original LASL Formulas for the Solar Saving Fraction (SSF)

The predictive general formula developed at LASL for the SSF (3)
SSF = 1-(1-F)k when:

[1]All tables appear at the end of the text.

$K = 1 + G/LCR$

$F = B-C\cdot\exp(-D\cdot X),\ Z > R$

$F = A\cdot X \quad ,\ X > R$

If $F > 1$, then set $F = 1$

$X = (S/DD)/(LCR\cdot F)$

When S = monthly solar radiation penetrating the glazing

DD - Degree Days

$LCR = \frac{\text{building heat load coefficient}}{\text{collection area}}$

The constants, A, B, C, D, G and R are given as discrete values for different "reference" details of the building (its thermal storage capacity, the nominal mass thickness, the mass-to-glazing area ratio, the number of glazings and the night insulation conditions. The auxiliary energy consumption (monthly) is computed by:

$Aux = (NLC)\ (DD)\ (1-SSF)$

where:

Aux = Auxiliary energy (Btu/month)

DD = monthly Degree Days

NLC = Net load coefficient (without the solar element)

b. The New Predictive Formula for Direct Gain (2)

The formula of the new model are as follows:

Inputs:

Climatic: I_v, DD; Monthly vertical impinging radiation, Monthly Degree Days

Building: NLC, Mass, Night insulation (Y/N)

Glazing: A_g, t_g, U_{ins} ($U_g^* = 1/\frac{1}{U} = 1/(\frac{1}{U_g} + \frac{1}{U_{ins}})$) (area, transmission, U glazing, U insulation)

Sequence of Calculations

Initial:

$H = 220*Mass/A_g$ (heat capacity)

$S = t_g*I_v$ (solar penetration)

$U_g^* = 1/(1/U_g + 1/U_{ins})$ (total glazing U value at night)

$BLC = NLC + A_g(12*U_g + 12*U_g^*)$ (total building loss coefficient)

Common calculations

$K = (NLC + 17*A_g*U_g^*)$

$X = S*A_g/(DD*NLC*K)$

Separate Calculations: Glazing Without Night Insulation

$C = 0.55 + 0.0028*H$

$D = 0.0042*H$

$R = 0.5 + 0.001*H$

If X>R then:

$F = 1-C*e^{-(D*X)}$

If X<R then:

$A = 0.40 + 0.00075*H$

$F = A*X$

Glazing With Night Insulation

$C = 0.71 + 0.0025*H$

$D = 0.36 + 0.0032*H$

$R = 0.65 + 0.0006*H$

If X>R then:

$F = 1-C*e^{-(D*X)}$

If X<R then:

$A = 0.48 + 0.0005*H$

$F = A*X$

Common Final Calculations

$SSF = 1-(1-F)*K$

$SS = SSf*NLC*DD$

$Aux. = (1-SSF)*NLC*DD$

$SHF = SS/(BLC*DD)$

Present Range of Models' Use:

Lower Limit of use - when $H<150(whr/C\text{-}m^2)$

Upper Limit of use - when H>500(whr/c-m^2)

If H>500 then let H = 500 (whr/C-m^2)

Table 1 shows also the correspondence between the measured auxiliary heating and that "predicted" by the new model.

c. Overall Comparison Between the LASL and the New Models

Strict comparison between predictions of performance of the LASL model and any other model can be done only for the "Reference" building designs. Two sets of computations were done, using the LASL and the new model, on the performance of the 9 reference buildings. Four conditions were assumed : 2 levels of NLC (6000 and 12000 whr/C-day) and 2 sizes of the solar glazing (15 and 30m^2). The results of this comparison are presented in Table 2.

The climatic conditions were :

$$S = 85000 \text{ whr/m}^2\text{-month}$$

$$DD = 220/\text{month}$$

As can be seen from Tables 1 and 2 there is close agreement between the prediction by the new model and the LASL model. This agreement indicates that the variations in the Constants of the LASL model are indeed functions of the variations in the heat capacity and glazing among the different Reference Designs.

4. RADIANT COOLING

The research on radiant cooling consisted of three stages:

a. Experimental studies of the performance of radiant cooling under different design details of the radiators (4,5)

b. Validation of the theoretical model which has been developed jointly by research groups at Trinity University and at Lawrence (5) Berkeley Laboratory.

c. Review and evaluation of the state of the art in view of the results of experimental studies by the author and other investigators (7).

4.1 EXPERIMENTAL STUDIES OF RADIANT COOLING

Two experimental studies were conducted at the Institute of Desert Research on radiant cooling.

In a study by Carol Ebele and B Givoni (4), outdoor air was blown at night under an exposed radiator, cooled and then passed through a gravel mass (0.2 m^3/m^2 of radiator). Under stagnation conditions the radiator was cooled to about 6-7°C below ambient night air temperature. With air flow the exit temperature was about 3°C below ambient. The gravel mass was cooled during the night to about the outdoor air minimum temperature.

In the second study, by M Mostrel and B Givoni (5) "stagnation" temperatures were measured of radiators with different design details. The variables included:

- exposed vs. screened radiators (with polyethylene films)

- single vs. double windscreens

Summary of the results

a Effect of windscreening by polyethylene It has been observed, as expected that the beginning of the experiments, in the evenings, the radiating surface which was protected from the wind by the polyethylene has been cooled down faster and attained a lower temperature than the exposed surface, (e.g., 10 vs 7^{o}C ambient air).

However, late at night condensation started to form on the polyethylene sheet and then the difference between the exposed and the "protected" radiating radiators practically disappeared. This effect of dew on the performance of the screened radiations was observed in about 80% of the night, even in the desert climate of Sede-Boqer.

Furthermore, the two surfaces were very sensitive to passing clouds. Whenever the sky became cloudy the temperature of the two "radiators" rose up and the difference between the exposed and the covered areas disappeared, In fact at times, when the sky became clearer, the exposed surface reacted faster and cooled down to lower temperatures than the surface covered by the polyethylene.

b Effect of the number of wind-screen layers No significant difference was found between the temperatures of radiators screened by either single or double polyethylene films.

4.2 EXPERIMENTAL VALIDATION OF THE MATHEMATICAL MODEL DEVELOPED BY TRINITY UNIVERISTY AND LAWRENCE BERKELEY LABORATORY

Measured temperatures of nocturnal radiators, under stagnation conditions, were compared with temperature predicted by the Trinity model (6) for the climatic conditions which existed during the various experiments (5).

Reasonable agreement existed between the predicted and measured radiator's temperature for the minority of the tests, when dew was not formed over the polyethylene wind screen. However, agreement between measurements and predictions was poor in most tests, when dew was formed, as the existing mathematical model does not take into account the formation of dew and its effect on the performance of screened nocturnal radiators.

4.3 REVIEW AND EVALUATION OF THE STATE OF THE ART OF RADIANT COOLING (F)

The experimental results obtained by Mostrel and Givoni (5) and by other research groups as well as various theoretical studies of this subject, were summarised and evaluated (7). The main conclusion from this study can be summarised as follows:

a. The Effect of Polyethylene Wind Screens

On most nights condensation formed over the polyethylene sheet at about midnight, or even earlier, and then the difference between the exposed and the protected radiating areas practically disappeared. Whenever the sky became cloudy the temperature of the two radiators rose and the difference between the exposed and the covered areas was greatly reduced. Consequently it has been concluded that, in view of the much higher cost of wind-screened radiators, wind screening is not justified on the basis of cost/benefit considerations.

b. Selective Surfaces

The results of all the studies reviewed in ref. 7 have demonstrated that, with the selective surfaces tested, no distinct advantage was observed in their radiant cooling potential over radiators with ordinary surfaces.

Another point which should not be overlooked is the probable effect of condensation on the performance of selective surfaces. The lower temperature attained by such surfaces may increase the likelihood of condensation over the selective surface itself. However, once the selective surface is covered by a water film it may lose its selective radiative properties. This may actually explain the observed inefficiency of the selective surfaces.

5. CONVECTIVE COOLING

The research in the area of convective cooling included experimental studies (8) and an analysis of the climatic applicability of this cooling system (9).

a. The Experimental Study

In the experimental study measurements were taken at the Institute for Desert Research in Sede-Boqer, of outdoor and indoor maximum, minimum and average temperatures between 3 and 18 July, 1979. The measurements were taken in a room-size thermal models of concrete walls, 20 cm (8") thick, insulated externally by 5 cm (2") of expanded polystyrene. One room was closed during the day and ventilated (one large opening - no cross-ventilation) at night. A second similar room served as a control and was closed day and night. Typical results are summarized in the Table 3.

It can be concluded from these results that night coolness can be stored in the structural mass and lower the indoor temperature during the following daytime hours by about 20% of the outdoor temperature range, provided that the building is well insulated and closed during the daytime.

b. Analysis of the Climatic Applicability of Convective Cooling

In this work (9) a detailed analysis has been made of the various design options for storing night coolness for use during the following day and the expected performance as related to the climatic conditions.

Convective cooling is applicable when the outdoor minimum temperature is below about 20°C. The outdoor air maximum temperature is not a significant factor from this view point.

When the structural mass serves for the cold storage and is cooled at night by ventilating the indoor space the limits of the attainable cooling are set by the requirements of the occupants for comfort, privacy and safety.

The potential of convective cooling can be greatly increased by pre-cooling the outdoor air by radiant or evaporative cooling.

6. INDIRECT EVAPORATIVE COOLING BY ROOF-PONDS

A series of experiments was conducted at the Institute for Desert Research on cooling by roof-ponds (10). The experimental facilities in the first series consisted of small boxes, 55 x 55 x 50 cm, made of panels of expanded polystyrene (5 cm), internal plywood (2.5 cm) and external plywood (0.5 cm). The "roof" consisted of a concrete plate, 4.5 cm thick. Different treatments were applied to the roofs in order to utilize them as cooling elements for the spaces below (the "room"), as follows:

1. Heavy insulation, to minimize the roof effect: a standard for comparison
2. Just white painting, to reflect solar radiation
3. Shading, while providing permanent ventilation
4. An exposed water-pond to provide continuous evaporative cooling without eliminating solar and longwave radiation effects
5. A shaded water-pond
6. A water-pond with operable insulation, exposed at night and insulated during the day
7. A thicker concrete roof with operable insulation, exposed at night and insulated during the day
8. Insulation over the roof, covered by pebbles and a water-pond

Measurements of the roof and indoor temperatures were taken from August through October, 1981. Summary of the results is given in Table 4.

7. MODELLING THE PERFORMANCE OF SHADED ROOF-PONDS

An experimental study (11) has demonstrated that shaded roof-ponds can provide effective indirect evaporative cooling. Consequently, formulae were developed which enable prediction of the maximum and minimum temperatures of shaded roof-ponds as a function of the ambient WBT and the depth of the pond.. Table 5 shows the comparison between the measured and predicted temperatures of shaded ponds with water depth of 2.5, 9 and 27 cm.

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Table 1: Comparison Between Auxiliary Heating (KWh) Measured and Computed by LASL Original Model and by the New Model

Test Cell No.	Data Source	Auxiliary Energy (KWh)			
		January	February	March	Total
2	measured	152	185	86	423
	computed LASL	179	190	105	474
	computed new model	153	170	86	409
3	measured	220	260	181	661
	computed av. LASL	219	260	174	653
	computed new model	207	251	170	628
4	measured	137	169	90	396
	computed av. LASL	148	153	100	401
	computed new model	137	142	90	369

Test cells materials (inside the insulation)

#2 = filled concrete blocks

#3 = hollow concrete blocks

#4 = lightweight concrete blocks (ρ = 600 kg/m^3)

*See next section.

Table 2: General Comparison of Predictions of SSF and Auxiliary Heating by LASL and the New Models. Climatic Conditions: S = 85000 whr/m^2 - month, DD = 220/month.

NLC	Ag	Mass (tons)	Double Glaz.				Triple Glaz.				Night Insul.			
			LASL		New		LASL		New		LASL		New	
			SSF	Aux.	SSF	Aux	SSF	Aux.	SSF	Aux.	SSF	Aux	SSF	Aux
6000	15	(170) 11.6	.36	847	.37	835	.45	730	.42	767	.51	653	.50	657
		(340) 23.2	.48	691	.47	697	.57	567	.55	591	.58	558	.59	541
	30	(170) 23.2	.56	583	.56	578	.69	414	.64	470	.77	303	.77	301
		(340) 46.4	.78	289	.78	284	.85	204	.84	208	.83	164	.88	152
12000	15	(170) 11.6	.20	2124	.21	2092	.25	1986	.24	2017	.24	2006	.25	1984
		(340) 23.2	.24	2011	.24	2017	.29	1876	.27	1940	.28	1897	.28	1903
	30	(170) 23.2	.36	1693	.37	1671	.45	1459	.42	1534	.51	1305	.50	1314
		(340) 46.4	.48	1382	.47	1394	.57	1135	.55	1183	.58	1117	.59	1083

Table 3: Effect of Convective Cooling

Temperatures (°C)	Minimum	Maximum	Average	Range
Outdoor	19	34	26.5	15
Test room	23	26	24.5	3
Control room	26.5	28.5	27.5	2
Cooling effects	-3.5	-2.5	-3.0	

Table 4: Maximum and Minimum Temperatures With Roof Cooling

Measurements	Roof surface				Indoor air			
Cooling System	Min.	Max.	Av.	Δmax	Min.	Max.	Av.	Δmax
Outdoor air (DBT)	14.5	27.0	10.7	-	14.5	27.0	20.7	-
Wet bulb (WBT)	14.0	19.0	16.5	-	14.0	19.0	16.5	-
Heavy insulation (standard)	18.5	24.0	21.2	-3.0	19.0	25.0	22.0	-2.0
White painting	10.5	31.5	21.0	+4.5	12.0	31.0	21.5	+4.0
Shading the roof	14.5	28.5	21.5	+1.5	15.5	28.5	22.0	+1.5
Exposed water-pond	11.5	29.0	20.2	+2.0	12.5	18.5	20.5	+1.5
Shaded water-pond	14.5	20.0	17.2	-7.0	17.5	22.0	19.7	-5.0
Water pond with operable insulation	12.0	18.5	15.2	-8.5	13.5	20.5	17.0	-6.5
Concrete with operable insulation	12.0	19.3	15.6	-7.7	14.0	21.3	17.6	-5.7
Insulation, pebbles and a water pond	15.5	21.5	19.0	-5.5	17.5	22.0	19.7	-5.0

Table 5: Comparison Between Measured (M) and Computed (C) Maximum and Minimum Roofs' Temperatures

Pond	Date		Jul. 31	Aug. 1	Aug. 2	Aug. 3	Aug. 4	Aug. 5	Aug. 6	Aug. 7
2.5	Min	M	19.3	18.8	16.0	14.3	19.1	19.6	19.0	15.9
		C	19.2	18.9	15.9	14.4	19.1	19.9	19.4	15.5
	Max	M	23.0	22.0	21.5	21.8	23.4	23.4	22.9	22.9
		C	22.7	21.6	21.1	21.1	23.5	23.2	23.2	22.9
9	Min	M	19.7	19.4	17.5	16.1	19.7	20.3	19.4	17.1
		C	19.8	19.7	17.3	16.1	19.7	20.7	20.2	17.5
	Max	M	22.8	21.6	20.6	21.7	23.2	22.8	22.8	21.6
		C	22.6	21.5	20.9	21.7	23.3	23.1	23.1	22.7
26 cm	Min	M	20.3	20.4	19.0	18.0	20.1	21.2	20.5	19.2
	Max	C	20.3	20.5	18.6	17.8	20.3	21.4	21.0	19.4
	Min	M	22.1	21.7	20.4	21.6	22.4	22.6	22.3	22.0
	Max	C	22.3	21.3	20.5	21.1	23.0	22.9	22.8	22.1
WBT	Min		18.8	18.1	14.6	12.8	18.6	19.2	18.6	13.7
	Max		21.7	20.6	20.2	21.1	22.5	22.2	22.2	22.0

THERMAL PERFORMANCE ANALYSIS FOR ELEVEN CALIFORNIA PASSIVE SOLAR AND ENERGY CONSERVING HOUSES BASED ON ONE YEAR OF MONITORED DATA

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ABSTRACT

Nine passive solar and two conservation houses in different California climates were monitored for a period of one year starting in July 1981. The two conservation houses were located next to passive solar houses for convenient comparison of performance. The Solar Energy Research Institute (SERI) Class B data collection methodology and instrumentation, modified to meet California needs, were used. This included continuous data collection with data stored hourly on cassette tape and printed daily, weekly and monthly on paper tape. In addition to the continuous data, one time measurements were made on each house to determine the building loss coefficient, infiltration rates and furnace efficiency.

The hourly data on cassette tape was transferred to disc and then used to analyze the thermal performance of each house. The solar contributions are obtained subtractively and comfort levels maintained are indicated by monthly plots of extreme, and binned inside and outside temperatures. The overall performance for each house is presented and compared to an equivalent non-solar house. In the two cases where solar and conservation houses are nearby, these performances are also compared. In general the energy savings attributed to the solar feature of these houses depended upon the weather and user interaction in a more dramatic manner than is commonly believed. The interaction between system components and weather is discussed.

KEYWORDS

Class-B; passive solar houses; conservation houses; data collection; equivalent non-solar house; thermal mass.

INTRODUCTION

During the past several years there has been a manyfold increase in the number of solar houses being built. Despite this popularity and a wide spread effort to collect data on the thermal performance of solar houses, little reliable field data is available. The sources of data and its usefulness existing before 1980 has been discussed in detail by Mahajan and co-workers (1980).

In an effort to organize the national data collection activities the Solar Energy Research Institute (SERI) promulgated three data collection strategies; Class-A (heavily instrumented research sites), Class-B (instrumented occupied houses) and Class-C (survey and billing data). The instrumentation of the houses reported on here was carried out using equipment, sensors and methodology which are compatible with the SERI Class-B strategy. However, modifications to the strategy were made to handle problems specific to the California situation. An overview of the process used in the present study is given in Fig. 1.

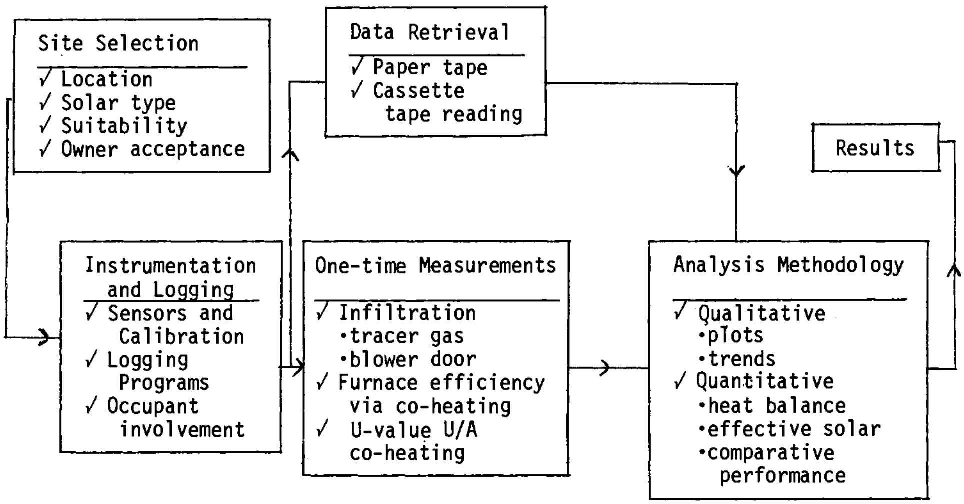

Fig. 1. Overview of data logging process.

The selection of the eleven sites to be monitored was based on several factors. First three of the solar houses were included in this study because they were winners of the California Passive Solar Design Competition and mandated by the California Legislature to be monitored for at least one year. The remaining six solar houses were chosen based on survey results (Class-C) from 63 passive solar houses and selected mainly because of the weather and system type but also the willingness of the home owner to put up with the inconvenience. Two conservation houses with no special solar feature were also chosen near two of the solar houses to get a side-by-side comparison of performance. These two houses met the current building standards of California. Shown in Table 1 is a brief description of the eleven Class-B sites that were monitored in this study.

INSTRUMENTATION

The Aeolean Kinetics PDL-24 data logger was used for collecting and processing the data. Shown in Fig. 2 is a functional diagram of this data logging system. The outside temperature and three or four inside temperatures were measured using the Analog Devices AD590 sensor mounted in double radiation shields. The horizontal and vertical insolation were measured using Li-Cor LI200S silicon pyranometers. Continuous wind measurements were made using the Aerolean Kinetics pulsing anemometer. The total electrical energy was monitored with a pulse initiating watt-hour meter and all major electrical appliances outside the living space were current-clamped. The total natural gas used was measured with a locally designed pulse initiating gas meter. And finally several types of on/off sensors were

TABLE 1 Class B Site Description

Site	Passive Solar Type	Living Area (ft^2)	South Aperture (ft^2)	Climate Zone
Truckee Solar House	Direct Gain	1158	271	Cold-Mountain CTZ 16
Yreka Solar House	Sunspace	1375	258	Cold-North Inland CTZ 11
Eureka Solar House	Direct Gain	2094	367	North Coastal CTZ 1
Sebastopol Solar House	Direct Gain	1493	228	North Bay-Coastal CTZ 2
Santa Barbara Solar House	Trombe Wall	842	198	Mild-South Coastal CTZ 6
Colton Solar House	Direct Gain*	1664	207	Warm-South Inland CTZ 10
Colton Conservation House	N/A	1660	50	Warm-South Inland CTZ 10
Rio Linda Conservation House	N/A	1199	40	Moderate-Central Valley CTZ 12
Rio Linda Solar House	Direct Gain	1215	135	Moderate-Central Valley CTZ 12
Sacramento Solar Condominium	Direct Gain*	1420	170	Moderate-Central Valley CTZ 12
Davis Solar Duplex	Direct Gain*	1273	256	Moderate-Central Valley CTZ 12

*Passive Solar Design contest winners.

used to determine the status of doors, windows, drapes, furnace burners and water heater burners, ventilation fans, etc. Typically a total of 20 sensors were used in each house. All the sensors were installed and calibrated using the SERI Installation Manual for Class-B Monitoring (1982).

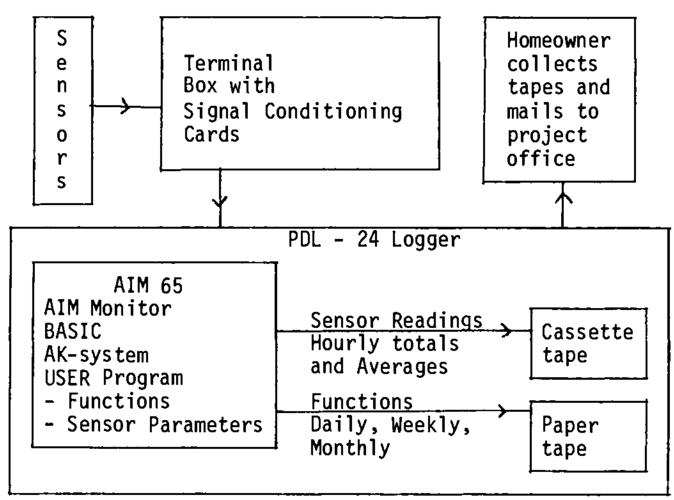

Fig. 2. Flow diagram of how the logger is used in data collection.

SOFTWARE AND DATA COLLECTION

The process used from data collection to analysis is shown in Fig. 2. The PDL-24 logger has a general purpose minicomputer, the AIM-65 and the AIM-65 operating system and is programmable in BASIC. Aeolean Kinetics has developed software to handle data collection on magnetic tape. The user must supply the sensor parameters and functions to be calculated. The functions are entered as BASIC program which is run by the PDL-24 after each data scan at 15 second intervals. The functions are accumulated (or averaged) and daily, weekly and monthly, values printed out on paper tape. A typical list of these functions is given in Table 2. Continuous sensor data is sampled every 15 seconds and recorded at the end of each hour on magnetic cassette tape. The status channel information was accumulated and also recorded on an hourly basis.

TABLE 2 Typical list of functions printed out at the end of each day, week, and month

Function Definitions	Units
Energy used by water heater	Watt hrs
Energy to heaters	Watt hrs
Internal heat gain when $T_{in} > T_{out}$	BTU
Energy to guest house and water pump	Watt hrs
Internal heat gains	BTU
Heat lost thru conduction and air infiltration	BTU
Heat lost thru venting of doors	BTU
Total solar insolation on horizontal surface	BTU/ft^2
Total solar insolation on vertical surface	BTU/ft^2
Energy to jacuzi and solar pump	Watt hrs
Energy to clothes dryer	Watt hrs
Heat lost thru cond. & infil. when $T_{in} > T_{out}$	BTU
Total electrical energy purchsed	Watt hrs
Heat balance of house	BTU
Average wind speed	MPH
Average inside temperature	°F
Average outside temperature	°F
Average sunspace temperature	°F
Average thermal mass temperature	°F
Max inside temp/time it occurred	
Max outside temp/time it occurred	
Max sunspace temp/time it occurred	
Max thermal mass temp/time it occurred	
Min inside temp/time it occurred	
Min outside temp/time it occurred	
Min sunspace temp/time it occurred	
Min thermal mass temp/time it occurred	
Maximum 5 minute electric power consumption	Watts
Time it occurred (6:27 AM PST)	

In addition to these continuously accumulated and processed data, a series of "one time measurements" required for the heat flow analysis were also made on each house. These included, the infiltration rate, the building loss coefficient, burner flow rates and delivery efficiency of furnaces. The details of these measurements will be presented in a separate paper at the Eighth National Passive Solar Conference at Santa Fe, New Mexico.

QUALITATIVE ANALYSIS OF INSTRUMENTED DATA

The hourly data on cassette tapes was transferred to floppy discs and nine track tape for processing and plotting using other computer medium. One of the first steps in processing the data was to plot the output of various sensors for three to five day periods during winter and summer months. These plots provide qualitative information on the performance of the houses. As an example shown in Fig. 3 are plots of four sensors from the Santa Barbara house for two clear days followed by a cloudy day in January. This plot shows how the Trombe wall passive solar system response to solar inputs, the charging and discharging of the thermal mass, and occupant activities. The double peaks on the inside temperature plot are first, due to solar gain and the second, due to occupant activities such as

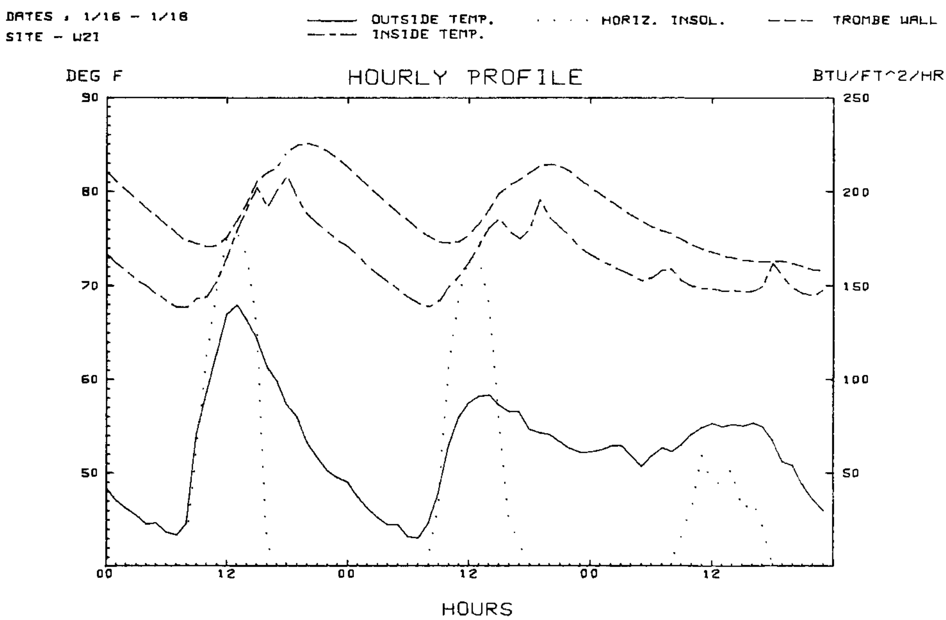

Fig. 3. Hour-by-hour plot of four sensors in the Santa Barbara Trombe Wall house.

cooking and use of appliances and the delayed heat pulse from the Trombe wall. As expected the heat pulse through the Trombe wall arrives about 8 hours after the peak solar gain. The transition from the two sunny days to the cloudy day is quite good and due mainly to the exponential decay of the Trombe wall thermal mass temperature. Other qualitative plots which are used in this way are the daily max-min temperature plots and the interior "binned" temperature bar graphs. With this level of information a good picture of how the house was operated and a qualitative understanding of the performance is possible.

PERFORMANCE SUMMARY

Three types of processed data were used to analyse thermal performance. These are; i) Extreme and binned interior temperatures. ii) Percentage of the gross heating load provided by internal gains, auxiliary energy and solar gains. iii) Comparison between the actual solar house performance and that of an equivalent non-solar house using the hourly data from the solar site. For two cases the equivalent house is replaced by the conservation house also monitored during this study.

Shown in Fig. 4 is a flow chart of the analysis procedure starting with the hourly data and ending with the comparison of performance with the equivalent non-solar house. After the one year of hourly data was processed, the next step was to run checks for accuracy and consistency. Using the billing data for electricity and gas and separate meter readings the corresponding values were calculated using the hourly data and computer software with generally perfect agreement. Probably the most important check on the data consistency is to test for heat balance over one month periods using the following equation.

$$Q_{Balance} = Q_{conduction} + Q_{infiltration} + Q_{internal} + Q_{solar} + Q_{vent} + Q_{storage}$$

The houses generally stayed in the comfort zone (65-80°F), however, most of them did drop below 65° in the winter and go above 80°F in the summer.

The heating load, internal gains, auxiliary energy and "useful" solar energy (determined subtractively) were calculated for the solar and the equivalent non-solar house for the entire heating season and presented as shown in Table 4.

TABLE 4 Comparison Between the Performance of the Solar House as Monitored and the Equivalent Non-Solar House Kept at 71°F for the Heating Season (November - April). All Energies are in MBTU.

	Q_{solar}	$Q_{internal}$	$Q_{auxiliary}$	Q_{total}
Solar House	14.4 (58%)	10.1 (41%)	0.4 (1%)	24.9
Non-Solar House	2.4 (12%)	10.1 (52%)	6.9 (36%)	19.4†

† Low by 0.6 MBTU because in September the internal gain exceded the gross load.

The auxiliary energies and energy savings for all the houses are tabulated in Table 5. The solar as percent of gross load is also tabulated.

DISCUSSION OF RESULTS AND CONCLUSIONS

In general all of the solar houses saved energy and performed about as expected for heating.

Some overall conclusions are:

- For well insulated conservation houses in mild climates any passive solar system added to meet heating load must be designed very carefully so as not to degrade the conservation features.
- The major thermal mass effects have a time constant of at most 24 hours. Thermal mass does tend to moderate indoor temperatures, but only for about one day.
- Climates which require some heating year round, namely those on the North coast of California, performed the best according to the results. The houses in the colder climates (mountains in California) also performed quite well. Solar houses in more mild climates did save energy but in most cases not a significant amount when compared to conservation houses.

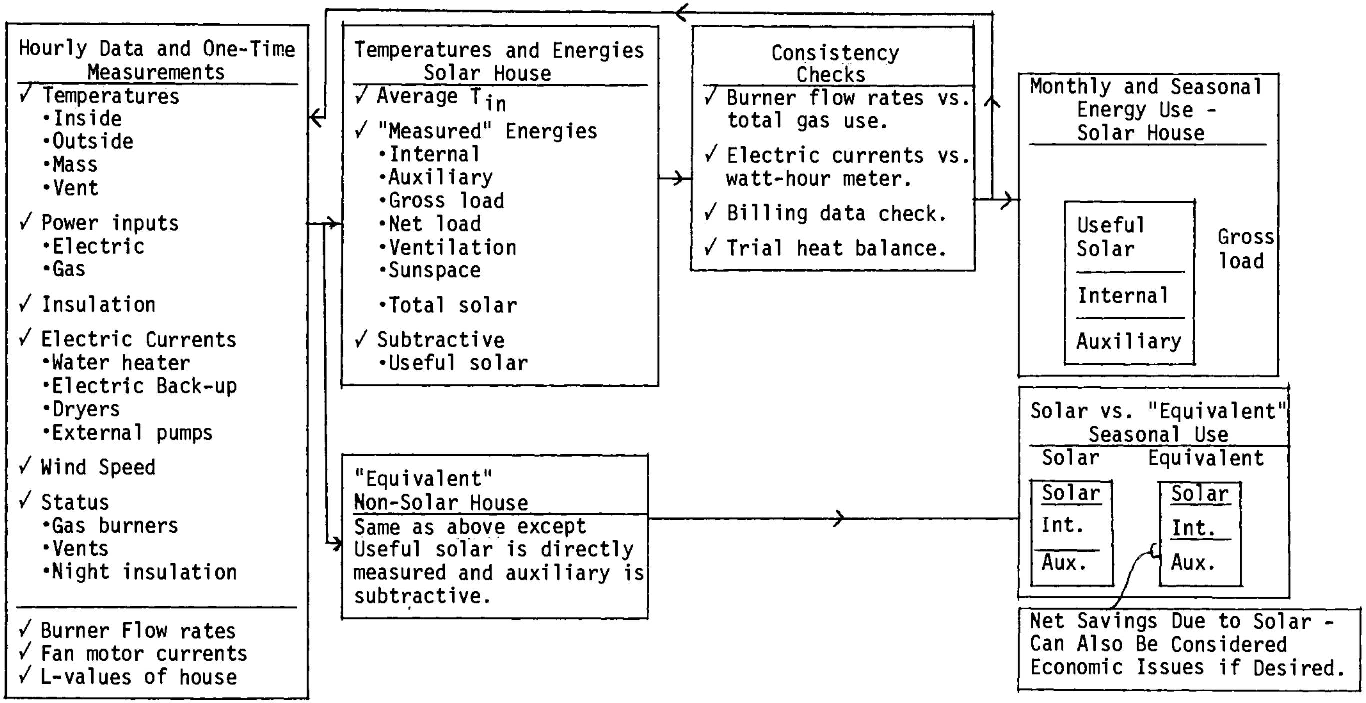

Fig. 4. Summary of analysis procedure.

TABLE 5 Energy Savings for the Heating Season Based Only on Auxiliary Energy

Site Location in California	Auxiliary Energy Used by House (MBTU)	Energy Required by an Equivalent House (MBTU)	Energy Savings (MBTU)	Solar % of Gross Load
Truckee	5.6	16.6	11.0	52
Yreka	12.9	27.3	14.4	52
Eureka	11.7	49.4	37.7	69
Sebastopol	0.4	15.9	15.5	68
Santa Barbara	0.4	6.9	6.5	58
Colton	3.2	9.0	5.8	34
Rio Linda	15.9	19.5	3.6	30
Sacramento	9.0	14.0	5.0	25
Davis	3.9	20.9	17.0	61
Rio Linda Conservation	12.8	-	-	-
Colton Conservation	5.3	-	-	-

- Solar house must be allowed to swing in temperature significantly in order to take full advantage of storage effects. This implies letting the house swing out of the comfort zone on most days for a few hours.
- Solar features if not managed properly lose the potential savings in winter and are a liability in the summer. Large direct gain apertures in the mild but often overcast winters and the hot but clear summers in California should be questioned.

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ROCK BED DESIGN AND CONSTRUCTION FOR HEATING AND COOLING

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ABSTRACT

Design parameters and contruction details of rock beds for heating and cooling thermal storage are outlined and discussed with emphasis on efficiency and economy. Two prototypical designs by the author that have been constructed are examined in detail; one for passive heating and one for hybrid and active heating and cooling. Rock beds for housing and small commercial structures can acheive up to 100% heating and cooling by their remote storage of the intermittant resources of passive solar heat and passive natural cooling.

KEYWORDS

Rock beds; thermal storage; passive thermal storage; hybrid thermal storage; active thermal storage; construction details; air systems; heating storage, remote; cooling storage, remote; economy.

INTRODUCTION

Before the advent of solar applications the thermal characteristics of rocks were a standard component of physics texts and scientific experimentation. Aside from the well known thermal attributes of rock cut temples and tunnels as well as stone buildings there were few applications of loose rock to the external problems of heating and cooling. Among the rare applications has been the use of rock beds to store heat from blast furnaces in smelting operations when they are unloaded for cleaning and rebuilding. Once the furnace is rebuilt and loaded the heat from the rock bed is reclaimed by the use of blowers as a preheat before combustion is initiated.

Rock beds for thermal storage have been a fascinating subject in the oral and written literature of recent solar energy enthusiasts. For a variety of reasons, there have been relatively few installed rock beds in comparison to other forms of thermal storage. Typically masonry walls and floors are used for passive thermal storage--architectural elements well within the normal conventions of construction practice. Active systems tend toward thermal storage using the cheapest fluid medium, water. Such systems are compatible with the pumps, valves and tanks characteristic of the dispersed components and connections of active solar heating and cooling systems.

Aside from their interesting thermal characteristics, rock beds require new construction forms and methods quite different from the conventions of the masonry walls and floors used for passive systems and the insulated tanks used for active systems. Rock beds can be used for both heat and cool storage and lend themselves to passive and hybrid coupling as well as totally mechanical activation. Fundamentally by providing a remote and often isolated thermal storage they allow an extended supply of energy to be on instant call and thus allow such intermittent thermal sources as the sun or evaporation to provide virtually 100 percent of environmental needs.

Among published design sources the most useful books for sizing active rock beds is by Balcomb, Jones et al (Ref. 1); and for passive rock beds by Baer (Ref. 2). However the richest literary sources are technical papers published in various conference proceedings, especially by the American Solar Energy Society (ASES), formerly the American Section of the International Solar Energy Society (AS/ISES) by this author, Scott Morris, Mark Jones and others.

DEFINITIONS

The term "rock bed" is used in solar applications for a three-dimensional containment of rocks through which air is passed between the rocks to effect thermal exchange, storage and release. Rocks arranged on a plane facing a heat source without air passage through their voids perform in a different way: only the exposed rocks are effective in heat transfer. The terms "pebble bed" or "gravel bed" are sometimes used for containers using smaller rock sizes such as pebbles, large gravel or crushed rock. However, rock beds usually are built with a rock diameter that is fist size or larger.

The spheroid shape of rocks used in rock beds is even more critical to successful thermal storage than rock diameter. In the descriptive geometry of packing perfect spheres, if all diameters are identical then the proportion of solid to void will be identical regardless of diameter dimension. It is 58 percent solid and 42 percent void. However, if different diameter spheres are packed together, the voids will become filled with smaller spheres and there will be a larger portion of solid material. Thus, in the design and construction of rock beds it is critical that all rocks have similar spheroid shape, such as river rounded rock. In addition, they must have similar diameter so that voids are consistent throughout for air passage.

The particular type of rock used is not of any great importance so long as the specific heat capacity is known. Hard, heavy rock is the most desirable. Thus, certain light weight rocks such as some volcanic types should not be used, because they have little storage capacity. Flat rocks are not good, because they do not leave voids when packed. In addition to smooth rounded shape, structural stability is desirable unless one wants to hand place each rock. Mechanical handling of quantities of rock has significant time and cost benefits. Broken rock will distort consistent air flow.

In spite of the appearance that much of the world seems built on rocks, experience in the design of construction of rock beds shows that rocks are not universally available. Importing rocks to a mountainous location can be both silly and expensive; and, sorting and washing dirty rocks can seem like an exercise in futility. Yet clean rocks of rounded shape and consistent diameter are the only acceptable material. Typical rocks in a rock bed will have the following characteristics:

Heat Capacity = Specific Heat (c) = 0.49 kJ/kg. (0.21 Btu/lb)
Density of solid = 2,640 kg./m^3 (165 lb/ft^3)
Proportions: Solid = 58% Void = 42%

Volumetric Thermal Capacity = Density x Solid x Heat Capacity = Thermal Storage

2,640 x 58% x 0.49 = 750 kJ/m^3
(165) x (58%) x (0.21) = 20 Btu/ft^3

The critical volumetric dimensions of a rock bed are derived from the bed length which is an expression of the air flow length. Thereafter, the front face or the average cross section area will provide the total volume. Dimensions of plenums or air distribution network need to be added to derive the gross construction dimensions.

Aside from these dimensions only the air flow characteristics or heat transport rate are needed to understand the performance of a complete rock bed thermal storage system. When the air through the bed is fan-forced the air flow rate or velocity at the face of the rock bed in meters per minute (feet per minute) will be consistent. However, where a variable rate of air flow is the result of passive phenomenon, an averaging technique or a parametric study is needed. Similarly the air temperature difference (delta T) must be known to calculate the exact thermal capacity of a rock bed within a given system. Since solar supplied air will have variable temperatures a typical design technique is to determine the range of maximum operating air temperature differences, the typical working air temperatures. Their range is divided by 2 to derive the working rockbed temperatures. This method also accommodates several other variables and allows the design to perform with an effective heat transfer above 95%. (see Ref. 1)

APPLICATIONS ADVANTAGES

Rockbeds are a component of air born heating and cooling systems and share characteristics of those systems. Thus air systems have relatively poor heat transfer experiences. But they are compensated by the ease of moving the medium. In terms of total efficiencies, air systems can compare very favourably with water and other fluid systems.

The particular attraction of air systems is that leakages are not the catastrophic potential of fluid systems. Air is clean and dry. However, these assets can encourage bad construction habits with systems constructed that are not air tight. Such tendencies obviously result both in lower efficiencies and also in systems which materially will deteriorate faster unless rebuilt or maintained.

Also from a construction point of view air systems are easier to construct. They require less specialized skills even if the level of craftsmanship should be of the same order as the plumbing fittings of fluid solar systems.

In terms of longevity rockbeds have a relatively indestructable core material. However rocks do expand and contract their dimensions as they are heated and cooled --a cycle that perhaps could be structurally destructive if tightly contained. Typical rock bed assemblies attempt to allow for this modest movement.

In use the rocks in rock beds absorb little water, and this moisture is quickly dispersed during the heating cycle. The principle maintenance problems to date have been foreign elements such as dirt, caused by accidental flooding, or from the nests of animals or insects that have tried to make a home in this clean shelter. Both problems can be solved by access to plenums and by having sumps or other drainage options to allow the rocks to be flushed with water without taking the rock bed apart.

Structurally rock beds can support floors and thus can even save in the cost of beams to span their tops. By locating rock beds within building enclosures their thermal leakage can contribute to the interior conditioning. And by planning the location of the structural sides of a rock bed to coincide with a continuation of building walls and foundations, their form can be an extension of the architectural and structural enclosures--an integration of built form with major economies in construction cost and time.

Thermally rock beds can be used both for heat and cool storage. In climates where a substantial amount of space cooling is necessary, as well as space heating, there is a certain logic and distinct economy in combining the purposes of thermal storage elements. Thus, rock beds can be used for both heating and cooling thermal storage, alternating in summer and winter and in various combinations of passive hybrid and active modes.

In climates where both cooling loads and heating are measured in degree days based on 18^{o} C. (65^{o}F), and where annual cooling loads are equal to or greater than the annual heating loads, the sizing of the rock bed is always determined by the cooling load. Primarily this is because the natural or passive/hybrid cooling potentials are always much less than the solar solar heating potentials.

Cooling design is typically based on night ambiant temperatures, or on the evaporative cooling opportunity as expressed in the wet bulb or dew-point temperatures. They always have a smaller temperature difference or delta T than the natural heating potential as produced to instance by solar air collectors. The authors experiences in designing several combined passive/ hybrid heating and cooling systems for arid climates where there is a large cooling potential from evaporative techniques have shown that the size of the rock bed for cooling must be three to five times larger than necessary for heat storage, even in the dryest overheated U.S. climates.

A PASSIVE ROCKBED FOR 100% HEATING

Natural convection collector systems have the particular advantage in passive heating systems of allowing remote thermal storage--rock bed storage thus permitting fine control of temperatures within living spaces. Few such systems based on remote thermosiphon loops have yet been constructed as integral parts of buildings, and even fewer have had any methodical investigation or published analysis.

The system was designed by Jeffrey Cook in 1975, with Herb Wade as consultant. The rock bin was completed with foundation work in July of 1976. The thermo-siphon loop system was completed 14 February 1978.

The site is a remote location in the mountains of southern Arizona at an elevation of 1500 M (4,800 ft.), with a heating load estimated at approximately 5000 degree days/year (F^{O}).

Because it is a retirement house constructed by the owners, independence from fuel or financial crisis were goals. The intention of the system is to provide reliable comfort throughout winters when electrical service often fails during storms.

The interior relationship of the solar heat collection and storage system to the spaces of the house are shown in a south/north section, Fig. 2. The rock bin which is used for thermal storage is located under the living spaces. Because of this arrangement of components, warm air can be supplied to the house either from the air collector or from the rock bin. A manually operated insulated damper at the top of the collector is used to eliminate loss of heat at night during the coldest part of the winter by back-siphoning.

Being owner-built, the house is extremely well constructed. The walls of the house are double with a layer of insulation between and consist of two widths of burned adobe bricks; a 10 cm (4") block outside and a 20 cm (8") one inside. The continuous 6 cm (2.5") cavity between is filled with foamed in place polyurethane. Generous double-glazed windows face a mountain view to the south. The passive direct gain and thermal storage aspects of the house itself have not been measured.

The proper sizing relationship of rock bed dimensions to thermal source is critical for good system performance and economy. The collectors occupy an aperture 2.65 M (8'-10") x 18.3 M (60'-0") for a net total area of 47.2 sq. M (508) sq. ft.). The upper 1/3 of the collector is double-glazed. The principal heat transfer surface consists of four to five layers of slit and expanded metal mesh. The blackened mesh is placed against the back insulation at the bottom of the collector and against the glass at the top of the collector. Thus, the line of the mesh makes a diagonal across the air space of the collector, Fig. 2 & 3.

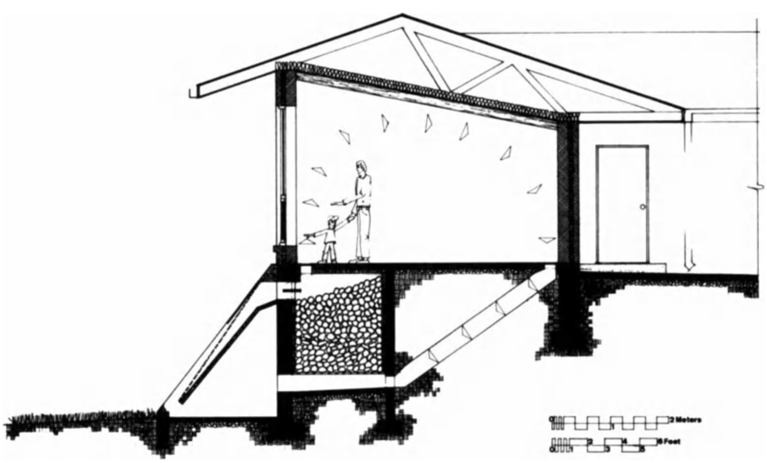


Figure 1. North/South Section through a 100% Passive Solar Heated House: The use of a rock bed for isolated diurnal storage allows several days heat to be stored. However, the passive aspect requires a stacked geometry since heat rises--the solar collector is at the bottom of the system, and the thermal storage must also be below the space to be heated.

The rock bin is approximately square in cross section to minimize thermal losses at the perimeter. Its dimensions are also related to the rock diameter--the air passage length conforms to Baer's recommendation of 12 times the rock diameter. The rock bin consists of approximately 54,500 K (120,000 lbs.) of round river rock with free air plenums on the top and bottom. Air flows vertically down through the rock bin, which is similar in design to rock bins for active, air-cooled systems. Care was taken (as it should be in all natural convection systems), to place the rock storage as high as possible within the convective loop. This allows storage of heat close to the top of the loop. To keep friction losses low, the rock size varies between 5 cm and 15 cm (2" and 6"), with 10 cm (4") as the predominant diameter. The measured packed density is approximately 1,600 kg/M^3 (100 lbs/cu.ft.).

The rock bin is well insulated with 2" of foam on the sides and top. The ceiling above the upper plenum supports the floor of the principal living space. The system is designed to take the best geometric advantage of collector/storage loops and storage/house loops.

Using .2 as a conservative figure for the specific heat of the rock, the relationship of the storage to collector surface = (.2) x (235) = 47 BTU/F/sq. ft. collector. Thus for each 1^0 F rise in storage temperature there has been a gain of 47 BTU per square foot of collector.

Both the design and a critical evaluation of the operation of this system as built confirm a particular feature that can cause poor performance. The construction included a large continuous butterfly damper extending the full length of the rockbed 18.3 M (60'-0") to close to the top set of apertures from the collector.

The reason for these dampers, of course, is to prevent the hot air in the rock bin from seeking its own level in the collector when heat is not being produced; thus exposing this warm air to the glazing. If this occurs, heat is lost through the glass and the tendency of the cool air to fall perpetuates a reverse convective loop, seriously robbing the storage of heat.

Heat loss due to reverse convection tends to negate one of the prime advantages of this type of passive system--isolating the glazing during the non-gain periods. The observed average air temperature behind the collector glazing one test night was 23^0 C (73^0 F) when ambientconditions were just above freezing. Thus, siphoning can lower the overall performance level of thermosiphon systems to the mediocre levels of direct gain and mass wall systems without movable insulation.

Fortunately, this reverse siphoning problem is relatively easy to remedy. The existing dampers were well made, but did not incorporate any special infiltration seals. Installation of such seals, as well as the addition of simple plastic back-draft dampers at the lower storage vents, alleviated the problem.

Another and even more fundamental solution to back-siphoning is latent in the system configuration. When the total heat storage can be located higher than the collection loop, no dampers may even be needed. However this configuration has major architectural and planning constraints.

As presently constructed, this 100% passive heating system is functioning admirably and should provide for controlled even heating to this residence indefinitely.

AN ACTIVE ROCK BED FOR HEATING AND COOLING

The design and construction of this active rock bed is for combined heating and cooling in a set of two-story townhouse apartments located in Phoenix, Arizona. This multi-family housing was initiated by an energy conscious investor group and intended for condominium purchase by retirees on limited incomes. Thus the feature of passive/hybrid heating and cooling was an important asset for sale and ownership since it would assure low utility bills for space conditioning. The design of these apartments was the only multi-family housing design premiated in the Arizona Solar House Competition of 1981. The first three units for an eight unit site were constructed and completed in 1982.

The space conditioning design is based on the climatic particulars of Phoenix, Arizona with its very hot summers and mild winters. In this arid climate there has been limited applied experience with passive/hybrid choices. Such systems work on a diurnal cycle and capitalize on the dryness of the air and the dramatic temperature differences between day and night.

Typically evaporative coolers are run at night when both ambient air temperatures and wet bulbs temperatures are significantly lower than during the daytime, this may give an advantage of 20°C to 25°C (30°F to 40°F) temperature difference when compared to daytime operation. Two sets of evaporative coolers are run, one to directly cool the dwelling, and one to cool the rock bed. Evaporative coolers to cool the rockbed are run continuously for an 8 to 12 hour period through the night and early morning to thermally charge rocks with coolness. During the heat of the day the system is in a discharge mode: hot outdoor air is first cooled by running it through the cool rocks. Then the cooled air passes through a single stage direct evaporative cooler and is delivered to the conditioned spaces.

The spent air from the house is exhausted to the outdoors through partially open windows or preferably through ceiling grills into a vented adjacent space such as an attic. Such an exhaust technique provides a secondary cooling effect by reducing temperatures in thermal transition spaces such as attics, garages or greenhouses/sunspaces thus reducing the cooling load on the core conditioned spaces.

Although in the reference design the recommended length of the rock bed (Ref. Peck) is 4.5 to 5.0 meters (15 to 16 feet) to optimally accommodate the diurnal pulse with a fixed flow rate; the architectural needs of the condomimium plan dictated a floor length dimension of 11.6 meters (29 feet). Thus, an open crawl space that is a much oversized plenum at one end of the rock bed was maintained under the kitchen to allow access and clearance for plumbing. By placing the rock bed itself only under the living room space, the interference of plumbing was avoided, and a continuous concrete slab which is carpeted could be cast directly on top of the rock bed well. Because of ease of construction as well as the use of vinyl tiles as a finish flooring surface in the kitchen, the floor under the kitchen is framed using wood joints and plywood deck insulated with fiberglass batts underneath.

Sizing The Rock Bed

The length of the rock bed which is the length of air passage under a fixed flow rate was established primarily by the diurnal pulse, as a product of the rock size. Theoretically by increasing the rock diameter, the air path can be lengthened and the thermal capacity of a rock bed can be increased while accommodating the same diurnal pulse. In this case the rock size was proposed as 0.1 to 0.2 M (4" to 8") diameter to allow the air path to be increased to 6.9 M (23 feet) from the reference design of 4.5 M (15 feet) using .08 to .15 M (3" to 6") rock diameters.

The width of the rock bed was established architecturally by the width of the plan at 5.6 M (18 feet). Thus the depth of the rock bed is the variable dimension to be established as the face area by the total cooling need derived from heat gain/loss calculations. Here the depth was fixed at approximately 1.35 M (4'-6").

When storing heat the operation is more conventional. Solar heated air is pulled off the top of a two story greenhouse by an electrically driven blower. The air is pushed through the rock bed where it looses its heat and then is returned to the bottom of the greenhouse. Heat is delivered to the house mechanically in the same way and using the same duct delivery system as cool air - except that in the heating mode a return is necessary to allow a closed air loop.

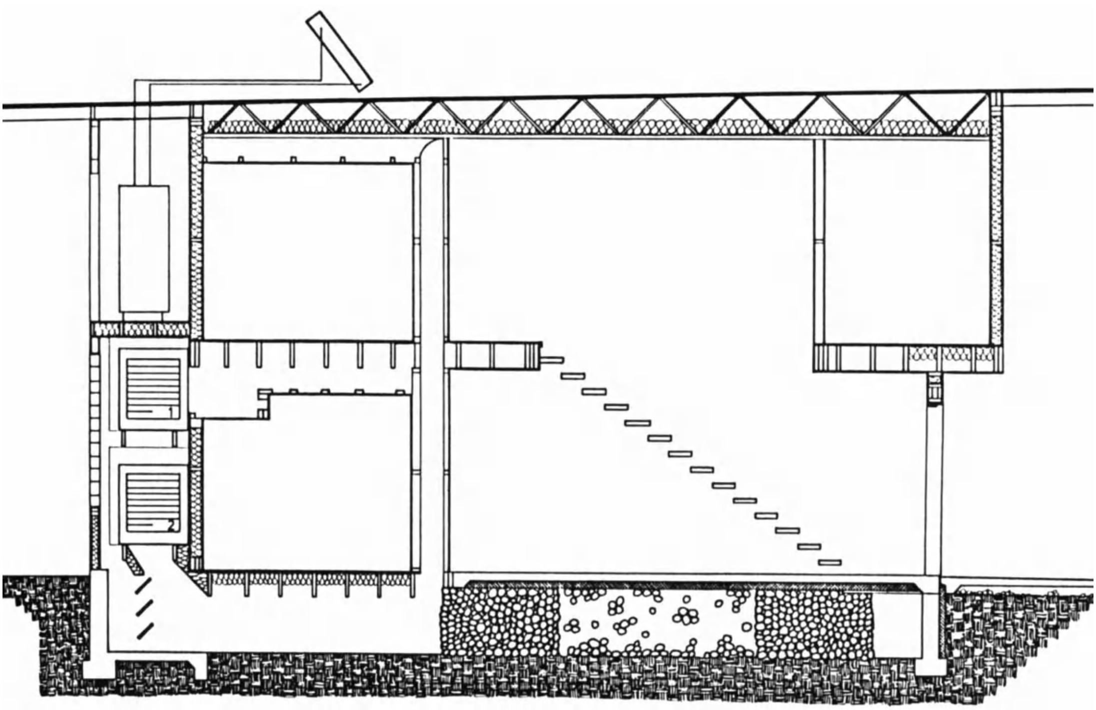


Figure 2. North/South Section through a Two-Story Row House with a Rock Bed for Both Heating and Cooling: The rock bed is constructed directly on the ground and has the concrete floor slab bearing directly on top. Since it is charged by a mechanical system the location of the rock bed has less restraints in its location than in a totally passive system. Here the heat source is a sunspace and the cool source is an open loop evaporative cooler. Thermal leakage through the partially insulated floor is part of the environmental delivery method.

Construction As Proposed

Because rock beds require a relatively large size architecturally in proportion to the quantity of thermal storage, they are typically used in smaller buildings such as houses or modest commercial structures. Such buildings usually have light construction methods and materials. Thus a number of successful rock beds have been built using #9 gauge chain link fencing for the open faces and insulated wood joint framing over the top.

For reasons of economy in this particular design, these rock beds were not placed on top of a concrete floor slab. Rather the earth was leveled and a vapor barrier of 6 mil polyethylene film was placed in a loose sand bed with the rocks placed on top. The floors of the plenum areas however, have concrete slabs.

In this case a concrete slab floor was poured directly on top of the rock bed. Gravel and sand were used to help level the top surface of rocks. Then two inches of polystyrene foam were laid as insulation and as permanent shuttering for the concrete which was cast in place without reinforcing steel. There is some concern that the leveling sand may work down through the rocks through time.

The open faces of the rock bin were designed to be retained by chain link fencing supported on 5.5 cm (2½") diameter pipe columns vertically cantilevered from the floor at 0.9 M (3 foot) spacing. Angle iron horizontal struts at the top of the pipe columns were braced to the outside foundation wall-- a detail that also provided support for the slab over the top of the plenum spaces. As designed and drawn the proposed construction did not pass the Phoenix Building Permit Department, a rejection which prompted a reconsideration of the rock bed construction details.

Construction As Revised

Instead of a rigid structural support, the working drawings were revised using a soft concept for holding up the faces of the rock bed. The solution is based on a variation of the "gabion", a wire basket filled with loose rock often used in heavy construction for retaining walls and structural rip rap. In this case loose cylinders of chain link fencing with a diameter of 1.4 to 1.5 M (4'-8: to 5 feet) and a height of 1.35 M (4'-6") were fabricated by weaving the ends of a flat strip together using a similar piece of wire.

The cylinders were hand held in place to be filled with rocks by a mechanical front loader. When full, the cylinders are not only self supporting they are also a stable retaining wall for the rock bed behind. Spanning the roof of the plenum was done by using corrugated metal as a permanent shuttering laid on top of the rock filled cylinders. In this case, rigid foam insulation from the top of the rock bed was continued over the plenum. The insulation was designed to control but not eliminate heat flows through the floor. Thus at all times a background radiant surface would be charged with thermal leakage from the rock bed underneath.

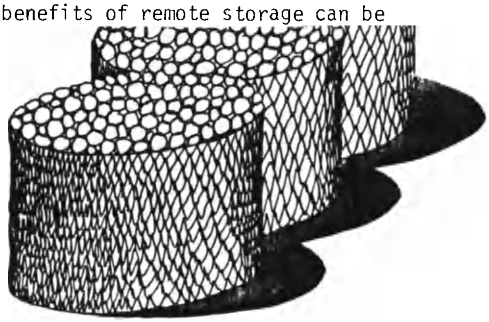
Thus use of gabions is a fast and economical construction method especially when compared with the other methods of rock bed construction. But it has other advantages. While the term "gabion" and its use is well known in heavy construction, it is not so well known in the building industry. Even so, there were no problems in getting a building permit on the revised construction details. In addition, the structural flexibility of the gabion through the years should allow a certain resilience to the constant expansion and contraction characteristic of rock beds used for thermal storage.

The economy of this revised construction method is indicated by the actual cost of $11,000. for three side-by-side rock beds as built. This cost includes excavation, footings, stem walls and retaining walls, rocks installed and the damper controls; everything up to the concrete slabs and wood joist floor decks. In addition, substantial time was saved by avoiding the hand placing of rocks which reduced the total construction period of the condominium complex.

Among the disadvantages is the physical need to hold the gabion cylinders open and in place until partially filled. The use of a front loader greatly accelerates the most expensive aspect of rock bed construction--placing the rocks. However, the rock bed has to be dimensionally large enough to provide space for manoeuvering of such equipment. In addition, the manoeuvering of such machinery can tear up the vapor barrier and sand base assembly. A crushed rock base, or a poured concrete slab underneath would cost more, but would make a more substantial building application that may be justified in other projects, and would provide a stable base of equipment operation.

SUMMARY

Rock beds are a viable generic thermal storage component of solar heating and cooling whether the system is passive, active or hybrid. In general because of their relatively large size rock beds are unlikely for large buildings, but they are suitable for housing and other small buildings such as commercial structures. In all cases the viability of rock beds must come from the economy of their construction. The thermal characteristics of rock beds are predictable, and the long term performance and maintenance offer no surprises. However, the custom design and hand work involved in the construction of experimental rock beds must be displaced by design and construction methods that are easy and economical so that the benefits of remote storage can be delivered at a reasonable cost.



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PRODUCTION AND STORAGE OF ICE FOR COOLING

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ABSTRACT

Ice production and storage systems can be designed to meet the cooling and dehumidification needs of new and existing buildings and to reduce the peak cooling needs and utility demand changes.

The ice production processes are classified as passive, low-energy and high-energy systems. In the passive ice production techniques no prime source of energy is used for ice production, whereas in the low-energy system energy is used for air or water circulation and in high-energy designs energy is used to operate conventional refrigeration machines.

In the passive systems ice production is primarily due to wind effects. Heat pipes may be employed to gradually freeze a pool of water. In the low-energy systems the cold ambient air is blown over the water surface while ice is produced gradually in above-ground or underground reservoirs. Soil freezing is another method for low-energy ice production.

The high-energy ice production involves the use of refrigeration machines to produce ice during off-peak hours and to use this ice for load leveling and utility demand charge reduction. The annual ice storage systems involve the production of ice/snow in winter, when the machine has a higher COP, and a heat pump for heating a building and producing ice in winter. The ice is stored to assist the summer cooling.

KEYWORDS

Passive and low-energy ice production, ice storage, soil freezing.

INTRODUCTION

Before the advent of mechanical refrigeration in this century any low temperature cooling provided in summer was through the storage of winter coolness. The mat-

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erial used for the storage was primarily water and the processes employed for energy transfer were natural and forced (due to wind) convection, evaporation and thermal radiation losses to the sky. Cold winter water was stored in deep cisterns and water was frozen in winter and stored in cellars, ice houses or ice pits for summer use [1,2]. The ice was used for direct consumption, to cool drinks, or for food preservation. Caverns, with inside temperatures of about mean annual ambient air temperature, were also used for food preservation. Ice export from the cold regions to warm countries was a thriving business.

In the storage of thermal energy a point of considerable economic significance is the mass or volume of the storage material, its abundance and low initial costs [3,4]. Phase changing materials with large enthalpy or latent heat of phase change and low change of volume are desired. Water (ice) is one of the most suitable materials for the storage of coolness. It is the least expensive material, has a high enthalpy of liquid-solid phase change (330 kJ/kg) and suitable melting point. Furthermore, the greatest amount of scientific information about its properties exists. The major disadvantages of water are its change of volume upon phase change and its corrosive potential [3,4]. Nonetheless, its many advantages have made water the most used material for thermal energy storage.

The sources of coolness for natural ice production may be the ambient air, thermal radiation losses to the sky and evaporative losses. In cold regions of the world, where the ambient air temperature drops well below the freezing point in winter, one has no difficulty of producing ice. The harvest of ice from lakes, rivers, ponds, etc. and its preservation in cellars or ice houses for summer use was practiced before the advent of mechanical refrigeration [5]. In the hot and dry regions of the world one had to rely on the other sources of coolness for ice production [1,2].

In this paper the state-of-the-art in gradual production, storage and utilization of ice for cooling is presented. Although one can produce ice completely passively [1,2], one should employ the present technology to produce, store and utilize the ice with the least costs. The system to economically compete with is the conventional vapor compression or absorption refrigeration.

The ice production technology may be broadly divided into passive, where no prime source of energy is used for the ice production; low-energy, where the energy used is rather small (for circulation of water or air); and high-energy ice production, where a mechanical refrigeration machine is used for ice making. The last case will be considered because of its potential applications in peak sharing or load leveling in the existing refrigeration systems and the savings involved in reduction of utility demand charges. In the following sections the current experience in gradual ice production, storage and utilization is briefly reviewed. Table 1 gives the summary of the discussion.

PASSIVE ICE PRODUCTION

In the cold regions of the world ice was harvested during winter from the lakes, rivers, etc., stored in cellars or ice houses for own use or sale to the public in summer [5]. In the hot arid regions of Iran, ice was produced gradually during the winter nights in shallow ice ponds to a desired height and was then removed and stored in deep ice pits (Yakh-Chals). Water evaporation and thermal radiation losses to the sky provided the major sources of coolness [1,2,6]. During summer ice was removed from the storage and sold to the consumers, either for direct consumption or for food preservation. Because of its relatively high costs the ice was hardly ever used for comfort summer cooling.

Both of the above passive ice production, storage and utilization techniques were labor-intensive and expensive operations. For health and economic reasons they are now abandoned.

In recent years the interest in passive or low-energy ice production has increased [7-18]. The systems employed are described below and in the following sections.

The Use of Heat Pipes for Ice Production

Gravity-return heat pipes, using a Freon, were employed for the ice production [7,8]. At Argonne National Laboratory, USA, the evaporator sections of the heat pipes were placed in a 75.7 m^3 pool of water while their condenser sections were exposed to the cold winter ambient air. Ice was gradually produced around the evaporator portions of the heat pipes. Heat pipes were also used to freeze a water-saturated soil [19].

Use of Wind for Ice Production

Wind blowing over a layer of water in winter may provide sufficient cooling for ice production. In an above-ground design of an ice box, ice was gradually grown to a height of 2.7 m, as a part of Public Works Canada demonstration project [9,10,12,16]. The box consisted of a 2.4 m x 2.4 m open louvered structure where water layers froze and subsequently sealed the openings. Wind blew through the open louvers. After completion of ice production an insulated building was constructed around the ice block.

In an underground design of a prototype ice pond at the University of Waterloo, ice was produced, stored and utilized in the same pond [17]. The pond, shown in Fig. 1, had an area of 2.7 m^2 and a height of 1.2 m. During winter nights about 2-3 cm of water was poured in the pond and was subsequently frozen by the wind blowing over the water surface. During several storms snow accumulated in the pond, making it necessary to remove this snow for further ice making. After growing an ice block 1.1 m high the pond was insulated on top and was stored for summer use. The pond was not insulated on the sides or bottom; as the result of which a major portion of the ice was melted during the storage months. The coolness in the remaining ice was utilized by circulating water through the heat exchanger pipe, which was placed at the bottom of the ice pond before ice making process. In another experiment the ice coolness was retrieved by spraying water returning from the load over the ice block and collecting the chilled water, as well as the melt, from the bottom of the pond.

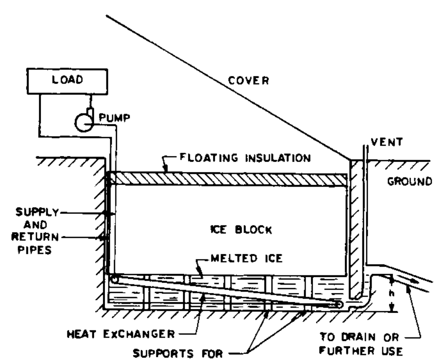

Fig. 1. Cross section of the experimental ice pond.

In a theoretical study of ice production and utilization to meet an annual cooling demand of about 1.5 TJ for an office building an underground open pond such as shown in Fig. 2 was considered [18]. The pond was protected against the sun, rain and direct snow fall by a shade. Snow fences were considered to

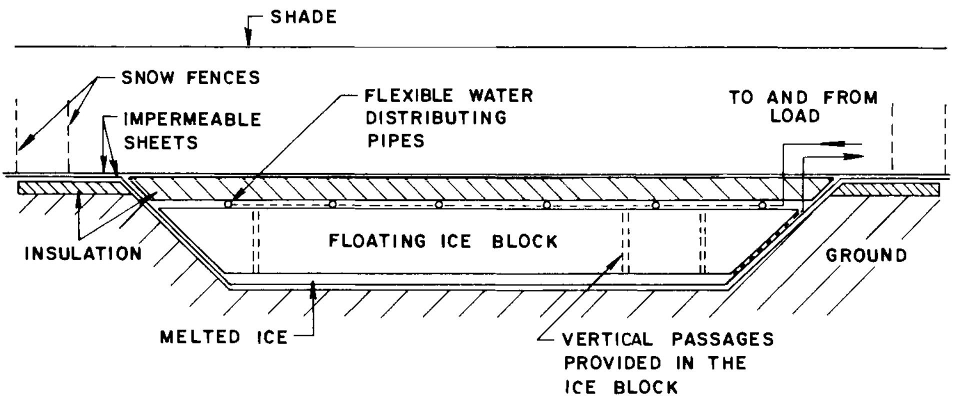

Fig. 2. An uncovered ice pond. The flexible pipes, insulation and the top lining are placed on the ice block at the end of ice-making period.

prevent the snow from drifting into the pond during the storms. Unlike the previous design, where the ice block was resting on ice block supports during ice utilization period, here the ice block was to float in the pond. Flexible water distribution pipes and the top insulation were floating with the ice.

Collection and Storage of Snow from the City Streets

In many cities located in the cold regions of the world removal of snow from the city streets constitute a major expense. To meet the cooling needs of a large office building in Ottawa (with a peak demand of 7 MW), Public Works Canada considered the collection of city snow and its storage in a nearby stone quarry of about 48000 m^3 volume [16]. The quarry was to be insulated and protected from the rain during the spring and summer months.

LOW-ENERGY ICE PRODUCTION

The open ice ponds of Figures 1 and 2, although use no prime energy for their ice production, have the following disadvantages:

a. The land above the pond can not be used for any applications. The cost of land, which is quite variable, can constitute the major initial cost for the ice production and utilization systems [18].

b. Snow can always drift into the pond, reducing the ice production and storage capacity of the pond. Snow with its remarkable insulating effects insulates any water poured in the pond for subsequent freezing. For the experiment at the University of Waterloo [17] it was necessary to remove the snow before any ice production could be continued.

c. The pond can become quite dirty, thus increasing the costs of ice utilization and pond maintenance.

For the reasons stated above one can cover the ice pond completely and blow the winter ambient air in it whenever ice production is feasible.

Above-Ground Ice Production

Centre de Recherche Industrielle du Quebec, Canada, has built and operated an ice warehouse [10,12,16]. The building, which is above ground and is well insulated, houses the ice making system. The building is of 5.18 m x 5.18 m area and is 4.88 m high. Inside the building an ice block of 2.4 m x 2.4 m area and 3 m height was produced. Water is frozen gradually in a simple wooden frame by blowing the ambient air into the pond very close to the ice surface. During the summer operation the water returning from a heat exchanger (supplying chilled water to an adjacent building) is sprayed over the ice block and the melt, collected at the bottom, is pumped back to the heat exchanger. Small electric heaters are used around the edge, inside the wooden frame, to make the ice release from the frame.

Underground Ice Production

The heat gain by the ice pond from its surrounding is generally lower when it is placed underground. Ground itself acts as a coolness storing medium. But the major advantages of this system is the elimination or minimization of the cost of land which should be charged to the ice making project. These ice ponds can easily be constructed under the existing parking lots of commercial, industrial, institutional and residential buildings, shopping centers, etc., or underground in open spaces, without altering the landscape of the site. This design extends the concept of ice production and utilization to quite a large variety of applications and places.

In an experimental study at Kansas State University, USA, a 3.785 m^3 reinforced concrete tank was insulated with 0.3 m of insulation on the sides and bottom and was then buried in the ground [10,12]. Ambient air was blown into the tank by a blower mounted on top. Ice was produced gradually in the tank and stored for summer use.

To make a cost benefit analysis for an ice making project to meet an annual cooling need of about 1.2 TJ for a non-residential building the underground covered ice pond designs shown in Figures 3 and 4 were considered [18]. Both designs consider freezing of a small layer of water, for example 1 mm, at a time and employ a blower to circulate the ambient air into the pond when the ice production is feasible. They both consider the ice block resting on ice block supports during the ice utilization period, thus reducing the water pressure in the pond to that corresponding with the height of these supports. The pond designs differ only in the method of ice utilization. Figure 3 uses a heat exchanger placed at the bottom of the pond, cooling the water returning from the load, whereas in Fig. 4, water returning from the load is sprayed over the ice surface and flows down through the ice block. Discharge of melt from design of Fig. 3 is such as to ensure a water-ice interface at the top of the ice block supports all the time.

For the economic analysis a pond of 1849 m^2 area and 3 m high, providing ice blocks of 2.5 m height and 1680 m^2 total area, was considered [18]. The heat gained by the pond was determined for Edmonton, Halifax, Toronto, Montreal and Saskatoon in Canada. The coolness recovery factor, defined as the coolness delivered to the building to that available in the ice block at the end of ice production period, was evaluated for these cities. They ranged between .825 for Toronto to .91 for Edmonton, the warmest and coolest of these five cities, respectively. The initial and annual costs of the underground covered ice ponds were

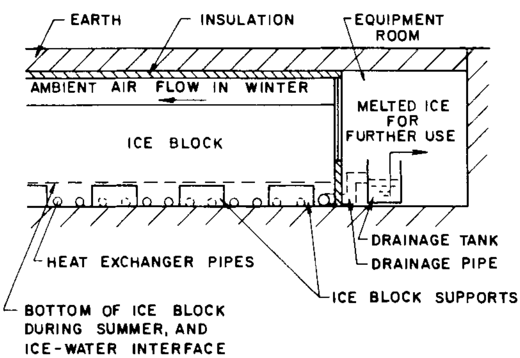

Fig. 3. Cross section of the ice pond. During summer the ice block rests on the supports.

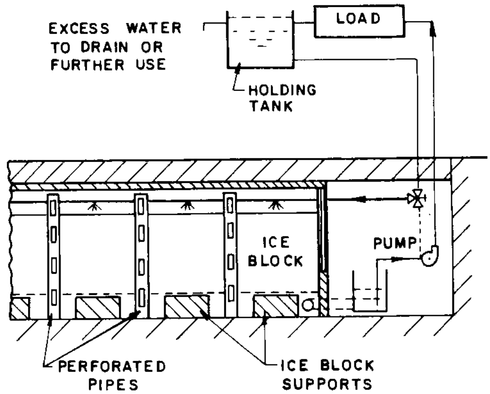

Fig. 4. Cross section of the ice pond, showing the ice utilization in summer by spraying water over the ice surface.

estimated and were compared with those of a conventional vapor compression refrigeration machine of comparable capacity. It was shown that for these ice ponds, where the land above the pond is used for car parking, landscaping, etc., and when the cost of land is, therefore, not charged to the project, the cost of 1 GJ of coolness delivered by the ice pond project was lower than that of the conventional refrigeration machine [18]. It was also shown that when the cost of land had to be considered it constituted the major initial and annual expense, depending on the cost of land and the interest rate. The cost of land surrounding the non-residential, particularly commercial, buildings (for which the ice storage system finds most of its applications) is high everywhere; one can not simply ignore this fact or assume very low values for it for his economic analysis [15].

Soil Freezing

Soil freezing and heaving have always constituted major problems in civil engineering works. However, one may store the winter coolness by freezing a saturated soil [12-14,18]. The major merit of the system is its potentially low cost of storage.

Ground is excavated to desired dimensions and then lined with an impermeable lining (for example polyethylene pool lining). The excavated pit is then gradually backfilled, placing heat exchanger tubes with suitable spacing in it. Plastic tubing (for example polypropylene) are used as the heat exchanger. The backfilled soil is made saturated by injecting water in it. A layer of dry soil on top of the saturated soil can accommodate water displacement due to freezing expansion of water. A layer of insulation and another impermeable sheet cover the storage, which can be further covered on top by a layer of top soil for landscaping. Figure 5 schematically shows this design.

In an experimental study to be undertaken at Illinois State University, USA, the storage pit has a volume of 170 m^3, and uses three rows of polypropylene tubing with a total length of 920 m as the heat exchanger [12,13]. A circulating pump

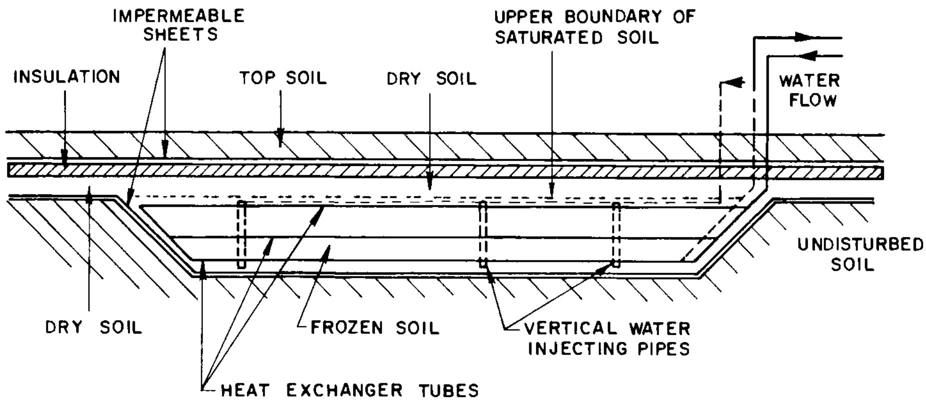

Fig. 5. Cross section of coolness storage in frozen soil

circulates propylane glycol through the heat exchanger and depending on the mode of operation, either freezes the moisture in the soil by extracting heat from it or thaws the frozen soil by supplying heat to it. One or two heat exchangers connect the winter ambient air and the conditioned space to the system.

In a theoretical study carried out to determine the feasibility of long term storage of coolness in Canada by means of soil freezing [18] a storage volume about 7450 m^3 was selected to meet an annual cooling demand of 1 TJ. Again, not considering the cost of land, it was shown that the cost of 1 GJ of coolness delivered by this system, although higher than that provided by the underground covered ice pond, is still lower than that produced by a conventional refrigeration machine. For this system about 46,500 m of 2-cm diameter plastic tubing at a cost of about $1./m was considered [18]. The key point to the economic competativeness of this system is the low cost of the heat exchanger tubes.

HIGH ENERGY ICE PRODUCTION

Vapor compression refrigeration systems may be employed to produce ice for daily or seasonal storage of coolness. The system employed by the center for Energy and Environmental Studies, Princeton University, USA, consists of a snow-making machine, like those used on ski slopes to prolong the skiing season. Water was sprayed into the cold air stream, atomized by the nozzles and subsequently frozen, producing ice crystals [12,15]. The snow/ice crystals were then blown into a pit of an inverted cone shape, 17 m diameter and 3 m deep. The pit was lined with a PVC lining and had a below-ground capacity of 300 m^3. A steel truss-supported fabric covered the pit. After the ice making period a polyurethane foam insulating blanket, about 10 cm thick, was placed on top of the ice mound. In the air conditioning mode water returning from the heat exchanger, supplying chilled water to a building, was sprayed over the snow/ice mound. The porous nature of the storage provided an excellent heat transfer area and the water was cooled to temperatures between 0 to 3^oC. An average coefficient of performance, defined as the coolness delivered to the energy expended for ice making, of 9.5 was obtained [15].

The production of ice to reduce the maximum energy demands for cooling at peak hours has attracted some attention in the past several years [10,14,20,21]. On a daily cycle a conventional refrigeration unit produces ice during the off-peak hours. The ice thus produced is utilized during the high cooling demands. Compared with a conventional system, where the chiller capacity is selected to meet the peak cooling demands (while it operates at partial capacity most of the time) here a smaller chiller, operating nearly at full capacity, is needed. Appreciable savings may be involved in reducing the chiller capacity and utility demand charges. Additional expenses are for the heat exchanger and ice production and storage tanks. The savings involved in using an all-plastic heat exchanger tubes and tank are appreciable [10,14].

On a seasonal cycle a heat pump supplying heat to a building removes heat from a tank of water and produces ice. The ice is then stored for summer cooling. This design, called Annual Cycle Energy System [21], finds applications in regions with warm and humid summer, where the ice stored from winter can help reduces the energy demands for peak summer cooling. In special applications, for example hospitals, restaurants, food processing plants, etc., where ice (or chilled water) as well as hot water are needed at the same, the use of both ends of heat pumps can have significant energy saving impacts [22].

A summary of the ice production, storage and utilization methods are presented in Table 1.

CONCLUSIONS

Seasonal storage of coolness in the form of ice is an old process and was practiced before the advent of mechanical refrigeration. The process was labor-intensive in ice production (in the case of Iranian ice making system), ice storage and utilization. All the systems employed today for ice production, storage and utilization attempt to minimize the labor required. All these systems use the same reservoir for gradual ice production and storage, and use water to transport the coolness to meet the cooling demands.

The technology for ice production, storage and utilization is not advanced and is available almost everywhere. In the cold regions of the world ice can readily be produced in winter and stored for summer use. In hot arid regions one could utilize water evaporation and sky radiation to produce ice. Special designs to minimize labor are necessary. In the hot humid regions the off peak operation of the existing mechanical refrigeration systems to produce ice for peak hour utilization reduces the maximum energy demands and utility demand charges. Although additional expenses for ice production and storage are involved, the overall savings can be significant.

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Table 1, Summary of Ice Production, Storage and Utilization Systems

Types of Ice Production and Storage	Major Sources of Coolness				Sites for Ice Prod., Stor., and Utiliz.		Energy Used for Ice Production			Energy for Ice Utili-zation		Ice Storage Volume			Nature of Project		Possible Use of Space Above Storage				Major Intended Applications			
	Ambient Air	Sky Radiation	Water Evap.	Mech. Refrig.	Separate	Same	None	Low	High	None	Low	Small	Medium	Large	Experimental	Analytical	None	Landscaping	Parking	Living	Drink Cooling	Food Preser.	Cool., Dehumid	Load Leveling
PASSIVE ICE PRODUCTION																								
Ancient, Iranian		√	√		√		√			√				√	√					√	√	√		
Ancient, Cold Regions	√				√		√			√		√	√	√	√					√	√	√		
Use of Heat Pipes																								
Argonne Nat. Lab.	√					√	√				√	√			√			√		√			√	√
Vermont Residence	√					√	√				√	√			√			√		√		√	√	√
Use of Wind																								
Public Works Canada	√					√	√				√	√			√		√						√	√
Univ. of Waterloo	√					√	√				√	√			√	√	√						√	√
Collection of City Snow																								
Public Works Canada	√				√		√				√			√	√		√						√	√

Table 1, Continued

Types of Ice Production and Storage	Major Sources of Coolness				Sites for Ice Prod., Stor., and Utiliz.		Energy Used for Ice Production			Energy for Ice Utilization		Ice Storage Volume			Nature Of Project		Possible Use of Space Above Storage				Major Intended Applications			
	Ambient Air	Sky Radiation	Water Evap.	Mech. Refrig.	Separate	Same	None	Low	High	None	Low	Small	Medium	Large	Experimental	Analytical	None	Landscaping	Parking	Living	Drink Cooling	Food Preser.	Cool. Dehumid.	Load Leveling
LOW-ENERGY ICE PRODUCTION																								
Above Ground																								
CRIQ*	√					√		√			√	√			√					√			√	√
Underground																								
Kansas State Univ.	√					√		√			√	√			√			√	√	√			√	√
Univ. of Waterloo	√					√		√			√	√		√	√	√		√	√	√			√	√
Soil Freezing																								
Ill. State Univ.	√					√		√			√		√		√	√		√					√	√
Univ. of Waterloo	√					√		√			√			√		√		√					√	√
HIGH-ENERGY ICE PRODUCTION																								
Use of Snow Machine																								
Princeton Univ.	√			√		√			√		√		√		√		√						√	√
Daily Storage				√		√			√		√	√	√		√					√				√
Seasonal Storage				√		√			√		√	√	√		√					√				√

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HEAVY MATERIALS AND PASSIVE SOLAR DESIGN

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ABSTRACT

Using a sample of 9 houses of the industrialized type, all with the same insulation level, the authors test the influence of the presence of heavy materials, such as concrete, in the make-up of the envelope walls and separation walls. The study has been caried out on two locations in France, one with a temperature climate and the other with a rigorous climate.

After presenting their calculation instrument, the authors show the double advantage of these materials. On the one hand the energy requirements for heating are reduced and on the other hand the level of comfort is much higher in summer and in between seasons. They then go on to give a certain amount of advice as to the implanting of the capacitive materials in the walls, and conclude by encouraging architects to take this particular data into account in the design of passive dwellings with a low energy profile.

KEYWORDS

Solar passive design ; Solar energy ; Heavy materials.

ARCHITECTURAL DESIGN PROBLEMATICS

Since energy problems have started to be posed in terms of heating and ambiance climatization, lived-in space designers have tried to work out a hierarchy in the parameters which are able to have a double influence on energy saving and thermal comfort. The available means which permit a reduction of heat consumption are relatively diversified. However, few of them have the advantage of acting simultaneously and in a positive direction on the two factors (consumption/comfort) and it is these factors which are of interest to designers. Amongst these means, certain are referred to as "technological" (thermal insulation, flat solar captors, heat pumps, etc...) and they usually lead to extra construction costs for which the builder has to point out depreciation which if it is not rapid must at least be compatible with the economic data of the problem.

The second category of means deals with actions which are specifically architectural and which tend to give the project a particular character which depends upon an affirmed design decision and which is generally linked to a bioclimatic constant. We can then observe transformations in the spaces, the structures and the envelopes with a better mastery of heat management and with heat whose quality is maintained or increased, but of course dependent on the level of success of the project. The most obvious expression of this new desire to let the building and its users "live" with the climate is the developement of glass façades which are correctly orientated for solar recovery and are used in passive architecture. Should these glass surfaces have nocturnal protection, we now know that they considerably contribute to a reduction in thermal requirements in temperate climates. However, the important place which is given to glass surfaces today, i.e. to the recovery of "direct solar gains", poses the traditional problem for thermal engineers, of the "digestion" of the thermal contribution by the dwelling. A simple and approximate reasoning points to the necessity for the presence of capacitive materials whose function is to modulate the real calorific contributions and the resulting temperature variations in the ambiance.

This qualitative approach to the problem of thermal masses in dwellings is relatively well understood by the members of design teams who prefer to speak of thermal inertia which is a global and difficult concept to manipulate. But at an advanced elaboration stage of the project, these principles must be concretized by a dimensioning and finally the question of the dósage of these heavy materials must be posed.

THE AIM OF THE STUDY

It is precisely this sort of preoccupation which we have tried to give an answer to in the study which we present below.

* On the one hand, we have tried to evaluate to what extent the presence of heavy materials contributed to the reduction of the energy requirement for winter heating. From this information it should be possible to obtain the general rules for "dimensioning of inertia" exploitable by designers and which can sometimes lead to the choice of constructive techniques.

* On the other hand, for the heating period, but especially for the summer we have studied how the resulting temperature of the dwelling evolued when heavy materials played then thermal buffer role. It is through the overheating frequencies that we observed the comfort conditions, but we also used various exterior temperature amplitudes corresponding to the stability factor which is highly appreciated by the inhabitant.

THE STRUCTURE OF THE STUDY

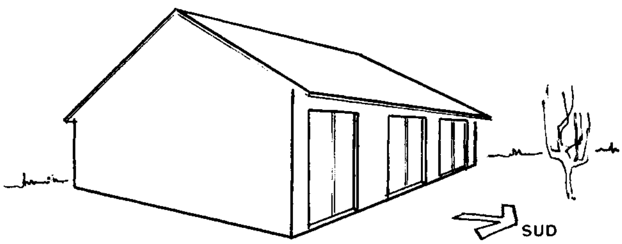
1. The directing principle of our study was to vary the quantity of heavy materials used in the composition of the envelope and the structure in our basic architectural model. This proportion of capacitive masses was the only variable in the study, but we are able to show its incidence on the characteristics studied. The other parameters of the dwelling were kept rigorously constant viz :
   - the orientation
   - the insulation level, i.e. the volumetric heat loss coefficient G ($w/m^{3\circ}C$)
   - the volume and the dimension of the façades
   - the glass surfaces on the various façades
   - the heat load of the equipment
   - the closing of shutters at night

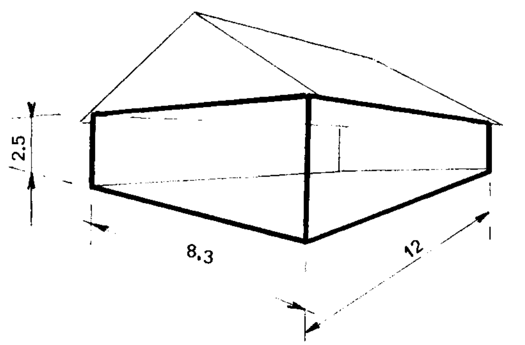
   Therefore, we only modified the make-up of the envelope walls or the inside walls in the various houses studied.

2. Our dwelling is an individual detatched single-storey house which is a good example of French industrialized building. The choice of this very slightly architectured module which is somewhat different from the bioclimatic replies proposed by

specialized designers can be explained by the necessity to produce information which if non generalizable is at least representative and applicable in the largest possible number of cases. More highly elaborated projects generally due to the architects often propose better and more interesting performances. But their special features are an obstacle to the didactic use of the results obtained and which can only be used with great circumspection in a wider project framework. The house chosen has living space of approximately 100 m^2 and its volume is 250 m^3.

Only the North and South façades have glass surfaces. Double-glazing is used and the windows care closed off at night by a rolling shutter which gives the building a thermal resistance of 0.5 $m^2 °C/W$. The surfaces are as follows. South 15 m^2, North 5 m^2. The volumic heat loss coefficient common to the various dwellings is G = 0.89 $W/m^3 °C$.





3. The walls of these dwellings have been designed along the lines of techniques which are commonly used in France. Their make-up varies a great deal, both from the point of view of the material used and from the point of view of the method of construction. We generally find wood, concrete, plaster and a thermal insulator.

The table in Fig. 1 shows how the dwelling studied is made up, from a range of basic walls for which the following symbols have been used :

light wall : plaster + insulator (+ possibly wood according to the wall's use)

half-heavy wall : plaster + insulator + concrete sheet (4 cm) + coating

half-heavy wall : plaster + insulation + concrete sheet (8 cm) + coating

heavy wall of hollow blocks : plaster + insulator + hollow blocks (20 cm) + coating

heavy wall : concrete + external insulator

The flooring is either light (wood + insulator) or heavy and constructed with the aid of a traditional system (joists and ceramic rough-cast). This latter type of flooring is still very popular in France but is not thermally insulated.

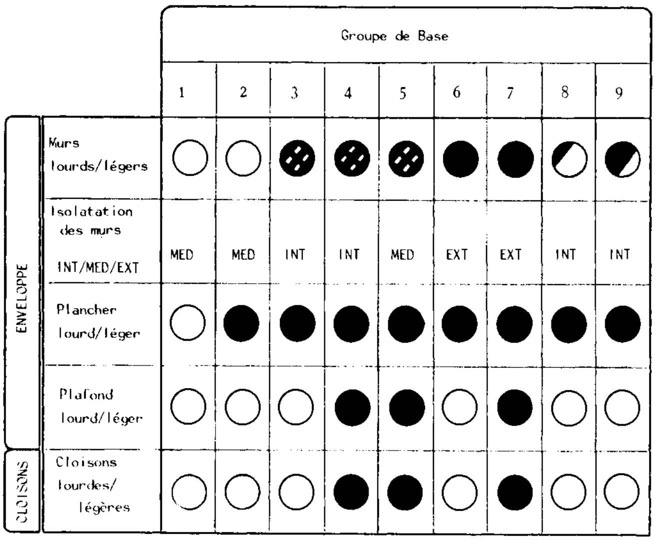


Fig. 1 - Mass characterization of different dwellings.

PRESENTATION OF THE STUDY INSTRUMENT

The study of the Q cases of thermal inertia was carried out with the help of LUCIOLE software. This research tool was designed in our laboratory is a series of programmes functioning in three stages :

1. In the first phase, the envelope and inner walls of the dwelling are described by their series of response factors.

2. Then all of the series together enable us to calculate the dwellings weighting factors.

3. Finally, we simulate the behaviour of the dwelling over a whole year, hour by hour, using a real climatic file we thus assess the energy requirements, month by month, during the cold season. We also go on to scrutinize the resulting temperatures and this enables us to identify the overheating to determine its frequence.

These results are obtained by cumulating the effects of the various (direct and diffused solar radiance, outdoor temperature, indoor temperature, equipment etc). Thus, for an excitation which we will call $E(t)$, we will obtain the associated ponderation factors Q_{EU} $(n\ \Delta t)$ and the response $Q(t)$ will be :

$$Q_E(t) = \sum_{n=0}^{\infty} Q_{EU}\ (n\ \Delta t).\ E\ (t - n\ \Delta t)$$

When the room is sollicited by m excitations, the total charge will be :

$$Q(t) = \sum_{j=1}^{m} \sum_{n=0}^{\infty} Q_v\ (j,\ n\ \Delta t).\ E\ (j,\ t - n\ \Delta t)$$

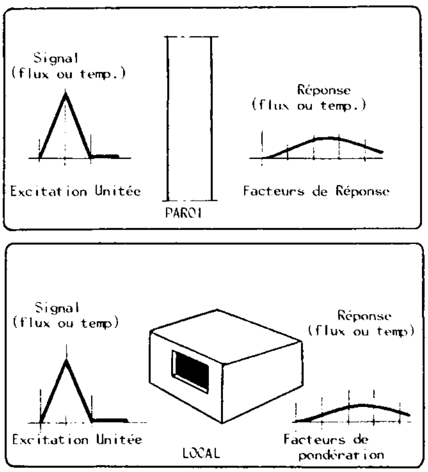


Fig. 2 - Definition of the response factors and the weighting factors.

N° de Code Cellule	SITE: TRAPPES		SITE: CARPENTRAS	
1	11340	+ 25%	6440	+ 63%
2	11350	+ 25%	5350	+ 36%
3	11220	+ 24%	5120	+ 30%
4	9770	+ 8%	4320	+ 10%
5	9230	+ 2%	4090	+ 4%
6	10020	+ 11%	4150	+ 5%
7 (GROUPE DE BASE)	➡ 9030	Ref	➡ 3940	Ref
8	10630	+ 18%	4860	+ 23%
9	10900	+ 21%	5070	+ 28%

Fig. 3 - Annual energy requirements (Kwh) for the 9 dwellings on the 2 sites Paris and Carpentras.

PRESENTATION OF RESULTS

1. On the energy requirements.
Two sites were dealt with. The first, in Paris, corresponds to a relatively cold climate. The second, in CARPENTRAS, is characteristic of the temperate climates of the South of France. The energy requirements are shown in the table in Fig. 3.

Overall, these results show that the presence of heavy materials can lead to very different results in climates with relatively marked characteristics. For example, the use of a heavy flooring in a light structure has much more influence on the thermal balance in Carpentras than in Paris. In both cases, it plays an important heat accumulation role and we can observe this in the interior temperature variations. However, because there is no underneath insulating barrier, the floor is subjected to the cold thermal drawing of the dry course. This is intense in Paris where the climate is rigorous and the heat loss is high. This only plays a minor role in the energy consumption. On the other hand, in Carpentras, where the temperatures are higher, the heavy flooring leads to a considerable gain by comparison with dwelling n°1.

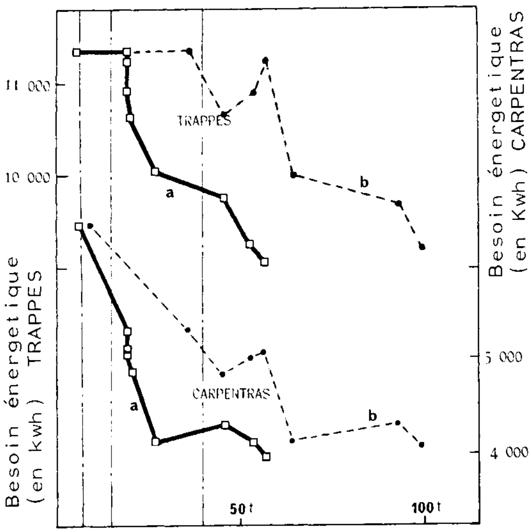


Fig. 4 - Annual energy requirements (Kwh) for the 9 dwellings on the 2 sites Paris and Carpentras.

Curve a : total mass
Curve b : int. mass

The progressive reinforcing of the presence of heavy materials leads to their being a decrease in energy requirements. These variations are relatively heterogeneous. This diagram represents the requirements variations with the quantity of the heavy material, that is to say, that which is in "contact" with the interior ambiance without any insulating protection. We can thus see that dwellings 4 and 6 give inversed results with reference to the climate. This is due to the fact that, in Paris, it is necessary to put on a little heating at the beginning and at the end of the summer. This necessity slightly favours dwelling n° 4 which is heavier, during a period when high accumulation capacity is appreciable.

The diagram also explicitly shows that the total mass of material is not representative of the economy qualities of the building. The position of the insulation is a determining factor for these materials to contribute effectively to the storage of the solar contribution and to be a temperature modulation factor.

2. On the temperatures
The influence of heavy materials is specially marked during the hot season, both in Paris and in Carpentras. The day interior resulting temperature variations are all the lower as the active thermal capacities are higher. In order to quantify these phenomena, we classified the temperatures and drew up frequency diagrams (cf Fig. 5). We can thus see that the heavy dwellings are relatively stable in summer.

They benefit from a "reduced" spectrum, whereas on the other hand the light dwellings give us a "wide" frequency spectum which is characterized by wide temperature variations, and a considerable amount of overheating. If we establish a thresholdof 27°C below which the ambiance is considered to be comfortable, the heavy dwellings are approximately satisfactory.

CONCLUSION

The heavy materials threshold seem to be part of those technical components in the project which the architect should make the best of in order to obtain better thermal results. These turn out to be :
* energy economy factors. If these active capacitive masses remain active (no insulating layer separating the material from the ambiance), they help to decrease the

requirement considerably.

* the temperature modulators neutralize the overheating and thus give the dwelling high free recuperation qualities (especially solar).

As far as possible, designers should try to integrate them into their projects all the more as the climate is temperate. The mass-insulation coupling gives excellent results which the user will not doubt appreciate, especially in temperate climates.

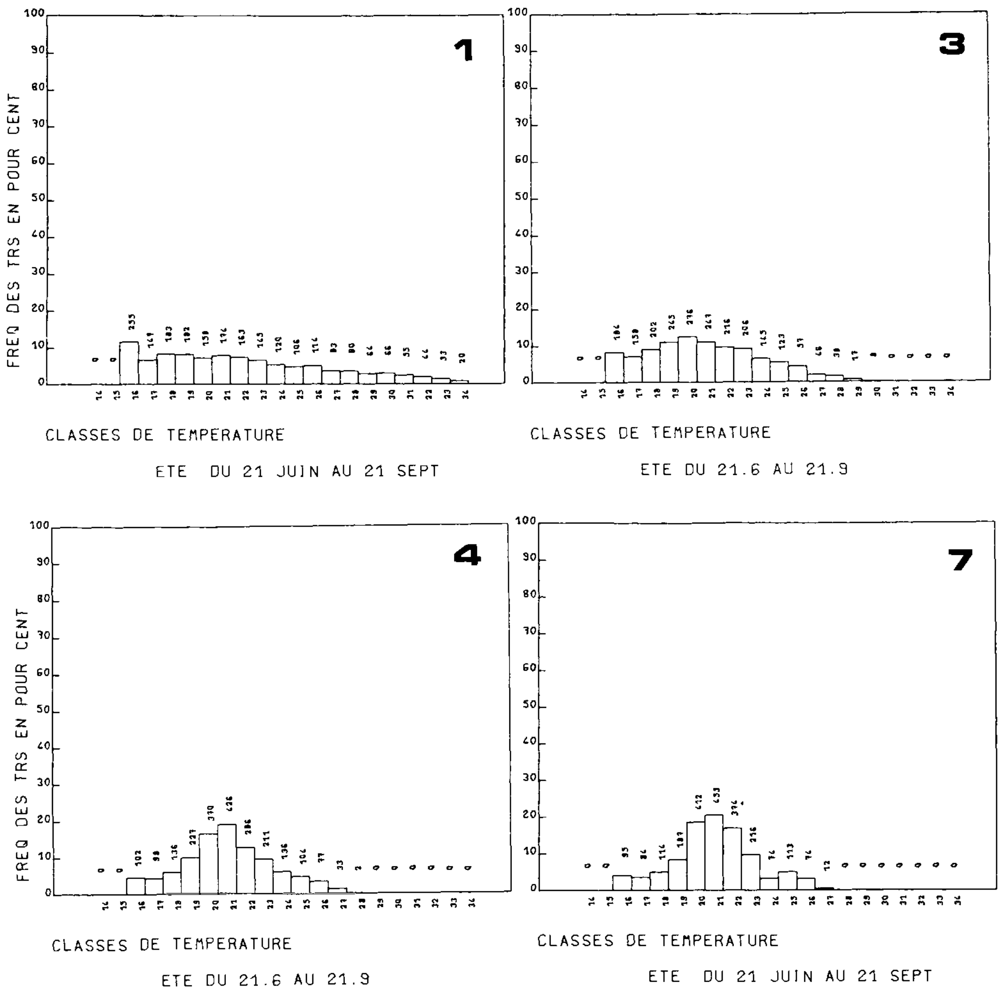


Fig. 5 - Interior resulting temperature frequency diagrams for 4 of the dwelling studied (Trappes site from June 21 st to September 21 st).

SELECTION AND SIZING OF LOW ENERGY COOLING SYSTEMS FOR MORE HUMID CLIMATES

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ABSTRACT

Traditional passive cooling systems are of limited effectiveness in the more humid climates. However, recently developed techniques can produce comfort with a lower power consumption than conventional air-conditioning. Indirect evaporative cooling systems and "roof dissipator" radiant and evaporative cooling systems are described and their sizing discussed. The need for dehumidification is discussed and alternative dehumidification systems are briefly described. The sizing of a simple solar regenerated desiccant dehumidification system is discussed. A unified approach to the selection of alternative cooling and dehumidification systems is presented.

KEYWORDS

Passive cooling; indirect evaporative cooling; radiant cooling; dehumidification.

INTRODUCTION

Traditional methods of cooling buildings have included the night-time ventilation of high mass buildings, earth sheltering, and the use of evaporative coolers. However, these methods tend to be less effective in more humid climates. In the hotter humid climates the ambient dry bulb temperature does not fall low enough at night to cool the mass of the building sufficiently to meet the cooling load during the day. Earth sheltering does little more than reduce envelope heat gains unless cold winters serve to produce a low deep earth temperature. In addition to their being less efficient in more humid climates, conventional evaporative coolers significantly increase the interior humidity, limiting their suitability to arid climates. Traditional responses in more humid climates have relied on load reduction and promoting air movement, usually in low mass buildings. However, there are now a number of cooling and dehumidification techniques which can provide greater comfort than traditional methods with lower power consumption than conventional air-conditioning. These include indirect evaporative cooling, radiant and evaporative cooling from roofs, and solar regenerated desiccant dehumidification.

Roof Cooling Systems

A building may be cooled by using the roof to dissipate heat by evaporation and radiation to the night sky. Thermal storage is required in order to provide cooling during the daytime. The thermal resistances between the occupied space, the thermal storage and the dissipating surfaces must be low because of the small temperature differences which can be produced. The best known system using this technique is the "Skytherm " system (Hay and Yellott, 1969; Niles, Haggard and Hay, 1976) which employs a roof pond and moveable insulation. An alternative implimentation, the "trickle roof" system, in which water is circulated over a conventional roof, has been proposed by Haves, Loxsom and Doderer (1982). The cooled water may either be circulated through pipes in the floor slab or it may be stored in an insulated tank and large radiators used to cool the building. Other roof dissipator systems have been described by Crowther and Melzer (1979), Givoni (1977), and Hand (1980). One important advantage of most roof dissipator systems is that they may easily be adapted to provide solar heating. Heat loss rates for roof dissipators have been discussed by Clark and others (1983) and Haines, Haves and Vollonk (1981).

The performance of the "Skytherm " system in U.S. climates has recently been re-assessed using a simulation validated by data from the Passive Test Facility for Warm Humid Climates at Trinity University in San Antonio, Texas (Haves and others, 1983). Preliminary results confirm the earlier findings (Clark & Allen, 1980) that "Skytherm ", aided by ceiling fans, can maintain human comfort in all U.S. climates during all hours of a typical summer and almost all hours of an extreme summer. Whilst this impressive result applies most directly to "Skytherm ", it can also be interpreted more widely as an indication of the potential of roof dissipator systems generally, provided the systems are designed to provide good thermal coupling between the dissipating surface, the thermal storage and the occupied space.

A validated sizing method for "Skytherm " roof pond cooling systems has been presented by Fleischhacker, Bentley and Clark (1982). This method may be extended to other roof dissipator systems, although errors will arise if the differences in the thermal resistances are not corrected for. The method is an iterative one in which the thermal mass and roof dissipator area required to produce a particular level of comfort are estimated from the ambient conditions on the design day. The first step is to estimate the temperature of the thermal storage at the end of the night. The next step is to calculate the temperature rise of the thermal storage due to the daytime cooling load. The amount by which the temperature in the occupied space exceeds the storage mass temperature is then calculated from the instantaneous cooling load and the thermal resistance between the storage and the occupied space.

In the "trickle roof" system which uses the floor slab for storage the coupling between the dissipating surface and the thermal storage depends on the flow rate of the water and the size and spacing of the pipes in the slab. Preliminary calculations indicate that the flow rate should be of the order of 1 litre per minute per m^2 of floor area and that the floor slab pipes (which may be plastic) should be 20 mm in diameter and spaced 10-20 cm apart. If a storage tank is used, the area of the radiators needs to be a significant fraction of the ceiling area if performance is to compare with that of "Skytherm ". Best use of a limited area of radiators would be made by clustering them above ceiling fans in order to increase the convective transfer. The large area required means that something cheaper than the conventional steel radiator is required for a cost-effective system. Various plastic products, including the adsorber plates for low temperature swimming pool solar collectors could be adapted to this purpose. The water is not cold enough to allow the efficient operation of conventional fan-coil units.

Roof cooling systems may be adapted to provide space heating in winter in a variety of different ways. The water bags in the "Skytherm " system may be equipped with an inflatable glazing layer which allows them to function as solar collectors. Similarly a portion of south facing roof may be glazed in the "trickle roof" system. Alternatively, solar gain through the south windows may either be distributed through the floor slab by circulating water through the pipes or reflected by special window blinds onto the radiators on the ceiling which then function as solar collectors.

Indirect Evaporative Cooling

Indirect evaporative cooling overcomes the principal disadvantages of conventional evaporative cooling by using a heat exchanger to prevent water vapour being added to the air-stream entering the building. This technique has been known for some time (see Watt (1963) for a comprehensive review of evaporative cooling systems), but has only recently become practical with the availability of suitable air-to-air heat exchangers. An indirect evaporative cooler in the "ventilation" mode is shown in Fig. 1. Outside air is drawn across one side of an air-to-air heat exchanger and cooled before entering the building. The air leaving the building passes across the other side of the heat exchanger, which is wetted. The evaporation of the water cools the heat exchange surface and hence the air entering the building. The indirect evaporative cooler enjoys two advantages over the conventional direct evaporative cooler: it does not increase the interior humidity, and the temperature approached by the air passing across the dry side is not the ambient wet bulb temperature but the (lower) interior wet bulb temperature.

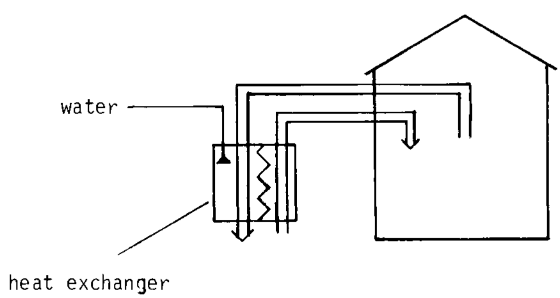

Fig. 1. Indirect evaporative cooler: ventilation mode.

System sizing is illustrated by a calculation for the following peak load conditions:

Ambient dry bulb temperature	- 36 C
Ambient dew point temperature	- 18 C
Interior dry bulb temperature	- 28 C
Building Cooling Load	- 3 kW

Since the relatively high ventilation rate will prevent the internal sources of water vapour adding significantly to the interior humidity, the interior dew point temperature will also be 18 C, and hence the interior relative humidity will be 54% and the interior wet bulb temperature 21.1 C.

If we assume a particular effectiveness then the required flow rate may be calculated. In estimating the effectiveness it should be noted that completely wetting the "wet" side increases the effective heat capacity of the air flowing across the "wet" side by a factor of about three because both latent heat of evaporation and sensible heat are removed. The resulting increase in effectiveness over the dry case can be calculated using standard heat exchanger theory.

Consider a unit with an effectiveness of 75% when wetted. The "dry" side air stream will have a 75% approach to the interior wet bulb temperature and will enter the building with a dry bulb temperature T_{in} given by

$$T_{in} = 0.75 * 21.1 + 0.25 * 36 = 24.8\ C \quad (1)$$

Since the interior dry bulb temperature is 28 C, the air flow rate must be such that the air experiences a rise in temperature of (28-24.8) = 3.2 C when the 3 kW load is added to it. Since the volumetric heat capacity of air is 1.2 kJ C^{-1} m^{-3} the required flow rate is

$$V = 3 / (3.2 * 1.2) = 0.8\ m^3\ s^{-1} = 800\ l\ s^{-1} \quad (2)$$

This calculation can be repeated using different values of effectiveness and the results used to select a heat exchanger. The power required for the blower can be determined from the flow rate and the pressure drop through the system. If the pressure drop is too large for economical operation the size of the heat exchanger should be increased. Note that increasing the size of the unit will increase its effectiveness at a given flow rate, hence the design process is an iterative one. Use of a variable speed blower will allow more efficient operation at times of less than peak load by reducing the pressure drop and increasing the effectiveness of the exchanger.

The indirect evaporative cooler can be operated in a closed loop mode, as shown in Fig. 2. Building air is recirculated across the dry side of the heat exchanger whilst outside air is used on the wet side. Cooling performance is reduced because the limiting temperature is now the ambient wet bulb. However, this factor is offset by the reduced amount of heat to be transfered due to the air entering the dry side at the interior dry bulb temperature rather than the ambient dry bulb temperature. This mode is compatable with dehumidification since outside air is not brought into the building.

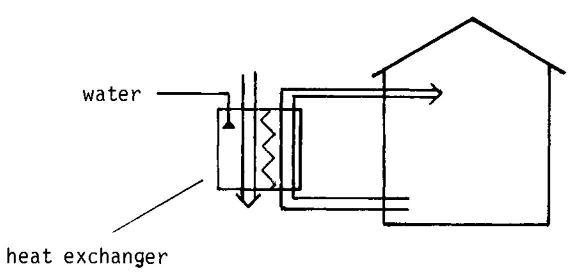

Fig. 2. Indirect evaporative cooler: recirculation mode.

The central component of the system is the heat exchanger. A counterflow unit has a higher effectiveness than a cross-flow unit of the same area, although the simpler manifolding of the cross-flow unit may give it a price advantage which offsets its lower effectiveness. In either case, flat plate construction is the simplest and most compact. Good performance as an indirect evaporative cooler depends on a large fraction of the plates on the wet side being covered with water. The plates should be covered with a hydrophyllic coating and the water supply system carefully designed to ensure good wetting of the plates.

Parasitic power consumption is an important consideration. Commercial units are often rated at high flow rates which produce significant pressure drops (~25 mm of water across each side) and hence require significant electrical power to operate the blowers. The pressure drop can be reduced by using a bigger heat exchanger or by using two or more units in parallel. It should be noted that as the humidity increases the required sizing increases and will eventually reach the point where it becomes less cost effective than conventional air-conditioning. In particular, the required sizing will increase with increasing interior relative humidity, and preliminary calculations indicate that the system starts to loose its cost-effectiveness relative to conventional air-conditioning when the interior relative humidity at the time of peak cooling load rises above ~70%. As is discussed below, the relative humidity must be maintained below 68% for at least part of the day in order to control micro-organisms. Thus a useful rule of thumb emerges that if the ambient humidity is low enough for ventilation to provide control over micro-organisms then indirect evaporative cooling is likely to be competitive with vapour compression air-conditioning.

An indirect evaporative cooler employing a cross-flow heat exchanger has been successfully operated in a residence in Phoenix, Arizona (Yellott, priv. comm.). The unit achieved an effectiveness of ~0.8.

DEHUMIDIFICATION AND CLIMATE

The work of Fanger (1970) and others shows that thermal comfort can be achieved at high relative humidities provided that the temperature is low enough and/or the air speed is high enough. The dehumidification requirement of the ASHRAE 55-81 Comfort Standard (a maximum dew point temperature of 16.5 C) is primarily for micro-organism control (ASHRAE, 1981). An upper limit of 68% on the relative humidity is required to control micro-organism growth (Groom and Panisset, 1933). As discuused by Clark and Blanpied (1982), if a relative humidity of 68% is used to define the upper limit of humidity in a building then interior dew point temperatures significantly greater than 16.5 C are permissible if the interior dry bulb temperature is no lower than is required to maintain comfort with the aid of air movement. Thus, at a dry bulb temperature of 29 C the dew point temperature can be as high as 22 C. (This argument does not apply to the same extent to commercial buildings where activity levels may be higher, dress requirements less flexible and higher air speeds less acceptable.) Furthermore, it is not clear from the literature whether the relative humidity must be kept below 68% for 24 hours per day in order to control micro-organisms. If, during the daytime, the interior relative humidity falls below 68% for long enough to control the micro-organisms then higher relative humidity may be tolerated during the night provided that comfortable conditions are maintained.

At the risk of oversimplification it is convenient to divide climates into two types. In "inland" climates the absolute humidity (and hence the humidity ratio and the dew point temperature) falls during the day as sun driven convection loops bring drier air from the upper atmosphere to ground level. The absolute humidity then rises again during the night. A very approximate rule of thumb is that the ambient wet bulb temperature remains constant throughout the diurnal cycle during stable weather conditions. This drop in absolute humidity may well allow ventilation to provide adequate humidity control, at least during the daytime, and possibly also at night if the daytime reduction in humidity is great enough and prolonged enough to control the micro-organisms. In "coastal" climates the absolute humidity remains approximately constant throughout the diurnal cycle due to the flow of humid air from the sea during the day. In more severe climates or more demanding applications dehumidification may well be required for at least part of the day.

If ventilation is unable to provide sufficient humidity control then a dehumidifier is required. Note that an unmodified conventional air-conditioner is an unsatisfactory dehumidifier since electrical energy is unavoidably used to supply sensible cooling as well as dehumidification. If sensible cooling is already being provided at lower energy cost then this energy is wasted. See Clower and others (1981) for further discussion and details of two alternative dehumidification systems, the solar regenerated desiccant dehumidifier and the "Improved Mechanical Dehumidifier" (sometimes known as the "geared heat pump"). The latter consists of a conventional air-conditioner coupled to an air-to-air heat exchanger so that the outlet airsteam precools the inlet airstream. This then increases the latent cooling performance at the expense of the sensible cooling performance.

Solar Regenerated Desiccant Dehumidification

The simplest desiccant dehumidification systems use small beads of a solid desiccant such as silica gel arranged in a packed bed. The design and sizing of a solar dehumidifier using a switched pair of packed beds has been described by Nelson and Haves (1981). This system can provide dehumidification 24 hours per day. However, if dehumidification is required only at night then a rather simpler one bed system may be employed. The sizing method given for the two bed system may be easily modified to deal with the one bed case. The first step is to estimate the amount of water vapour to be removed during the design night. The mass of silica gel required is then approximately five times the mass of water. The air flow rate required through the desiccant bed in litres per second is obtained by multiplying the rate at which water vapour must be removed (in kg per hour) by 40. The solar collector area required varies with the available solar radiation and the ambient humidity. However, a useful rule of thumb is 1 m^2 of collector per kg of daily load. For example, if 10 kg of water vapour must be removed during the course of the night then ~50 kg of silica gel and ~10 m^2 of solar collector are required. The air flow rate during the night would be ~40 litres per second. During the day the usual rule of thumb for solar air heaters can be used i.e. 10 litres per second per m^2 of collector, giving ~100 litres per second.

One disadvantage of simple (adiabatic) desiccant dehumidifiers is that the latent heat of adsorption is added to the airstream being dehumidified, raising its dry bulb temperature to ~40 C. It is usually desirable to precool the dehumidified air before it enters the occupied space. If an evaporative cooling system is used then the dehumidified air may simply be added to the airstream entering the "dry" side of the heat exchanger. If a roof dissipator system is used then an air-to-water heat exchanger or a small indirect evaporative cooler may be employed, depending on the type of system and the timing of the dehumidification load. Note that an indirect evaporative cooler will function in this role even in rather humid climates because of the high temperature at which the air enters and the lack of need to cool the air below the interior dry bulb temperature.

SYSTEM SELECTION

The first step in system selection and sizing is to determine the comfort conditions required. The maximum operative temperature inside the building is determined by the activity level and dress of the occupants and the maximum air speed which can be tolerated. The humidity control requirements may depend to some extent on the nature of the contents of the building. The next step is to determine whether ventilation can provide adequate humidity control for any part of the day. This may be done by determining the relative humidity which corresponds to the ambient dew point temperature and the interior dry bulb temperature. (Only an approximate value of the interior temperature is required.) If dehumidification is required for only part of the day in order to control micro-organisms then there are a number of advantages to scheduling this at night. Even in coastal climates ventilation will produce a lower interior relative humidity during the daytime than at night. Also, a desiccant dehumidifier would require only one bed instead of two and dissipation of the latent heat of adsorption is easier at night. Thus, there are three cases to be considered; continuous ventilation, dehumidification only at night, and dehumidification during the daytime or continually.

If the building is to be ventilated continuously then either the indirect evaporative cooler or a roof dissipator system may be used. In the latter case the building should be ventilated through an air-to-air heat exchanger in order to avoid unnecessary heat gain. If the building is to be dehumidified at night and an indirect evaporative cooler is employed then the cooler should be capable of operating in the recirculation mode (Fig. 2) whilst the dehumidifier is in operation. If dehumidification is required during the daytime then the indirect evaporative cooler is unlikely to be practical since the ventilation mode would not be usable and some form of roof dissipator becomes the system of choice.

The performance of roof dissipator systems decreases more slowly than that of indirect evaporative cooling systems as the ambient humidity increases because they make use of radiative cooling. Their other advantages include low parasitic power consumption and adaptability to solar heating. Their disadvantages include the integration of unconventional elements into the building fabric and the difficulty (or impossibility) of retrofitting some of the systems. Thus, buildings in inland climates which already have duct systems, or have only modest heating requirements, or are multi-story are likely to be more suited to indirect evaporative cooling. The disadvantages of indirect evaporative cooling include relatively high parasitic power consumption due to the pressure drops across the heat exchanger and an inability to handle large cooling loads when dehumidification is required.

Once the possible systems have been identified, they may be sized and estimates made of construction and operating costs. Careful attention to both cooling and dehumidification load reduction is essential in optimising building design.

ACKNOWLEDGEMENTS

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WINDOW SUNSPACE SYSTEMS AS HEATING AND COOLING COMPONENTS

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ABSTRACT

Two window sunspace systems which operate as a heating component in winter and as a solar chimney to achieve good ventilation in summer are presented. These systems were built in a single family residential unit in Haifa, Israel. The first one is a small local window sunspace system that resembles the direct solar gain system. In this case, solar radiation penetrates the building by natural convection and direct gain. The second one is a large central window sunspace system that is designed between two tilted roofs. The heat collected by this sunspace is driven down into the living area by forced ventilation. The central window sunspace system collects sufficient amount of energy to heat the first floor which is shaded by the neighbouring building from its south side. This is a common problem in high-density residential areas. The solution realized here can be applied to any low-rise high-density residential quarters. Measurements to validate the thermal performance of the passive systems during winter are presented.

KEYWORDS

Passive and hybrid solar systems; heating and cooling components; south window system (SWS); local window sunspace system (LWSS); central window sunspace system (SWSS).

INTRODUCTION

Designing passive and low energy buildings in countries with mild temperatures like the Mediterranean countries presents few dilemmas in winter and summer. When winter is especially cold and long, passive solar heating systems can serve for several months each winter. This means that the first investment in the system can be paid off after a few winters. Hence, even if the system is relatively an expensive one, calculations of life cycle cost will demonstrate its economical attractiveness. However, when winter is mild, as in Israel along the Mediterranean Sea (average January temperature is 13.9°C in Tel Aviv (Ashbel, 1972) or 11.2°C on Mt. Carmel, Haifa) it is difficult to economically justify an expensive system. We are driven to the conclusion that for such mild climates a very simple and inexpensive solar heating system should be designed. Estimates show (Shaviv, 1979) that even double glazing will never pay for itself under such conditions.

On the other hand, the summer along the Mediterranean Sea is quite hot and humid. However, frequently it is not too hot to justify the use of air-conditioning units for residential buildings. Even in Tel Aviv, where the average maximum August temperature (the hottest month) is 31.7^{o}C, comfortable climatological conditions inside the building can be achieved by means of proper building design (Shaviv, 1978), let alone on Mt. Carmel, where the average maximum August temperature is only 28^{o}C.

A proper design for the summer under such conditions can be:

1. Window shading, usually by means of external sunshades to prevent any direct radiation from penetrating the building.

2. Provide the building with sufficient thermal mass so as to achieve a time-lag of about six hours. Under such a condition, the inside temperature reaches its maximal value in the evening when the outside temperature is already low.

3. Provide evening cooling by circulating cold outside evening air through the house and allow the thermal mass during the night to cool to almost the ambient air temperature (23.2^{o}C in Tel Aviv, 22.1^{o}C on Mt. Carmel). This can be obtained by either natural or forced air ventilation.

Since summer conditions are not very severe and simple solutions are effective, we again face the problem that a very complicated and expensive passive cooling system will never justify itself.

The combined design considerations for summer and winter lead to the conclusion that only systems that can be used throughout the year might be economical, especially if such systems supply daylight and outside view. Moreover, if the system performs well only in winter and introduces heat to the building in summer, its annual performance may be found poor in terms of energy balance.

Traditional Mediterranean architecture is characterized by careful design for the summer. In most of these countries external shutters are used. The regular material for residential buildings is masonry (concrete slabs and walls), which provides long time-lag. This is the frequent situation in Israel. However, most of these buildings are not well insulated and no attention is paid to the orientations of the building and its windows. Consequently, winter conditions inside a typical residential house on Mt. Carmel can be very unpleasant, even though the winter is not very cold.

The question, therefore, is what kind of passive heating and cooling systems can be economical in Mediterranean countries? This paper discusses three passive and hybrid systems experimented in a residential building on Mt. Carmel. The systems are: southern window with a shutter, local window sunspace with natural convection and central window sunspace system with forced convection. Solar energy is stored in all three systems, mostly in the thermal mass of the building. A comparison between measured results of the passive system's performance without additional mechanical means is given.

SOUTHERN WINDOW SYSTEM (SWS)

Direct solar gain through SWS is the simplest system and probably the most economical one. Windows are required for daylighting, view and information about what is happening outside. A south facing window supplies solar energy in winter at essentially no extra cost. However, if extremely large southern windows are designed as solar collectors, they should be considered as passive solar systems and not as simple windows.

The SWS includes the following elements (see Fig. 1):

A. Southern single glazing as a collector for winter sun.

B. A typical rolling plastic shutter (called "Haifa type") to prevent summer insolation and to add insulation when desired.

C. Sliding window panels to allow summer natural ventilation.

D. Insulated external walls to reduce heat losses.

E. Heavy thermal mass (the outside walls are made of 15 cm concrete or concrete blocks insulated from the outside, and concrete slabs) to store the solar energy in winter and the "coolness" of night in summer.

The SWS satisfies our basic demand of being a simple, economical and good system for winter and summer.

The Drawbacks of SWS

There are some drawbacks that hinder the general application of SWS:

1. Not all rooms can have southern windows.

2. Direct solar radiation cannot be allowed into all rooms, especially in places where glare problems arise or where furniture colors may fade.

3. The system cannot easily be automated. For instance, in winter the shutters may remain closed during the day and potential solar radiation is lost. This happens when the weather changes on short timescales and nobody is at home to open the shutters.

4. Natural ventilation through open windows may not be sufficient to cool the indoor air and the thermal mass during the evening and night.

5. It is very difficult to control the distribution of hot and cold air between the rooms and the storage, so as to approach the desired inside temperature. For example, in a room with SWS, the temperature swing during a sunny winter day (with 50% sunshine) was 3°C (max 21, min 18), while in a northern room with Central Window Sunspace System (CWSS), the swing was only 0.7°C (max 19.2, min 18.5). On the next day, which was a rainy one (10% sunshine), the temperature dropped to 16.5°C in the room with SWS and to 17.5°C only in the northern room with SWSS (see results in Table 1).

The comparison given in Table 1 shows that on both days the average temperature in the northern room with the CWSS was above 18°C, while in the southern room with SWS, the average temperature dropped to 17.5°C. Attention should be paid to the fact that both rooms are children's rooms in the same house having the same thermal conditions but with different orientation and passive solar systems.

TABLE 1 Comparing Measured Temperatures (^{o}C) of SWS and CWSS During a Sunny and a Rainy Day

		Outside ambient air	Room with SWS	Room with CWSS	Sunspace air
	Tmax	17.0	21.0	19.2	28.2
Sunny day	Tmin	11.0	18.0	18.5	19.0
	ΔT	6.0	3.0	0.7	9.2
	Tave	14.0	19.5	18.8	23.6
	Tmax	15.2	18.5	18.6	23.5
Rainy day	Tmin	9.0	16.5	17.5	14.9
	ΔT	6.2	2.0	1.1	8.6
	Tave	12.1	17.5	18.0	19.2

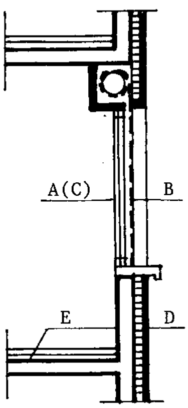

Fig. 1. Southern window system

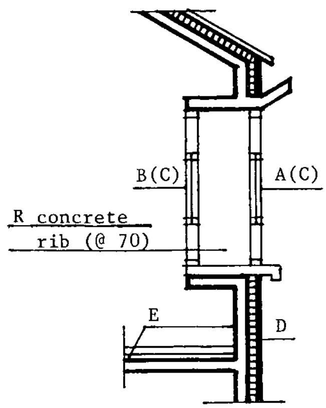

Fig. 2. Local window sunspace system

LOCAL WINDOW SUNSPACE SYSTEM (LWSS)

The LWSS is free of some of the drawbacks found in the SWS. It includes the following elements and operates as follows (see Fig. 2):

A and B. Two vertical sliding windows (each single glazing). The external window A is always in the sun. The internal window B is partially in the sun during winter and never in the sun during summer, spring or autumn. The depth of the window sunspace provides the required external shading for the internal window and replaces the shutter of the SWS. Therefore, this system is not significantly more expensive than the SWS.

C. Vertical sliding panels to induce natural ventilation in summer. When the external windows are positioned halfway, summer heating induces air circulation. Air flows in through the lower part, heats up and flows out through the upper part.

This flow creates a Venturi effect, which enhances air sucking from inside the house on days without wind.

D. Insulated walls and thermal mass as in the SWS. However, in this system, there are also concrete ribs (R), painted dark, located between the two windows. (In light structure buildings this can be the only thermal mass.) The ribs and the internal window B allow better control of the heat distribution between the room air and the thermal storage. This control will be explained in more detail in the next paragraph.

The fact that some of the solar energy collected during day time can be used during the evenings resembles the performance of a Trombe Wall. However, in the LWSS the view is not obstructed and daylight can be obtained through it. So in general, this system, which can also be called an "Open Trombe Wall", can function as a regular window. This window is a self-shaded structure and therefore operates well in summer. The system should be contrasted with a Trombe Wall that frequently calls for non-trivial means to prevent excessive heating in summer.

Performance of the LWSS During Winter

Table 2 provides a summary of the measured temperatures during two successive days. The first is a summy day (50% sunshine) and the second is a rainy day (10% sunshine).

TABLE 2 Measured Temperatures (^{o}C) in the LWSS During a Sunny and a Rainy Day

		Outside ambient air temp.	Living room air temp.	LWSS rib temp.	LWSS air temp.
	Tmin	12.5			
Sunny day	7 AM	14.0	19.0	19.5	19.0
	Tmax	17.0	20.1	23.0	26.0
	7 PM	13.9	20.9	22.0	19.9
	12 AM	12.9	20.1	20.1	19.5
	Tmin	11.0			
Rainy day	7 AM	13.0	19.5	19.0	18.0
	Tmax	15.2	20.1	20.1	20.1
	7 PM	12.2	20.1	18.1	18.0
	12 AM	10.0	19.3	17.5	17.0
	Tmin	9.0			

Let us discuss first the temperatures observed during the rainy day. The temperature inside the building on this day was higher than that of the LWSS ambient air or its concrete rib. For this reason, the inside window was kept closed during day and night in order to reduce heat losses through the window. However, the heat losses were reduced significantly because the average temperature difference (ΔT) between the inside air and the sunspace air was only 1.5^{o}C. At the same time, the average temperature difference between the inside and outside air was

7°C. The U value of a window with single glazing is 5.5 w/m^2°C. As ΔT decreases from 7°C to 1.5°C, the results of the heat losses are approximately equivalent to a decrease of the U value from 5.5 to 1.2 w/m^2°C. This is a U value of a window with good night insulation. When compared with a regular window with night insulation, we find the advantage that our system remains transluscent with the ability to introduce daylighting.

We now turn to measured results during a sunny day. During this day the internal windows were kept closed until 7 PM in order to allow the concrete ribs to reach a high temperature of 22°C, while the room air temperature reached 20.9°C. At that time the inside window was opened and the heat exchange between the hot concrete rib and the room air improved. At 12 AM the room air temperature and the rib temperature equalized to 20.1°C and the inside window was closed to reduce heat losses. From 7 PM to 12 AM the temperature of the ribs dropped by 2°C. We can calculate approximately the energy that was available through each 1 m^2 of south glazing and for each hour of the day. According to the design of the LWSS there is 1.1 m^2 of vertical concrete rib of 22 cm deep and 1.1 cm^2 of horizontal concrete ribs of 15 cm deep. (This is equivalent to a Trombe Wall with 40 cm deep concrete.) For a 2°C drop in temperature during the five hours of evening, we get 430 wh, or 86 w per hour. For the eight night hours, we get a reduction in heat losses of 260 wh due to the high sunspace temperature. (During these hours the average ΔT between inside air and sunspace is only 1°C.) This means a reduction of 33 w per night hour. The total radiation penetrating through 1 m^2 of the external window during that day was 1470 wh (including the evening and night hours). Therefore, only 780 wh were available during the 10 hours of sunshine, i.e. 78 w per hour. These numbers can be twice as high on a day with 100% sunshine. Contrary to the SWS, the inside window (B) provides means to control the room air temperature according to demand.

CENTRAL WINDOW SUNSPACE SYSTEM (CWSS)

The LWSS as the SWS can be used only in rooms with southern orientation. The CWSS was designed to provide solar energy for other rooms. In the particular building described here the first floor is shaded by the building located to its south. Therefore, even rooms with southern orientation cannot have SWS or LWSS. This is a phenomenon common to low-rise high-density areas. The central sunspace is located in this case between the two tilted roofs so as to maximize solar exposure (see Fig. 3). The hot air is transferred from the central sunspace to the living area by forced convection. The CWSS includes the following elements and operates as follows:

A. Vertical sliding windows as in the LWSS. These windows are in the sun during winter and closed. They are open during summer.

B. Partially horizontal sliding windows and the rest is insulated wall. These windows allow the penetration of daylighting into the living room. The window B at one end of the sunspace facing the staircase is kept open throughout winter. This window serves as the air inlet into the sunspace. In summer these windows are fully shaded by the roof between windows A and B.

C. Vertical masonry duct with a big fan. The fan is automatically controlled by differential thermostat. The duct is located at the end of the sunspace, opposite to the staircase and the open window B. During winter the hot air from the upper central sunspace is forced down by the fan. The air returns to the sunspace through the open staircase.

D. Horizontal masonry tunnel which leads the hot air to three rooms on the first floor. At the connection between this tunnel and each room there is a small fan that can be operated manually. When only the big fan operates, most of the solar energy is used to heat the masonry duct and tunnel. This energy is stored there for later use in the rooms. However, if during hours of sunshine the room temperature is low, the small fans are turned on manually by the persons inside the room. In this case, most of the hot air is transferred immediately into the room.

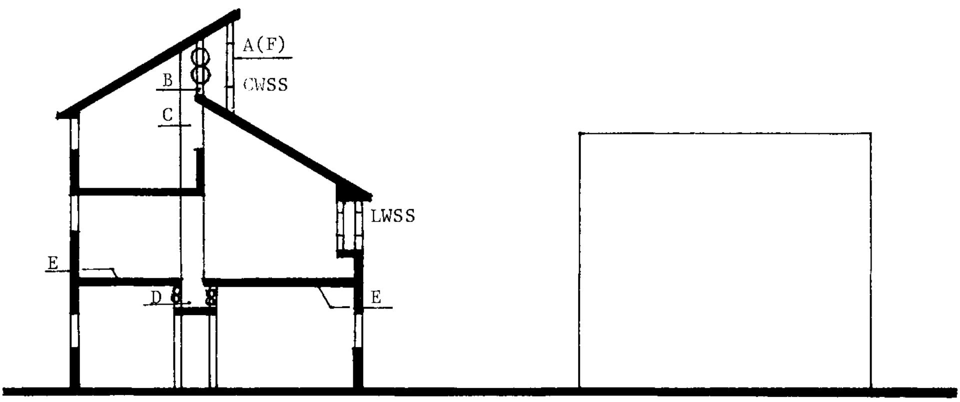

Fig. 3. Central Window Sunspace System

E. Insulation and thermal mass as in the SWS and LWSS. The masonry duct and tunnel serve as active thermal storage also. The structure provides space for additional heat storage like water containers. As this winter was an unusually cold one, almost without any sun, no extra storage was added. However, in a usual winter, with many sunny days, an extra storage may be found useful.

F. Vertical sliding panels in windows A. With these panels the CWSS can be used in summer as thermal chimney to increase air movement inside the house. When the external windows A are located in middle position, an effect as discussed in the LWSS is created. In the evenings the thermal chimney effect is not efficient. However, if both upper windows are opened on the northern and southern sides of the top floor, we get a regular chimney effect, which again will cause air sucking from the first floor. We find that it is better for the summer to locate the central sunspace at the top of the building to allow the natural ventilation, although in winter it is better to have it in the lower part of the building. When there is no wind at all, the fans which are used in winter to drive the air down can be used in summer for forced ventilation.

Performance of the CWSS During Winter

Measurements of the performance of the CWSS for a northern room show better results than the performance of the SWS in a southern room. This was discussed in detail previously and will not be repeated here (see Table 1).

In Fig. 4 the measured temperatures of the ambient air, the CWSS and the northern room with the CWSS are shown during two successive days and during a third day one week later. (The results of the first two days are also summarized in Table 1.)

On the first day which was a sunny day, the fan operated from 11 AM until 4 PM. The maximum temperature obtained in the CWSS was only 28.2°C. However, on the third day, the fan did not operate at all. The temperature of the CWSS reached 38°C while the maximum outside air temperature was only 17°C (exactly as on the first day). The operation of the fan prevents the formation of very high air temperature in the CWSS. This decreases most of the heat losses that might occur by having large temperature difference between the sunspace and outside ambient air temperature. For this reason, night insulation is not required as would otherwise be the case.

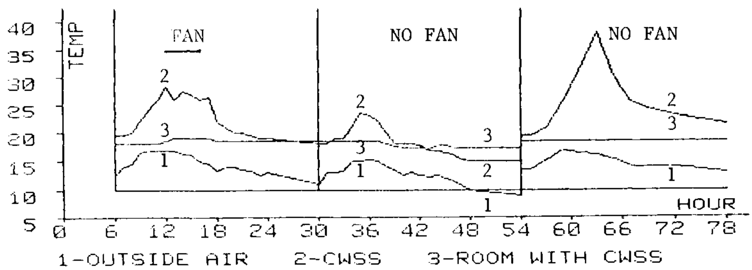

Fig. 4. Measured temperatures of ambient air, CWSS and room with CWSS during three days

The second day shown in the graph is a rainy day without sunshine. On this day the fan was not operated because the CWSS temperature was most of the time lower than the inside room temperature. However, the temperature of the sunspace was much higher than the ambient air temperature and therefore it served as an excellent buffer zone and reduced heat losses. Again, because of the existing buffer zone, night insulation is not needed. This fact improves the economy of the system and satisfies our demand of inexpensive passive systems for countries with mild winter climate.

CONCLUSIONS

The three window systems presented in this paper have common features, which are:

1. Simplicity in construction and operation.
2. Provide daylighting.
3. Suitable for winter and summer use.
4. Economical passive systems.

Of these three systems, the CWSS is the most versatile, as it provides a solution for northern rooms as well as for southern ones. It does not have the drawbacks of producing too much glare and fading of furniture paint as the SWS. The heat distribution between collecting area, the room and the storage can easily be controlled and automated. Finally, it provides good summer ventilation. However, this system is more expensive than the SWS or the LWSS. In general, the LWSS is a solution that stands in-between the SWS and the CWSS in performance and cost. A mixture of all three systems can yield the best results from economical and performance points of view.

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LATENT HEAT VENETIAN BLIND

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ABSTRACT

Overglazed dwellings are often associated with solar design. This association however is incorrect because it does not take into account the solar gains and losses balance or also the radiative field correlated with the comfort and habitability problems. Moreover, the effective living zone space is usually reduced by a 1.2 M band in the glazed environment.
So, complementary elements are necessary to maintain the comfort in the whole volume and to get the best energy management from a bay window. This is precisely the function of a phase change material venetian blind patented by the french C. N. R. S. and produced by Griesser Company in collaboration.

KEYWORDS

Radiative cooling; phase change material; comfort parameters; overheating; overglazed environments.

INTRODUCTION

The modern architectural style is suitable for dwellings with a large opening to the exterior. Likewise, solar architecture incites opening and sometimes overglazed environments, but that should not mean living in a solar collector.
Indeed, if the search of passive solutions leads us to consider houses as solar cells with storage, then human comfort criteria necessitate some considerations. The control of thermal radiation in overglazed environments is generally carried out by different elements : shutters, curtains, venetian blinds; but each of these elements offer only a partial and momentary conciliation.
The P. C. M. venetian blind (patent : C. N. R. S. - A. N. V. A. R.), a rotative passive heating system, integrates several functions into one component :

- the shutter function : to give protection against intruders and a respect of inhabitants privacy.

- the blind function : to give a uniform distribution of infrared and solar radiances inside the room and to provide a view to the outside.

- the solar function : solar collection, storage, time lag and restitution in one element. It avoids overheating during the day, uniformizes radiation temperature in the overglazed volume and maintains the comfort temperature (Fanger, 1972) untill nightfall.

- the cooling function : by chimney effect and reverse operating mode.

The P. C. M. venetian blind is a passive solar heating system. The storage uses a latent heat material developped by the "Laboratoire d'Ecothermique Solaire" (C. N. R. S.) called Chliarolithe (temperature of fusion Tf = 28°C, latent heat L = 170 kJ/kg).

The experimental program has consisted of two concurent activities : prototype testing and system computer simulation; and it has led us to believe that the system is feasible.

THE BLIND AS A WAY OF MAINTAINING THE COMFORT FEELING

Before being an energy collector, the main thermal function of the blind is to provide and maintain the habitability of radiatively out of balance volumes. Comfort feeling of the human body (Deval, Berger, 1983) is a consequence of the various thermal actions (convective, radiative, evaporative...) with its environment. The radiative field is responsible for about 40% in the expression of the "comfort temperature" (Schneider, Berger, 1980). It is the reason why the blind has to have multiple actions :

- diffusion of a part of the incident energy to insure a uniform lighting and to maintain a pleasant feeling radiatively (if necessary by supplying to a cool air)

- avoidance of overheating caused by irregular solar gains, while permitting the penetration of the total incident solar energy and not impeding the view of the outside.

- at night, or in bad weather, suppression of the cold radiative influence of large glazings; even, to create buffer spacing at the times when the external has to be completely insulated from the internal volume.

- in hot dry countries, radiative cooling of the dwelling by an inverse use, that is by being a cold radiative source regenerated during the night. In this case a P. C. M. with a lower temperature of fusion (15°C<TF<22°C) must be used in place of the Chliarolithe as discussed.

The traditional venetian blind only provides some of these functions; the presence of Chliarolithe (a P. C. M. with TF = 28°C and L = 170 kJ/kg) inside thick blades, one face absorbant and the other reflective, adds a thermal role to the traditional blind (Berger, Pelletret, Deval, Sté Griesser, 1982).
The excess energy sometimes (coming from the outside in the case of a heating function, and from the inside in the case of a cooling function) is efficiently collected by the material because of its high effusivity. Losses and radiative discomfort are avoided because of the slight temperature rise.

Storage is achieved in situ without transfer; restitution is passively obtained according to the needs, radiatively in two parts out of three.
In addition to these, the thermal performance of this system has several aspects :

- a heating gain reaching 25% for a large volume with a south glazed ratio greater than 70%.

- an increase in the effective living area and a comfort improvement.

- an increase period of comfort, double the normal one and therefore long enough for needs.

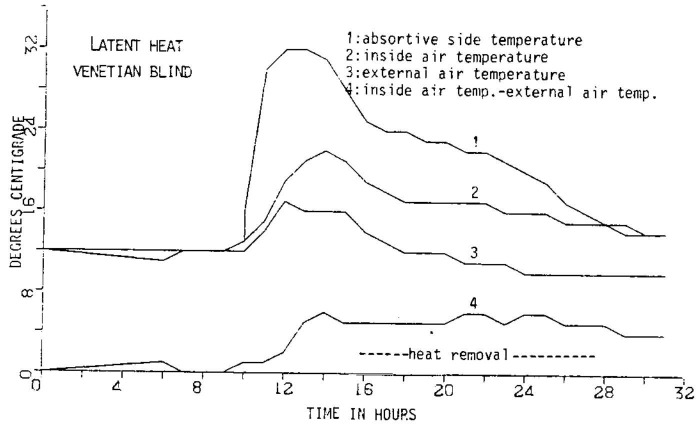


Fig. 1. shows a few aspects of the computed simulation which point out different functions assumed by the blind.

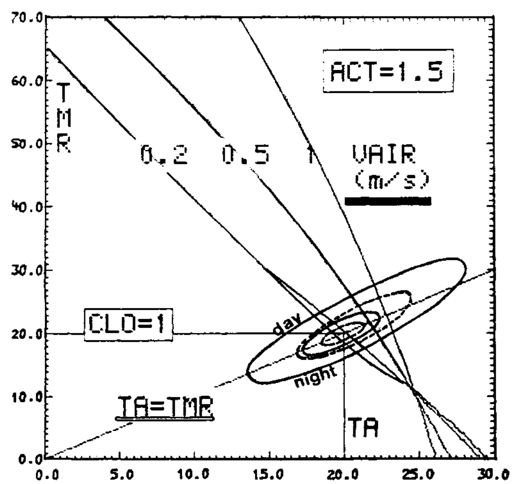


Fig. 2. shows the comfort cycle as measured with our experimental cell described below, in comparison with that of an ordinary well insulated volume. This point out the comfort effect of the P. C. M. venetian blind.

INDUSTRIAL PROTOTYPE

Creating a commercial module implies solving some technical as well as commercial constraints :

- because only one element can be added to the window then the shutter must also be an anti-theft device. For this reason, and because of the weight of the blades, the system is contained in a rigid frame. The blades are equidistant and of constant position, but with the possibility of rotation. The size and horizontal disposition of each blade have been adopted to satisfy some amenity criteria and solar necessities : interception of solar radiation, presenting the landscape view in broad bands.

- The blades can be dismantled for their installation or replacement, but only from the inside.

- To keep free access to the glazings (cleaning and passage), the frame can be moved on a rail, but also blocked out. The association of two frames is one of the best integrated solution.

The solar overcost in low because it must be compared with reference to a standard shutter.

EXPERIMENT

A 13 m³ cell, genuine little house made of cellular concrete outside insulated, has been built. Its south glazing ratio is 60% and its air renewal rate 0.8 vol/hour. For one year, it has been used for testing one of the four prototypes made by Griesser industry, and also a traditional blind. The measured values are recorded in a Vax 750 computer and then analysed.

Fig. 3. Prototype and test room (photo)

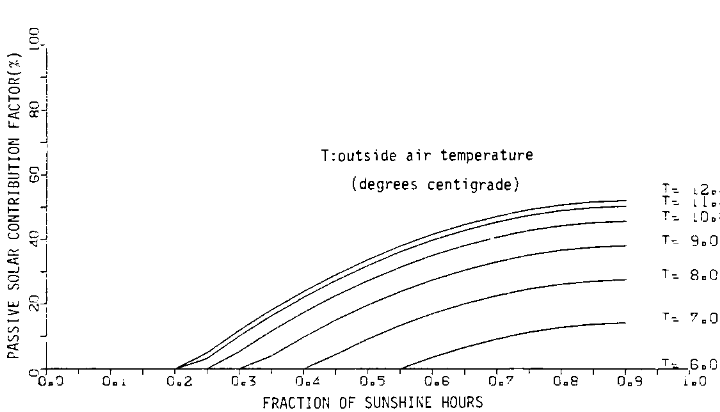


Fig. 4. shows the regression formula obtained from the measurements which express the rate of heating insured by the blind in January for Nice (south of France) as a function of the mean outside temperature and of the ratio of effective to maximum theoretical possible sunshine duration. The blind looks clearly as a control system for the comfort and only accessorily appears as a heating system.

INTEGRATION INTO DWELLINGS

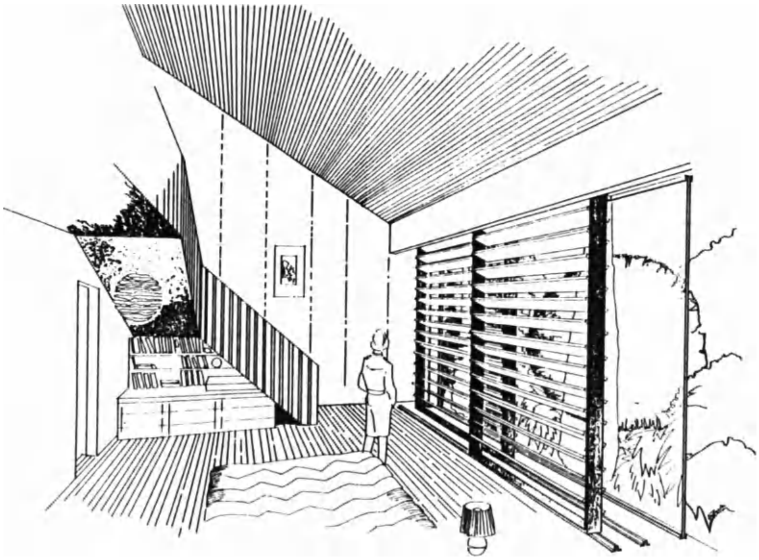
The latent heat venetian blind, due to its increased facilities as compared with traditional blinds may be used in many different unusual ways :

- as a separation between a greenhouse and a living room of an appartment. By adding a selective glazing on the external side, one can create a "diode radiative" pannel (Clement, Berger, 1980).

- as an internal storage filled twice a day, once with sunshine, and the second with a resistor taking advantage of the night cheaper rate of electric power (Schneider, Berger, 1982). Such a use is optimal if electricity is the adopted set-up power.

- as a large cold wall for radiative cooling in hot dry countries, the efficiency in a volume then beeing amplified by selective coating of the facing walls (marbles, mozaics...).

- as a component usuable for architectural design. The pannels can be decorated with geometrical paintings and their disposition can create original spaces in a large hall. In this case, intentionaly, they are not facing the bay - window.



CONCLUSION

The P. C. M. venetian blind improves the functions of the windows by creating a perfectly integrated unit which provides optimum habitability, carries out as well as its thermal functions those of privacy protection and anti - theft shutter. Due to all this, its payback time is no more than two or three years in the mediterranean countries.
These countries are by their climate and their temperatures the first ones concerned by this system.

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EXPERIMENTATION AND DEVELOPMENT OF A MOBILE INSULATION SYSTEM FOR PASSIVE SOLAR ARCHITECTURE

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ABSTRACT

This paper describes a mobile insulation system for window areas that meets the technical and architectural needs of direct gain passive solar buildings.

Although the principal aim is to maintain optimal heat flow conditions during all seasons, other considerations such as daylight control, natural ventilation, storage area needs, maintenance and aesthetics must also be taken into account.

Three houses in the South of France are shown as examples in order to assess the importance of the different and sometimes contradictory needs so as to minimise inevitable compromises necessary in developing an industrial product.

KEYWORDS

Mobile insulation; Direct gain solar architecture; Daylight control; Solar protection; Natural ventilation.

OPTIMAL HEAT FLOW CONDITIONS IN WINTER

Heat loss through window areas can be controlled either by using insulating glass (double, triple or special glazing) or by means of a mobile insulation system.

Figure 1. compares the heat loss (represented by the "U" factor) through single and double glazing with night insulation of varying thermal resistance. The curves "A" and "B" show the average "U" values for a window component equiped with a mobile insulation system that is used twelve hours each day.

This graphic display ignores the orientation of the window area and does not take any solar gain into account; under these conditions the heat losses are greater during the day than during the night if night insulation is used and it is clear that double glazing reduces the overall heat loss.

The curves "C" and "D" show the "U" values for single and double glazing with mobile insulation in place. It can be seen that the increased thermal resistance of the mobile insulation has progressively less effect on the heat losses through the window component and that there is little variation due to the type of glazing.

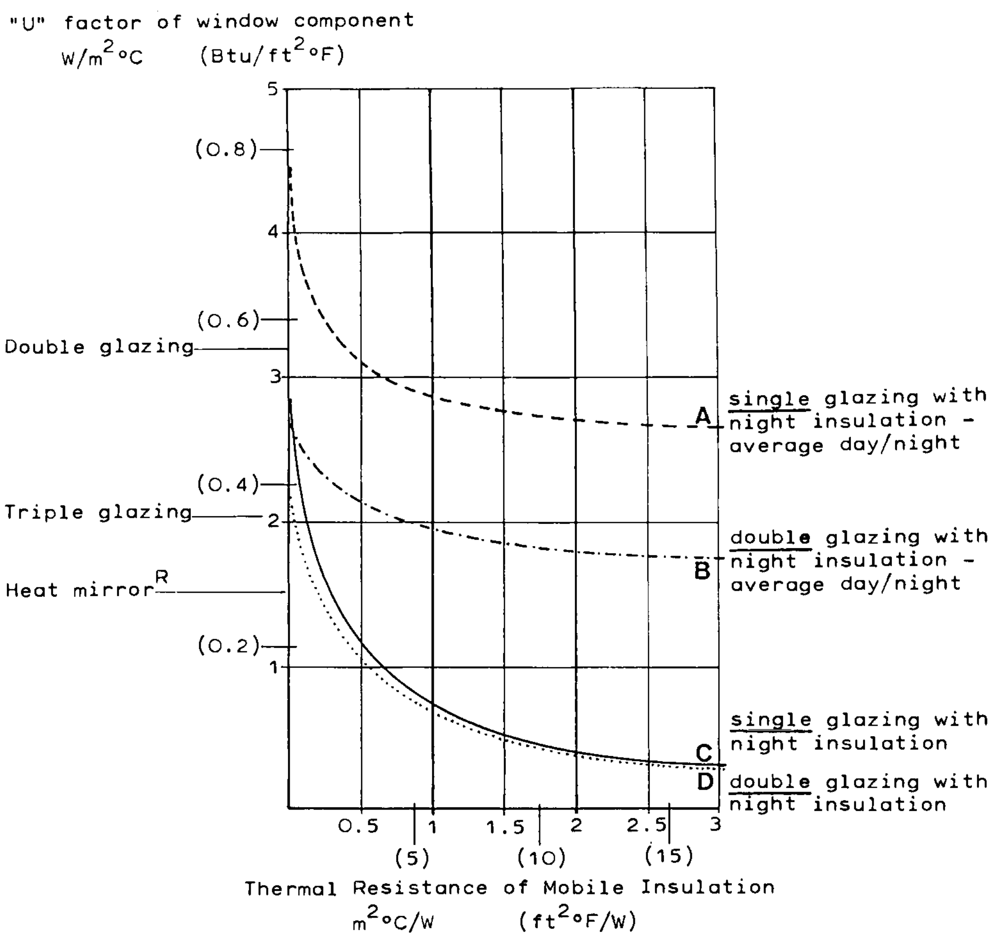


Fig. 1. Variations in the "U" factor of a window component due to the use of mobile insulation.

Passive solar buildings face the sun and in most temperate climates the thermal balance of the South facing glazed areas is positive during the day and the heat loss is limited to the night.

Figures 2 and 3. show the variation in the thermal balance of a South facing window component in the region of Paris and in the South of France. The importance of night insulation is evident in both climatic regions; not only does the night insulation reduce the heat loss but it also improves the efficiency of the glazed solar collector areas, which makes it possible to reduce their surface area for the same solar gain and so reduce the dangers of over-heating.

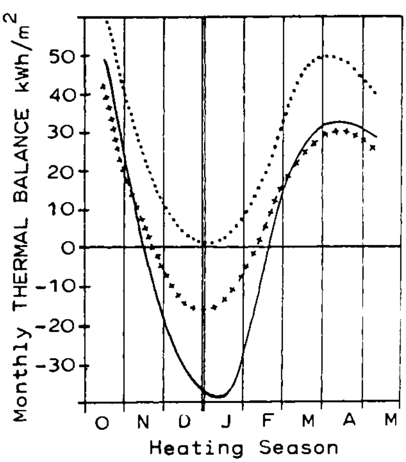


Fig. 2. PARIS REGION

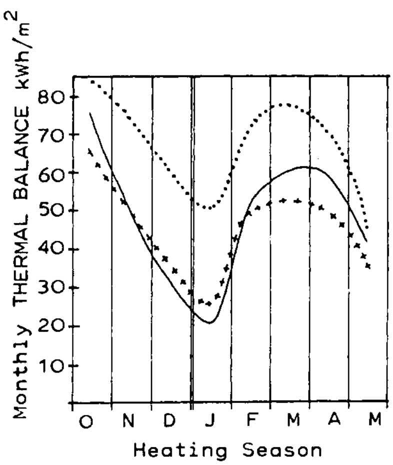


Fig. 3. SOUTH of FRANCE

VARIATIONS IN THE THERMAL BALANCE OF A SOUTH FACING WINDOW COMPONENT

Key : ——— single glazing

++++ double glazing

........single glazing with night insulation, R = 1 m^2°C/W

The mobile insulation systems that we have experimented in the three houses, shown at the end of this paper are composed of rigid panels with a thermal resistance of 1 m2°C/W used on the inside of South facing glass areas. The choice was largely due to the importance of maintaining an air tight space between the glass and the insulation, which is much easier to realise on the inside of the window component. The thermal resistance of the insulation used could have been improved but the increased cost and volume of the mobile elements did not seem justified, particularly in a temperate climatic region.

DAYLIGHT CONTROL, SOLAR PROTECTION, NATURAL VENTILATION

The large glass areas in passive solar buildings can be a cause of discomfort due to glare and over-heating. The pivotting shutter systems that we have experimented meet a need to control the sunlight without notably reducing the solar gain in winter. When there is no need for solar gain, the same mobile system can be used for solar protection. The surface of the insulating shutters is designed to absorb little of the solar radiation, but due to the green-house effect, radiant heat is produced between the glass and the shutters; in certain cases, this heat can be recovered for heating needs (Trial House I) or it can be used to encourage natural ventilation.

Figures 4, 5, 6 and 7 show the different possibilities offered by interior pivotting insulating shutters for controling the daylight and heat flow through South facing glass.

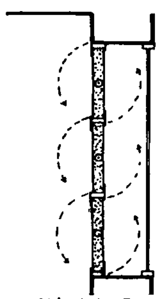


Fig. 4. Night Insulation

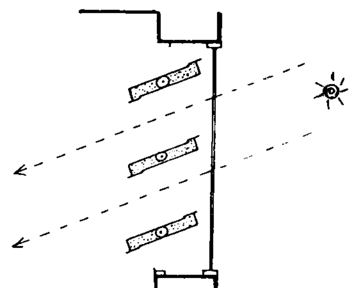


Fig. 5. Direct Gain

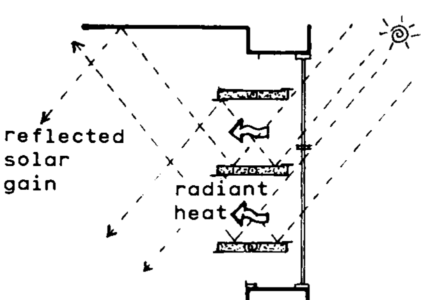


Fig. 6. Daylight Control

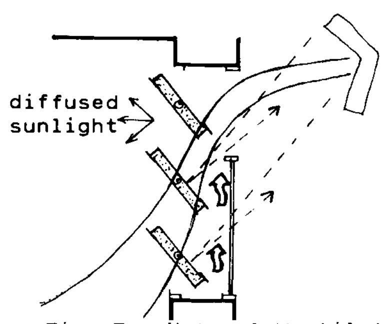


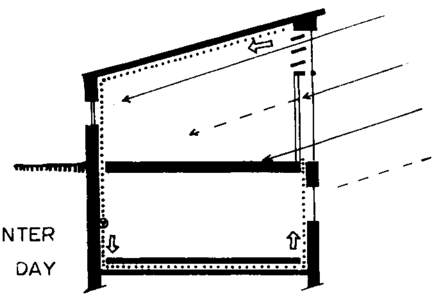
Fig. 7. Natural Ventilation

MANIPULATION

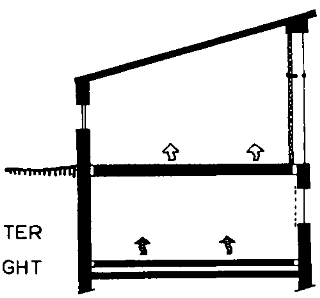
One of the advantages of inside shutters is that their use modifies the aspect of the interior of a room which makes a clear visual difference between the position "day" and the position "night". The sliding and pivoting shutters experimented are operated by means of an almost instantaneous action with the result that this type of mobile system is used regularly; this is perhaps the most important quality for maintaining the thermal efficiency of a window component in passive solar architecture.

TEST HOUSE I

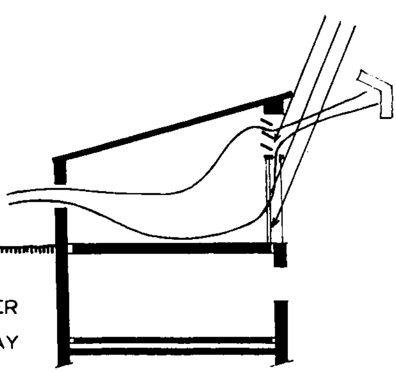
Solar Retrofit : Rodes, P-O. France.
Architect : M.M. Tjoyas.
Mobile Southwall insulation : Isomobile.



WINTER DAY



WINTER NIGHT



SUMMER DAY

20 m2 of South facing glass is equipped with sliding and pivoting insulating panels.

The 6 sliding panels are made of expanded cork board (40 mm.) with a wooden frame. Two of these panels are faced with perforated sheet metal painted black, so as to absorb the solar radiation and work as hot air collectors; the other panels slide infront of these during the day to allow direct gain heating.

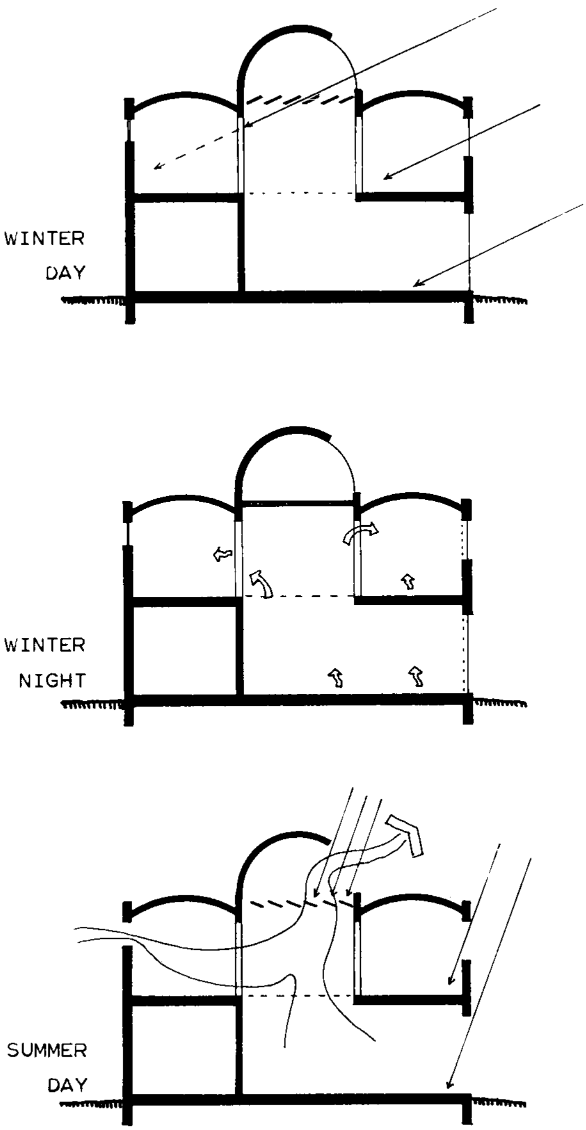
The excess hot air is blown through a lower floor heat stock.

The pivoting panels are made of cork board covered with white painted ply-wood; they are manipulated with a crank.

The upper glazing can be opened for summer ventilation, encouraged by the chimney effect.

TEST HOUSE II

Passive solar house : St. Laurent de la Salanque, P-O. France.
Architect : J.R. Peres.
Mobile insulated ceiling : Isomobile.



6 pivoting panels (3,00 x 0,60 m.) form an insulated ceiling during the night to reduce heat **loss** through the vaulted clearstory in the center of the house.

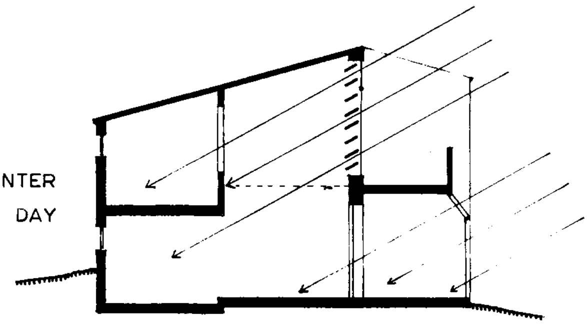
In summer they protect the house from excessive solar gain.

The panels are made of polyurethane foam, covered with washable wall paper. A metal bar linking the pivots at each end assures the rigidity of these very light weight panels. They are manipulated with a crank.

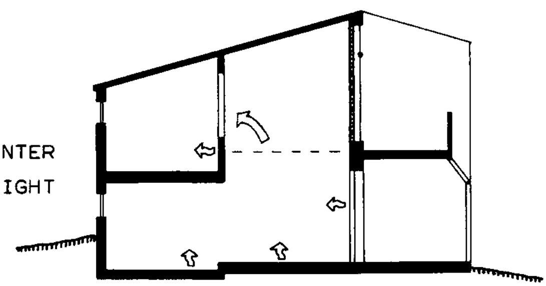
TEST HOUSE III

Passive solar house : Villeneuve de la Raho, P-O. France.
Architect : M.M. Tjoyas.
Mobile Southwall insulation : Isomobile.

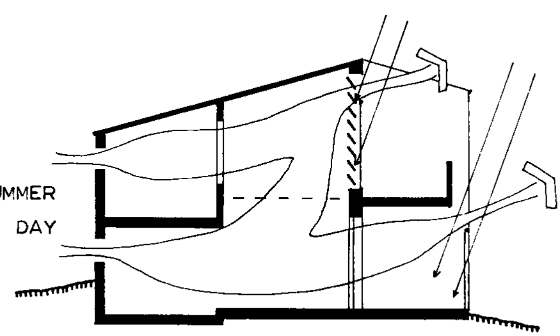
WINTER DAY



WINTER NIGHT



SUMMER DAY



The mobile insulation of the 8 m2 South facing clearstory is composed of two groups of 15 PVC louvers filled with expanded polystyrene.

Each group is manipulated separately with a cord.

A double covering horizontal joint and a brush joint at each end create a dead air space between the glazing and tne closed louvers.

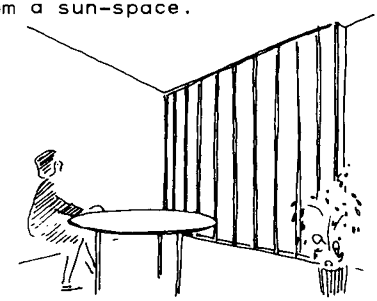
CONCLUSION

The mobile insulation systems shown in the three test houses were designed specially for the particular needs; the dimensions and materials used are different in each case. In order to develop an industrial product to meet the growing demand for economic passive solar buildings, it is necessary to design a standard model that can be adapted to different architectural situations.

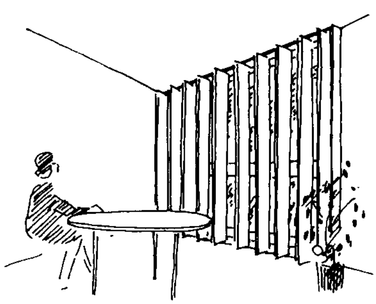
Horizontal pivoting shutters have many advantages but their use is limited to fixed glazing, clearstories and conservatories; in many cases, the mobile insulation should be able to clear the glazed window space completely, as shown in Test house I, where sliding panels were used.

Figure 8. shows a system of vertical pivoting insulating panels that can slide to one side. This type of mobile insulation covers the needs of most types of window and can also be used as a mobile partition, dividing a living room from a sun-space.

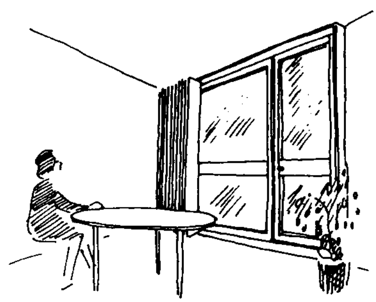
Fig. 8. Vertical shutters, pivoting and sliding.



Night Insulation



Daylight Control



Direct Gain

We are actually developing a foam filled PVC section (165 x 32 mm.) that can be used as a pivoting panel up to three meters long, either in a horizontal or in a vertical position. The thermal resistance of this panel will be 1 m2°C/W.

GOLD HEAT REFLECTIVE GLASS: CAPITAL SAVINGS AND ENERGY SAVINGS FOR MODERN OFFICE BUILDINGS

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ABSTRACT

The evolution of modern office buildings designed with large windows in order to allow an open, consistent distribution of light, and to give building occupants an uninterrupted view and contact with the outside world, has led architects and engineers to seek ways to design these glass skyscrapers to be energy efficient in the face of rising energy costs. Plain glass windows, of course, allow heat energy to pass through them by conduction and transmission, resulting in an undesired net loss of heat during winter, and heat gain during summer to a building's interior. Architects and engineers have developed innovations in building design and construction to mitigate, neutralize, or even reverse these effects. The most important solution has been the incorporation of thermal insulating glasses. This paper describes the most efficient development, one that has produced a very high level of benefit in comparison with its relatively low cost; heat reflective gold-coated glass. The information compiled in this paper presents (1) a comprehensive overview of the energy saving advantages of gold-coated heat reflective glasses and (2) follows with a detailed cost-benefit analysis comparing gold-coated glass to other leading metal heat reflective glasses. The results of which indicate the superior reflective capabilities of gold in the visible light and in the infrared region of solar radiation, and show that gold-coated glass with all its beauty does not increase, but significantly decreases the capital cost and the operating cost of large modern buildings.

KEYWORDS

gold; glass glazing; heat reflective glass

INTRODUCTION

A large portion of the energy consumed by buildings is due to heat flow inward in summer through the glazing material and outward during winter. A variety of techniques have been developed to make glass more efficient, the earliest being double light, which cut heat loss by 50% but heat gain by only 10%. Later efforts concentrated on heat absorbing glass or tinted glass such as the solar bronze and grey, which is commonly seen in buildings. These are better performers on heat gain, excluding as much as 45% of heat. In areas where there is a great deal of solar radiation, as in the semi-tropics, the amount of heat that tinted glasses can absorb becomes a major consideration in terms of safety due to the thermal expansion of the hot glass in its mountings.

In the early 1970s the procedure of depositing a fine layer of a metallic substance on the inner face of one sheet of double-light unit became feasible for use in buildings; producing reflecting or mirror glass. Dramatic improvements in thermal performance resulted.

Public attention was drawn to the merits of gold coating when the National Aeronautics and Space Aministration (NASA) provided gold-coated visors to protect its Apollo astronauts, and gold-coated surfaces to protect their satellites from the intense solar radiation. Over the past 10 years considerable effort has been expended to improve the rate and uniformity by which metal-reflective coatings may be applied to large glass units.

ENERGY SAVINGS

In modern buildings, large windows give an open distribution of light. These broad areas of glass give the people in the building an uninterrupted view and a sense of contact with the world outside. Such large windows, however, create problems. In warm weather, intense sunlight causes overheating of the interior, necessitating extensive air conditioning systems; in wintry weather heat generated by the heating plants is lost to the outside.

Ordinary window glass is almost completely transparent to all solar radiation from ultraviolet to infrared. Not only visible light, but also heat, go through it with little difficulty.

The best solution to both the cooling and the heating energy problems is the use of reflective glass units that have a microscopically thin coating of pure gold between two layers of glass. (As little as 1/000 of a troy ounce of gold is required per square foot of gold glass.) This permanent gold coating is applied on the airspace side of either the inboard or outboard pane of the insulating glass unit. Window units thus made with a gold metallic layer provide both a low transmittance of solar rays and high insulating efficiency.

On a warm summer day, gold insulating glass windows can reflect over 90 percent of the infrared solar heat rays striking it, while transmitting 20 percent of the visible light. These ratios are important because infrared radiation is by far the largest single cause of interior heat gain, and 20 percent of the visible sunlight is typically all that is desirable for comfortable visibility by the building's occupants. When facing full, direct outside sunlight, the total indoor heat gain can be as little as 31 Btu/hr/ft^2 of window area using gold coated insulating glass, compared with corresponding figures of 116 for similar glass coated with metals other than gold, and 310 for ordinary single sheet window glass. These figures are indicative of the amount of air conditioning energy and capacity that can be saved by using gold insulating glass.

This type of insulating glass used in windows is just as effective in the winter and in permanently cold climates. Gold insulating glass reflects room heat back into the building even when the outside temperature is much colder. The thermal transmittance of gold insulating glass is very low. In one example, a typical gold insulating window unit has a U value of .31, whereas the same unit without the gold coating has a U value of .55. Again, it is not difficult to envisage the heating capacity and costs that can be saved by using this type of window unit.

Gold insulating glass conserves a great deal of heating and cooling. But at what cost? In order for it to be economically advantageous, the additional cost of installing gold insulating glass must be less than the costs of the energy and equipment it will save. The cost of gold insulating glass is, indeed, less. This advantageous cost-benefit ratio for gold also holds in comparison with insulating units coated with metals other than gold as well as over clear insulating units.

It is just as good a business decision to build with gold insulating glass as it is a beautiful one.

Furthermore, the cost of gold insulating glass is recoverable not just over years of lower heating and cooling costs, but much of it is recovered immediately through reduced construction costs. Buildings that use gold insulating glass window units require smaller capacity (and therefore, less expensive) heating and cooling equipment as well as less space alloted to this equipment. These are primary cost savings directly resulting from the use of this type of window.

COST-BENEFIT ANALYSIS

The economic effectiveness of gold reflective glass has recently been illustrated in a study directed by Thomas E. Johnston, P.E., President of Keen Engineering Co., Ltd., 214-545 Clyde Avenue, West Vancouver, Canada. The study compared four different types of insulating glass; namely clear double glazing, bronze double glazing, silver reflective glass and gold reflective glass. A comparison was made incorporating each of these types of glasses in a building located on Energy Square in the cold climate of Edmonton, Alberta, Canada. The building is owned by Integrated Building Corp., Ltd.; and its construction was engineered by Keen Engineering Co. The architect being John A. MacDonald of Edmonton. It is a thirteen story, 193,000 gross ft^2 office building for which the decision was made to employ gold reflective glass on all transparent surfaces. The benefits that the owners are reaping from this decision are evident from the study.

The findings of the study overwhelmingly support the use of gold reflective glass. It was shown that although the cost of gold coated glass itself was greater than the costs of each other type of insulating glass, 89% to 117% of this extra cost, depending upon the type of insulating glass compared, is recovered immediately through reduced capital outlays for heating and cooling equipment. As compared with clear double glazing and silver reflective glass, the gold coated glass resulted in a reduction in capital costs for air conditioning and heating equipment which was greater than the additional glass costs when using gold. When compared with solar bronze glass, the gold glass itself costs more to install, but 89% of this excess glass cost was recovered by the decrease in capital costs for air-conditioning and heating installations.

Additional savings result from the fact that drapes are required for all other types of glass in order to shield the interior of the building from glare of sunlight. Gold reflective glass serves to reduce 80% of the brilliant sunlight leaving only a comfortable, soft visual environment.

In addition to the effect on capital costs, the gold glass is much more energy efficient, so that additional savings begin immediately when the building starts to operate. Even at the especially low energy rates prevailing in Edmonton, the annual energy savings of gold glass, as compared with solar bronze glass produce savings enough to compensate for the difference in glass costs between gold glass and solar bronze glass, in less than five years of daily operation of the building, attributable to gold's heat reflective capabilities.

For example, the operating costs of a building in Edmonton using gold glass are $3,566 less per year than the costs of a building using solar bronze glass and $5,272 less per year using clear double glass. When this study was extended to include regions of the United States with moderate climates or warm climates and normal energy rates, the savings were even more striking ! The total capital costs for glass, air conditioning and heating installations would be $21,286 less if gold glass rather than solar bronze glass is used and $82,447 less if gold glass rather than clear double glass is used. In addition, the operating costs of a building using gold glass would be $7,204 less per year using solar bronze and $10,365 less per year using clear double glass -- producing large savings every year the building is in operation !

BEAUTY

Buildings that use gold reflective glass have a distinct beauty of their own. A look at the mirror-like surface of one of these buildings, reflecting clouds, trees and other structures, brings great pleasure. Furthermore, gold glass provides the architect with a whole range of color experiences to fit any environment. Gold reflecting glass is made in a variety of tones and hues from bright gold to a deep bronze-like appearance, to coral, to azure, and through a range of blues to a shimmering silver. The creative architect can use gold reflecting glass to blend or to contrast with many different surroundings. There is still more creativity built into gold reflecting glass. It undergoes subtle variations in appearance with changing conditions in natural light. Thus, window units of gold glass are the answer to one of the age old architectural challenges. The architect's creativity continues even after the building has been completed.

INTERNAL ENVIRONMENT

The attractiveness of gold reflective glass windows is not only on the outside surface of the building. These units also enhance the appearance of everything inside the building by shielding the internal environment from over 80 percent of brilliant sunlight. Thus, they eliminate the glare that would be reflected by furniture and fixtures within the building. The gold glass serves not only the temperature comfort but also the visual comfort of the occupants. Gold reflective glass reduces glare and helps lessen eye strain. It tends to produce a soft uniform visual environment right up to the windows, so that the room has less light areas and dark areas, light spots and shadows. The low shading factor is constant. It doesn't depend on whether the occupants keep blinds or drapes open or closed. It enables building engineers to manage an optimum and constant visual environment. Gold reflective glass helps the architect in his total design for comfort within the building.

CONCLUSION

The superior heat reflective capabilities of gold, the distinctive cosmetic beauty of gold glass in its full range of colors, and the soothing internal environment produced, all point towards the desirability and practicality of the incorporation of gold heat-reflective double glazing units for modern office buildings. The carefully conducted cost-benefit study by Thomas E. Johnston emphasizes the economic feasibility of gold glass, even at gold prices exceeding $500 an ounce.

The cost effectiveness of employing gold-coated glass in these times of rising energy costs had not been generally known throughout the architectural community, but it has been shown by the Johnson study, and by the experiences of many building owners who use this energy-efficient glass.

EXPERIMENTAL DETERMINATION OF EMPIRICAL FLOW COEFFICIENTS FOR AIR INFILTRATION THROUGH PITCHED ROOFS

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ABSTRACT

The heating and cooling loads due to air infiltration may be estimated by a mathematical model that requires the knowledge of the leakage characteristics of each component of the envelope. To extend the modelisation to pitched roofs, empirical coefficients pertaining to the leakage characteristics of roofs were determined by a differential pressure method.

KEYWORDS

Roof structures; air leakage; modelling; building thermal performance.

INTRODUCTION

Roofs play an important part in the global energy balance of a building. The relative importance of the roofs depends on several parameters such as number of stories, the U-value of the walls, area of glazings and infiltration losses. The importance of the thermal exchange in the roof increases as the tightness and overall U-value of the walls and glazings increase and as the number of stories decreases. In addition, certain types of roofs also influence the air exchange rate in a building: whenever there is a communication between the roof and stairwells or elevator shafts, the stack effect is increased and infiltration is enhanced.

In Portugal, during the 70's, about 50% of the new construction had a single storey and 95% had no more than two storeys. The vast majority of these buildings has a sloped tiled roof with an attic space which can be accessed from within. Usually, no insulation is used in the roofs and attics, resulting in a roof U-value of 3 W/m^2K. Under these circumstances, it is clear that the thermal exchange through the roof in Portuguese buildings is responsible for a significant portion of their energy consumption for heating and cooling. A survey has shown that one third of the thermal exchange in such a building is through the roof, while infiltration is responsible for another third (Abrantes, 1980).

It is therefore important to be able to quantify the thermal performance of a roof-attic system, namely the air exchange rate in the attic and how it interacts with the rest of the building. The most common methods that can be used to estimate infiltration rates are the air change method and the crack length method. In addition, there are some more complex mathematical models which usually require numerical methods to obtain a solution (Kusuda, 1976). These models are more rational and less empirical than the other two methods and were thus chosen for this project.

INFILTRATION MODEL

This model considers the building as a control volume with the building envelope as the boundary. In the earlier versions, the control volume was considered as a single zone to simplify the mathematical treatment. Nowadays, however, the building is divided into several zones, usually one for each major room or group of rooms. This is important because significantly different pressure differences may occur within a building, in particular when there are horizontal partitions. Each zone is then treated as a separate control volume where the principle of conservation of mass applies, i.e., the sum of all flow rates entering or leaving a particular zone is nill.

For each zone (i), it is possible to write:

$$\sum_{j=1}^{n} \sum_{\ell=1}^{m} C_{ij\ell} \; A_{ij\ell} \; (\Delta p_{ij})^{n_\ell} = 0 \qquad (1)$$

where:

- n - number of zones
- m - number of boundary elements in zone i
- $C_{ij\ell}$ - flow coeficient, defined as the volume air flow rate per unit area (or linear unit of length of crack) and per unit pressure difference between both sides of the component $[m^3/s.m^2.Pa]$ or $[m^3/s.m.Pa]$
- $A_{ij\ell}$ - area or crack length of component ℓ $[m^2]$ or $[m]$
- ΔP_{ij} - pressure difference between zones i and j $[Pa]$
- n_ℓ - exponent between 0.5 and 1, usually about 0.65 for cracks.

For each of the n zones in a building, an equation of the type of eq. (1) can be established, thus resulting in a system of n simultaneous equations. It should also be noted that, given the dependence of the density of air upon temperature, all flowrates must be referred to the same temperature level.

Flow measurements of infiltration air through cracks are difficult if not impossible to make with enough accuracy because the pressure differences between the sides of any component and the resulting air flow rates are very small. Thus, rather than measuring the flow itself, indirect forms of measurement are usually employed, such as the tracer-gas method, the blower-door test method, and the component pressurization method, e.g., the method specified by ASTM standard E 283.68 for measuring window leakage. While the tracer-gas determines air leakage by measuring the changes in concentration of a gas, the other methods amplify the pressure difference between both sides of a component or building envelope, thus increasing the air flow rate and making its measurement easier.

MEASUREMENT OF FLOW COEFFICENTS IN PITCHED ROOFS

The element pressurization method was chosen in this case. It consists of sealing off a portion of the roof with a plastic sheet and pulling a vacuum between this sheet and the roof. The pressure difference and air flow are then measured and the flow coefficient deduced from the measurement of leakage rates at various pressure differences.

Due to the difficulty in completely sealing off a section of an actual roof in a building and to the little mobility possible in most attics, in-situ measurements were not made. Rather, a model was built in a laboratory and the measurements then taken under completely controlled conditions. Pressure measurements were taken with an electronic micromanometer having a resolution of 10^{-5}mm of water gauge and air flow was measured with two rotameters, one for flowrates up to 27 m^3/hr and the other for flows up to 175 m^3/hr. The rotameters had a 2 % precision.

The air flow is driven by an air pump with 700 W, capable of drawing a flow of 70 m^3/hr, which is much larger than the leakage possible through the element under study. The flow rate is then regulated with two valves.

The experimental facility is schematically show in Fig. 1, while Fig. 2 shows a detail of the evacuated space between the roof and the plastic sheet, including the connection between the plastic and the tube through which the air is aspirated.

Prior to studying the roof itself, the equipment and method were used to measure the leakage rate through windows. These values are known and have been tabulated (ASHRAE, 1977), and it was thus possible to compare the measured and tabulated values to check the validity of the procedure.

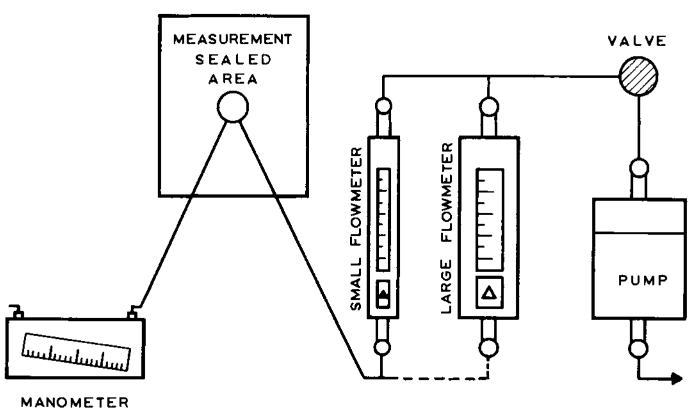

Fig. 1 - Schematic representation of the leakage measuring equipment.

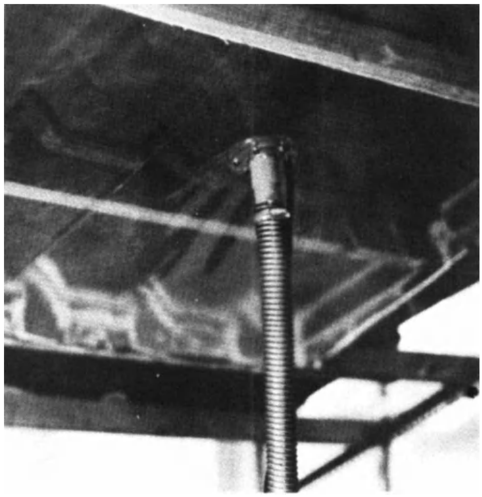

Fig. 2 - View of an experimental model.

RESULTS

The most common types of roofs in Portugal (Abrantes, 1980) are shown in Fig. 3

The measurements for each type of roof were then correlated to an equation of the type

$$Q = C \Delta p^n \qquad (2)$$

and a least squares fit was found. The results are shown in Fig. 4 and are summarized in Table 1, which lists the values of C and n for each roof type, as well as the statistics that were obtained.

In Table 1, the values of the flow coefficient C and flow exponent n are shown for a variety of roofing materials, and two values obtained from ASHRAE (1977), one for windows and the other for a wall, are given for comparison.

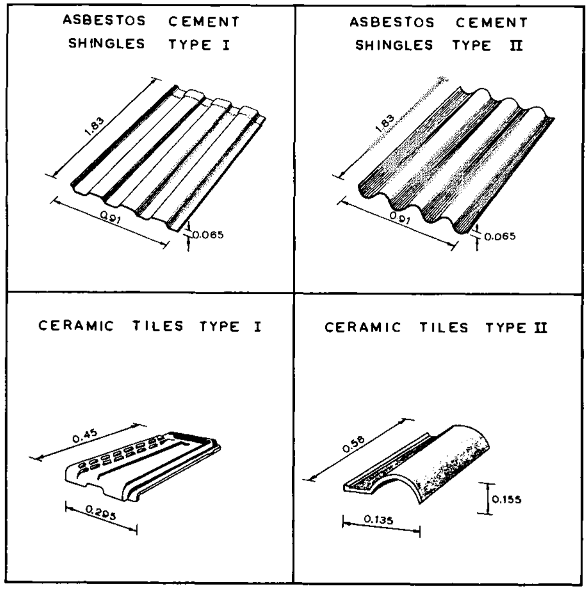

Fig. 3 - Common types of roofs in Portugal.

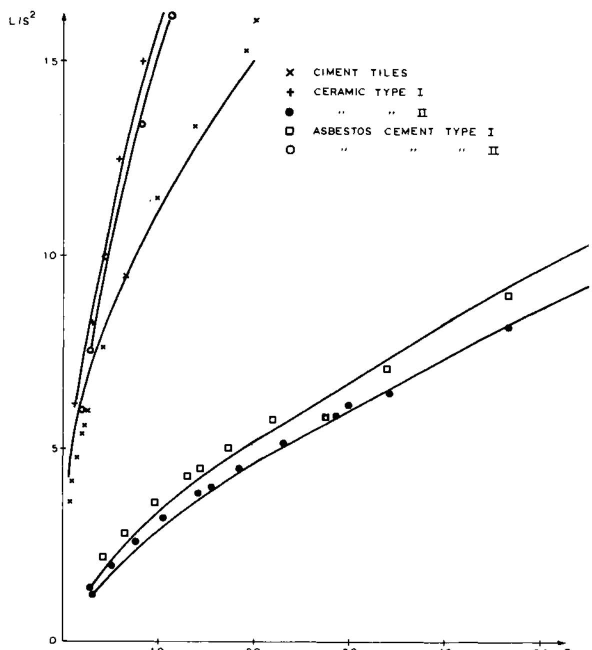

Fig. 4 - Leakage characterics of the studied roofs.

TABLE 1 - Experimental Values of Flow Coefficients

Type of roof	Flow Coefficients C [ℓ/sm²Pa]	n	Statistics[1] N	r^2
Ceramic Tiles				
- Type I	4,593	0,537	11	0,999
- Type II	3,970	0,595	12	0,997
Cement Tiles	4,642	0,385	12	0,976
Asbestos Cement Shingles				
- Type I	1,076	0,936	12	0,933
- Type I[2]	0,670	0,688	14	0,972
- Type II	0,642	0,668	14	0,997
Window[3,4]	0,29	0,65	-	-
Loose Wall[4]	0,18	0,65	-	-

[1] Number of experimental points and correlation coefficient.

[2] Weatherstripped

[3] Non weatherstrippes loose fit with around frame in masoney wall not caulked.

[4] From ASHRAE (1977).

CONCLUSIONS

The pitched roofs that are traditionally used in Portugal are characterized by large leakage rates. This contributes significantly to the large infiltration rates that occur in typical Portuguese buildings.

The flow coefficients of roofs with ceramic tiles are much greater than those made of asbestos-cement shingles. This results in larger ventilation rates in attics below the former type of roof, which is a favourable situation during the summer. Conversely, if there is an opening to the main portion of the building, ceramic tiled roofs will also result in larger air exchange rates in the building itself.

The availability of flow coefficents for these roofs will allow the simulation of the global air exchange in buildings, treating the attic as a separate zone (Abrantes and Galanis, 1981, and 1982).

Finally, the equipment and method that were used in this project are simple tools that can and have been used in energy-audit procedures to verify "in-loco" the leakage characteristics of building components and locating possible energy conservation opportunities.

ACKNOWLEDGEMENT

The authors express their gratitude to Dr. E. Maldonado and Mr. Figueiroa Gonçalves for their valuable cooperation.

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THERMAL INVESTIGATION OF SHADED AND INSULATED ROOFS IN HOT ARID CLIMATES

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ABSTRACT

Five rooms model were constructed on the test field at the Egyptian Building Research Center, Cairo. The internal dimensions were 3.4m x 3.15 m and 2.7 m high. All windows and doors were facing the south/north orientation. The walls were built from ordinary red bricks(250mm thick) and plastered from inside. Four roofs of different building materials were constructed namely; hollow concrete blocks, gypsum blocks, corrugated asbestos sheet and expanded polystyrene. As for the fifth roof, it was built from reinforced concrete with a slab being 100mm thick. That roof was investigated with and without external shading device. All roofs were investigated under typical summer and winter conditions of Cairo, Egypt. This investigation showed that the use of insulation or shading device on the roof achieved a minimum heat flow and hence a substantial reduction of about 15% in the internal temperature could be achieved.

KEYWORDS

Thermal performance; temperature control; shaded roofs; insulated roofs.

INTRODUCTION

Roofs unlike other building components which are more important, often do not receive adequate attention to their thermal performance at the early design stage. They form a considerable proportion of the external surface of the building, specially at the top floors in a multistorey building, and are particularly receiving a great deal of solar radiation and exposed to the outdoor environment. The running cost, size and capacity of an air conditioning plant depends to a large extent on the thermal efficiency of the building envelope, in minimizing the effects of the adverse weather conditions.

One of the most important problems that faces both architects and inhabitants of buildings is the control of indoor thermal environment, to make it more comfortable. Uncontrolled heat gains and losses through roofs have a great influence on indoor thermal conditions. The effect of temperature control on the design of roofs in most countries with hot-arid climates and an abundance of solar energy is very often given inadequate attention. A lot of attention has been given to the effect of temperature control on the external walls and windows (e.g. Hanna, 1983), but little has been done to study its effect on the roofs.

In hot arid climates, such as Egypt, during a large part of the year, the overheating period may be of 4 to 6 months diuration, the temperature by day is usually too hot to be tolerable and reaches to 40°C or more, while the weather is relatively cool at night. Usually, our problem is that of protecting the interior of building by day because the heat in summer is sometimes unbearable. Due to large number of variables considered, consequent complexity and numerous assumptions had to be taken into account for the theoretical approaches, it was decided to tackle the problem experimentally where a series of measurements have been carried out in the field of tests at the Egyptian Building Research Center under typical weather conditions of Cairo.

In this paper, five test room models with different forms of flat roofs construction have been designed and investigated experimentally. Previous studies (Mukhtar,1978; Anderson, 1981; Harris, 1982) in this field were investigated, but with different techniques (theoretical or experimental) and different climates.

TEST ROOMS DESCRIPTION

Five test room models were built with internal dimensions of 3.4m x 3.15m and 2.7m high, each has a 1x1m window with a shutter in the north facing wall and has a door of 2.0x0.75m in the south facing wall. The floors and walls of all models were similarly constructed of the same materials. The walls were of 250mm thick red-bricks and plastered from inside by 20mm thick cement sand mix. The floors were double layer ordinary concrete slabs each of 70mm thick with traditional insulation of 20mm inbetween to ensure good water proofing. The floor concrete slabs were insulated by a layer of expanded polystyrene(50mm) and cement tiles.

The roofs for tne test rooms were built using reinforced concrete and each had an additional building material with different form of design, as shown in Fig.1. In room I, the roof was built by the traditional Egyptian way of construction (30mm thick cement tiles on the top, 70mm thick cement morter, bituminous layer and 100mm thick reinforced concrete). This roof was investigated during January and April without an external shading and was also investigated during May and September with an external shading device on the top roof surface with and without ventilated air underneath. The roof A contains tiles and cement as above but with 250mm expanded polystyrene and 165mm reinforced concrete. The third test room model contains a roof of type II which contains tiles, cement & sand as above but with 50mm reinforced concrete, 250mm thick hollow concrete blocks and 20mm plaster from inside. There are 250x100mm reinforced concrete in between bonding the hollow blocks, as shown in Fig.1. Roof III contains the same thickness of tiles and sand but with 50mm reinforced concrete, 200mm gypsum blocks and 20mm plaster of ordinary concrete. The last roof IV have 100mm span corrugated asbestos sheet and 250mm thick concrete beam.

FIELD MEASUREMENTS

The thermal responses of the roofs have been monitored for an extended period of one year. The five roofs are instrumented with (Cu./Con.) thermocouples to measure and record the external and internal surface temperatures and also the temperature at the interface surfaces between the different materials. Continuous measurments were recorded for 24 hours using two multichannel recorders each with 24 channel manifactured by Honeywell. A multipen recorder Type 3061 by Kogawa with 9 channels were also used to monitor the wind velocity, direction, external humidity and total solar intensity on horizontal surface using Black & White Epply pyranometer The wind speed and the solar radiation were also measured by using a thermoanemometer GGA 23S,

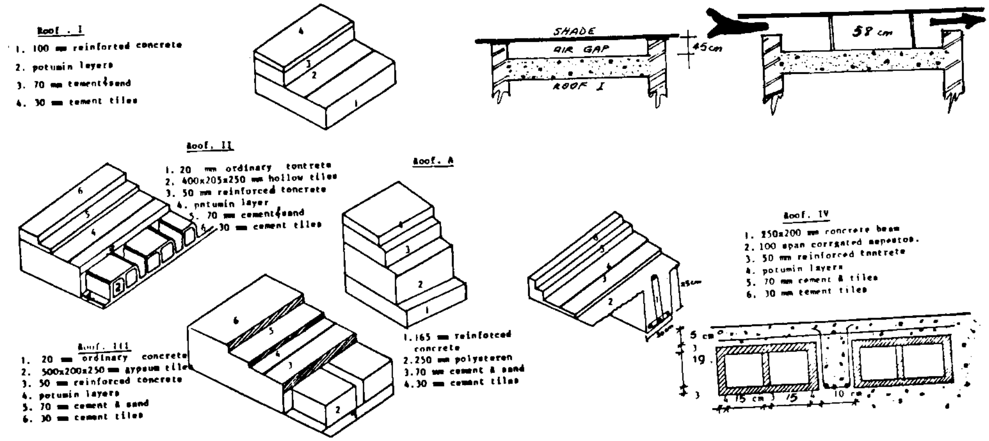

Fig.1 Isometric projections of sections of five roofs construction.

and a solar sensor SS-100 with a chart recorder model AS 60 TIE by KBE, respectively. The indoor room air and global temperatures($\simeq$ environmental, defined as the weighted combination of the mean radiant temperature and indoor air) were also measured at the rooms center 1.70m high from the floor level.

The measurements started March 1982 and ended in February 1983. During winter seasons, roof I was investigated without any shading device on the roof and all rooms were unventilated, i.e. doors and windows were closed. During summer time, three systems were used:

1. Roof I was directly shaded (i.e. without ventilation under the shade) and all rooms were closed (i.e.closed windows, shutters and doors) .
2. Roof I was shaded and ventilated under the shade and ventilated under the shade and all rooms were closed.
3. Roof I was shaded and ventilated under the shade and all rooms were opened,i.e. opened shutters.

RESULTS AND DISCUSSION

Results of the various field measurments to determine the effect of various roofs construction on the ceiling and indoor air temperature are shown graphically in Figs 2 to 11. The main points of interest are discussed briefly below.

Figure 2 shows a comparison between typical diurnal temperature variations of the roof, ceiling, global and indoor air of rooms A and I. It can be seen that the roof surface temperature of room A shows higher maximum temperature and higher fluctuation range with respect to room I. The difference in the maximum temperatures and in the fluctuation range are about 7°C and 10°C, respectively. It is clear that the ceiling temperature of room A is much flatter and less than the ceiling temperature of roof I by about 6°C on average during the afternoon hours. During the hottest period, the global temperature of room A is less than that of room I by about 2°C.

Figure 3 illustrates a comparison between typical diurnal variation of global and indoor air temperatures for rooms A and I as well as outdoor air temperature and solar radiation. It is seen that there is clear difference between the global temperatures of room A & I during night and morning hours and reaches to 2.5°C with a time lag of about 4 hours. Also, during the same period, the figure shows that the indoor air of A gives higher temperatures than I by about 1.8°C. During the hottest period and the afternoon hours, the global and indoor air temperature of A shows very close temperatures. Also during the same period, the global temperature of I shows larger values than the indoor air. The global temperature of I reaches its maximum above the indoor air by about 1°C and 2 hours behind the maximum outdoor air and 2 hours ealier than the maximum indoor air. The figure also shows that the global temperature of A gives higher temperatures than the indoor air during the morning hours and visa versa at night hours. This is understandable since the heavier the building material (i.e. higher thermal capacity of the roof), the less heat will be passed to the indoor air. i.e. smaller fluctuation range and more time-lag.

Figure 4 demonstrates the diurnal temperature variation through roof II of hollow concrete blocks. The maximum temperature at the top surface is 41°C with a diurnal range of 24.5°C, while the maximum indoor air is 26°C with a time-lag of 11 hours behind the maximum roof temperature. The figure shows that the temperatures were gradually decreased with increasing depth. It is clear that the upper inner surface of the air gap gives higher temperatures than that given inthe solid material above the gap. This is understandable since the trapped air in the gap nearer to the top surface is much warmer and helped to heat up the corresponding surface by natural convection. The figure also shows the time-lag curve.

Figure 5 shows the temperature variation of roof A as a function of time at different hours. In early morning and late night hours the temperatures increased with increasing depth. During the hottest period, the upper top surface temperature is gradually decreased with increasing depth. Finally all the temperature curves were nearly the same at the ceiling surface. The figure improves the benefite of using thermal insulation in the roof construction for damping the temperature fluctuation throughout the day.

Figure 6 illustrates a comparison between the indoor air temperature response of five rooms with different roof construction under typical summer conditions. The figure also includes measurements of solar radiation on horizontal surface, outdoor wind speed and outdoor air temperatures. It is clear from the figure that the roof IV of corrugated asbestos sheet shows higher temperatures (3°C above the others) during daytime and night hours, i.e. has bad thermal performance. It can be shown that roof I with external shading device gives lower maximum and lower minimum,i.e. has good thermal performance. During early morning hours, room II & I have very close indoor air temperatures. During the hottest period between 1000 a.m. and 1900 p.m., the indoor air temperature of rooms II, III & A gives very close temperatures and the difference is less than 1°C. The indoor air of room A behaves thermally close to room I.

Figure 7 shows a comparison between roof and ceiling temperatures of rooms A, I & III under typical summer conditions. It can be seen that the maximum temperatures for the roofs A, I & III are 48.8°C at 1400 p.m., 53.5°C at 1230 p.m. and 42°C at 1400 p.m., respectively. The heavier the material, the more heat it can store and the less heat will be passed onto the indoor air during the day. Similarly at night, as the roofs contain a great deal of stored heat to lose to the outdoor environment, it will only have a limited cooling effect on the indoor air. The figure illustrates that the ceiling temperature of room I with an external shading device gives a lower temperature with respect to the other cases by about 3°C during daytime. The average ceiling temperatures of room A & III are practically equivalent where the average ceiling temperature of room I is less by about 1.5°C.

Figure 8 shows the influence of external shading on the thermal response of room I. It is clear that air gap temperature under the shade is much decreased and reaches a maximum of 29°C at 1500 hour which is equal to the maximum outdoor air and less

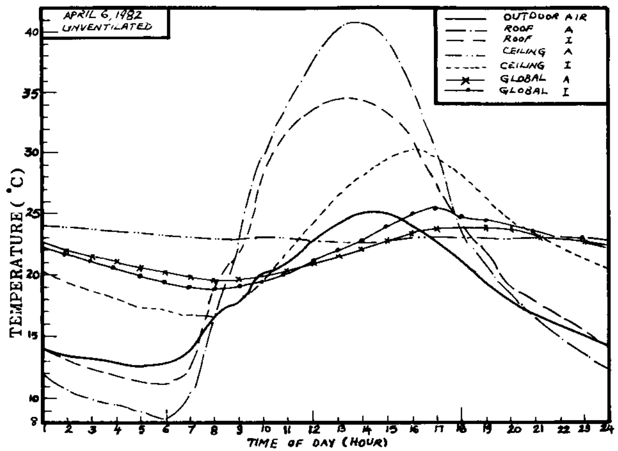

Fig.2 Comparison between temperatures of roofs A & I.

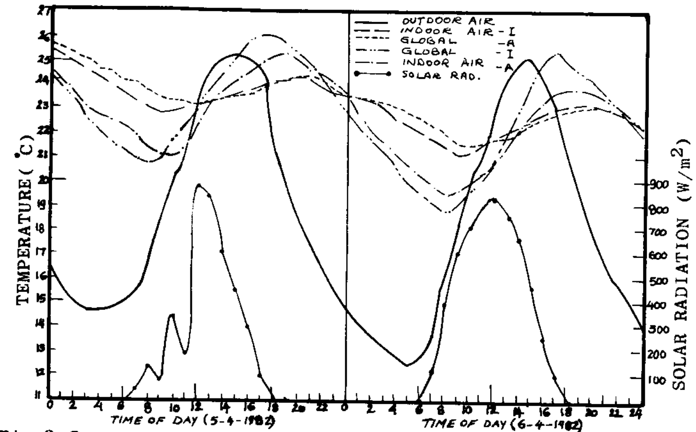

Fig.3 Comparison between global&air temperature of I & A.

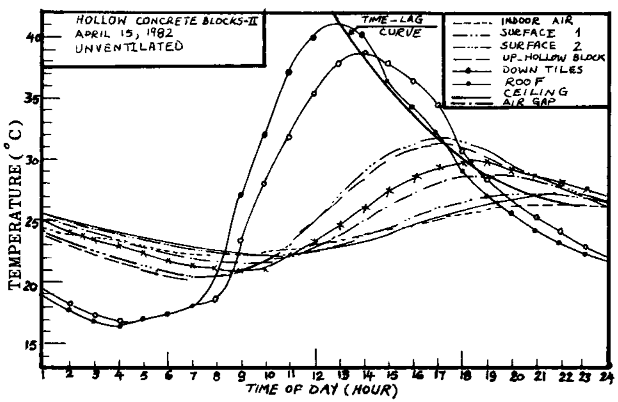

Fig.4 Diurnal temperature variations of roof II.

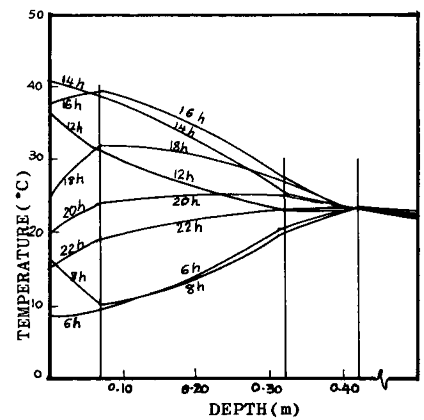

Fig.5 Temperature distribution within
roof A at different hours(6/4/82).

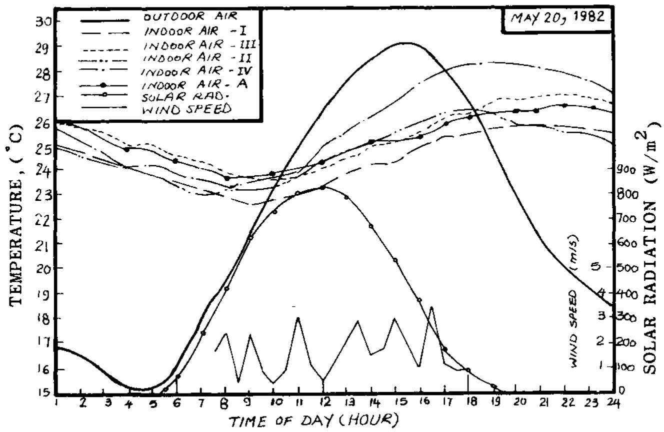

Fig.6 Comparison between thermal performance of five rooms under typical summer condition.

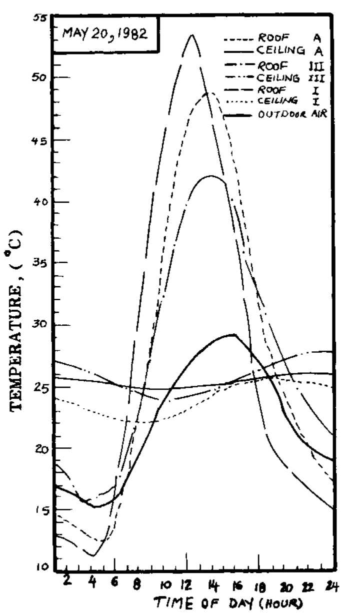

Fig.7 Comparison between roof & ceiling temperatures of rooms A , I & III.

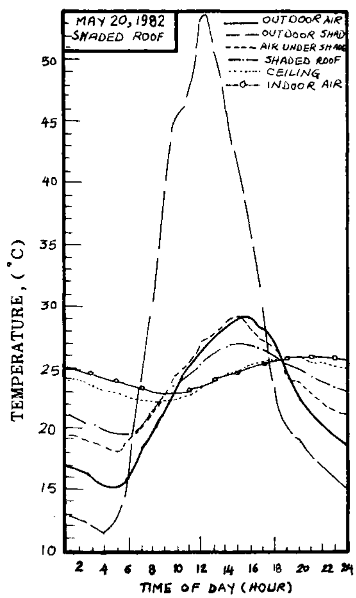

Fig.8 Influence of external shading on indoor temperatures.

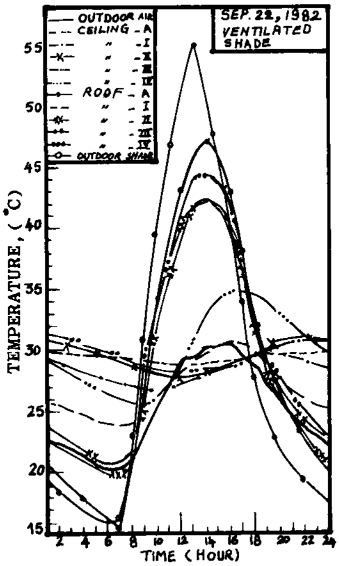

Fig.9 Comparison between roof& ceiling temperatures of the five roofs.

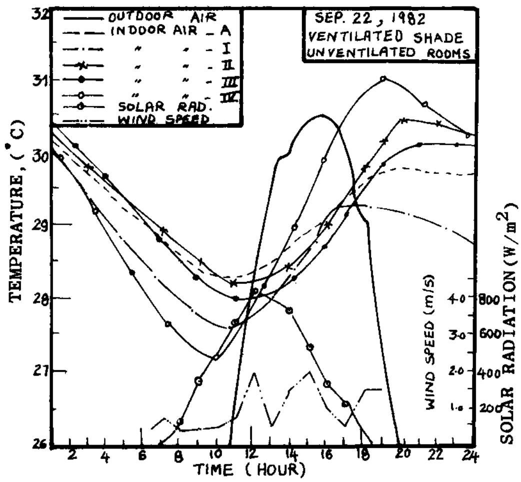

Fig.10 Comparison between indoor air temperatures of the five rooms.

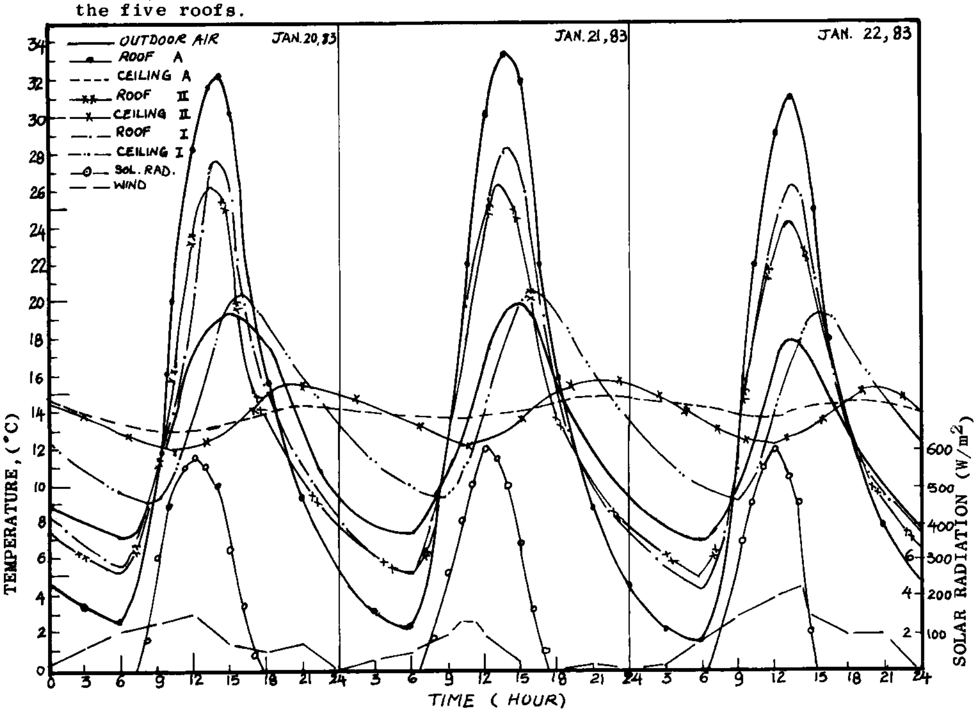

Fig.11 Comparison between roof and ceiling temperatures of rooms I,II&A for the days 20, 21 & 22 Jan. 1983.

than the maximum top shade surface temperature by 25°C. During early morning hours, the ceiling temperatures are less than the indoor air by 1°C. During the hottest period, both the indoor air and ceiling temperatures are practically equal. During night hours, the ceiling temperatures decrease gradually relative to the indoor air. The maximum indoor air temperature is 25.7°C occurs at 2100 p.m. with a diurnal range of 3°C.

Figure 9 illustrates a comparison between the ceiling and roof temperatures of the five tested rooms. The figure also shows that the ceiling temperature of room IV with asbestos sheets gives higher thermal response with respect to the other four cases. It gives reasonably rapid cooling responses in the early morning hours. It is also clear that the insulated roof temperature of A demonstrates a reasonable improvement in the ceiling temperature profile. It can be seen that the curves having a close temperature to 30°C occurs at 1800 hour. This is due to the fact that the steady state condition exists at these particular time where no heat is transferred in or out of the rooms. It is quite evident that the use of ventilated shade on the top surface achieves good reduction in the maximum temperature response by about 3°C on average. The diurnal range is also decreased with an increase in the time-lag by about 4 hours.

Figure 10 demonstrates a comparison between indoor air temperatures of the five rooms. It shows that both room A & I represent substantial improvements in the indoor air temperatures and room I shows reasonably rapid cooling response in the early evening. It is clear that room I reaches its maxima (29.2°C) one hour later than time of maximum outdoor air and 2 to 4 hours ealier than the indoor air temperatures for the other four cases.

Figure 11 shows a comparison between roof and ceiling temperatures of rooms I, II & A for the days of 20, 21 and 22 January 1983. The external shading device used during summer had been removed. It indicates that the maximum roof surface temperature of A which reached about 31°C occurs at 1300 p.m. is higher than roof I & II by about 5°C and 7°C, respectively. The top roof surface of A shows a reasonably rapid cooling response in the early morning and evening hours with respect to roofs I & II. The figure also shows that ceiling temperature of A achieved a good reduction in the maximum temperature, less diurnal variation and showed an increase in the time lag (> 2 hours). The ceiling temperature of room II responds much rapidly and faster than room I. It is interesting to state that, the average indoor air temperatures of the rooms are approximately equal to the outdoor air temperature.

CONCLUSIONS

The aim of this experimental study was to investigate and compare the thermal response of different forms of roofs as well as insulated and shaded roofs, under typical summer and winter climatic conditions of Cairo, Egypt. The experimental results have shown that the use of external shading device could perform quite satisfactory results during unbearable summer conditions and that a better thermal performace of about 15% could be achieved. Also, the insulated roof achieves a reasonable thermal reduction and helps in stabilizing indoor room air temperature.

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COMPONENTS FOR PASSIVE HEATING AND COOLING IN GREECE

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ABSTRACT

Components of Passive Solar Systems are primarily presented in this paper. Greek market research has been done to find out which components are really available and how to make the non-available ones. Comparative costs and probable peculiarities of the Greek architectural designs and structures as well as an example from the Greek area are also analysed in this paper.

KEYWORDS

Adjusting flow damper; backdraft damper; plastic tube; fan exhaust; airtight exit grill.

INTRODUCTION

Components for passive heating and cooling are the adjusting flow dampers "Fig.I.", the backdraft dampers "Fig.2.", the plastic tubes "Fig.3.", the airtight exit grills "Fig.4.", the small windows, the small fans 5W-IOW and the kitchen fan exhausts.

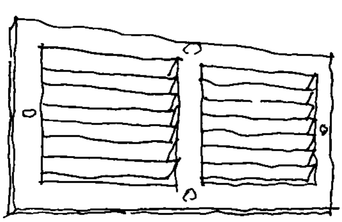

Fig. I. Adjusting flow damper

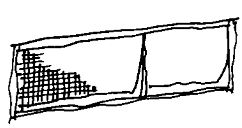

Fig. 2. Backdraft damper

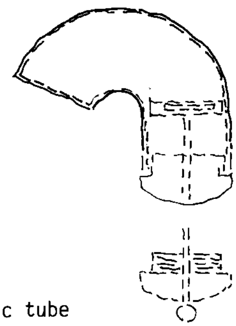

Fig. 3. Plastic tube

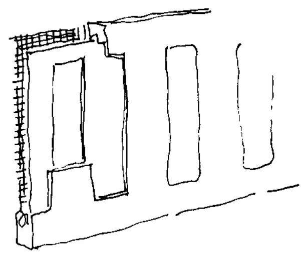

Fig. 4. Airtight exit grill

DESCRIPTION

Adjusting flow dampers can be metalic, aluminium or plastic. These are also used in airconditioning systems. It is characteristic that when the vents are closed, the system is not airtight but they can be improved with the use of rubber tape. Backdraft dampers must be constructed by the builders. They consist of strong cloth and a sheet of polyethelene or fluoride film. Their fitting must be done very carefully in order to achieve air tightness and free-movement of the sheet. The thickness of the sheet is usually 0.5mm.

Plastic tubes are a good solution for summer exhaust systems because they are cheap and watertight. Airtightness during winter is a problem but it can be solved with self constructions. They are placed high, sotheir position makes them handy for interseasonal use.

Airtight exit grills are also watertight. Probably the best solution in passive solar construction. They can be easily controlled and therefore are very handy. But these are expensive in Greece because they are manufactured in other countries. Also they need very careful adjustment, and that is a problem with the technical standards of the Greek builders.

Small windows are always high therefore the need of controls is compulsory for handy use.

Fans are easily adjusted and cheap. They help the summer night cross ventilation. Can be used as kitchen exhaust fans also.

These components are used in trombe walls, water walls, greenhouses and thermosiphonic panels. The full or half use is shown in the following table.

TABLE 1. Passive Systems in connection with the Components.

	Vented Trombe Wall	Stagnant Trombe Wall	Water Wall	Green-houses	Thermosi-phoning Panels
Adjusting Flow Damper	■	□	□	■	■
Back Draft Damper	■	□	□	■	■
Airtight Exit Grills	■ *	■ *	□	◪ *	◪ *
Plastic Tubes	□	□	□	■	◪
Small Windows	■	■	□	◪	□
Components With Fan assist	□	□	◪	■	◪
Fan Exhaust	□	□	□	■	□
Kitchen Exhaust Fans	◪ **	□	□	◪ **	◪ **

* Summer Exit

** Summer Night Cooling

■ Full use

◪ Half use

□ No use

Some notes are necessary:

For vented trombe walls, thermosiphonic panels and greenhouses backdraft damper can be used in all solar systems where an inlet damper is needed.

Exhaust damper is an adjusting flow one in order to control the quantity and direction of airflow in the house.

During summer airtight exit grills are open.

Instead of them small windows which are part of the glazing can be opened.

For stagnant trombe wall only an airtight summer exit is needed.

Characteristics which will help the designers to make a good choice are the anticipation in new constructions, the adjustment in old buildings, the easy use, the architectural design in Greece, the cost, the specifications and the fact to be industrial products or selfmade structures.

EXAMPLE

In solar retrofitted house in Arkadia are used the most of these dampers "Fig. 5." and "Fig. 6.".

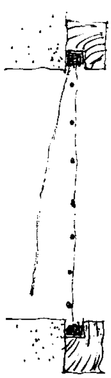

Fig. 5. Dampers

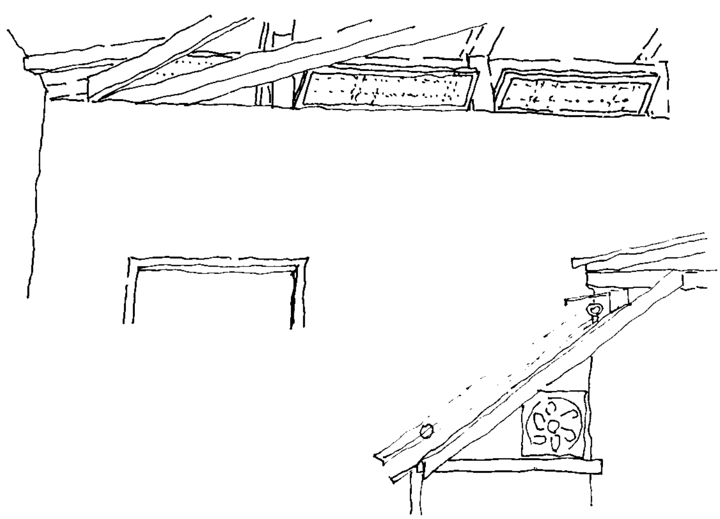

Fig. 6. Small windows and fans

Adjusting flow dampers are built at the indoors. Space is left between the upper side of the walls and the roof. Kitchen exhaust fan was in mind during the calculations. Fan exhaust will be built next summer in the greenhouse if necessary.

CONCLUSIONS

Table 2 and 3 have been drawn after a research in the Greek market for variety and cost in combination with the special materials and other building components. The knowledge of the greek builders to construct and adjust these systems, the fact that the inhabitants are not used in such systems and the Greek architectural design have been taken in mind.

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TABLE 2. Characteristics of Passive Solar Components

	Manufactured Comp.	Self-made Comp.	Specifications	Cost
Adjusting Flow Damper	■	□	■	◩
Back Draft Damper	□	■	◩	□
Airtight Exit Grills	■	□	■	■
Plastic Tubes	■	◩	◩	◩
Small Windows	◩	◩	□	◩
Components With Fan assist	■	□	◩	◩
Fan Exhaust	■	□	◩	■
Kitchen Exhaust Fans	■	□	■	■

TABLE 3. Passive Systems in connection with the Components.

	Anticipation in new Construction	Adjustment in old Building	Easy use	Problems with Architectural Design
Adjusting Flow Damper	■	◩	◩	□
Back Draft Damper	■	◩	■	□
Airtight Exit Grills	■	□	■	◩
Plastic Tubes	■	□	□	◩
Small Windows	■	■	◩	□
Components With Fan assist	■	□	■	◩
Fan Exhaust	■	□	■	◩
Kitchen Exhaust Fans	■	■	■	□

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ABSTRACT

The physical and economic capability of Foamglas ® for passive solar applications, particularly retrofit applications, are discussed. The properties of this material work synergistically to provide an outstanding collecting-insulating structure. Desktop and rooftop models have been developed in the laboratories at Providence College. A major retrofit application is soon to be implemented. The progress and implications of current studies will be reported.

Foamglas® is a product of the Pittsburg Corning Company.

KEYWORDS

Solar Collectors; Retrofits; Passive Collectors; Solar Systems

INTRODUCTION

Much of the emphasis in renewables technology in recent years has been on physical performance. Indeed, the intrinsic nature of any technology is such that efforts tend to dwell on physical efficiency. Yet, one criticism of advanced 'renewables' devices is that they tend to be expensive. Large scale adoption of technologies such as photovoltaics are held back by prohibitive costs. Even solar thermal heating systems, particularly retrofit applications in many areas of the United States, are less attractive more as a result of cost than as a result of performance. This paper deals with the early phases of work on a product, Foamglas®, that holds promise for cost effective applications particularly in a retrofit environment.

While the use of Foamglas® as a collector surface will not produce collection efficiencies that parallel the most efficient collector absorbers, its performance in this regard is respectable and is expected to be competitive with typical products on the market today. More significant is the fact that Foamglas® has physical properties that serve several functions associated with the application of a passive system. These and other attributes contribute to a low total system cost particularly when the product is used in certain new and retrofit applications that can utilize systems of low thermal mass.

SYSTEM FUNCTIONS AND PROPERTIES OF FOAMGLAS

The functions involved in a solar thermal system are collection, transport, storage, distribution, and control. Figure 1 highlights the sub-functions of a collector design including: positioning, focusing, absorbing, glazing, insulating, and supporting. This kind of functional analysis allows one to depict alternative collector concepts by the conjunction of sub-functions and options. The illustration in Fig. 1 is a fixed, flat plate, non-selectively coated, single glazed, separately insulated frame, boxed collector typical of the many types commercially in use around the world. Foamglas® has properties which lead one to consider its use to satisfy two or three of the functions associated with solar collection: absorption, insulation and, in some circumstances, support. Loth (1977), reported an active flat plate collector using Foamglas®. The material was grooved to enhance the heat transfer characteristics required when the product is used in a traditional active collector. The work reported in this paper relates to other solar applications of Foamglas®, particularly its application in passive collectors constructed on-site to conform to the variety of building shapes, types and cuts that one encounters in typical retrofit situations.

The physical properties of Foamglas® are listed in Table 1.

TABLE 1 Physical Properties of Foamglas® (from Pittsburgh Corning product data sheet FG-115M 7/27)

PHYSICAL PROPERTIES	ENGLISH (METRIC)
Absorption of moisture % by volume	Non-absorptive. Only moisture retained is that adhering to surface cells after immersion.
Acid resistance	Impervious to common acids and their fumes except hydrofluoric acid.
Capillarity	NONE
Combustibility	Noncombustible, Pure glass,
Composition	totally inorganic.
Compressive strength, average	100 psi (7.0 kg/cm)
Density, average	8.5 lb/sq.ft.(136 kg/m)
Dimensional stability	Excellent
Flexural strength, block average	80 psi (5.6 kg/cm)
Hygroscopicity	No increase in weight at 90% relative humidity.
Linear coefficient of thermal expansion	4.6 x 10 /F (8.3 x 10 /C)
Service temperature range	-495 deg F to +900 deg F (-273 deg F to +482 deg C)
Modulus of elasticity, approx.	1.5 x 10 psi (10,700 kg/cm)
Shear strength	50 psi (3.5 kg/cm)
Specific heat	18 Btu/lb F (.18 kcal/kg C)
Strain point (glass)	940 deg F (505 deg C)
Thermal conductivity	50 F:0.36 Btu in/hr sq ft. F (10 C:.045 kcal/m h C) 75 F:0.38 Btu in/hr sq ft. F (25 C:.047 kcal/m h C)
Thermal diffusivity	.020 sq.ft./hr (.0052 cm /sec)
Water-vapor permeability	0.00 perm-in (0.00 perm-cm)

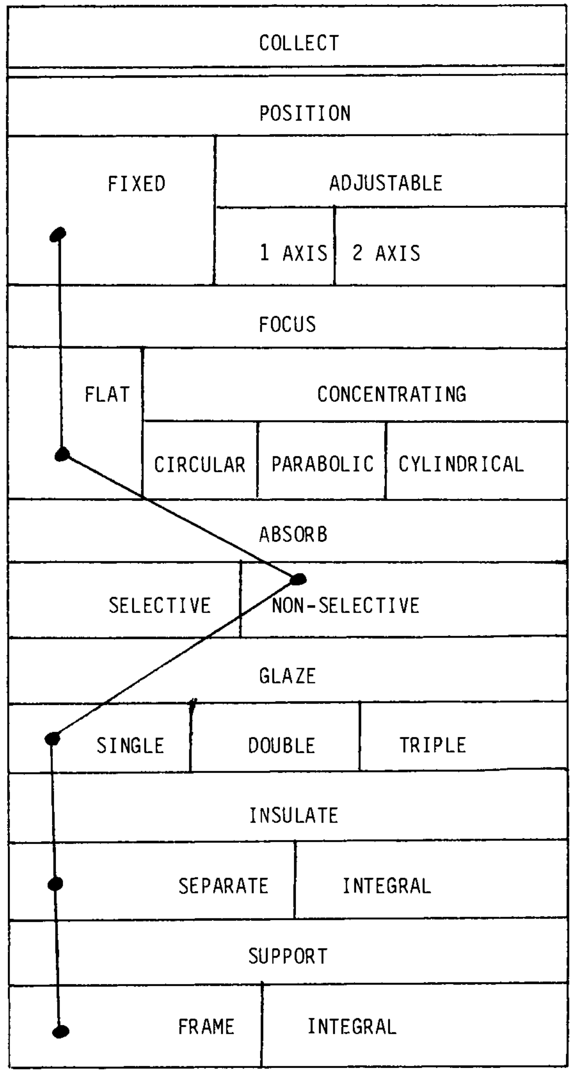

Fig. 1. Collector Functions - Subfunctions

In connection with collector functions, the attractive features of this product are its wide surface temperature range, low combustibility, low thermal conductivity, small linear co-efficient of expansion and low vapor permeability. Its physical properties remain rather constant over a wide range of temperatures. The 'crusty sponge-like' surface will accept various paints and adhesives. Absorbtivities will depend on the choice of surface treatment (paint, etc.). Loth (1977) notes absorbtivities comparable to those of the surfaces employed in more traditional collector absorbers.

APPLICATIONS

While Foamglas® can be used as an absorber-insulator in an active air collector, its applicability in retrofit situations as an insulator, for an uninsulated wall, and as a collective absorber in a passive retrofit holds exceptional promise. Following some preliminary studies with a bench top model, a 4 ft x 8 ft panel was constructed in 1982 in order to study the installability of the product in a retrofit situation and to ready an array for detailed efficiency testing. Since the product is thermally light, the latter activity has required the use of fast temperature and insolation acquisition electronics, which is currently being assembled, tested, and installed.

A number of interesting observations have emerged as a result of our efforts thus far. Foamglas® is a product which is extremely easy to cut and shape. A hand-held hacksaw blade is all that is required to cut a thick slab of the product. The product is readily available in various rectangular sizes and thicknesses. In our test system shown in Fig. 2, we have used 1 ft x 1.5 ft x 1.5 inch thick blocks which can be fastened to wood or masonry surfaces utilizing a standard mastic adhesive product. Pretacked finishing nails may also be used to secure the blocks to the wood surfaces. Foamglas® blocks can be pushed through the nails and a locking aluminum cap can be pressed over the surface. This detail is shown in the photograph of Fig. 3.

An array of approximately 765 sq. ft. is being planned for on-site fabrication and installation in an existing home in Worcester, Massachusetts. The elevation plan is shown in Fig. 4. Dimensional lumber will be used to provide perimeter frames and the Foamglas® blocks will be glued directly to the existing 'grooved' siding. In the initial phase, the array will function as an insulator-passive thermosyphoning system. An interior 'Casablanca' fan will be used to reduce the thermal gradient in the interior space of the home.

PERFORMANCE EXPECTATIONS

When Foamglas® is used in retrofit applications on south-facing non-insulated walls, there are two benefits that must be folded into the performance analysis: 1) the insulating effect (reduction of heat loss) and, 2) the solar gain. Table 2 gives the annual net thermal gain from these two effects for different combinations of degree day load and annual insolation rates.

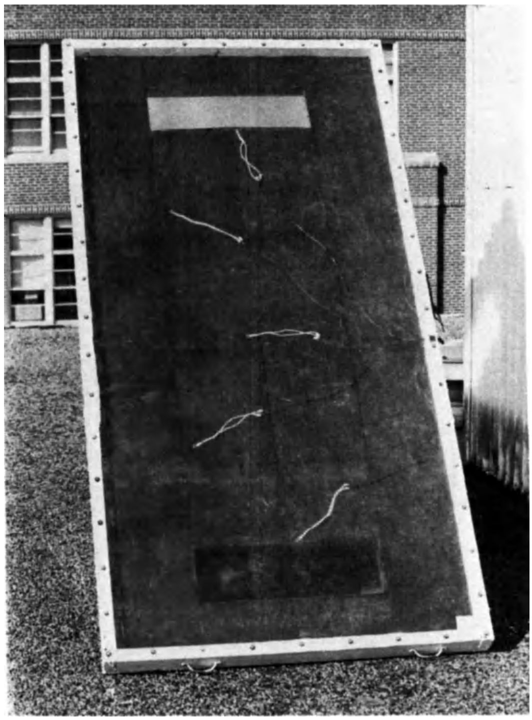

Fig. 2. Photograph of test collector

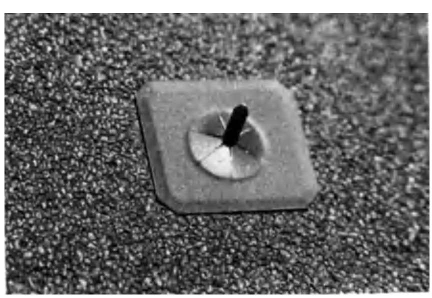

Fig. 3. Photograph of Foamglas® attachment detail

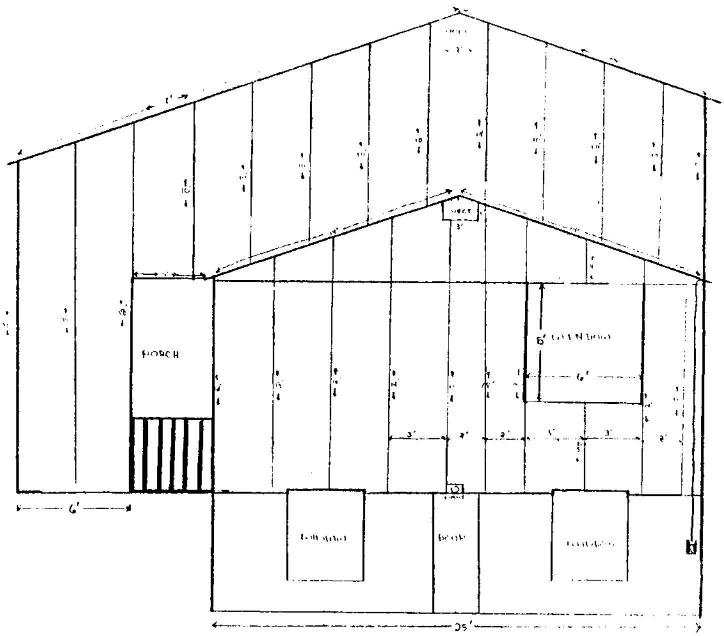

Fig. 4. Elevation plan for planned on-site fabricated system

TABLE 2 Annual Energy Savings (MBTU/sq ft)

INSOLATION (BTU/SQ.FT.-YR)	DEGREE DAYS 2000	4000	6000	8000
100000	0.0407	0.0513	0.0620	0.0727
150000	0.0557	0.0663	0.0770	0.0877
200000	0.0707	0.0813	0.0920	0.1027
250000	0.0857	0.0963	0.1070	0.1177
300000	0.1007	0.1113	0.1220	0.1327

These figures were calculated using an annual effective collector efficiency of 30% and the assumption that the system will be applied to a non-insulated, R-3 wall. A single glazed array was assumed in generating these figures. It should be pointed out that actual efficiencies may be somewhat higher. The response of the system under conditions of alternating direct sunshine and cloudiness is expected to be quite good as a result of the low thermal mass.

Using the above results for conditions similar to those prevailing in Southeastern New England, i.e., 6000 annual degree days and 200,000 annual BTUs per sq. ft. insolation, one obtains the expected cost-savings per sq. ft. of the applied system. Table 3 gives these savings as a function of fuel type using current prices prevailing in Rhode Island, USA.

TABLE 3 Current factors for Rhode Island

Fuel type	Fuel Cost $/unit	Fuel Cost $/MBTU	Energy Cost $/MBTU	Cost Avoidance/sq ft. System	Assumed Efficiency %
Electrical	0.077/KWH	22.56	22.79	2.10	99
Oil	1.15/GAL	8.33	13.89	1.28	60
Gas	7.50/MCF	7.50	10.71	.99	70
Coal	125.00/TON	5.68	9.47	.87	60
Wood	100.00/CORD	5.00	10.00	.92	50

Using current retail material prices, the initial costs of the system with 1.5 inch Foamglas® and Kalwall® Sunlite II in a large array are $2.75/sq.ft and $5.20/sq.ft. for single and double glazed units respectively. This compares very favorably with commercial systems which run currently in the range of $11/sq. ft. to $14/sq. ft. less installation and venting costs. Using the above Foamglas ® System data one can calculate the usual payback and investment indices. For conditions similar to those prevailing in southeastern New England, and produced-energy costs of $14/MBTU, the results are shown in Table 4.

TABLE 4 Investment Indices

Initial Cost Materials	2.75
Initial Cost Fabrication/Insolation	2.00
Initial Cost TOTAL	4.75
Energy Savings	.09 MBTU/sq ft
Annual Savings	1.36 $/sq ft
Simple Payback	3.5 yrs
Present Value Net Benefit (i=10% e=0% n=10 yrs)	$3.61
Savings Investment Ratio (i=10% e=0% n=10 yrs)	1.8

The last two indices, the Present Value of Savings less costs and the Savings Investment Ratio, were calculated using a 10% discount rate, a zero fuel escalation rate, and a 10 year lifetime. The later assumptions were made in the interest of being conservative.

CONCLUSIONS AND RECOMMENDATIONS

Foamglas® has shown itself to be an easily workable multifunctional product that serves two or more functions associated with solar collection. When used as an insulator and collector in retrofit applications, conservative estimates of performance and costs demonstrate a highly cost effective system. Previous studies by Loth (1977) suggest that active applications using his patented grooving procedure are also cost effective. (Production costs in reworking or reforming the Foamglas® surface using the suggested V-groove has not been analyzed.) Installation skills for the retrofit application described in this paper are minimal. Basic carpentry and caulking crafts are the main skills involved. The performance indices are conservative projections based on the single glazed configuration that serves as a test model in our laboratory. While such a configuration can be performance optimized for local conditions, e.g., using double glazing. The single glazed test configuration (with Kalwall glazing) is more attractive when the actual costs are folded in.

Foamglas® is not limited to the applications mentioned herein. The author, in collaboration with Professor Mark N. Rerick, have proposed other applications and have made preliminary design estimates for Foamglas® window units. These systems would be applied in situations in an existing building having excess south-facing, single glazed windows that are being considered for permanent shading. Foamglas® applied to the backside of an interior decorative panel suitably vented and framed would turn the single glazed window, having conductive stand-by losses of 1 BTU/per hour per sq. ft. per deg. F, into a system which cuts these losses by 80% or more and yet, maintains a sizable fraction of the direct gain that is present.

Our work with Foamglas® suggests that increasing emphasis should be paid to such products in low energy architecture, not for their potential to increase physical performance (efficiency, etc.) but rather, for their potential to be cost effective.

ACKNOWLEDGEMENT

The author acknowledges Mr. Paul Curry, B.S. for the construction of the test Foamglas® collector in connection with his senior thesis in the Department of Engineering-Physics-Systems at Providence College. Dr. Mark N. Rerick, Professor and Chairman of the Chemistry Department at Providence College, who has provided many of the original ideas for passive applications of Foamglas®, is gratefully acknowledged.

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PERFORMANCES AND COMPUTER SIMULATION OF AN HYBRID WATER COLLECTOR SYSTEM PUSHED ON BY SOLAR PUMP

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ABSTRACT

The LESO building is a passive solar laboratory designed for simultaneous testing of up to 9 different passive or hybrid experimental energy collecting devices. Among them, an hybrid watertype collector system is carefully instrumented and monitored since March 1982.

Composed of 6 double glazed flat plate collectors, the solar circuit of the system is activated by a solar water pump, supplied by solar cells. Thanks to the dependence of water flow rate against solar radiation, a "natural regulation" of the system is realised. By this simple design, improvement of efficiency of the overall device is obtained, compared to passive thermosiphon or active "plugged-in pump units.

A dynamic simulation model, developed for purpose of predicting thermal behaviour of the hybrid system under two operating modes (DHW production and domestic solar heating) is presented here. Computer simulation as well as monitoring results are exposed in this paper.Efficiencies improvement due to better optimisation of water flow rate regulation for such an hybrid system is shown, by means of computer code.

KEYWORDS

Hybrid system; regulation; solar pump; heating; hot water preparation; system efficiency.

INTRODUCTION

Flat plate water collectors are certainly the most common and expanded solar energy collecting systems used around the world.

Due to the stochastic nature of solar radiation, various controlling strategies of the water flow inside the collectors have been developed. Among them, thermal differential regulations based on alternate switching between zero and maximum flow rate are the most important {1-3} . In spite of its development, problems always exist as regards to the pratical setting-up of this "controlled driving" (difficult optimisation of Δt value, location of the probes difficult to choose, ...).

Thanks to the low thermal inertia of a water type collecting system,solar radiation can be directly used for purpose of solar system's control. Use of a DC water pump, supplied by an adequate photovoltaïc panel is the simplest way to realize this "natural regulation".

Such an hybrid solar energy collecting device has been developed and implemented on the solar energy laboratory LESO {4} . Using the LESO facilities, the system has been monitored since March 1982, allowing its study during both summer period (DHW production) and heating season period (domestic solar heating).

For purpose of obtaining a more complete analysis of the system (sensivity and parametric studies), a computer model of the two operating modes has been written. Thanks to the computer code improvement of collector efficiency due to the "natural regulation"is demonstrated.

1. CHARACTERISTICS OF THE HYBRID SYSTEM

The system is composed of 8.5 m^2 of double glazed flat plate water collectors (2 rows of 3 serial collectors; ηo=o.74 , Ko=3.5 W/m^2K)setted out under the 8.7 m^2 direct gain southern windows of the cell. Inclination of the collector is 70^o relative to horizontal plane.

Two 33W-peak power photovoltaïc panels, at same inclination angle, are used to supply the 30W DC water pump activating the entire system.

By means of a 3 ways valve, collectors can be coupled to a 360 liters water storage for purpose of DHW production (summer operating mode).

During the heating season, solar heat is supplied to a couple of 300 liters heating radiators designed for heating of the 50 m^3 cell (heating season operating mode).

A strong correlation between solar insolation and water flow rate has been established (see fig. 2 and fig. 3).

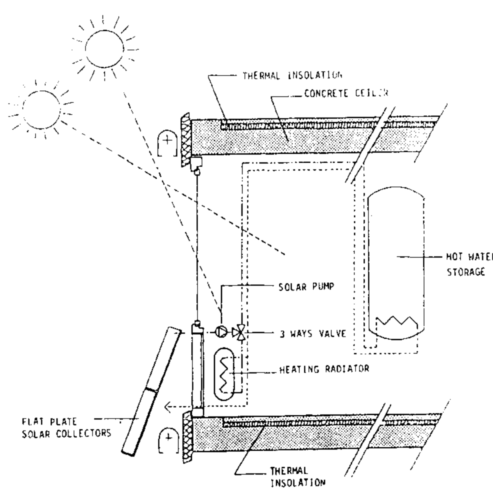

Fig. 1: Hybrid solar energy collecting device.

Thanks to a really simple threshold regulation, running of the pump is avoided when the south vertical radiation is less than 150W/m^2. Response of the system to radiation solicitations is very rapid (typical less then 10 seconds) and maximum flow rate, reached for 700 W/m^2 south vertical radiation, is close to 6.0.10^{-5} m^3/s (216 liters/hour).

By means of an automated data acquisition unit, monitoring of the system is made, using a 1 minute integration interval and a 30 minute recording cycle step.

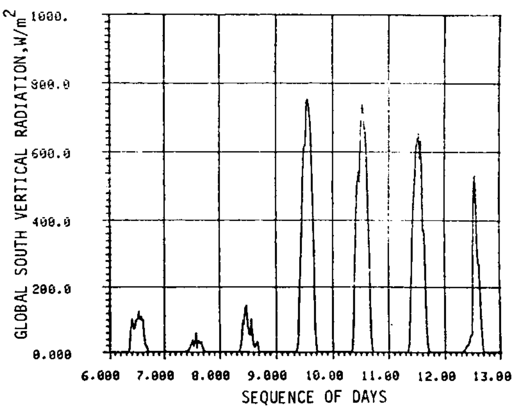

Fig. 2 : Global south vertical solar radiation
(Period from the 6th to 12th January 1983)

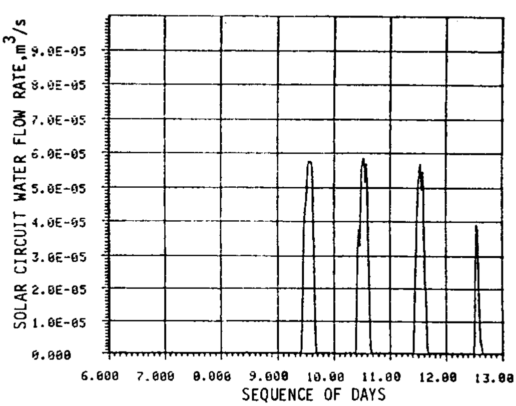

Fig. 3 : Water flow rate in the solar circuit, during the same period

2. COMPUTER MODEL OF THE SYSTEM

2.1 Water collector equations.

The model used in this computer dynamic simulation is similar to those proposed by Whillier {8} . Dynamic thermal balance of a collector can be described by relation (1):

$$McCp^{c}dTc/dt = (\eta o G_{c} - Ko(Tin - Text))\ Ac - Qc\rho Cp^{w}(Tin - Tout) \qquad (1)$$

Where Tc is the absorber plate temperature (K)
Tin, Tout are the inlet and outlet collector temperature resp.
Text, the ambient air temperature (K)
ηo, Ko, the optical factor and the overall losses coefficient (W/m^2K)
Ac, the net collector surface (m^2)
C_p^c, Cp^w, the specific heat capacity of collectors and water resp.
ρ, Qc, the water density (Kg/m^3) and flow rate through collectors (m^3/s)
G_c, the solar global radiation impinging the collector (W/m^2)

For purpose of reducing (1) to a single variable linear differential equation, depending on Tin, one assumes equations (2) and (3):

$$dTc/dt = dTin/dt + dTout/dt \qquad (2)$$
$$dTout/dt \approx \beta dTin/dt \qquad (3)$$

(real factor β is fitted thanks to the validation)

Assuming that stationary approximation for purpose of defining a relation Tout = f(Tin) is available, one writes relation (4) {1} :

$$Tout = (Text + (\eta o/Ko)G_c) + (Tin - Text - (\eta o/Ko)G_c) \cdot \exp\left(\frac{-KoF'L'L}{\rho QcCp^w F_R}\right) \qquad (4)$$

With L'L as characteristic lengths of the collector (m)
F_R, the heat removal factor of the collector {1}
F' ,the collector efficiency factor {1} evaluated by (5)

$$F' = \frac{-Qc\rho Cp^w F_R}{AcKo} \, Ln\left(1 - \frac{AcKo}{Qc\rho Cp^w}\right) \qquad (5)$$

Using expressions (2) to (5), numerical solution of equation (1) can be found, and inlet collector temperature calculated by means of a Runge-Kutta algorithm and an optimisation of factor β during validation of the code.

Outlet temperature Tout of a collector can be calculated using stationary approximation of the collector energy balance, expressed by relation (6):

$$Qc\rho Cp^w(Tout - Tin) = \eta oG_c - Ko(Tin - Text)\, A_c \qquad (6)$$

Strong correlation from water flow rate against solar radiation can be used to define a relation between these two variables. Fig. 4 shows this logarithmic type dependence (mean correlation factor : 0.97)

Equations (7) and (8) express this fact by mathematical relation, allowing use of measured data like horizontal (Gglob hor.) and south vertical global radiations (Gglob sud).

For period from April to Sept. : $Qc(m^3/s) = -1.1.1o^{-4} + 2.1.1o^{-5} Log(Gglobhor)$ (7)

For period from Oct. to March : $Qc(m^3/s) = -3.1.1o^{-4} + 5.6.1o^{-5} Log(Gglobhor)$ (8)

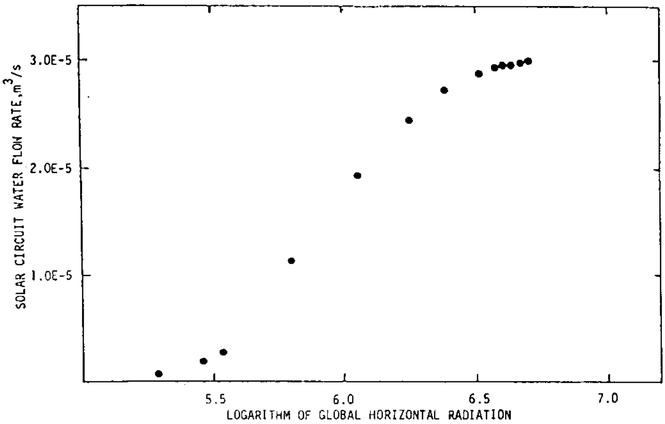

Fig. 4. Logarithmic correlation between solar circuit flow rate and global horizontal radiation (period from October to March).
Accuracy: flow rate ~ 1%, solar radiation ~ 5%.

When the pump is running (Qc ≠ o), coupling of the collector is assumed, equaling outlet and inlet temperatures of two adjacent collectors.

Figure 5 illustrate the simulation's results; measured and simulated values of inlet first collector temperature are represented.

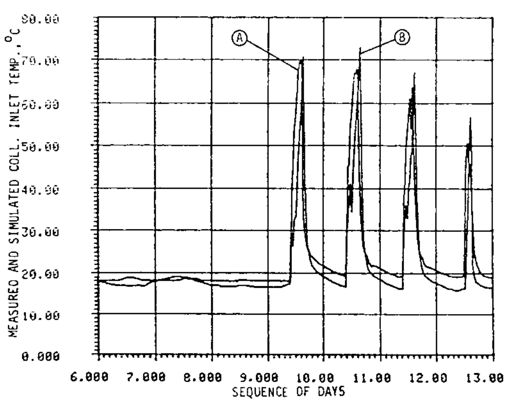

Fig. 5. Measured (A) and simulated (B) inlet first collector temperature.

Validation of the model using the 6th to 13th January 1983 period, reported accuracy better than 5% on the simulated overall collectors energy output {7}

2.2 Water storage and heating radiators equations.

Dynamic model used to describe the thermal behaviour of water storages

(DHW production) and heating radiators (heating season), is a wellknown multilayer model as defined by Close in his first paper.{5}

Originality of our model is its ability to describe heat exchanger's effects on the waterbody, accounting for the waterthermal stratification. Precise description of the water store model is presented in another paper {6} , and will not be discussed here.

Figure 6 shows the stratification effects in the solar heating radiators as issued from simulation. Such a result is also dearly described for DHW storage simulation (see ref. {6})

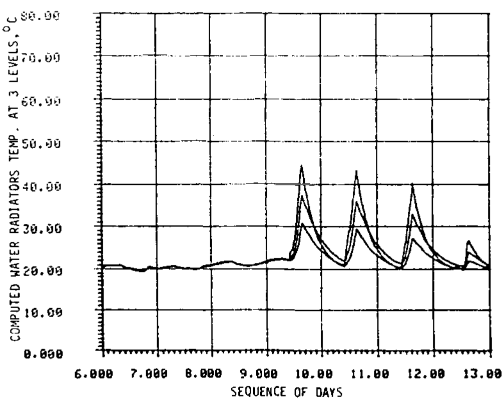

Fig. 6. Simulated water stratification in the solar heating radiators. Temperatures calculated at 3 different levels.

3. COMPUTER SIMULATION RESULTS

First runs of the computer code have been used for purpose of studying the DHW production thermal performances.

Meteorological data measured in Ecublens (latitude 46.5°, altitude 410 m) during year 1980, have been used for this purpose. DHW demand corresponding to a 6 persons family (300 liters DHW/day) have been simulated. Statistical behaviour of such a standard load have been introduced, accounting for a practical use of the DHW production (50% of DHW demand at 7 AM, 20% at 12 AM and 30% at 7 PM) (see fig. 7).

Thermal efficiency of collectors obtained by means of simulation during these months are reported on table I. Same calculations made for a differential regulation are also represented on same table.

Efficiency improvement obtained by means of a "solar drived" regulation is close to 2.5%. For comparison same modification on efficiency is obtained by using double glazed flat plate collectors instead of single glazed, as issued from simulation (computed value of improvement is 3%).

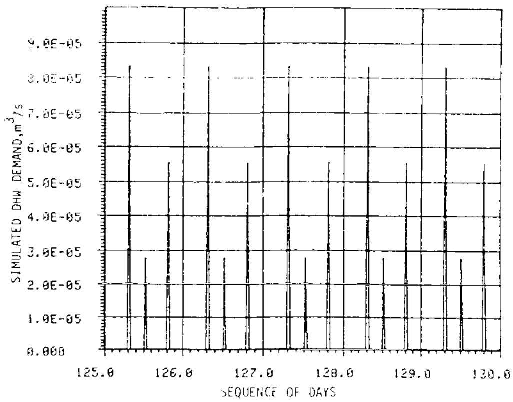

Fig. 7. Standard DHW demand assumed for simulation, represented for 5 days in May. (6 persons family demand assumed)

TABLE I Computed thermal efficiencies of collectors for differential and "natural" regulations.

Months	"Natural" regulation	Differential regulation
April	34.5%	31.3%
May	38.5%	34.3%
June	36.1%	33.4%
July	36.6%	36.5%
August	41.1%	39.4%
September	56.6%	38.8%
Mean efficiency value for the 6 months period	38.1%	35.6%

4. CONCLUSION

The hybrid water collector system presented in this paper, is the simplest device designed to improve regulation solar circuit flow on a water type collecting device.

Functioning of the system at LESO Laboratory, has proved its real efficient working in practical conditions of use (no fine optimisation of the regulation has been necessary).

The dynamic computer model of the two system's operating mode (DHW production and solar heating) has shown to allow an accurate evaluation of device's efficiency by means of simulation. Use of this code demonstrates an improvement of 2.5% on mean collectors efficiency compared to a differential regulation of the solar panels and evaluated for a 6 months period of DHW production.

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SOLAR MOTOR FOR DEVELOPING COUNTRIES

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ABSTRACT

The paper describes how a solar powered motor can be constructed at a cost affordable commercially in a developing country. The motor operates on the solar thermal principle because such a motor can be constructed by local labour in locally available materials. In this way the cost is minimised and foreign exchange problems do not arise. Flat plate solar collectors using freon 12 as a working fluid have been constructed and tested and have good efficiency. They operate using technology borrowed from the refrigeration industry. A cheap expander based on a gear motor has also been tested and works well. It remains to test a suitable array of collectors with the expander. This experiment is based on sound thermodynamic principles and is expected to be successful.

KEYWORDS

Affordable cost; minimal foreign exchange; local manufacture; solar thermal; refrigeration technology; long life; available maintenance skills.

INTRODUCTION

Solar energy research has been carried out for the past six years at Fourah Bay College. The research described in this paper is on the development of a solar motor for use in Sierra Leone for such purposes as irrigation, generating electricity and driving machinery. In the application be be described the solar motor will drive an irrigation pump capable of watering an acre of land.

The unit has fourteen solar collectors each of area 1.8 m^2. The working fluid of the system is freon 12 and drives a small totally enclosed motor generator set. The motor is a cheap gear motor expander which drives both the generator and a small circulating pump. The collector tubing is of small bore so that the freon circulates at sufficient speed to carry round the lubricating oil, in a similar manner to normal refrigerator practice.

The solar motor is in fact very similar to a refrigerator working in reverse, and the technology is therefore well established. Since commercial refrigerator plants are known to have a life in excess of fifteen years, it is expected that the solar motor will have a similar life. There are refrigerator plants in Sierra Leone which have given no trouble in twentyfive years, maintained by local labour. Diesel and petrol engines used for small generator sets are known to have a life of less than seven years, probably because they are made as cheaply as possible. Similarly photo voltaic pumps are unreliable. In a recent trial in Pakistan 70% of the PV pumps failed in under a year, though the makers claim a seven year life. Unreliability of this magnitude could not be tolerated in commercial usage.

A cost benefit analysis of a solar motor and a diesel motor working under the conditions that prevail in a small and poor country such as Sierra Leone. The solar motor is shown to be more cost effective under these conditions, even if the fuel was available which is a big "if" in such a country.

There is little doubt that there is a great cost advantage in manufacturing as much as possible in a very poor country. This is because of the problems of foreign exchange and the difficulty of obtaining permission to buy abroad, and obtaining credit facilities. Photo voltaic technology is unlikely to be endogenous for at least the next decade, and it is significant that no photo voltaic systems are available in Sierra Leone.

The cost of building a solar thermal motor locally runs out at about US Dollars 2000, which is considered an acceptable price for commercial use especially if government credit facilities are available to buy the solar irrigation units, as they are for the purchase of seed.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to the University of Sierra Leone for their active encouragement and financial assistance. Also the support of the Ministry of Agriculture is greatly appreciated.

WHERE THE SUN IS: A Brief Review of Solar Geometry for Architectural Designers

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The following discussion and illustrations of sun-angle geometry provide a brief overview and reference for architectural students and practitioners involved with sun-shading design. The basics of solar geometry should be well understood by architects worldwide so that the sun is used in every building to augment human comfort and to reduce energy cost. Indeed, to know "where the sun is" could be considered one of the elemental tasks of architectural design analysis.

1 - THE EARTH VIEWED FROM THE SUN

The earth's position, tilted with respect to its orbital plane around the sun, provides the geometric basis for the annual variation in solar energy received on the earth's surface (Fig. 1). The earth's polar axis is tilted 23°27' (assume

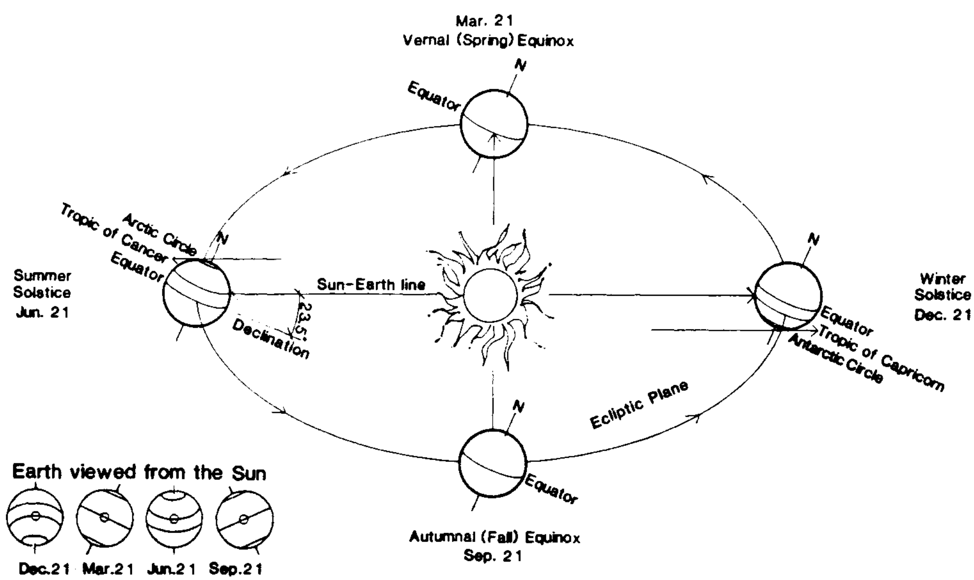


Figure 1: Sun-Earth Geometry

23.5° for practical purposes) with respect to the plane of the earth's orbit around the sun. This plane, geometrically described by the Sun-Earth line, is called by astronomers the solar "ecliptic." It is useful to visualize the Sun-Earth line as a cluster of parallel light beams. On two days of the year, March 21 and September 21 (Spring and Fall Equinox), the sun's light beams are parallel to the earth's equitorial plane. From the earth's point of view on these two dates, the sun rises and sets due east and west, respectively. From the sun's position, an observer would see the earth's tilt at 23.5° with respect to the ecliptic. The angle measured at any point on the earth's surface between the sun-earth line and the plane defined by the earth's equator is the "solar declimation". Because the two are parallel at the Spring and Fall Equinox, the declination angle is 0° on these two dates. The declination angle varies between +23.5° on June 21 and -23.5° on December 21.

To understand sun angles for purposes of building design, the earth's orbit can be considered circular with the sun at its center. In fact, the orbit is an eclipsewith the sun off-center, with resulting changes in orbital speed, slowing as the earth moves closer to the sun and accelerating as it moves away. The eccentricity and obliquity of the earth's orbit result in differences between Solar Time, measured by the sun's position in the sky, and Mean Time, measured by our clocks running at constant speed. The Equation of Time is a formula by which to correct the discrepancies between Solar Time and Mean Time (Reference 1).

2 - THE SUN VIEWED FROM THE EARTH

To an observer on earth, the sun appears to revolve around the earth once a day. If this daily path could be observed for twenty-four hours, (through a "transparent" earth), the sun's rays (the Sun-Earth line) would describe a solar ray cone drawn between Sun and Earth (Reference 2). The shape of the cone varies each day according to the sun's declination (Fig. 2). (Coincident with the ecliptic, the solar ray "cone" would in fact be a flat plane on the equinox dates).

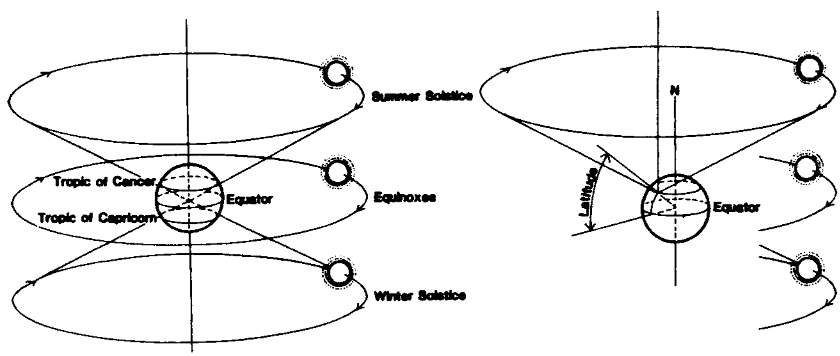


Figure 2: **Solar Ray Cones generated by the Sun-Earth Lines.**

If, as did our ancestors before the time of Copernicus (1543 AD), one imagines a "celestial dome" overhead with the observer on earth at the center, the sun's apparent path would be traced on the dome as it "intersects" the solar ray cones (Reference 3). Fig. 3 illustrates how the sun's daytime positions can be marked upon an imaginary dome with the observer's eye at its center. The ecliptic plane can now be perceived as coincident with the flat plane of the sun's rays on the Equinox dates.

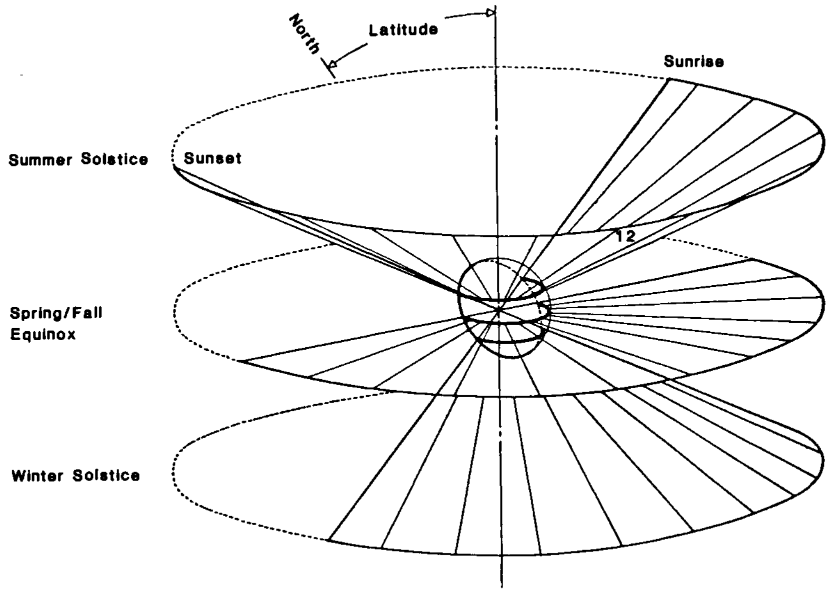


Figure 3: Dome with Sun-Paths generated by solar ray cones (after Knowles)

The Sun Dome. A "model" of the celestial dome, which can be constructed as shown in Fig. 4, provides a simple aid by which to make solar angles clear with respect to a horizontal observation plane.

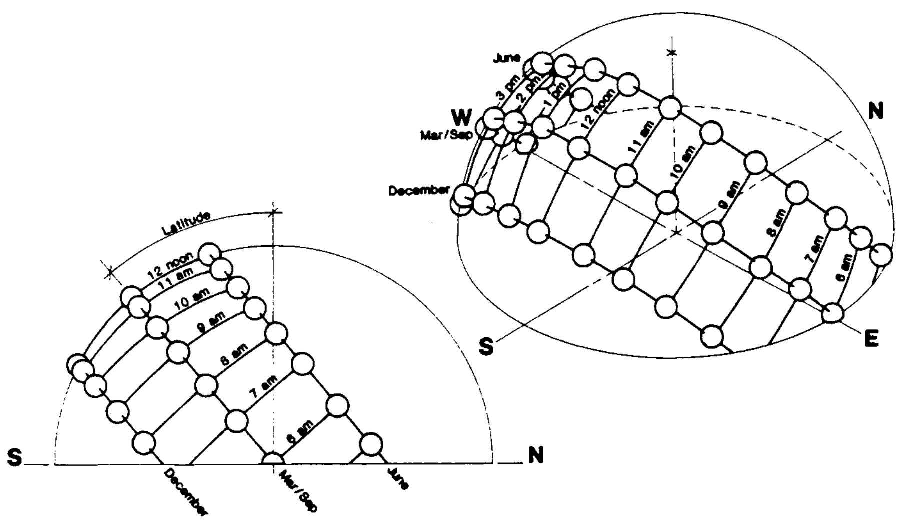
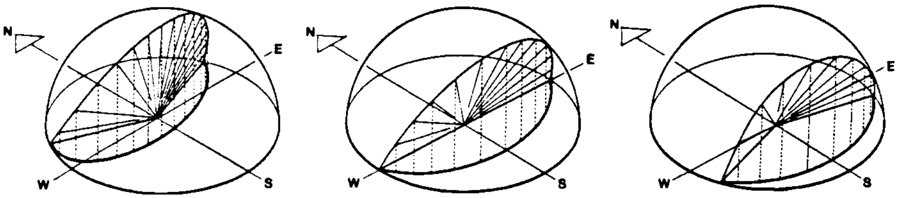


Figure 4: The Sun-Dome transcribed with sun paths

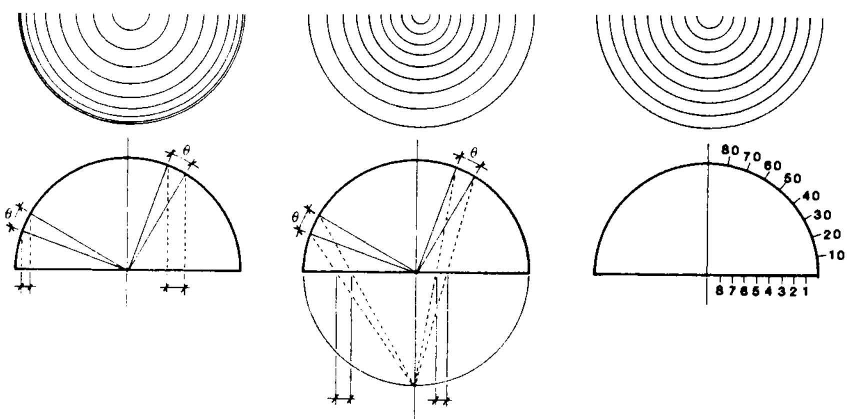


Summer Solstice Spring/Fall Equinox Winter Solstice

Figure 5: Orthographic Projection of Sun-Paths (after Knowles)

Sun-Path Diagrams. As illustrated in Fig. 5, modeling the solar rays with the sun dome helps one to visualize the various projection methods commonly used to record sun-path diagrams. If one projects the points from the hemispherical surface of the dome onto the horizontal observation plane, the east-west sun paths appear as arcs with equal segments indicating sunlight hours. An "orthographic" projection as illustrated in Fig. 5 presents difficulties for use as a sun-path diagram in recording solar positions which are too close to one another near the horizon (Fig. 6a). A correction is offered by the "stereographic" projection method which extends the points closer to the center of the horizontal chart by establishing a focal point below the horizon plane at a distance equal to the height, or radius, of the hemisphere (Fig. 6b). While this is adopted in some texts (such as Reference 11), the most common method is to record solar altitude along "equidistant" circles on the horizontal plane (Fig. 6c). This graphic method is used in the Sun-Path diagrams in Graphic Standards (Reference 10) and for the Libby-Owens-Ford Company (LOF) Sun Angle Calculator (Reference 9).

Another commonly used sun-path diagram is a vertical "cylindrical" graph (Fig. 7 and Reference 6). Perhaps the one advantage of the cylindrical projection method is that sun-path diagrams approximate (though not exactly) the elevation view of the horizon that one "sees" from the observation point. Both types of sun-path diagrams can be used for sunshading analysis.



(a) Orthographic Projection (b) Stereographic Projection (c) Equidistant Projection

Figure 6: Various Projection Methods for Sun-Path Diagrams (after Knowles)

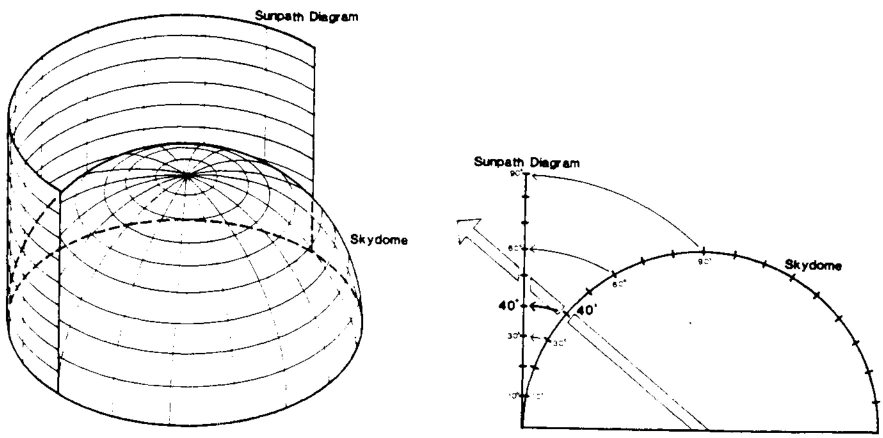


Figure 7: Cylindrical Projection Method (after Mazria)
Note: the vertical sun-path graph cannot be used as a "window" for site shading analysis (Actual sight-line shown by arrow).

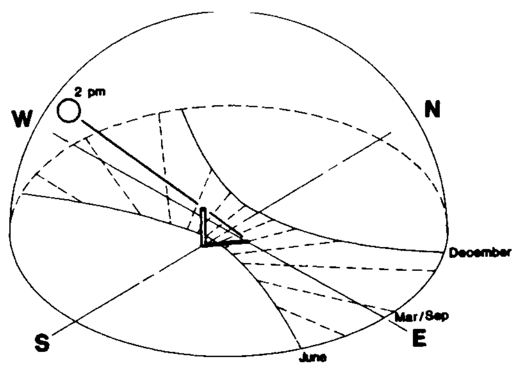
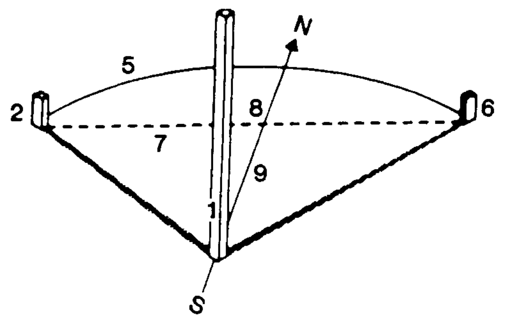


Figure 8: : **Sun Dial in relation to solar positions on the Sun Dome**

3 - SHADOWS CAST ON THE HORIZONTAL PLANE

Solar rays have been described above as imaginary lines between the sun and an observation point on the earth. If a point or staff is used as a gnomon to cast a shadow on the horizontal, another method of recording the sun's path is created in the form of a sun dial (Fig. 8). Reference 7 provides a set of gnomic sun-path projections for all latitudes (at 2° intervals), as well as a "universal" sun dial which is needed for sun-shading and daylight model studies, a copy of which is appended to this paper.

On the equinox dates, shadows trace a line directly east-west. On these two dates of the year, the sun's rays coincide with the ecliptic plane: the sun's altitude measured with respect to true south (the "profile angle" of a south-facing surface) is the same at all times from sunrise to sunset and is equal to (90° - Latitude). On other dates of the year, the morning-to-night shadow follows a curved arc (an inversion of the solar ray cone). From inspection of the sun dial, one can also understand the geometric basis of the method used since the time of Vitruvius to determine "true" south (Fig. 9). The shadowing effects on the horizontal plane are easily calibrated when the sun is high and shadows close to the gnomon. However, as can be seen in Fig. 8, early morning and late afternoon shadows are literally "off the page." For this reason, many sun dials are folded or curved in order to indicate all hours from sunrise to sunset (Reference 8).



1. *Drive the five-foot-long staff into the ground in an open area.*
2. *In the morning, scratch a mark at the end of the staff's shadow and place a wooden stake at this point.*
3. *Tie a string loosely to the staff.*
4. *Stretch a string to this stake, and at this point, attach the string to a pointed stick.*
5. *Draw an arc on the ground with the pointed stick from this stake to the other side of the staff.*
6. *Place another stake where the late afternoon shadow touches the arc.*
7. *Draw a straight line between these two stakes.*
8. *Find the halfway point along this line, then draw a line from this point to the staff.*
9. *This meridian line indicates a true north-south line.*

Figure 9: Finding True North-South

4 - SHADOWS CAST ON VERTICAL SURFACES

There are mathematical equations for deriving solar angles to predict and analyze the effects of sun control designs (Reference 9). The discussion here, however, is based on graphic methods which are more directly related to the way that designers visualize a building, for which the following terms are useful (Fig. 10):

solar altitude β, measured from 0° to 90° from the horizontal plane along the Sun-Earth sight line of an observer directly facing the sun.

solar azimuth ϕ, or bearing angle measured in plan. (Although some texts on solar angle calculation measure azimuth with respect to true south where azimuth = 0°, the convention that conforms to navigational observation is to measure true north at 0° and to read clockwise around the entire 360° compass, so that south equals 180°).

profile angle **P**, is the angle of the sun when viewed "in profile" to a wall, when the horizontal leg of the angle is perpendicular to the vertical building surface. It is the height of the sun when constructed with reference to the cross-section of a building wall or window (Fig. 10b)

incidence angle **i**, also a function of a specific wall or orientation with respect to the Sun-Earth line, is the angle of the sun's ray striking a plane, measured by reference to a line perpendicular to the plane (Fig. 10c). The incident angle is not needed for shadow construction, but is used in representing the amount of insolation received by a building surface.

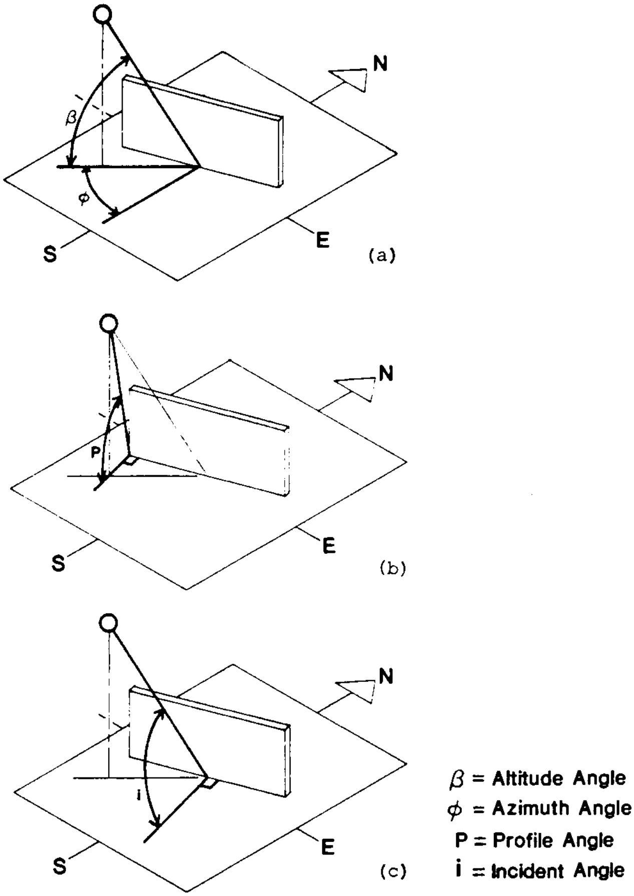


Figure 10: Solar Angles with respect to Walls and Tilted Surfaces

While other solar angle measurements are used for solar calculations, only the altitude, azimuth, and profile angle measurements are needed for two-dimensional shadow construction on building plans and elevations. Reference 10 provides a graphic method by which to draw shadows for a specific orientation, latitude, time of day, and date. As an alternate to graphic construction, the profile angle value can be found with the LOF Sun Angle Calculator. Either method for deriving the profile angle eliminates longhand calculation. The Shading Masks described in Reference 2 (for horizontal sun charts) and in Reference 6 (for vertical sun charts) also provide shortcut calculation procedures.

It should be noted that these methods indicate how to shade a building or a window wall, but not when to shade. In temperate climates with combined heating and cooling requirements and in buildings in any climate with combined cooling and daylighting requirements, calculation of optimum shading fraction is judgmental, as a function of occupancy, local energy costs and "overheating" controls such as ventilation and thermal mass. (References 11 through 13).

5 - HELIODONS

Another method of determining shading effects and perhaps the only accurate method for complicated shapes is to use physical modeling, in which case a shading design is built and analyzed with a heliodon. A heliodon is simply a "simulated" sun light and a model base, either one of which is moved to approximate the sun's position. The sun itself can be used in outdoor model tests with a tilt-table. Indoor light sources need special lenses to provide near-parallel light rays. Heliodon types can be characterized as follows, depending upon whether the light source ("the sun") is moved, or the model base ("the earth"), or both:

moving earth-fixed sun: The model base is moved or tilted. The light source is fixed. The light source can be artificial. This type also describes a tilt-table used outdoors in the sunshine.

moving earth-moving sun: A combination of tilted base and movable light source.

fixed earth-moving sun: The model base is fixed in the horizontal position; the artificial light source is moved along the daily sun paths.

Moving Earth-Fixed Sun Heliodons. With reference to a fixed light source, a tilt-table is adjusted to a fixed position for the seasonal solar declination angle and for the latitude (Fig. 11). With these positions fixed, the table top is then rotated on its "polar" axis to follow the time of day. (Construction details for these and the other heliodon types are given in Reference 13). A tilt-table that can be used with a fixed sun, either with an artificial lamp indoors or with the sun out-of-doors, is also useful in testing daylighting models.

Moving Earth-Moving Sun Heliodons. To establish the proper angle for each day, fixed-sun heliodons require two angle adjustments, one for solar declination (or season of the year) and another for latitude. A common variation is to move an artificial light source on a vertical staff as in Fig. 12 to adjust for declination, with the result that the tilt table requires only one angular adjustment for each daily setting. The tilt-table is still rotated about its "polar axis" to follow the hourly rotation of the earth. This type of heliodon is the simplest to construct and can be easily set up in any architectural office. One disadvantage is the difficulty of achieving parallel light, since the light source is located relatively close to the model table.

Fixed Earth-Movable Sun Heliodons. The disadvantage of "moving earth" or tilt-table heliodons relates to the process of design study and modeling. It is desirable that the designer visualize sun motion as it affects the building design, and further, that design changes be easy to make on the model while working with the heliodon. The "fixed earth-moving sun" heliodons meet this goal, making visualization of sun shadows extremely easy since the light source moves about the building model just as it would appear in reality. "Fixed earth-moving sun" heliodons thus provide the most effective sun simulator type for educational needs and for design research.

Figs. 13 and 14 show two variations of the fixed earth-moving sun heliodons (others are depicted in Reference 2). Fig. 13 is a design developed by Professor Ralph Knowles, at the University of Southern California. The sun moves along its daily arc automatically at controllable speeds. As the "sun" moves at an even rate of speed, the "speed" of shadows is easily perceived relative to the angle of incidence (Reference 3). Fig. 14 is a design developed by Sandra Olenik with Professors William Van Altena and Donald Watson at Yale University. It is a demountable and transportable version of the fixed earth-moving sun heliodon, with the sun sweep operated manually.

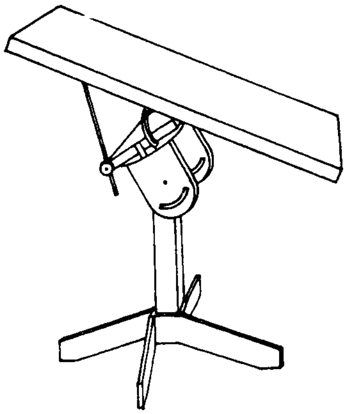


Figure 11: Moving Earth-Fixed Sun Heliodon (after Benton)

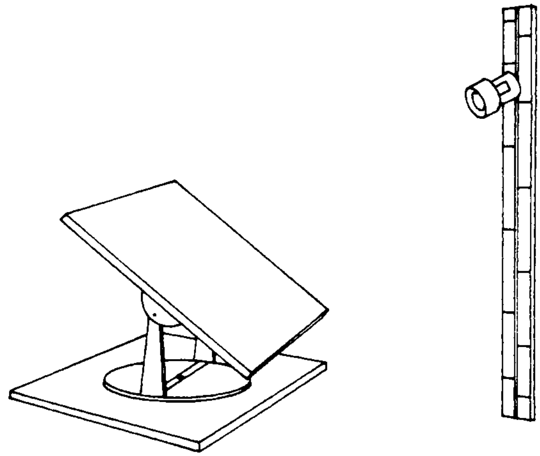


Figure 12: Moving Earth-Moving Sun Heliodon (after Dufton and Beckett)

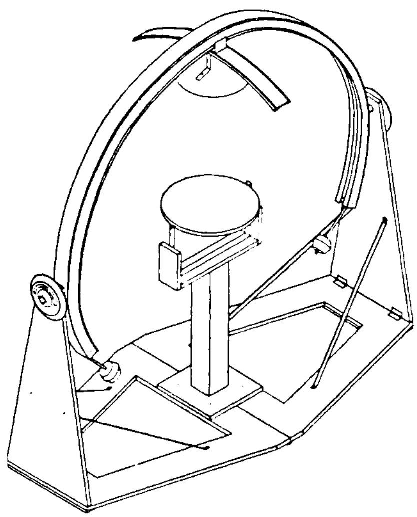


Figure 13: Fixed Earth-Moving Sun Heliodon (University of Southern Calif.)

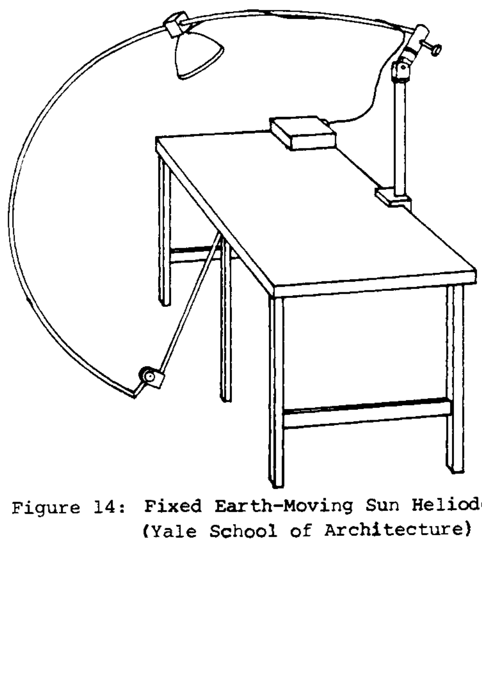


Figure 14: Fixed Earth-Moving Sun Heliodon (Yale School of Architecture)

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*Acknowledgement

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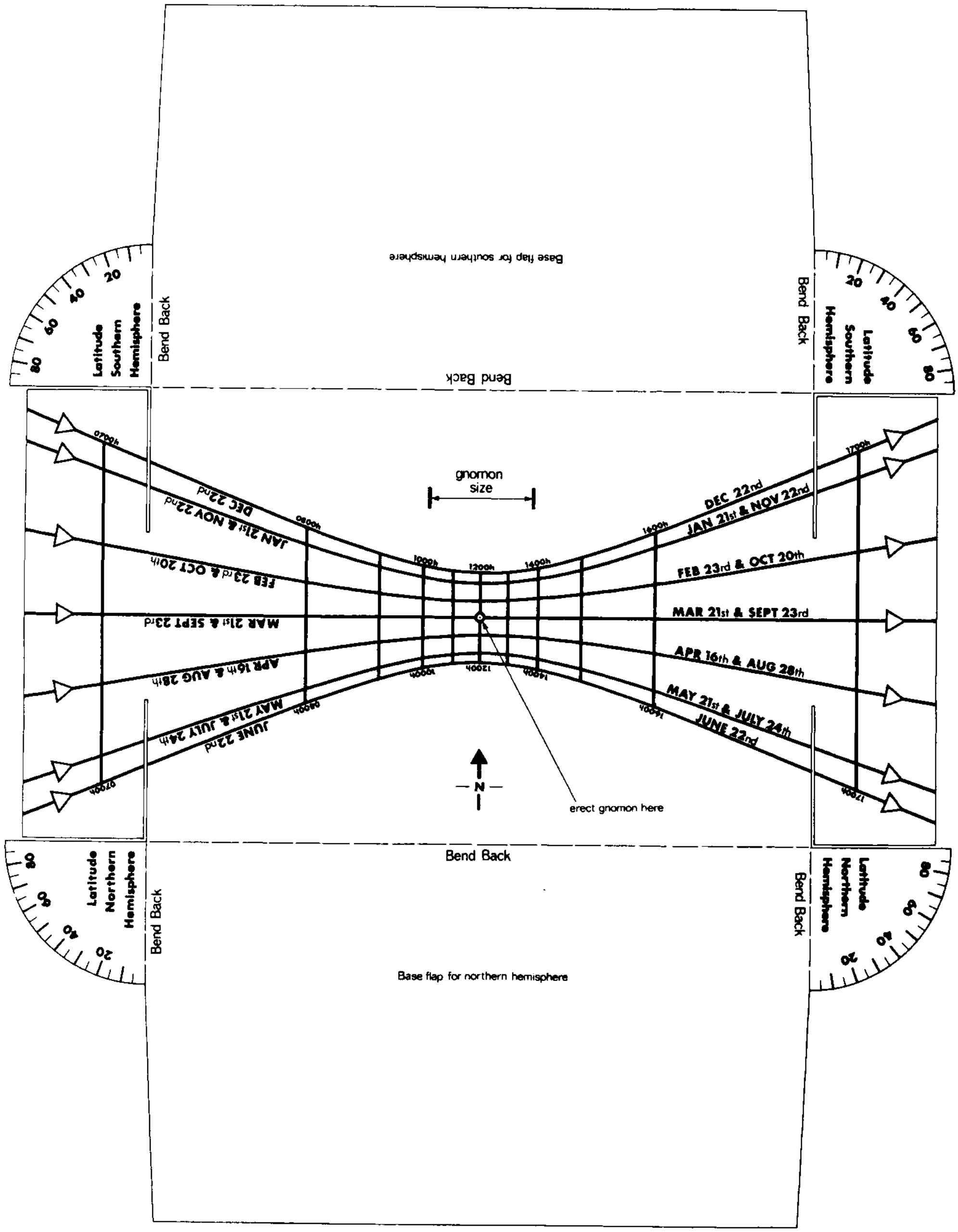

APPENDED FIGURE: Universal Gnomic Projection Sun Dial (courtesy Pilkington Indust.)

MODIFYING THE SUN AND WIND TO CREATE FAVORABLE MICROCLIMATES

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ABSTRACT

This paper describes a method for evaluating microclimates formed in the exterior spaces adjacent to buildings in terms of human comfort. An analysis of a free-standing cube in three U.S. climate zones is presented and applications to larger scale projects are discussed.

KEYWORDS

Microclimate, climate analysis, comfort, climate, sun, wind.

INTRODUCTION

Exterior spaces -- streets, plazas, parks and yards, constitute 30-70% of a city's ground level, and form important meeting and work places. Using natural energy to produce thermal comfort extends the usefulness of these spaces, decreasing the pressure to build enclosed space to accommodate all activities at all times of the day and year. Designing for sun and wind access results in the need for less built area per inhabitant and therefore less non-renewable energy consumption. An energy-conscious city provides the most livable area for the least energy cost. While many older cities in Europe and the Mediterranean region were designed with principles related to outdoor thermal comfort, most modern designers have lost that intuition and need specific guidelines for making outdoor spaces comfortable and therefore useable.

Our work is predicated on the "Modified Comfort Zone", or MCZ, a range of temperature and humidity in which comfort is achievable with the appropriate moderation of the sun and wind. An outdoor space can be comfortable in chilly weather if the wind is blocked and the sun is available for warming, or in hot weather if the sun is blocked and the wind is available for cooling. Our computer analysis of three U. S. locations has demonstrated that the number of potentially comfortable hours in a year can be anywhere from 24% (Madison, Wisconsin) to 50% (Charleston, South Carolina). Using a conventional definition of the Standard Comfort Zone, or SCZ, these percentages would be 6% and 16% respectively.

In this paper, we concentrate on outdoor spaces at the residential scale. The generalized model we use a cube-shaped, free-standing, single-family dwelling. The surrounding areas are analyzed by how often they perform well thermally. For each hour in the year which falls within the MCZ, each space around the dwelling is evaluated according to whether it a) admits the sun and blocks the wind, when it is chilly (MLO), or b) blocks the sun and admits the wind when it is warm (MHI). All blocking and admitting are a function of the actual patterns of the wind and sun around the cube, as determined by wind tunnel studies and conventional sun angle calculations.

The result of the analysis is a "contour map" of the cube's surround, indicating effective performance. A designer can use this information in determining the appropriate location for various outdoor functions. Similar monthly evaluations are also available, so that seasonally variable functions can also be located appropriately.

METHODOLOGY

Although the importance of building form and spacing in the determination of microclimates has been discussed by several authors (Robinette, Chandler, and Miess), their work does not include specific design recommendations based on human comfort. However, specific relationships between climate elements architecture, and human comfort have been studied by Olgyay, Fanger, Arens, and Brown and Novitski. Separately, the effect of building form on sun penetration (Knowles) and wind speed (Beranek and van Koten, Gandemer, and Cermak) has been determined for some building configurations. Our work builds on these studies and investigates the combined impact of building form and climate on the comfort of exterior spaces adjacent to the building.

We define the Standard Comfort Zone, or SCZ, as that temperature range (varying with humidity) in which comfort results from the balanced interaction of the sun and wind. The cold code C is broken into three levels of insolation to indicate which solar gain heating systems may be appropriate. The hot code H is broken into three levels of relative humidity to indicate which passive cooling systems may be appropriate.

We have developed methods for presenting information at several levels of generality corresponding to levels of detail encountered in the design process.

The primary concept in our description of climate is the pattern. A pattern is a sequence of climatic events (and their associated architectural responses) that occur in a 24-hour period. For example, a typical spring pattern is C-MLO-SCZ-MHI-SCZ-MLO-C. The interpretation of this pattern is: Cold at night; warming in the morning to the point where comfort is possible if the wind is blocked and the sun is admitted; warming more around midday to where the sun and wind are in a comfortable balance; heating up in the afternoon to the point where comfort is possible if the wind is admitted and the sun is shaded; and then back down again in a more/less symmetrical fashion. (The major deviation from true symmetry results when the afternoon MLO is skipped because the sun has gone down and is unavailable to balance the dropping temperature.)

This rise and fall in the pattern sequence is reminiscent of a simple temperature curve for the same day; but it is much more informative because it suggests architectural solutions at the same time as it describes the climate.

THREE CLIMATES

Madison, Wisconsin is an example of a cold climate. See Fig. 1. From November through March, enclosure against the cold is required all day, with few exceptions. For the rest of the year, however, some degree of non-enclosure is possible, most days. There are brief summer periods when temperatures are in the Modified Comfort

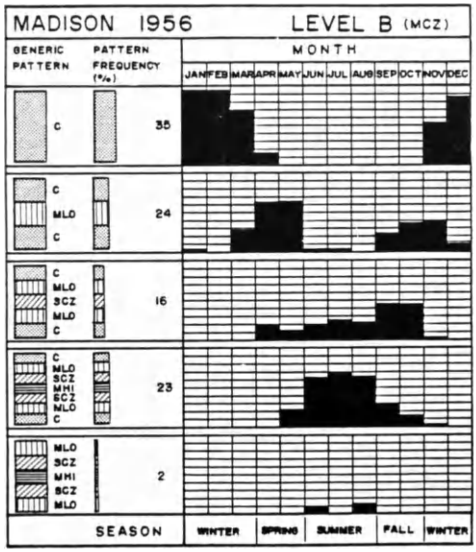

Fig. 1 Madison, Wisconsin

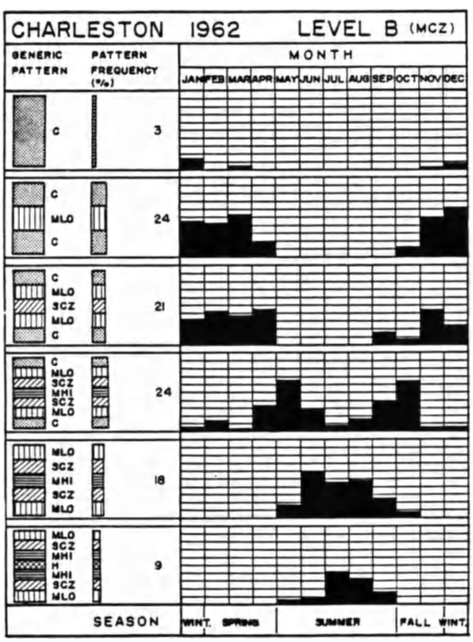

Fig. 2 Charleston, South Carolina

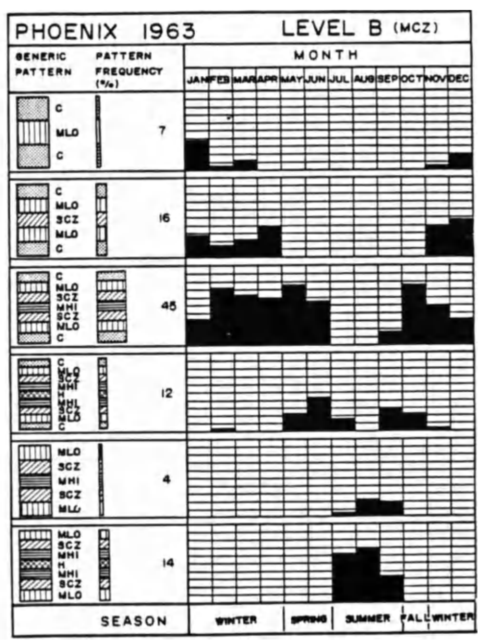

Fig. 3 Phoenix, Arizona

Zone all day and night. More typically, summer MCZ (June - August) occurs 7am - 7 pm. Spring (April - May) and Fall (September - October) MCZ happens primarily 11am - 3pm. This suggests the feasibility of day use outside spaces in the summer and, to a more limited extent, in the spring and fall.

There is very little opportunity for non-enclosure in the winter.

The architectural response which governs the design of these non-enclosure spaces is "block wind - admit sun" in the spring and fall and "admit wind - block sun" in the summer. There is also a substantial number of times, in April - October when the peak of the day exhibits the Standard Comfort Zone, or SCZ, with no architectural response required.

Charleston, South Carolina is an example of a hot-humid climate. See Fig. 2. Only 3% of the year does it remain cold, below the Modified Comfort Zone, all day. Most of the year is dominated by the "C-MCZ-C" pattern, requiring enclosure at night but warming up to comfortable conditions during the day, even in the winter. In the summer, especially July - September, this warming trend frequently results in overheating beyond what is solvable by simple shading and natural ventilation.

In the spring and fall, though always cold at night, the daytime maximum temperature usually reaches up into the Standard Comfort Zone or to just below it, where comfort is achievable if the wind is blocked and the sun is admitted. In the summer, the typical daily maximum is solvable by shade and ventilation, with or without overnight cooling. On days when the maximum is very hot, the accompanying nights may not cool off enough to make cooling by night ventilation feasible.

Phoenix, Arizona is an example of a hot-arid climate. See Fig. 3. Some degree of non-enclosure is possible all year long. This happens during the day in the winter and during the night in the summer, suggesting seasonal shifts of space use patterns. Enclosure against extremes of cold or hot is needed on winter nights and summer afternoons. Occasionally, during transitional periods, especially in June and September, both extremes may occur in a single 24-hour period. Infrequently, in August and September, are mild days exhibiting neither extreme. The most typical day type (45% of the year) requires enclosure at night and shade and ventilation during the warmest part of the day.

While all climates exhibit the level A pattern C-MCZ-C the annual distributions differ by time of year. The frequency and the universality of MCZ establishes the importance of studying the exterior spaces which, while not enclosed, are modified in terms of sun and wind.

We have developed a computer model which describes a building or a cluster of buildings. Shading patterns throughout the year are calculated for the surrounding field. Similarly, a physical model is built and subjected to wind tunnel tests for a variety of wind directions in configurations for which there is no existing data.

Wind data for the cube studies were based on the work of Kamai and Maruta. Selected points in the field are evaluated for every potentially comfortable hour in the year. For each hour, resultant wind and sun intensities are calculated, based on real hourly weather data and modified by the adjacent building configuration. The final computer printout gives a "score" for each point analyzed indicating the percentage of time that that point, by virtue of its orientation around the building, is thermally comfortable. Results are also presented for each month separately so that seasonal variations can be detected. These results can then be compared to a "base case" for evaluation.

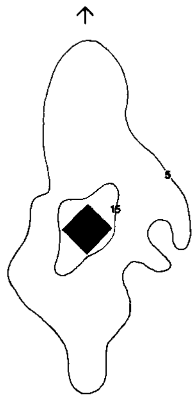

Fig. 4 MLO Charleston

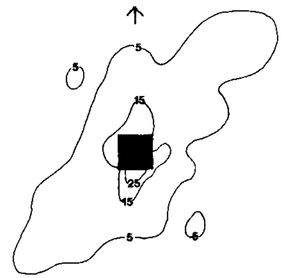

Fig. 7 MLO Charleston

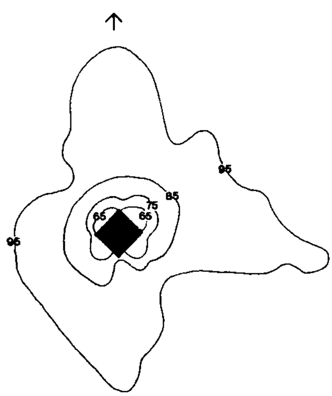

Fig. 5 SCZ Charleston

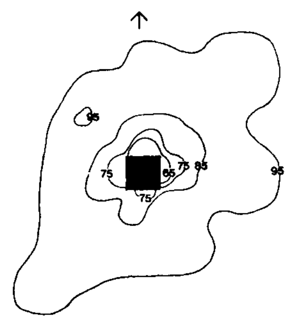

Fig. 8. SCZ Charleston

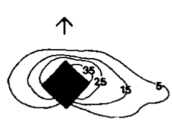

Fig. 6 MHI Charleston

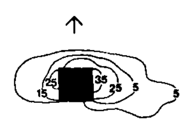

Fig. 9 MHI Charleston

RESULTS

The contours around the cubes represent the percentage of the time that that area is comfortable compared to the amount of time it could theoretically be comfortable for the conditions noted. In Charleston, Figs. 4-9, the exterior spaces don't reach their potential for any condition. The MLO reaches a maximum of 30% on the south side of the cube when it is orthagonal to the compass points. The SCZ reaches a maximum of 90% and the MHI reaches a maximum of 40%.

In the case of the cube which is diagonal to the compass points, under the MLO condition, the southeast and southwest faces perform the best because they have access to the sun, and when the wind blows from the north, they experience reduced wind velocities. The northwest face also performs well because a significant number of MLO occurances are after sunset and the northeast face is sheltered from the predominant southwest wind. The 10% contours which extend well beyond the faces of the cube are probably a result of reduced wind velocities.

The MHI zones are elongated East-West due to the longer shadows cast in the morning and afternoon. The highest percentages are on the east side because MHI occurs primarily in the afternoon. The theoretical maximum isn't reached because the predominant southwest winds result in a wind-sheltered area on east and northeast sides of the cube rather than the required (for MHI) wind-swept area.

Because the SCZ is by definition the time when the sun and wind are in balance, the imposition of a building will create uncomfortable conditions around it by upsetting that balance. As the diagrams indicate the affected area is extensive on all sides of the cube although the south sides usually perform the best because the sun is unaffected.

The poor performance of the spaces near the cube under SCZ conditions almost offsets the improvements in the same spaces under MLO and MHI conditions. For example, when the cube is diagonal to the compass points the best point on the northeast side is comfortable 20% of the hours in the year. This is 5% better than the 15% SCZ which would result in an open field. The best point on the southeast side is comfortable 20% of the hours in the year on the southwest side 19%, and the northwest 18%.

In the cold climate, Madison, Wisconsin, the MLO condition is dominant and occurs 15% of the hours in the year. See Fig. 10-12. The northwest and southwest sides of the cube perform the best, reaching 20% of their theoretical value. The southwest face, which one might expect to perform the best because of its access to the warm afternoon sun, actually doesn't perform any better than the shaded northwest face due to the predominant southwest wind direction, which offsets the suns radiation. On an annual basis most gains in the MLO and MHI conditions are offset by losses in the SCZ conditions. The best locations along the northeast and southwest exceed the 8% of the hours which fall in the SCZ by 1%. The southwest side offers no improvement over the SCZ condition and the northwest side performs 2% worse.

In Phoenix, Arizona, a hot arid climate, MLO, SCZ, and MHI account for 18, 16 and 24% of the annual hours respectively. See Figs. 13-15. The MLO pattern is elongated in the east-west direction unlike the other two climates because the MLO condition occurs in the morning, afternoon and night rather than at midday and the predominant wind direction is east-west. On an annual basis the northwest, southeast, southwest and northeast faces are comfortable 21, 20, 17, and 18% of the year respectively, each offering some improvement over the 16% (SCZ) of the year one could be comfortable without modifying the sun or wind.

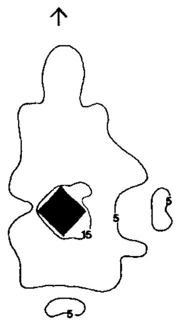

Fig. 10 MLO Madison

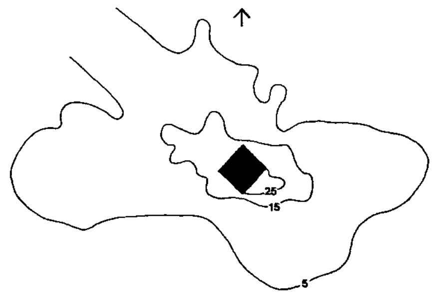

Fig. 13 MLO Phoenix

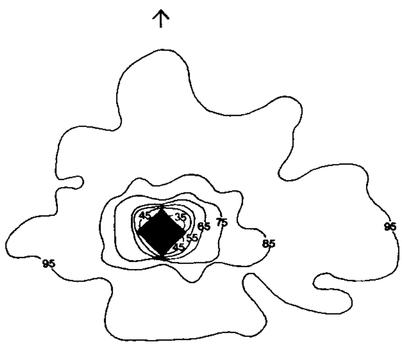

Fig. 11 SCZ Madison

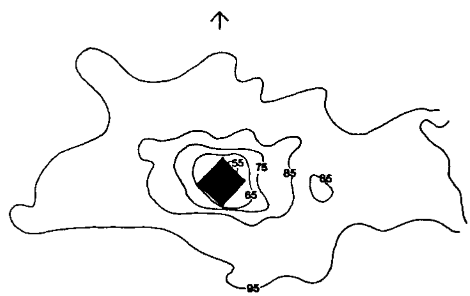

Fig. 14 SCZ Phoenix

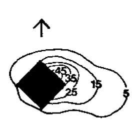

Fig. 12 MHI Madison

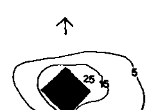

Fig. 15 MHI Phoenix

CONCLUSIONS

The MLO condition is particularly vulnerable to adverse wind directions. This indicates that the sun-exposed faces of the cube could be greatly improved by the creation of wind breaks that do not shade the sun between the cube and the wind direction which predominates during MLO conditions.

The improvement to ambient climate conditions on each face of the cube in the MLO (admit sun if available and block wind) and MHI (block sun and admit wind) conditions is largely offset by degrading of the ambient conditions when they are comfortable by unfavorable modification to the sun and wind by the cube indicates that designers should be equally concerned with not making microclimates worse as they are with making them better.

ACKNOWLEDGMENTS

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VENTILATION AND LANDSCAPING
Design Implications for Hot Humid Climates

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ABSTRACT

This paper explains for the architect the physics of airflow patterns, the aerodynamics of buildings and their implications on effective ventilation. Also discussed are ventilation influenced design strategies of sunshading, daylighting and landscaping.

KEYWORDS

Ventilation; landscaping; passive cooling; sunshading; daylighting; Hot-Humid climate design.

INTRODUCTION

Human comfort requirements in hot humid climates can only be achieved through reduction of solar insolation and increased air movement (as explained in Reference 1). The architect can maximize air movement by site manipulation, building orientation, fenestration, roof design and landscaping. However, this form of ventilation oriented design results in large window space and hence requires design for daylight control. Also important is the reduction of solar insolation through techniques of roofing, sunshading and landscaping. The first step in ventilation oriented design is to understand the underlying principles of airflow and their design implications.

PRINCIPLES OF AIRFLOW

The exact analysis of airflow patterns in buildings is extremely complex (Chandra, 1980) and involves the modeling of three dimensional bluff bodies with appertures in turbulent shear flow and constant varying flow characteristics due to variation in openings and external landscape. However, a qualitative understanding of airflow characteristics is adequate for building design. These are:

(I) Air moves from high pressure regions to low pressure regions;

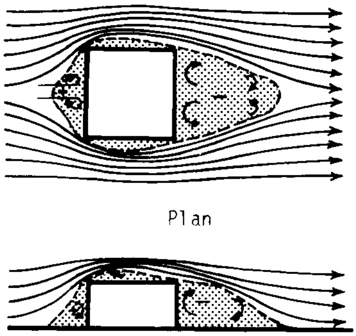

Fig. 1 Airflow for a "Box" building.

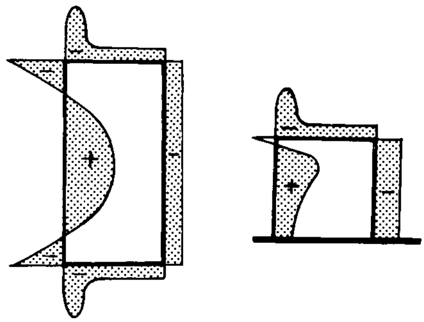

Fig. 2 Pressure distribution for the "Box" building of Fig. 1.

(II) Air has inertia and, hence, changes direction only when obstructed (it does not always travel in straight lines);
(III) Friction is developed when moving air comes in contact with surfaces and this causes the air stream to slow down and form eddies;
(IV) Airflow is laminar, but when it comes into contact with buildings or other obstructions, it turns turbulent.

We now examine the airflow past a rectangular "box" building (Fig. 1). The elevation view shows how a wedge of high pressure is built up on the wall facing the wind (windward side) and a low pressure region is created at the rear (leeward side). The plan view shows the extent of these regions and it is noticed that a large area on the leeward side is protected from the wind. This region of low air movement is termed "windshadow". Fig. 2 describes the relative pressure distribution on the "box" building of Fig. 1.

BUILDING LOCATION

Locating the building directly on the leeward side of a neighboring structure (i.e., in its windshadow) will result in low airflow around the building and hence poor ventilation. It is very important during design to locate the building away from the wind shadow of neighboring structures. Conventionally the windshadow depth is taken as "six times width". Fig. 3 illustrates how staggering of buildings greatly reduces the wind shadow problem and in fact increases the wind velocities due to a funneling effect, aiding ventilation.

BUILDING ORIENTATION:

Conventionally, it is supposed that maximum ventilation is achieved when the building faces the wind direction, but Fig. 4 explains how a 45 degree orientation is superior as it causes a larger "width" of air (b>a in Fig. 4) to act on the building. But in an unsymmetrical building, the long direction should face the wind as this makes cross ventilation easier.

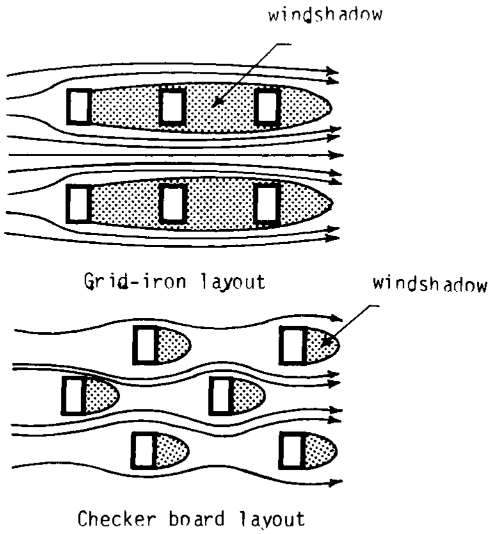

Fig. 3 Building layout influence on windshadow.

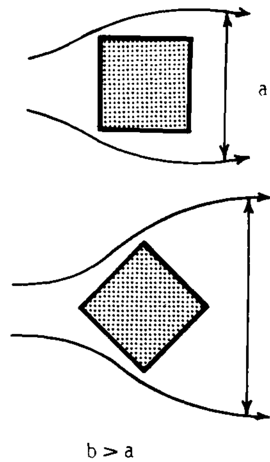

Fig. 4 Building orientation effects.

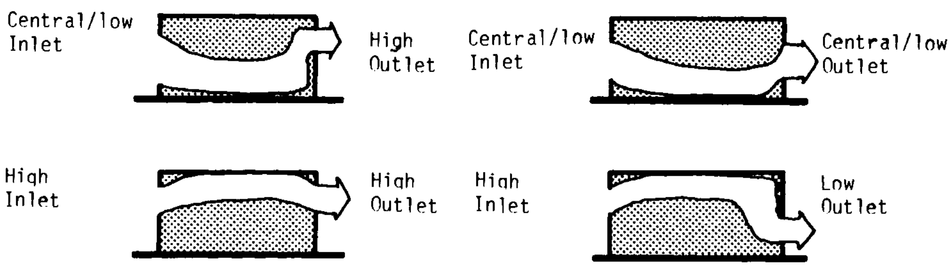

Fig. 5 Window location effect on airflow.

FENESTRATION

The actual entry of air into the building is through its fenestration (windows) and so ventilation is greatly influenced by the size, shape and location of the windows. For air to flow through a building, there should be an opening (inlet) in the high pressure region which causes air to enter the building, a passage through the building, and a corresponding opening (outlet) in the low pressure region to allow the air to exit from the building. As shown in Fig. 2, the center section of the windward side has the highest pressure and so this is the ideal location for an inlet window.

To maximize cooling, the airflow should be at the body surface level and this in turn depends on the activity being performed in the room (like bed level in a bedroom and sitting level in a dining room). The height at which the windows are located affect this airflow height and Fig. 5 shows the effect of window location on airflow patterns.

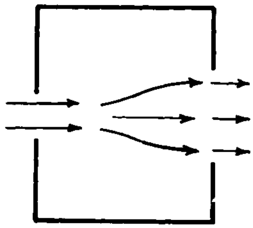

Fig. 6 In-line windows.

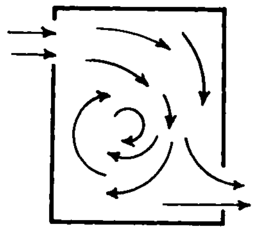

Fig. 7 Staggered windows.

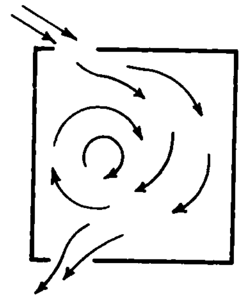

Fig. 8 Inclined winds.

Of the four window location strategies shown in Fig. 5, the central/low inlet combined with high outlet is most effective. The high outlet also helps exhaust hot air as it rises to the top of the room, while the inlet can be positioned to cause maximum airflow at body level.

Air movement in a room is also influenced by the relative location of windows in plan. For windows directly facing each other (Fig. 6), air tends to just pass through the room and causes air movement in only a small portion of the room. But if the windows are staggered as shown in Fig. 7, the air is forced to change direction and this causes air movement in a larger section of the room. Another effective strategy as shown in Fig. 8 is to position the wall containing the inlet at an incline to the wind and cause the air to enter the room obliquely. The above effects of windows can be further enhanced both internally and externally. Internal partitions can be used both to deflect the incoming airstream for greater air movement and to channel the airstream to desired locations. Moveable partitions allow the occupants to channel/ deflect the airstream to suit the activity in the room internally. Wing walls and extended eaves can be used to increase airflow in a room or to modify the direction from which the wind enters a room. As shown in Fig. 9, these external projections can even be used to create an inlet for a wall which is usually in a low pressure region.

Window sizes should be determined by the function of the room, but the inlets should always be smaller than the outlet as this creates desirable higher windspeeds near the inlet and the entering fast airstream can be directed to required spaces using internal partitions.

Another approach (traditionally used in India) is "breathing walls" or hollow brick walls. These are walls built up of bricks in a lattice form with many variations. The resulting geometric pattern is aesthetically pleasing, allows ventilation and protects from glare. Applications include double layered exterior walls with a 4" gap (which satisfies exterior load bearing wall criteria) and interior partitions which separate space but enhance volume by giving the place an airy look.

In hot humid climates during the time it is actually raining, there is usually a strong wind outside but windows have to be kept closed to prevent the wind from driving the rain inside. Louvres can be used to allow air entry without rain. Conventional louvres can be used in conjunction as double layers or special louvres as tested by Koenigsberger, Milar and Costopoulos (Reference 3).

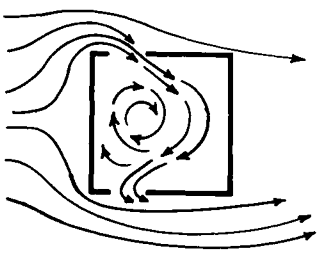

Fig. 9 Wing walls.

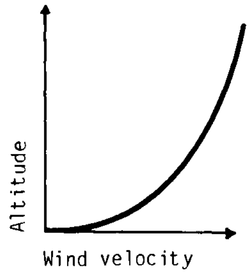

Fig. 10 Wind velocity gradient.

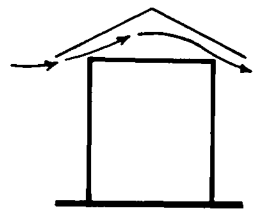

Fig. 11 Double roof.

ROOFS AND STILTS

These two techniques are included here as they are both based on airflow and airflow gradients. Air velocity is low, close to the ground and increases with altitude as shown in Fig. 10. For stilts to be usable, there should be a strong, cold airstream near the ground as in seaside areas. If this is not there, stilts are ineffectual and in fact, contact with the ground can help cool the building as the ground can be regarded as a "reservoir of coolness". Often roofs in urban areas are waterproofed flat concrete slabs which are terrible from the solar input viewpoint. In summer the sun heats up the roof and hence the air below it. This hot air should be vented by upward cross drafts with outlets at the highest point in the room (as hot air accumulates there). Alternatively, pitched roofs with appropriate openings can be used. But in some parts of the world (as in India), people use the roof to sleep on at night in summer and so pitched roofs are not applicable. Another approach is to use a double roof, the exterior pitched roof is constructed at a height of about 6 feet above the flat roof and wind is allowed to circulate in this area (by supporting the exterior roof on a porous structure like pillars or hollow brick wall). Shown in Fig. 11, this acts as an insulation from solar heat during the day and also provides a cool, ventilated area in the evening and night. An effective technique used by the British colonials in the tropics is to have houses with very high roofs. During the day the hot air rises to the top, this is vented out at night, replaced by cool night air and this cool night air is used to provide coolness the next day.

Correct selection of colour and material of the roof can increase reflection and hence decrease heat buildup inside. Insulation adds to this effect, and a layer of aluminum foil on the roof increases reflection.

SUNSHADING

Sunshading is required to minimize heat buildup from solar insolation (both direct sun as well as reflected heat from neighbouring structures). This can be through sunshading devices on the house or extraneously through landscaping and neighbouring structures. An important criteria for the design of sunshading is that it should

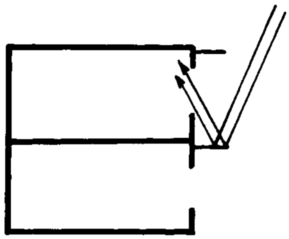

Fig. 12 Horizontal Sunshades.

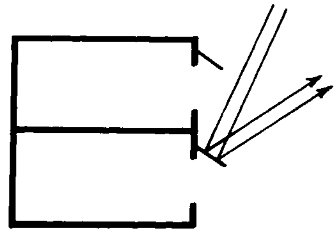

Fig. 13 Inclined Sunshades.

not decrease ventilation. Hence, the shade from a neighbouring structure can be used only if it doesn't coincide with its windshadow. Landscaping is very effective for sunshading, and this topic is discussed under "Landscaping". Sunshading on the house itself can be by shades that are vertical, horizontal or a combination thereof. (One such combination is the "egg-crate" shade). Vertical shades are essential on the north side as they obstruct the morning and evening sun. However, vertical shades are ineffectual on the east and west sides and long horizontal shades are preferable. The superposition of sunpaths on the building plans can be used to determine the types of shades required and their dimensions. Shades should be separated from the building to prevent heat conduction into the building and also to allow venting of the hot air that collects below the shades. Conventional horizontal shades (as shown in Fig. 12) reflect heat onto the upper sections of the house, but this can be averted by inclining the shades (as shown in Fig. 13). Shades need not be restricted to windows, but can also be used on entire walls. An extension of this concept is a verandah extending around the house which acts both as a shading device and helps cool the air entering the house. Since shading devices have no structural function, they need not be made of concrete, and can be made from cheaper, lighter, nonstructural materials. Other ways of shading are by hollow brick facades (an extension of the "egg-crate" concept) and reflective louvres. In addition to shades, heat buildup in the house can be reduced by having reflective exterior walls. This can be easily done by whitewashing exterior walls.

DAYLIGHTING

Daylighting can be in the form of direct (or reflected) sunlight or diffused sunlight. Direct sunlight has a glare problem, i.e., if part of a room is lit by an external concentrated light (direct sunlight), then for visibility in the room, the background light (provided by artificial lighting) must be of a comparable intensity. Hence, as direct sunlight requires intense internal lighting, it is not desirable. Since most houses have external shades for sunshading and rain protection, these obstruct direct sunlight and reduce the glare problem. Luckily, due to ventilation requirements, houses in hot humid climates have large window area and the diffused light entering from these windows is adequate lighting for most rooms. Some of the internal rooms may require additional lighting through skylights or north lights. For lighting requirements in the evening and night, fluorescent lights are superior to incandescent lights as they provide "cooler" light. Light-coloured walls with a "matte" finish also help diffuse artificial lighting and make it more comfortable. It is interesting to note that individuals have inherent differences in the rods and cones of their eyes, so there can be no common universal criteria for a "comfortable" lighting level.

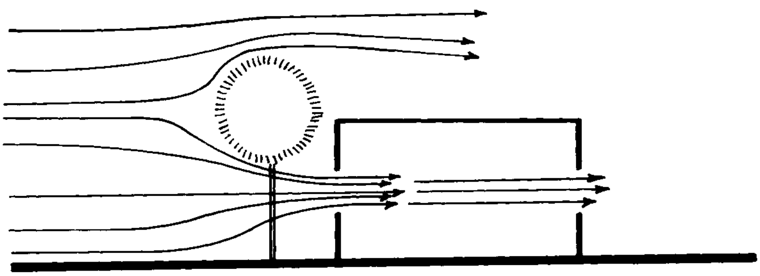

Fig. 14 Airflow control through landscaping.

LANDSCAPING

The micro-climate of a site can be greatly improved through landscaping. Landscaping can help decrease the heat buildup in the house through shading. A major advantage of natural shading is that plants constantly rearrange and reposition their leaves for maximum solar exposure and hence maximize shading, while man-made shading is inflexible. However, as ventilation is more crucial in hot humid climates, landscaping should be used for shading only if it doesn't decrease airflow into the house. Vines and creepers on pergolas and vertical trellis works provide excellent shading without decreasing airflow. Bushes and shrubs can be planted on the east and west sides to prevent insolation due to morning and evening sun. Vegetation can be used as ground cover to reduce ground reflectivity and thermal emission (dark green plants are less reflective than lighter ones). In urban areas, trees can be used to block thermal reflection and radiation from asphalt roads, sidewalks, parking lots and bare ground. Vegetation also helps reduce noise effects in urban sites.

Plants can be used to obstruct, filter and guide airflow and hence affect ventilation. They are better than man-made wind controls as they do not re-radiate heat. Plants (hedges) can be used as wing walls to deflect wind into an opening as shown in Fig. 9. Trees can help increase ventilation by acting as windcatchers over elevation as shown in Fig. 14. Plants can also be used as windbreaks to keep out undesirable hot dry summer winds and cold winter winds.

Actual plant selection for landscaping depends on the function (like short grasses for ground cover and bushy hedges for wing walls). Selection is also controlled by local site conditions and factors affecting plant survival like soil preference, growth rate and habits, life expectancy, moisture requirements, disease susceptability and leafing habits. Local site conditions like restricted water supply will affect selection. An example of site location is that deciduous trees in U.S.A. are very good landscaping material as they provide shade in summer and yet in winter, being leafless, allow the sun to heat the house. In contract, deciduous trees in India are less obliging as they are leafless in summer and provide shade in winter! It is advisable not to plant large trees very close to houses as their root systems may damage the foundation and there is the danger of falling branches during storms and strong winds. Other disadvantages of plants are that they may harbour insects or snakes and that they require maintenance (pruning and dead leaf removal).

CONCLUSION

In this paper, basic airflow principles have been used to explain and evolve design strategy. This should be supplemented and reinforced by local observation of air-flow patterns in already constructed houses in the vicinity of the site. A word of caution is required on natural ventilation, as this is based on winds and in nature there are days with little or no winds. Hence, a ventilation based design should include a back-up mechanical ventilation system consisting of suction fans (placed near the floor to suck cold air into the house) and exhaust fans (placed near the roof to push out the hot air from the house).

A well ventilated house is the only affordable design strategy to provide comfort in hot humid climates.

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LOW ENERGY ALTERNATIVES FOR SITE PLANNING THROUGH THE USE OF TREES IN A HOT ARID CLIMATE

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ABSTRACT

The use of trees to control direct solar radiation can provide a more acceptable site micro-climate, and in addition reduce the energy requirements for cooling and heating buildings. This paper proposes alternatives for site organization by using trees in a way that maximizes their total shaded ground area. This can be achieved by using rows of trees, or combining rows to form enclosures. In both cases the average shadow depth and the optimum spacing for a row of trees is derived from an analysis of the different shading configurations of typical model trees, using a simulated solar path for a latitude of 33 N.
A preliminary attempt is made to coordinate the optimum planting spacing for the trees with the internationally accepted modular design standards. This would provide for more orderly outdoor spaces and ensure a stronger unity between the building complex and its surrounding site.

KEYWORDS

Landscape design; site planning; trees; control of solar radiation; buildings. heating and cooling; modular design.

INTRODUCTION

A common sight in the city of Baghdad is the large expanse of barren grounds found in the site of large building complexes and public housing projects. Such overexposed large areas, in a hot dry climate, prevents their active use by the occupants, and affects the site climate adversely, both in the cooling and heating season. Even when trees are planted, they are haphazardly scattered over the site with no consideration to the daily and seasonal movement of their shadow pattern. More commonly, trees are planted in a single row along the site boundary line, regardless of the general site orientation, or the resultant shading depth of this row. The planting of trees on such large sites should be derived from a better understanding of the shading geometry of trees, leading to a set of rules and guidelines that would render an energy conscious landscape strategy.
Research in support of the use of trees to temper the site climate is

increasing. Bowen, for example, in comparing the cooling effects of plants and man-made structures, points out to the many advantages of shading by trees. Being a living organism, a tree will constantly position its canopy and leaves to take the best advantage of the sun's rays, thus, maximizing their cooling effect. Furthermore, experiments conducted by Kelly and Ittner using artificial shades for livestock, illustrate that bare ground temperatures cooled as much as 40 F(22.2 Centigrade)in five minutes after arrival of the shadow line. In view of these facts and when considering the total ground area covered by the shade of a tree during a day, one can well appreciate the importance of shading on the ground temperatures and those of the adjacent air layers.

METHODOLOGY

The cooling potential of trees lies in the shading geometry of their structures, which is determined by their height at the age of maturity, and the shape and size of their canopy. Four tree types have been distinguished and their dimensions fixed. These are : 18 meter high tree, its canopy 10 meters in diameter; 12 meter high tree, its canopy 8 meters in diameter; 12 meter high palm, its crown 5 meters in diameter; and an 8 meter high tree, its canopy 6 meters in diameter. All the tree types, having been selected from a list prepared by the author for a previous parallel study, are decideous; their complete leave fall-out occuring in october/november, and flowering in march. Furthermore, all four tree types have a round canopy. Scaled models were constructed of the four tree types, a simulated sun path, having been adjusted to a latitude of 33 N, was used to trace the complex shading pattern of each tree type on the horizontal surface it stood on. Readings were taken at a two hourly interval and for seven selected days, approximately representing the cooling season in Baghdad city. The dates for these days are as follows:
21 march/ 24 september; 16 april/ 28 august; 21 may/ 24 july; 22 june. The results of these tests, as shown in Fig. 1, include shading performance sheets for each of the four types of tree.

FINDINGS

In general, the total ground area covered by the shade of all tree types during a day, is appreciable.This total area is calculated from the shading configurations presented in Fig. 1, taking an average between the maximum shaded ground area of september 24th, and the minimum of june 22nd. The average shaded area for the four tree types, 18m tree, 12m tree, 12m palm, 8m tree are 1711 sq.m., 861 sq.m.,453 sq.m.,and 613 sq.m. respectively. The palm tree despite its height had the smallest shaded ground area.

To make practical use of the shaded ground area of each tree type, two factors are need and should be derived from the shading configuration. The first of these factors is the depth of the shadow created' by each of the four tree types. The second factor is the optimum center to center spacing for rows of trees.

Figure 2, gives the depth of shadow for the four tree types. This shadow depth is given in meters, and as an average between maximum shadow depths of september and the minimum of june. A look at Fig. 2, shows daily variations in shadow depth reaching a minimum around noon, when the tree is facing the high altitude south sun, and increasing during the late and early hours of the day, because of the lower sun altitude For example, a 12m tree provides a 7.5 meter deep shadow around noon,

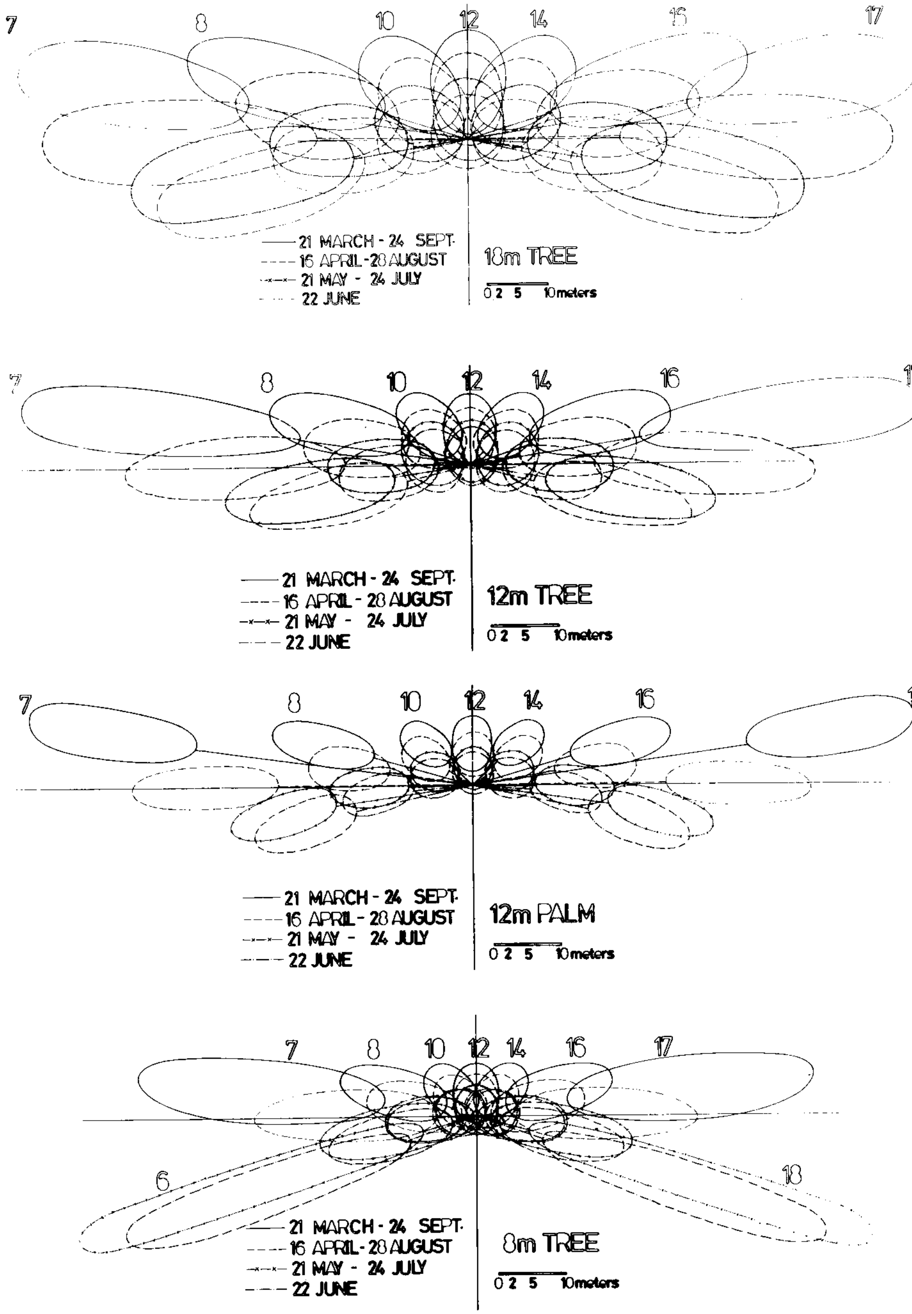


Fig. 1. The shading performance of the selected tree types.

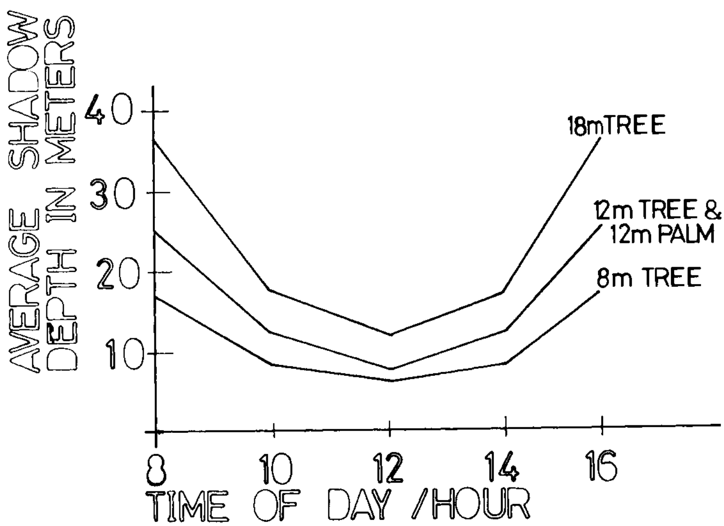


Fig. 2. The average daily tree shadow depth.

this depth then increases to 12.5 meters at 10.00 and 14.00 o'clock, reaching a maximum of 20 meters at 8.00 and 16.00 o'clock.

Two important facts can be concluded from the findings presented in Fig. 2, firstly, because of the daily movement of shadow, changing shape and size, and direction, rows of trees would provide much more efficient shading than individual trees. The reason lies in the fact that the second and third tree up the row would shade the otherwise exposed ground resulting from the movement of the shadow line of the first tree. The second fact, concerns the direction of the proposed tree rows. Rows of trees with an east-west direction should be avoided in a site layout because they receive the south sun which provides a minimum average shadow depth. Conversely, rows of trees with a north south direction receiving the east and west sun are preferred because they provide a much bigger average shadow depth. Rows with a northeast southwest direction,or a northwest/southeast direction are acceptable and have an average shadow depth slightly above that of the east/west tree row.

The optimum center to center spacing for tree rows is measured in meters from the shading performance configuration of the four tree types, Fig 1. The results are presented in Table 1 (A). Because ofthe variety in shadow size and direction, as seen in their shading configuration, the resultant center to center spacing for each tree type differs according to the time of day - the different sun orientations. For example, a row of 18m trees with a north/south direction will require an optimum center to center spacing of 15 meters, whereas, a row of the same tree type positioned in an east/west direction will require a much smaller spacing, 12 meters, in order for the tree row to create an uninterrupted shadow on the ground.

TABLE 5 The Optimum Center to Center Tree Spacing

time of day/ orientation of sun — tree type	A: the actual optimum center to center tree spacing					B: suggested modular tree spacing				
	8	10	12	14	16	8	10	12	14	16
	E	SE	S	SW	W	E	SE	S	SW	W
18m TREE	15	12.5	12	12.5	15	14.4	12	12	12	14.4
12m TREE	9.5	8	8	8	9.5	9.60	7.20	7.20	7.20	9.60
12m PALM	7.5	6	6	6	7.5	7.2	6	6	6	7.2
8m TREE	8.5	6.5	6.5	6.5	8.5	8.40	6	6	6	8.40

COORDINATING FINDINGS WITH MODULAR DESIGN STANDARDS

An attempt is made to modify the optimum center to center spacing presented in the previous table in accordance with the internationally used modular design standards. The basic unit used in this paper is multiplications of 1.20 meters. The results are shown in Table 1 (B). Among the reasons prompting this attempt is the creation of a more orderly outdoor environment , because the spacing for the different tree types become correlated the repetition of the modular unit. This correlation becomes even more important when organising the site with enclosures of different tree types and varying enclosure sizes. Furthermore, using the modular design standards ensures a stronger unity between the building complex -usually using the same proposed modular standards - and its surrounding site.

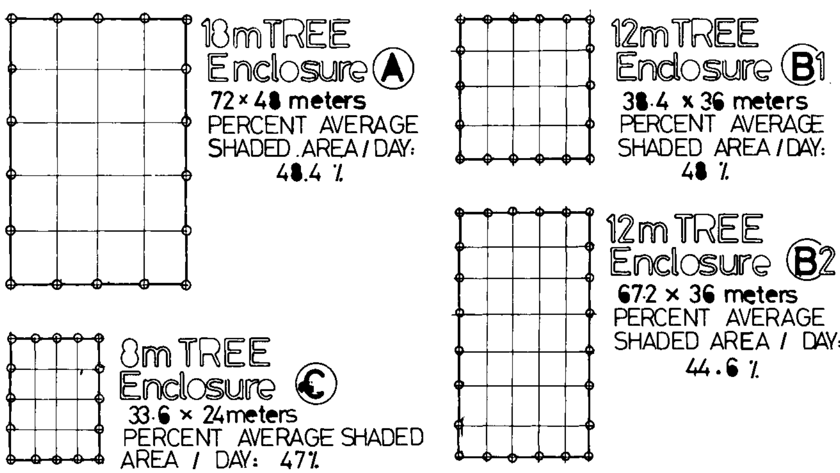
AN EXAMPLE OF MODULAR ENCLOSURES

Enclosures can be created through the systematic combination of the tree rows, utilising the findings presented in Fig. 2, and Table 1(B). Enclosures are successful means of controlling the climatic conditions of out-door spaces in a hot-dry climate. Enclosures made of walls, or likewise tree rows, serve as a protection from the scorching hot wind, dust, and in limiting evaporation, softening glare, and above all, shading the ground area of the site.
To illustrate the shading efficiency of enclosures, and the workability of their modular properties in organizing the site, a combination of modular enclosures is herein suggested and presented in Fig. 3.
The steps and criteria followed to arrive at this end result are:

1. Three tree types were used, the 12m palm being excluded because of its inferior shading efficiency.
2. In accordance with the findings, and because a better shading efficency is achieved during the earlier and later hours of the day, rectangular enclosured are preffered to square ones, having their longer sides facing east/west and their shorter side facing the less efficient south orientation.
3. Using the modular tree spacing suggested in Table 1(B) and apply-

	① width of enclosure facing south				
center to center tree spacing	single	NUMBER OF OPTIMUM SPACES PER ROW			
		4	5	6	7
18mTREE	12	48	60	72	84
12mTREE	7.20	28.8	36	43.2	50.4
8mTREE	6	24	30	36	42

② length of enclosure facing east & west				
	NUMBER OF OPTIMUM SPACES PER ROW			
	4	5	6	7
14.4	57.6	72	86.4	100.8
9.6	38.4	48	57.6	67.2
8.4	33.6	42	50.4	58.8



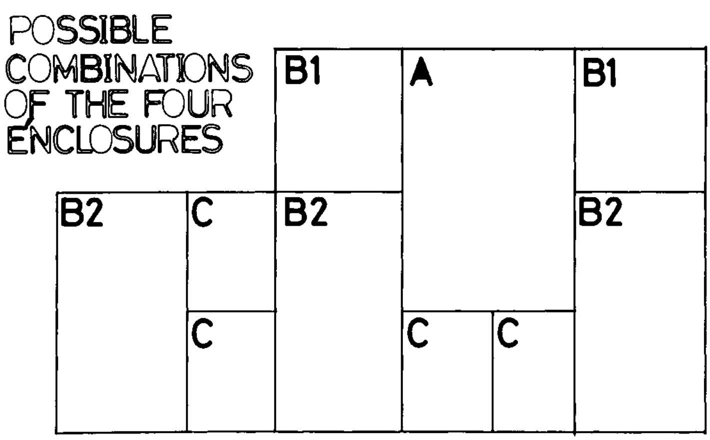


Fig. An example of modular enclosures.

ing it to a row with a minimum of five trees - four modular center to center spaces - two sets of a series of tree spacing were arrived at, for each of the tree types; one for enclosure side facing east/west, a second one for the shorter side facing south and north orientations.
4. Four basic enclosures have been suggested for the three tree types, Fig. 3, Two factors determined the choice of these four enclosures; firstly, its shading efficiency, arrived at by testing the daily shaded area as a percentage of the total enclosure area. In all cases this percentage was very close to 50%, meaning that as an average daily figure, almost half the enclosure area is shaded. Secondly, the modularity of the dimensions of the proposed enclosures, to allow a variety of combinations that best fit into the specific form of the site. This factor of modularity can be seen in the possible combinations of the four suggested enclosures, lower part of Fig. 3. The flexibility of the modular enclosures enables them to extend in all directions, however, always having their longer sides facing east and west.

CONCLUSION

Excluding the 12m palm tree, the remaining three tree types provide a considerably large shaded ground area. The shading efficiency of these trees, however, increases when they form a row or rectangular enclosures made up of these rows. The findings also show that these enclosures are most efficient when their longer sides are facing an east/ west orientation, and their shorter sides south/north.
The main purpose of this paper has been to illustrate the steps to be followed, and the criteria to be considered, in arriving at a low energy landscape strategy ; i.e. site organisation through tree enclosures. As a result important variables have been held constant, and others excluded. These variables in order of importance are as follows:
1. The whole range of possible enclosures, arrived at through a computer program , the results analysed and catalogued to facilitate its use.
2. The width to Length ratio for the optimum enclosures for each tree type, derived from the computerised programme of the range of enclosures.
3. The combination of the different enclosure shapes and sizes, tested against the different orientations ; i.e.having the corners of the enclosure facing east/west and thus having two sides of the enclosure exposed to the low sun altitude instead of only one.
4. The shadow configuration for other trees of different shapes.
It is our intention to further the work carried on in this paper by including one or more of these important variables.

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OPTIMIZATION OF LANDSCAPE PATTERNS FOR REFLECTED RADIATION AND THE DESIGN OF BUILDING FACADES/ENVELOPE

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ABSTRACT

All design elements of landscape are exposed to the incoming solar radiation and react to it according to their natural characteristics. Trees respond in terms of reflection and evapotranspiration. Other materials either absorb or reflect the impinging solar radiation. In cool and temperate climates the need for sunshine and in hot dry regions the inavailability of abundance of plant materials gives rise to a landscape pattern which has more ground for walking, sitting and other recreational activities and also to derive visual pleasure. Most such surfaces consist of paved walkways, parking lots, pools and ponds, grassy lawns, tarmac surfaces, etc; and mostly adjoin buildings for human uses which are exposed to the thermal impact of the landscape pattern. Reflected radiation from these surfaces sometimes constitute a significant portion of the total radiative budget of a building facade and needs investigations for the purpose of siting windows and other openings. These openings may form an important part of the total design affecting the thermal and luminous environment of the internal spaces. Thus the reflected radiation from the outside landscape pattern affects the thermal behaviour of building envelope and has been closely looked into in the present paper. Mathematical modelling and the use of digital computers made it easy to investigate the effects of a variety of surface arrangements of various materials having different albedoes (reflectivities) upon different points on the facade of a building. This strategy was applied further to study a building for a number of landscape patterns under two different geographical conditions to highlight the effect of latitude on such an approach. The investigations have yielded important informations for the consideration of the environmental designers in general and landscape architects in particular which may help them in their attempts to create a better, healthier and more conducive physical environment for the future generations.

KEYWORDS

Landscape patterns;reflected radiation; building envelope; albedo; sunny and shaded portions; microclimate; building material; irradiation.

INTRODUCTION

Landscape is an activity carried out from times immemorial. It draws the man closer to nature. It provides pleasing enclosures for working, relaxing, recreation and other activities and is an important branch of an over all process of design concerning man's total environment. Apart from visual pleasure the landscape designers are also concerned with the physical characteristics of the proposed design. Ecological balance of soil, geological and hydrological structure of earth, vegetation and planting technologies, use of water and other elements are all important issues to the landscape designers. But by far the most important and immediate concern of a landscape architect is to investigate the prevailing physical environment on a given site and to propose a compatible and adaptable solution for the sake of the user. Spatial heat transfer factors constitute an important contribution to the quality of thermal environment of which the solar radiation component is predominant. The decision about inviting or rejecting sun's radiations has to be taken in light of the prevalent as well as desired microclimate.

Inter-reflections between buildings and ground surfaces is dependent upon the geometry of the enclosures and their surface reflectivities (albedoes). In tropical and sunny areas this external reflected component constitutes the bulk of daylight and sometimes is a major source of glare. Design of windows is very important in these conditions and shading of this external reflected component is desirable under the summer sun. The reflected component is so strong sometimes, that, depending on the albedo of the surface, it shows a directional quality in which the angle of reflected rays, however diffuse, still corresponds roughly to the angle of incidence. In such a situation the geometrical solutions applied for shading devices can roughly be used in reverse position to minimise the reflected component on windows. An alternate to this approach may be to analyse a given landscape pattern quantitatively for the reflected radiation regime of the enclosure and then modify either by shading or readjusting landscape patterns or by redesigning building envelope to account for the reflected component. Mirza (1973) has emphasised the influence of reflected radiation from ground surface received by louvre systems and highlighted the effect of shaded and sunlit surfaces. This effect should be further pronounced when materials of high reflectivities are used. According to Landsberg (1947) quality of microclimate shall be largely affected by the geometrical arrangements of the built environment and the type of groundcover used. These ground covers may reflect or store solar energy resulting in glare or high ground surface temperature causing discomfort to the inhabitants. This has also been highlighted by Gajzago (1973) who noted temperature difference of more than $10^{o}C$ between sandstone and dry sand surfaces on a hot summer day in Hungary.

Anis (1978) has also studied the variation of sol-air temperature distribution on the facade of buildings under built up obstructed conditions and has identified the reflected radiation patterns as a tool used by traditional designers to passify the effect of glare. A study conducted by Anis and Ward (1978) emphasises the effect of shadow pattern with streets in built up areas on the reflected radiation received by fenestrations and building envelope. They concluded that low rise buildings in low density grouping receive larger amount of reflected radiation at low latitude sites compared to sites in high altitude areas. In high latitude sites the streets are usually covered in shade due to low solar altitude and thus reflect less radiation on to nearby building surfaces.

The literature cited in this paper and numerous other studies elsewhere demand the assessment of the thermal impact of a given landscape pattern upon the immediate environment of a built space. Most of the thermal environment is manifested in short wave solar radiation regimes and therefore should be investigated deeply. In the present work this investigation is based upon mathematical modelling and computer simulations.

Reflected Radiation Environment of Building Facades due to Varying Landscape Pattern

Reflected radiation from a horizontal surface onto a vertical building facade is affected by the incident radiation regime and albedo of the surface. A horizontal surface may consist of small patches of different materials according to the landscape patterns & since each has a different reflectivity it is obvious that the reflected radiation leaving such an area will be greatly modified. In this case the reflected radiation onto a vertical surface can be conveniently calculated by determining the diffuse view factor each small portion of the horizontal surface subtends on the point under consideration. Fig. (1) shows irradiation of a small area dA_1 on a vertical surface by diffusely reflected radiation from a horizontal surface of area A_2. Consider a small area dA_2 on the horizontal surface. Portion of the reflected radiation leaving surface dA_2 that is intercepted by dA_1 is given by $E_{(dA_2 - dA_1)}$, thus:

$$E_{(dA_2 - dA_1)} = \frac{L \cos\theta_1 \cos\theta_2 \, dA_2}{r^2}$$

where:

θ_1 = angle between r and normal to dA_1

θ_2 = angle between r and normal to dA_2

$\cos\theta_1 = \frac{a}{r}$

$\cos\theta_2 = \frac{x}{r}$

L = intensity of reflected radiation leaving surface dA_2. It is given by:

$L = P_2 G_h / \pi$

where G_h is the intensity of total incident radiation on the horizontal surface, and P_2 is the albedo of the surface. Therefore:

$$E_{(dA_2 - dA_1)} = \frac{P_2 G_h \, a}{\pi (x^2 + y^2 + a^2)^2} \qquad (1)$$

The total reflected radiation from area A_2 and incident on dA_1 is given by integrating equation (1) between the limits of its dimensions thus:

$$E(dA_1) = \frac{P_2 G_h}{\pi} \int_{c_1}^{c_2} \int_{b_1}^{b} \frac{ax}{(x^2 + y^2 + a^2)2} \, dx \, dy \qquad (2)$$

$$= \frac{P_2 G_h}{\pi} \cdot F$$

where

$$F = a \int_{c_1}^{c_2} \int_{b_1}^{b} \frac{x}{(x^2 + y^2 + a^2)^2} \, dx \, dy \qquad (3)$$

A general solution of equation (3) is given below:

$$F = \frac{a}{\sqrt{2 a^2 + b_1 2}} \left[\tan^{-1} \left(\frac{c_2}{\sqrt{a^2 + b_1 2}} \right) - \tan^{-1} \left(\frac{c_1}{\sqrt{a^2 + b_1 2}} \right) \right]$$

$$- \frac{a}{\sqrt{2a^2 + b^2}} \left[\tan^{-1}\left(\frac{c_2}{\sqrt{a^2 + b^2}}\right) - \tan^{-1}\left(\frac{c_1}{\sqrt{a^2 + b^2}}\right) \right] \qquad (4)$$

Equation (4) is extremely useful in evaluating the reflected radiation from a given pattern of landscape where different areas reflect varying amounts of radiation and thus affect the distribution of radiation on the building facades. The importance of equation (4) can be highlighted in the case of a window being irradiated by diffusely reflected radiation from different ground surfaces whereby an analysis can yield which area is impinging greatest radiation on the window. Then depending upon the environmental requirements the position of a particular patch of landscape can be best located for the desired effect.

It can be seen from equation (4) that the value of the view factor, and hence the reflected radiation, is strongly affected by the position of the point 'a' on the vertical surface. It follows therefore that the reflected radiation on the vertical surface will vary along both of its dimensions. These uses of equation (4) have been studied first for some general cases to highlight the effect of positioning a reflecting surface in relation to a vertical building facade and secondly to study the distribution of reflected radiation on the southern facade of the Arts Tower block of the University of Sheffield (UK) for a variety of patterns in its front court. These will be described in detail one by one.

Equation (2) was applied to three different cases to see the effect of location of reflecting surfaces on the resulting irradiance of a vertical surface. All three cases are shown in Fig. (2) to (4). In the first case both vertical and horizontal surfaces share a common corner. The dimensions of both horizontal and vertical surfaces are the same in all three cases. In the second case the horizontal surface is moved away from the vertical surface by a distance equal to half its depth. The effect of reflected radiation from the intermediate strip is not considered. In the third case the reflecting ground surface has been shifted to one side of the vertical surface so that lower right hand corner of the vertical surface meets the upper left hand corner of the ground surface. In all three cases albedo of ground was kept at 0.2 and incident radiation G_h was assumed equal to 900 W/m^2 .

In the first case the vertical surface is irradiated as one would expect i.e. lower points receive more reflected radiation, being closer to the ground, compared to the upper points. Moreover at a given height a horizontal strip is symmetrically irradiated across the central line of the vertical surface. This central line always receives more radiation compared to the edges. The difference is as much as 50% more on the central points on lower strips. Up the vertical surface the difference between irradiance in the central vertical strip and the edges becomes less and less and eventually tends to diminish suggesting that positioning of windows on a vertical surface much higher from the ground with respect to the reflected radiation is not as critical as on lower parts. This difference is expected to be further affected by the size of the reflecting surface, dimensions of the vertical surface and the albedo of the ground and also by the amount of incident radiation on the horizontal surface. As can be seen from equation (2) the reflected radiation is linearly related to the albedo of the surface provided all other geometric parameters are kept constant. This means that with reflecting surfaces of high albedo the reflected radiation received by windows can be significant e.g. if the ground surface were to be whitewashed in case I giving it an albedo of 0.93, the reflected radiation on the centre line of the vertical surface at a height of 2 metres would be 288 W/m^2 compared with 62 W/m^2 with an albedo of 0.2 in the present case. This high reflected energy is mainly due to the part of the ground near to the vertical surface as it has greater view factor for lower points. This is confirmed in the second case where the shift in the reflecting ground surface by half its width has reduced the maximum radiation by more than two thirds of case I. The maximum reflected radiation received by any point in case II is only 23W/m^2as compared to 68W/m^2

in case I. Another interesting change has occurred and that is the irradiance of the lower half of the vertical surface in case II has been reversed compared to the same part in case I. In case I there is a continuous fall in reflected energy with increase in the height of consideration on the vertical surface but in case II this has been changed into a continuous rise with increase in height up to half the height of the vertical surface where it starts falling down to reach its lowest value at the top. The lowest value in case II occurs on the lowest horizontal strip while in case I the top strip is least irradiated. However the radiation on top horizontal strip in case II is greater than in case I. This is due to the greater view factor on the top line of the vertical surface in the case of the shifted ground surface in case II as an increase in the value of 'x' (Fig. 1) will increase cos θ_2 and the integrated result would be higher view factor from all individual unit areas of the ground surface and hence greater radiation on the top line.

In case III the irradiance patterns of reflected radiation on vertical surface has departed away completely from those in case I and case II. The reflected radiation is no longer symmetrically distributed over the whole vertical surface. Instead it is the vertical column nearest to the reflecting ground surface which receives most radiation. This column receives the radiation in much the same way as all columns in case I although the intensity of maximum reflected radiation is reduced by about 30% in this case. However, this pattern of irradiance changes towards the far off column where the reflected radiation is distributed in the same way as in case II although the variation is limited to a very small change in this case. The reflecting surface in case III has not been shifted any further for it is anticipated that the irradiance pattern will not change though a fall in the intensity is apparent.

These three cases considered here represent some general patterns usually applied in landscaping of ground surfaces. While landscaping is generally considered a decorative and aesthetic art it is possible that sensible siting of different ground surfaces in front of a building wall and windows can help optimise the radiative loads and create a more pleasant microclimate. Pavings and walkways generally made of bricks and concrete have a high albedo and can cause great heat loads on nearby building walls and fenestrations. This is particularly important for tropical sites where incident radiation on ground surfaces is usually very high. A careful location of such surfaces can be of great help in reducing the thermal stress in an enclosure and the existing surfaces can be shaded by trees or other similar structures to minimise the input of direct radiation which is greatly responsible for reflected radiation.

Case Study of an Existing Building for a Variety of Situations.

The above results initiated the study of an existing surface for its reflected radiation regime and to compare it with some assumed situations to highlight the effect of reflected radiation and the impact of landscape pattern on it. For this reason a study was conducted related to the reflected radiation environment of the southern facade of the Arts Tower of the Sheffield University. A computer model based on equation (2) was prepared to study reflected radiation from different landscape patterns of the Tower Court. This included the existing arrangement of different surfaces. All these four patterns are shown in Fig. (5) - (8).

Strategy: Simulation was performed for the day of highest solar altitude i.e. 22nd of June assuming clear sky conditions and at solar noon. Any partial shading of ground surfaces was ignored as at solar noon there is very little shade on the tower court and that too exists far off from the Arts Tower's southern facade. For the sake of comparison another simulation was performed assuming as if the whole building arrangement was located at Lahore (lat.31.5^{o}N)keeping all other factors constant. Results are shown in Fig. (9) to Fig. (12) for Sheffield and in Fig.(13)

to Fig. (16) for Lahore. The incident reflected radiation due to the court has been plotted as percentage of incident direct on the southern facade for the same time against the varying height of the point of consideration. Irradiation of only three vertical columns of the facade has been presented i.e. the left hand column, the central column and the right hand column. It is assumed that these columns are representative of the whole facade. Values of albedoes (reflectivities)for various groundcover as used in the analysis were taken from work by Brook (1961).

Results: As the court is not symmetric about the facade of the Arts Tower the reflected radiation is asymmetrically distributed over the whole surface. This asymmetry is shown in Fig. (9) to Fig. (12) where the left hand column is always receiving more reflected energy. This difference is at its greatest between the height of 5m to about 25m where it starts to diminish reaching its minimum value at the top of the facade. The tower building is nineteen floors high.

The reflected radiation on the central column, on the other hand, is higher or lower than the corner columns depending upon the landscape pattern of the court. Only in case 3 the central column receives more radiation than the other two columns but the difference quickly vanishes at a height of about 15m. It can be seen that in no case the reflected radiation on any column exceeds 33% of incident direct. With direct incident radiation on the facade equal to 364 W/m^2 this gives 120 W/m^2 of incident reflected radiation as its highest value. This value occurs for lower surfaces and reduces to an average of 90 W/m^2 at a height of 5m. Therefore the reflected radiation is significant for windows and other surfaces on the facade close to the ground.

Simulations at Lahore show higher reflected radiation at all levels resulting from higher intensity of total solar radiation on the horizontal plane which in this case was 1022 W/m^2 As can be seen from Fig. (13) to (16) the reflected radiation on the lowest point is as high as 115% of the incident direct solar radiation. This high proportion arises not only from greater incident radiation on the horizontal surface but also due to smaller values of direct radiation incident on the vertical surface, due to the high solar altitude (82^o). This results in a wide difference between the highest and lowest values of reflected radiation. Fig. (15) shows a difference of 46% in the irradiation of two different points on the lowest horizontal strip of the facade.

The main parking area in the tower court in case I is made of tarmac (albedo = 0.15) and in case 4 it has been changed with concrete (albedo = 0.3) and yet the irradiation of different points of the tower facade by reflected radiation is remarkably similar in pattern. There is apparently no change for lower areas in both the cases and the higher areas receive slightly more reflected radiation in case 4. This is due to the insignificant view factor subtended by the parking area on lower points on the facade. On higher points, however, the view factor by parking area becomes significant and hence the difference in reflected radiation in the two cases.

When reflecting surfaces such as concrete and grass in case 2 are changed with surfaces of lower reflectivities like water and tarmac as in case 3 the result is lower irradiation of the left and right hand side columns while radiation on central column is significantly higher for lower surfaces than the two outer columns.

The above case study suggests that due to the ever changing view factor for different locations on a vertical surface the positioning of different reflecting surfaces in front of a building facade has great importance for a desired irradiation effect. It has been shown by the study of these different cases that the horizontal surfaces in the immediate vicinity of a facade have greater influence on its reflected radiation regime than the far off areas. The solar altitude will affect in the way that for lower altitude angles it will impinge less energy on horizontal surfaces which will result in lower reflected radiation leaving the surface.

Although shading of the tower court by the surrounding buildings has not been considered it is anticipated that reflected radiation from the enclosing facades should be a balancing factor. It can also be argued that as higher points on the facade of Arts Tower see much of the urban terrain in front of them, there will be added reflected radiation due to urban albedo according to Craig (1970). To this the reflected radiation from roofs of surrounding buildings should make substantial contibutions.

CONCLUSIONS

The importance of reflected radiation has been highlighted in the present study. The following conclusions are drawn for consideration of designers and research workers.

- An appraisal of shortwave reflected radiation from horizontal ground surfaces onto walls reveals the quantitative impact upon irradiation of building envelope. Under tropical conditions when the sun is high in the sky, reflected radiation on building facades can be higher than the incident direct component.

- Variations in the arrangement of landscaping surfaces drastically alters the distribution patterns of reflected radiation on building facades.

- A horizontal reflecting surface in the immediate vicinity of a facade has greater influence on the reflected radiation budget compared with far-off patches of landscape. This is due to a larger view factor the nearer surface subtends at the wall.

- Lower points on building facades receive higher reflected radiation compared with higher locations.

- Latitudinal effects on landscape patterns with respect to reflected radiation suggest that low latitude sites are more affected due to higher solar altitudes and hence more reflected radiation from the ground surfaces.

ACKNOWLEDGEMENT

The author wishes to thank the Government of Pakistan for the financial support regarding the present study. The guidance provided by Prof. J.K. Page and Mr. I.C. Ward of the University of Sheffield,U.K. is gratefully acknowledged. Special thanks are due to the staff of the Computer Center of the University of Sheffield, U.K.

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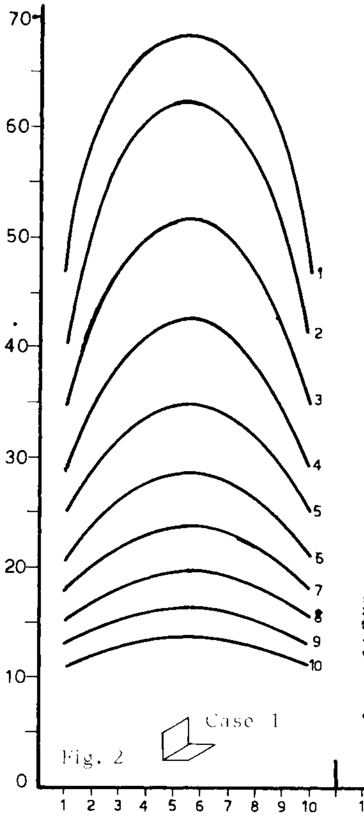


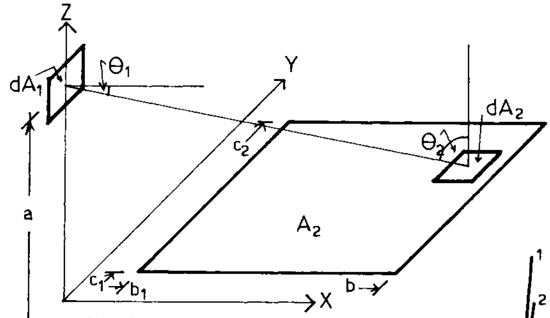


Fig. 1

View factor subtended by horizontal elemental area on a point on a vertical surface.

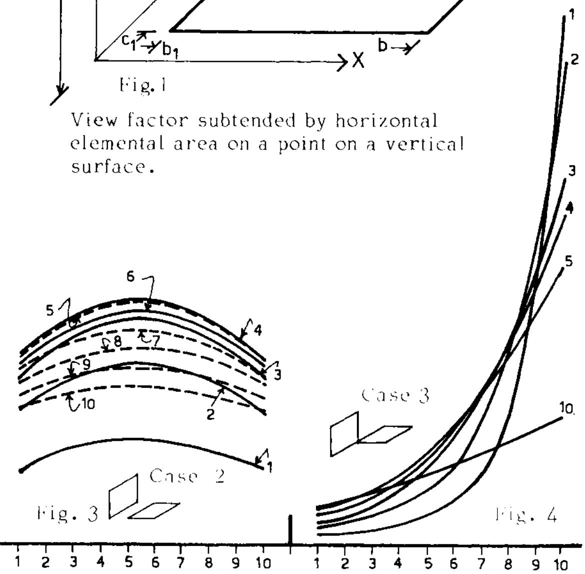


Fig. 2,3,4   Distance from left hand corner of the vertical surface

Distribution patterns of reflected radiation on a vertical surface due to horizontal surface. All three cases.

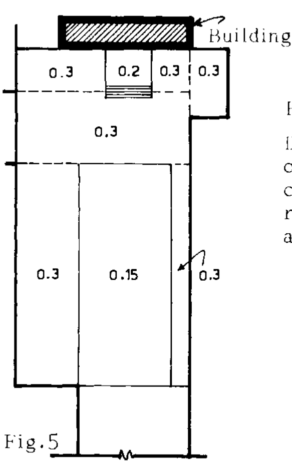


Fig. 5

Fig. 5,6

Different landscape patterns in front of the court of the building under consideration for the case study of reflected radiation. Numbers denote albedoes of various ground surfaces.

0.08 – water
0.15 – tarmac
0.2 – dirty conc.
grass
0.3 – average conc.
0.4 – paving

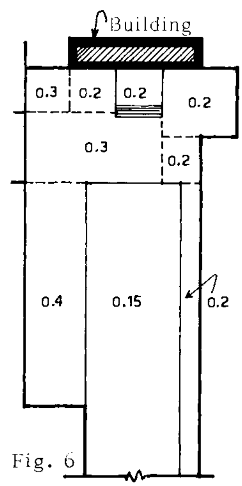


Fig. 6

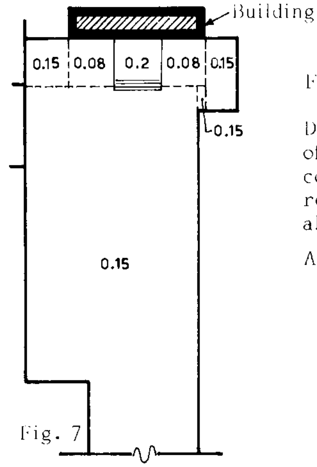


Fig. 7

Fig. 7, 8

Different landscape patterns in front of the court of the building under consideration for the case study of reflected radiation. Numbers denote albedoes of various ground surfaces.

Also see figures 5 and 6.

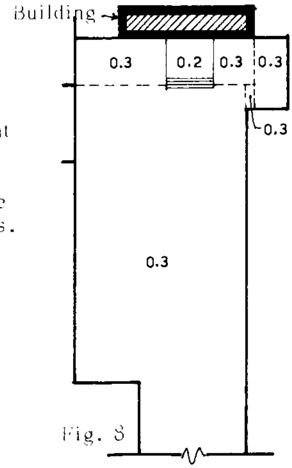


Fig. 8

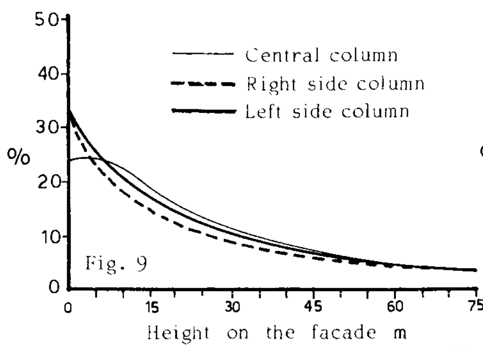


Fig. 9

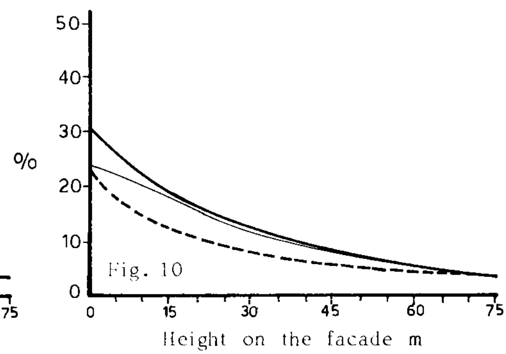


Fig. 10

Fig.9,10,11,12

Reflected radiation (expressed as % of incident direct solar radiation) on three representative columns on southern facade of the building under consideration.

Results for Sheffield (lat. 53 N), June 22

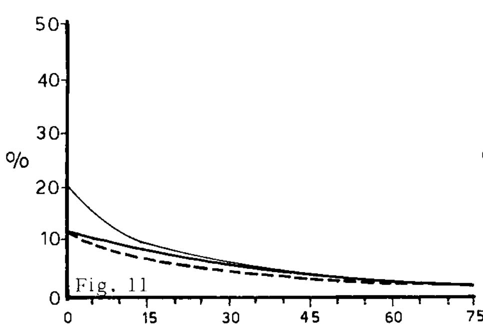


Fig. 11

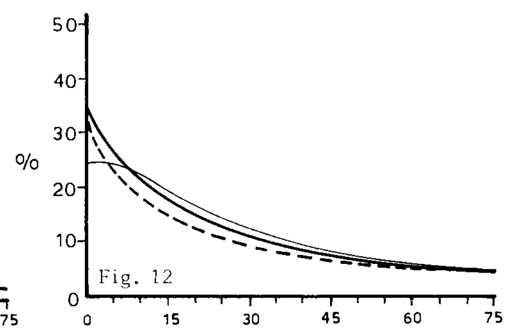
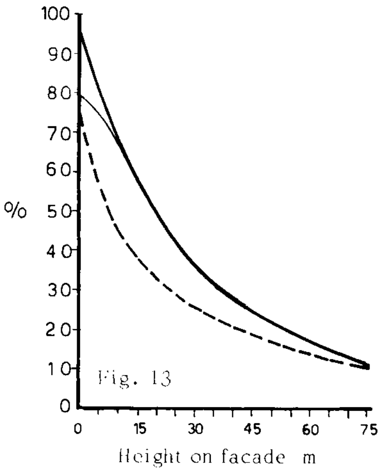
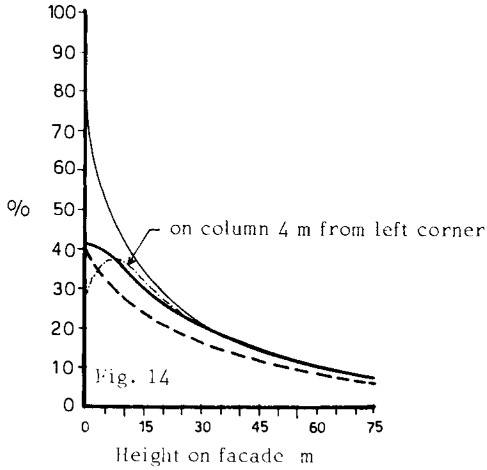


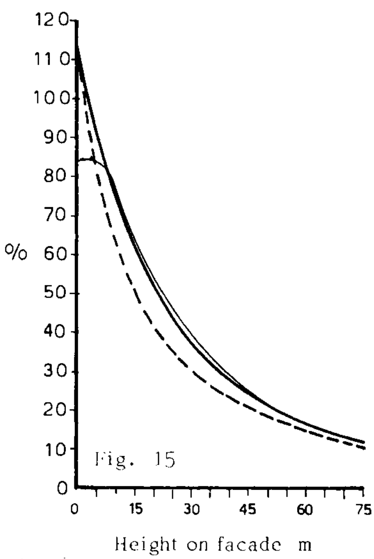
Fig. 12





Results for Lahore (lat. 31.5 N)
June 22

—— Central column
- - - - Right side column
——— Left side column



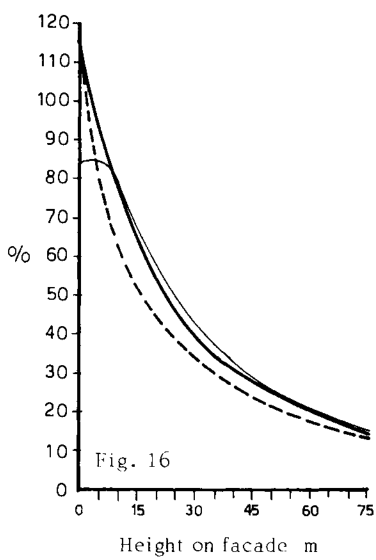


Fig.
13, 14, 15, 16

Reflected radiation (expressed as % of incident direct solar radiation) on three representative columns on southern facade of the building under consideration.

DESIGN GUIDELINES ON LATERAL AIRFLOW THROUGH AND AROUND BUILDINGS

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ABSTRACT

A mass of sketches are available, in professional literature, on air movement through building interiors and around groups of buildings Much of this information is misleading, as it is frequently based on the limited knowledge and expansive imagination of designers, who have not thoroughly researched this topic. This paper records airflow patterns established in reliable laboratory experiments and field studies and identifies their original sources. It is intended to assist architects, builders and designers of the urban environment.

This global survey was supported by a grant from U.S. Department of Energy No. DE-AC03-80C511510.

KEYWORDS

Airflow, Airmotion, Movement, Openings, Inlet, Outlet, Pressure, Positive, Negative.

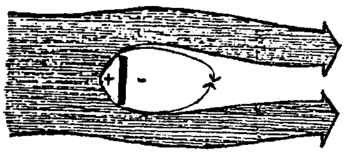
INTRODUCTION

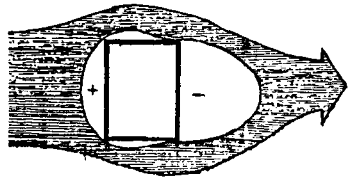
This work is the result of an 18 month literature survey on air flow through and around buildings. The search focussed on the causes and effects of low velocity lateral airflow and excludes the literature relating to high speed winds. One hundred and fifty documents surfaced, of which forty-seven were annotated.** Space does not permit inclusion of the full bibliography or of the annotated references (75 pages). However a "Subject Matrix" of the 47 annotated references is included here, to assist those who wish to further their interests.

The "Vocabulary of airflow patterns" has been collected from photographs and drawings of full-scale and model testing records in the literature. Velocities are not mentioned as they invariably are not mentioned in the recorded reports. Each diagram, totalling 89, has been identified for its source. The obvious omission is the work of B.Givoni, who has recorded his findings in another format.(figs. 90 & 91).

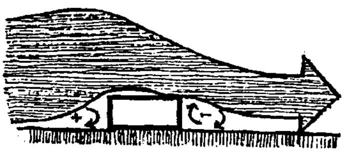
* On sabbatical leave from the University of Miami, Florida, U.S.A.

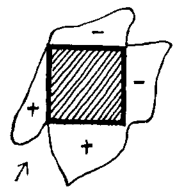
** See report on "World Literature Review and Annotated Bibliography on Air Movement in and Around Buildings" by A.Bowen to Florida Solar Energy Center, Jan.'82.



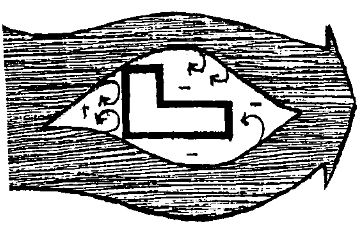


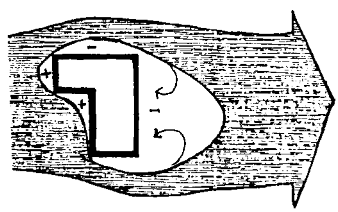
1. When air in motion meets an obstacle, a region of high pressure is created, generally, on the windward surface and the air will flow around the obstacle and reform in a laminated manner beyond a low pressure zone that will result on the leeward side (40).
2. Plan showing low pressure zone along the sides parallel to the wind and on the leeward side of the building (3).



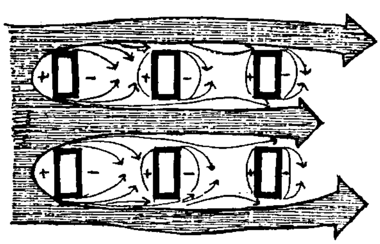


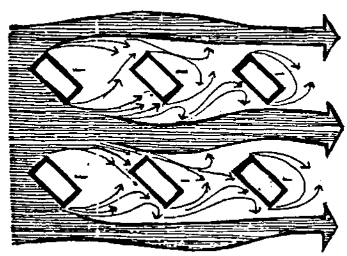
3. Section showing low pressure zone along the sides parallel to the wind and on the leeward side of the building (3).
4. When wind blows at an angle to a structure, the airflow divides at the windward leading corner. When wind blows at an asymmetrical angle, conditions for the two windward sides will vary, causing greater pressure on the side presenting the larger face to the wind. There is less upward flow over the roof (3).





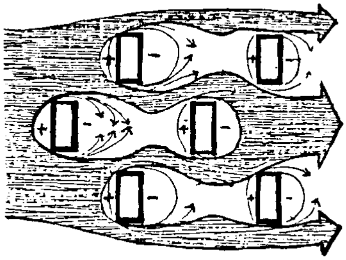
5. An L-shaped structure with a leeward projection, causes a large eddy in its recessed corner, with reversed airflow in its sheltered side (1).
6. When the "L" projects into the wind, the pattern alters with noticeable eddies on the leeward side (30).

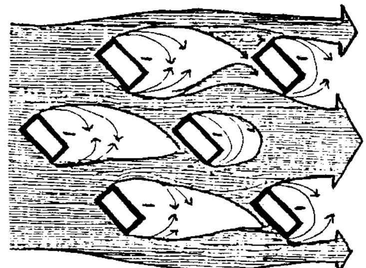




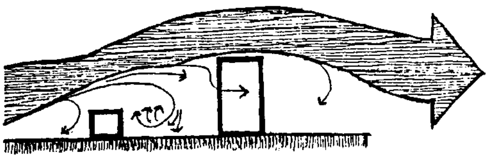
7. Multiple low pressure zones are caused by linear building arrangements (39).
8. An inclined linear arrangement produces turbulence in the wind shadow (39).

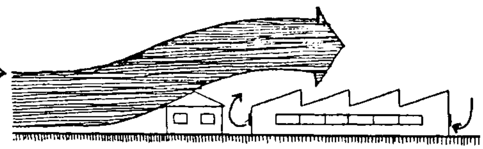
VOCABULARY OF AIRFLOW PATTERNS



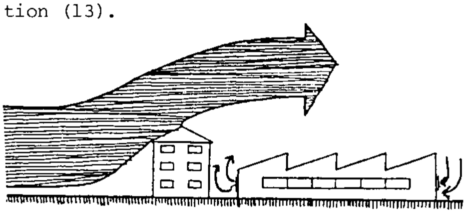


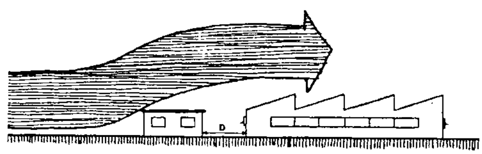
9. Staggered building arrangements further reduce the area of the wind shadow and low pressure zones (39).
10. Inclined staggered arrangements minimize low pressure zones (39).



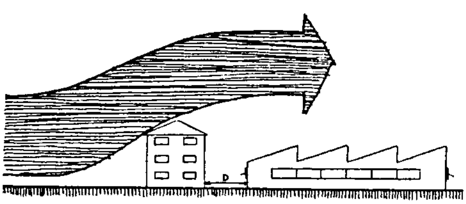


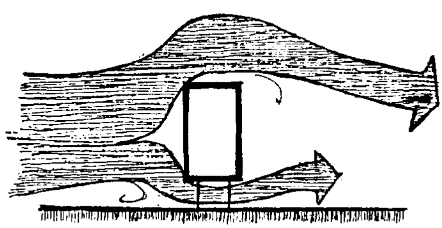
11. A low building placed in the windward path of a tall building produces much turbulence between the two (30).
12. A low obstruction can prevent increased pressure on the windward wall of an obstructed building but may not provide as intense a reduced pressure as a high obstruction (13).





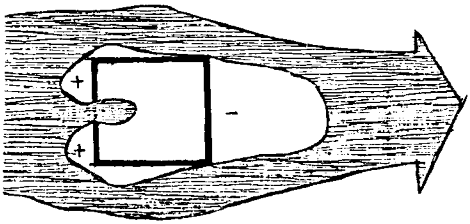
13. When there is little separation between buildings, a high obstruction can induce better air movement in an obstructed building than can a low one, because of the greater intensity of the reduced pressure behind it (13).
14. When an obstruction is low, increasing the distance of separation produces an immediate improvement in air movement in the obstructed building (13).

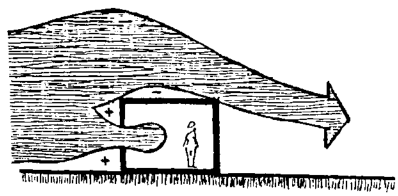




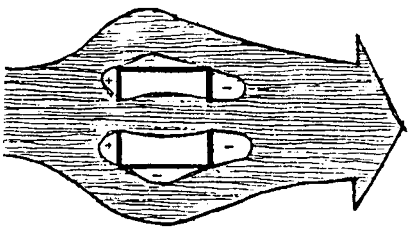
15. When an obstruction is high and the distance of separation small, an increase in distance causes an initial reduction in air movement in the obstructed building (13).
16. Raising a tall building on piloti reduces the high pressure in the windward side by allowing additional airflow under the building (30).

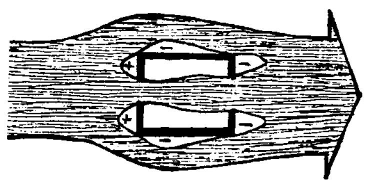
VOCABULARY



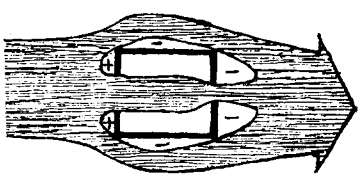


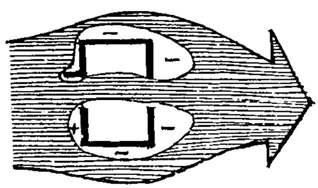
17. One opening in windward side results in poor ventilation, in plan (3).
18. One opening in windward side results in poor ventilation, in section (3).



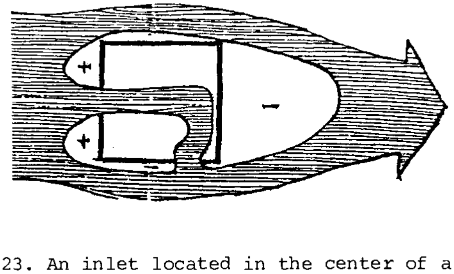


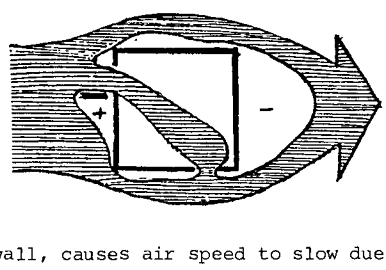
19. Openings on opposite walls relieve high pressure on the windward side, permitting good cross-ventilation of interior space (39).
20. Small inlet and large outlet increases velocity of airflow through interior space (39).





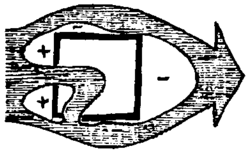
21. Large inlet and small outlet reduces velocity of airflow through interior spaces (39).
22. A baffle wall, placed at right angles to the opening, changes the direction of airflow through interior space, with small reduction in velocity (39).

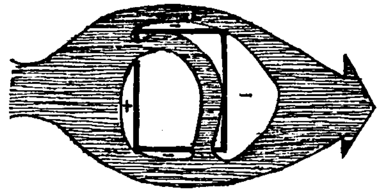




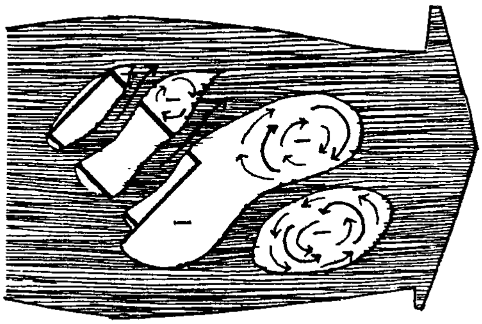
23. An inlet located in the center of a wall, causes air speed to slow due to an abrupt change in direction (3).
24. ~~An~~ inlet, with baffle, in an eccentric location on the windward wall, will promote unequal pressures on both sides of the opening, causing air to enter the opening diagonally, until it finds the outlet in a remote corner of an adjacent wall (3).

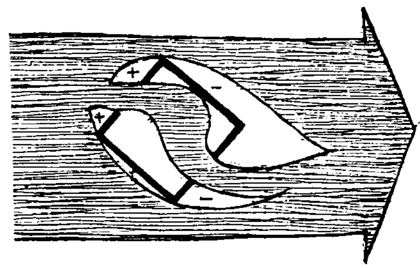
VOCABULARY



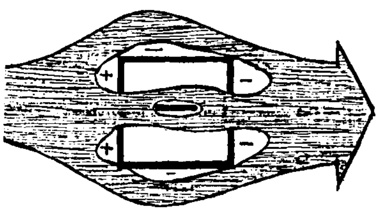


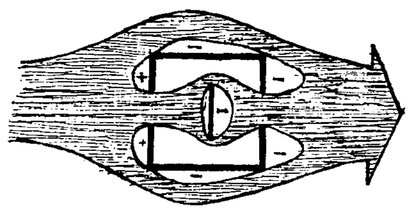
25. Air entering a centrally located opening, tends to keep moving straight into the interior for quite some distance, before being finally overcome by differences in pressure, causing it to turn and seek the outlet at the side (3).
26. Undivided interior spaces vented by eccentrically located openings, results in airflow at an angle responding to unequal external side pressure. Inertia carries the motion in the same direction until it finds the outlet in a smooth curve (10).



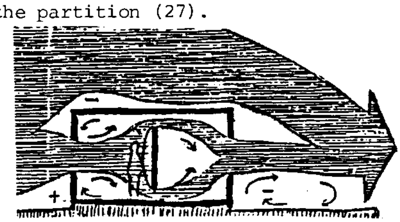


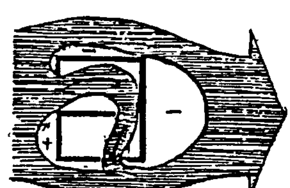
27. When a building is angled into the direction of the airflow much turbulence and eddying is experienced on the leeward side (19).
28. Pressure increases according to the dimensions, inclination and size of openings, of a solid (28).





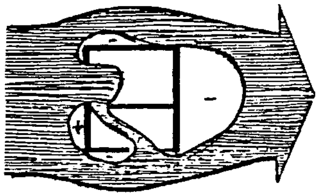
29. A partition located parallel to the direction of wind flow, only slightly affects the existing wind pattern (27).
30. A barrier placed perpendicular to the airflow within a room, re-directs the airflow pattern resulting in high and low pressure zones immediately in front and behind the partition (27).

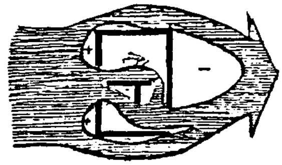




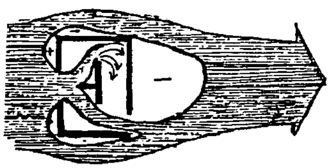
31. The same effect is seen in section (27).
32. A partition wall located close to the opening will not interfere with the airflow pattern, as the main airstream far exceeds the velocity of the cartwheeling eddies (39).

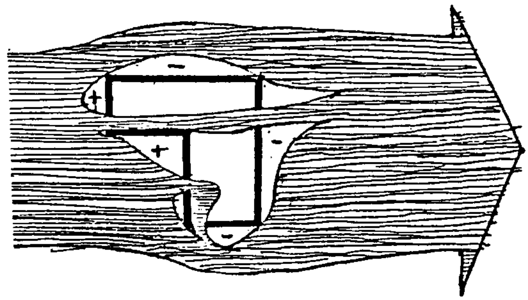
VOCABULARY



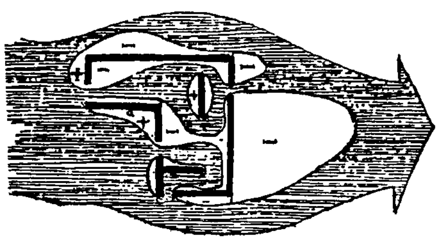


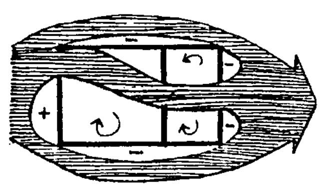
33. However, when the partition is attached to the opposite wall and an opening near the entry window, then the pattern is considerably altered, with the airstream seeking the shortest exit; velocity is decreased with little air entering the anteroom (39).
34. A partition placed parallel in the initial entry path, splits the airstream resulting in an acceptable flow in rooms serviced with an outlet, with a very poor airflow in other areas (39).



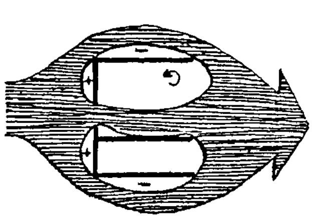


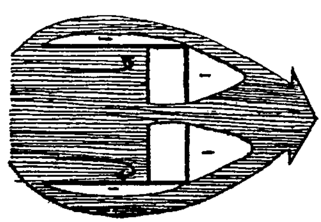
35. Back room, is meagrely supplied with air at cooling speed, when a partition is located perpendicular to the entry flow (39).
36. Air pattern results from the airstream seeking the nearer outlet whether the outlet is located in adjacent or opposite walls (40).





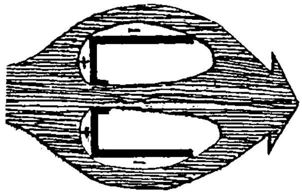
37. The location of internal partitions results in small deviations of airflow that will always seek the nearest outlet (40).
38. The direction of the airstream is altered by unaligned openings (10).

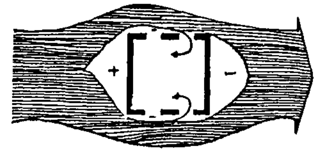




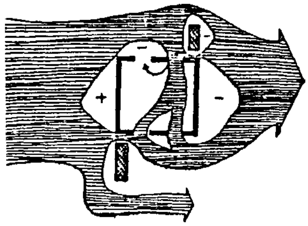
39. The direction will coalesce with parallel walls (10).
40. Airflow discharged through windward openings is increased by close proximity to a similarly aligned downstream opening (10).

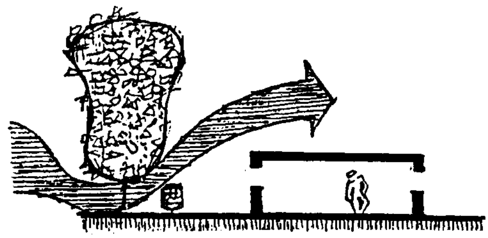
VOCABULARY



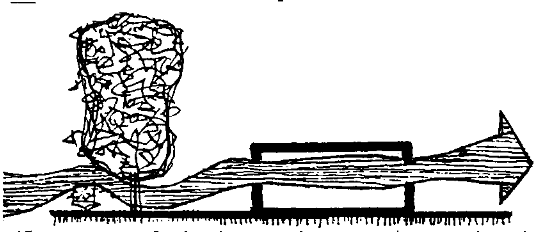


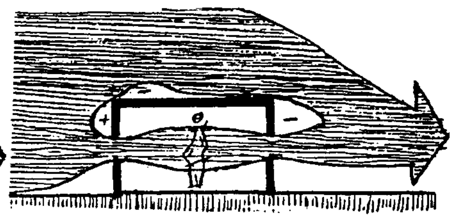
41. Deep reveals restrict air passage, so reducing turbulent losses in airstream(10).
42. A poor cross-ventilation pattern (3).



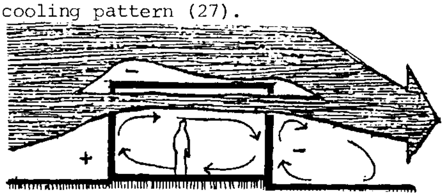


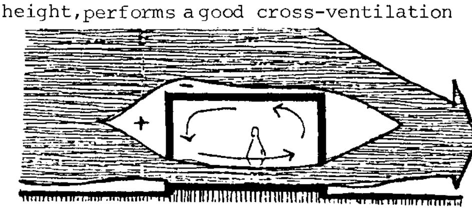
43. A poor cross-ventilation pattern may be improved by the strategic locations of wind barriers (3).
44. Trees and shrubs may be used in combination to divert wind around a building(3).



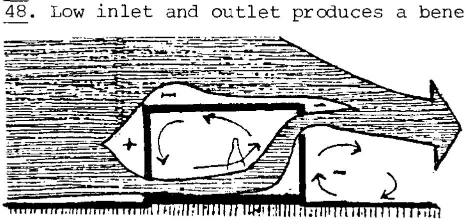


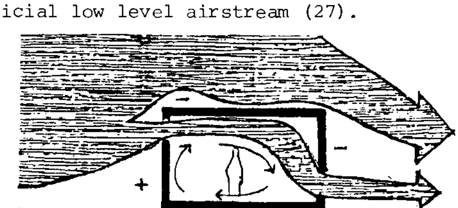
45. Trees and shrubs may be used in combination to divert wind through a building's interior space (3).
46. Identical inlet and outlet, at body height, performs a good cross-ventilation cooling pattern (27).





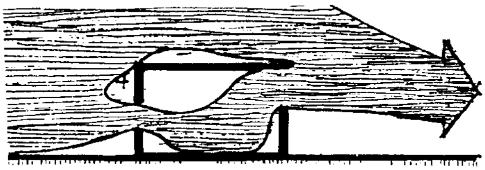
47. High inlet and outlet do not produce a good pattern at body height (27).
48. Low inlet and outlet produces a beneficial low level airstream (27).

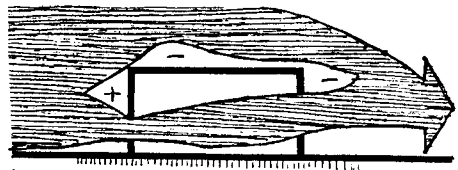




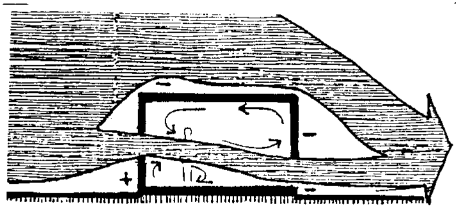
49. Low inlet and high outlet produces a good airflow pattern (27).
50. The bad pattern caused by a high inlet is not corrected by a low outlet (27).

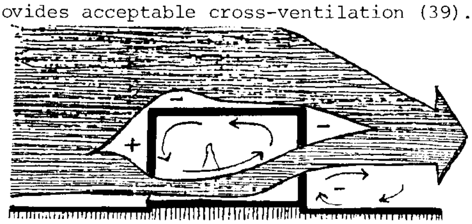
VOCABULARY



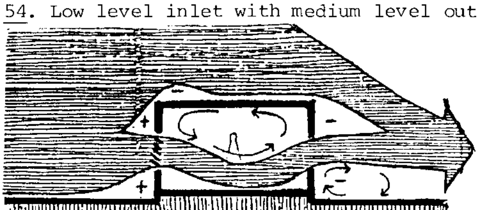


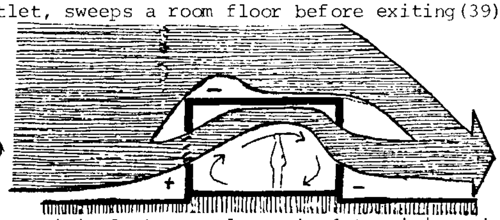
51. Medium height inlet and high outlet provide an acceptable downward flow despite the high outlet (39).
52. Low inlet with medium level outlet provides acceptable cross-ventilation (39).



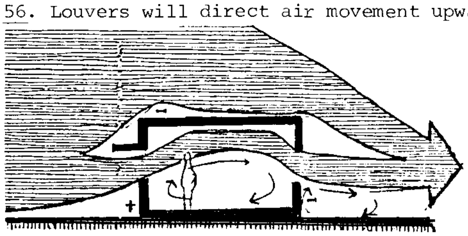


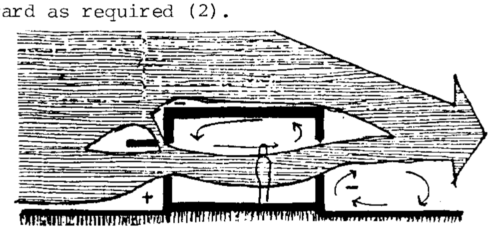
53. Medium height inlet and low outlet also provides agreeable cross ventilation off floor (39).
54. Low level inlet with medium level outlet, sweeps a room floor before exiting(39).



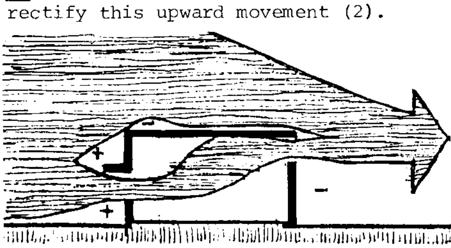


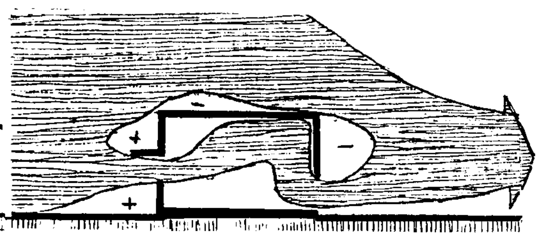
55. The conclusion is that inlets are more critical than outlets, in determining air circulation patterns. Louvers will direct air movement downward as required (2).
56. Louvers will direct air movement upward as required (2).





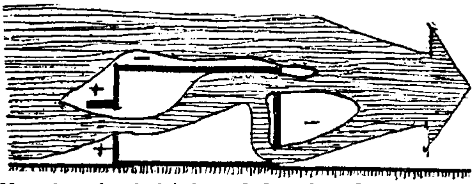
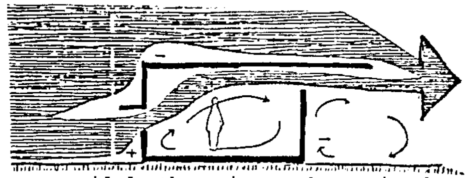
57. A solid overhang over a window results in an upward air circulation pattern (2).
58. An overhang separated from the building equalizes the external pressures to rectify this upward movement (2).



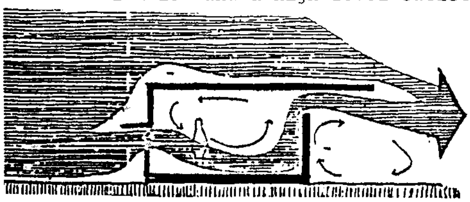
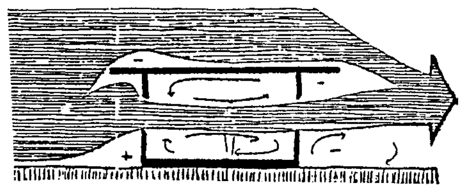


59. Overhang over inlets with high outlets will cause air to flow up to the ceiling on its way to the outlet (46).
60.Low outlets follow the same upward pattern until the rear wall,when there is a downward flow to seek the outlet (46).

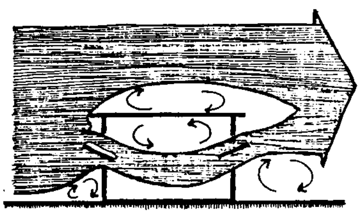
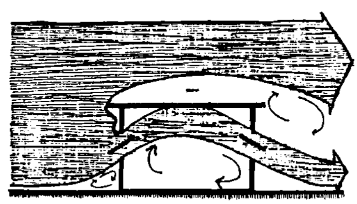
VOCABULARY

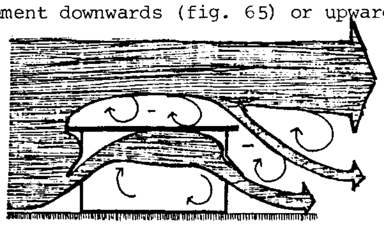
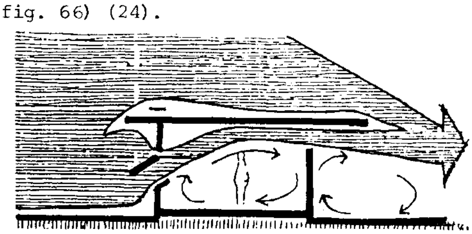
61. When both high and low level outlets are provided, there is no change in the upward flow of air (46).
62. It may be assumed that the location of an outlet is unimportant when there is an overhang over the inlet. An upward airstream will result when canopies exist over a mid-level inlet and a high-level outlet (46).

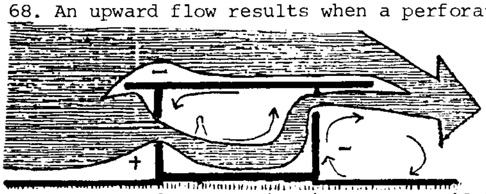
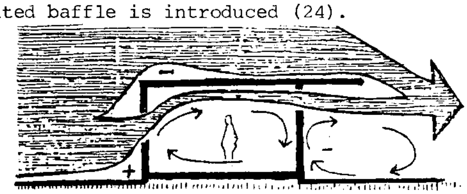
63. This circulation pattern will alter by using directional louvers in the inlet(46).
64. Elevated roof projections over symmetrically located opening,enhance a good cross-ventilation pattern (40).

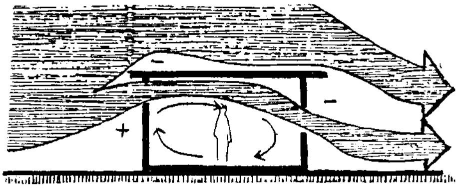
65. Window system for summer ventilation (24).
66. Window system for winter ventilation. Window systems may be used to direct air movement downwards (fig. 65) or upward (fig. 66) (24).

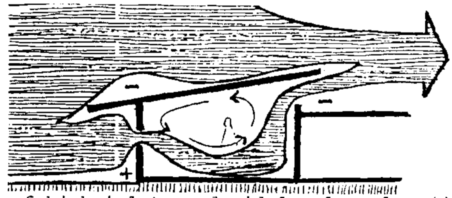



67. An upward movement within the interior space occurs when inclined awnings are placed over windows in opposite walls (24).
68. An upward flow results when a perforated baffle is introduced (24).

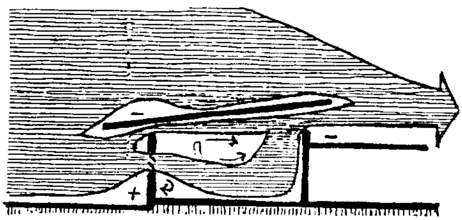



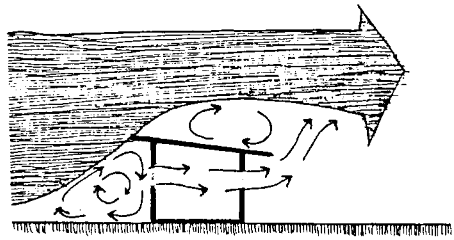
69. Roof overhangs projecting over a mid-level inlet and high-level outlet, cause a downward air pattern (40).
70. Removal of the inlet overhang alters the airflow into an upward stream (40).



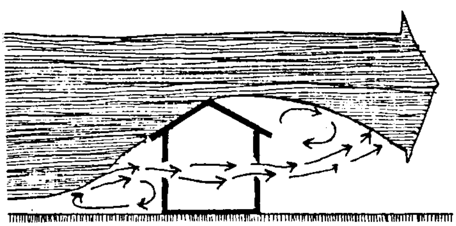


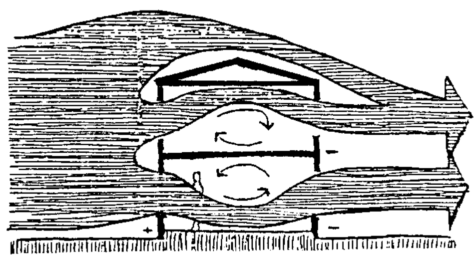
71. Roof overhangs do not alter the pattern of high inlets and mid-level outlets(40).
72. A projecting mono-pitch roof with a high outlet and mid-level inlet produces a downward airstream (3).



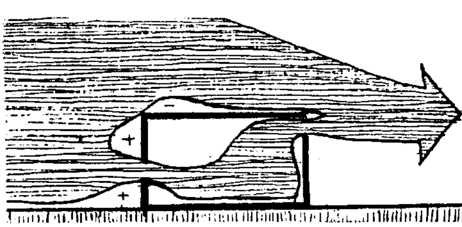


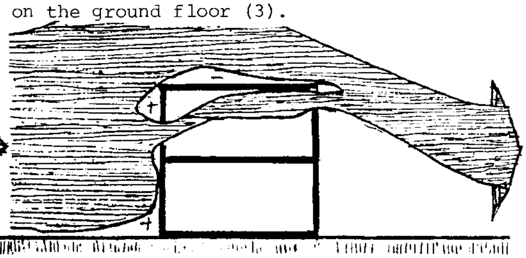
73. When a second high level inlet is added, the pattern takes an upward direction which may be modified by introducing louvers in the lower inlet (3).
74. Airflow is lifted over a mono-pitched roof, resulting in eddies on the windward wall and the above roof (19).





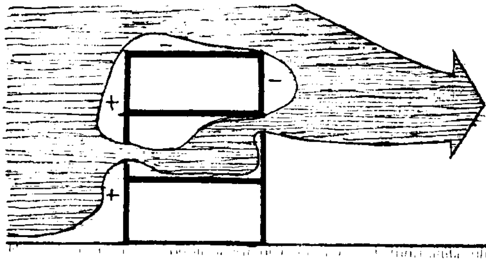
75. Airflow over a dual-pitch high roof, results in a flow pattern that is directed over and hugs the windward slope, while producing negative pressure zones and eddies on the leeward slope. Turbulence is also experienced on the windward wall (19).
76. Symmetrical inlets and outlets in a two-story building, result in an upward flow in the second floor and a downward flow on the ground floor (3).

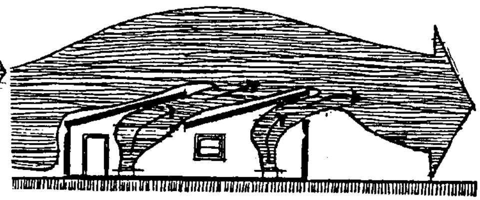




77. A medium-level inlet and a high-level outlet results in a downward airstream in a single-story structure (3).
78. When a similar configuration is located in a second floor structure, with no openings at ground level, an upward airstream is achieved (3).

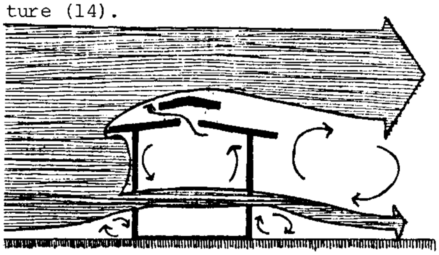
VOCABULARY

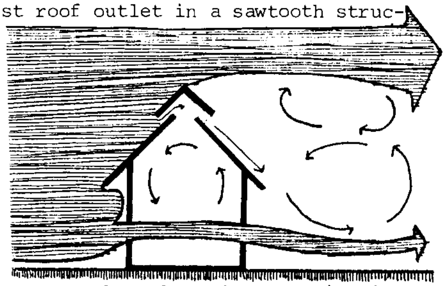




79. However, if similar openings are located in a multi-story structure, devoid of other openings, the airstream resumes a downward trend as though the openings were in a single-story structure, as in Fig. 77 (3).

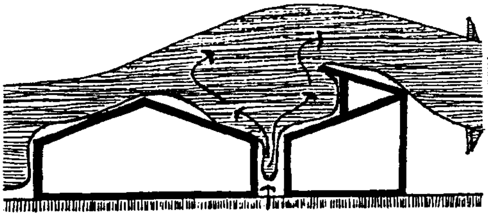
80. Anabatic interior airflow seeks the nearest roof outlet in a sawtooth structure (14).

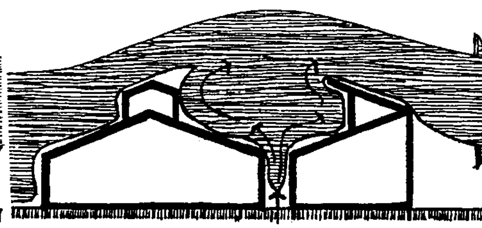




81. A roof with a shallow slope is adequately vented through a ridge opening in an anabatic action (24).

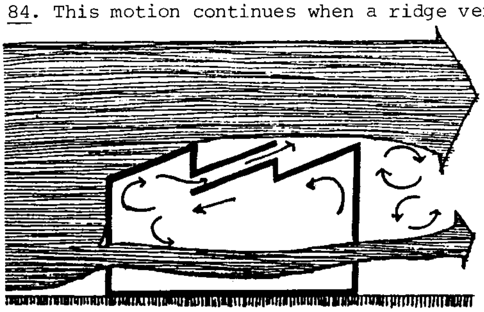
82. When the pitch of the roof is increased to a steep angle the anabatic action decreases (24).

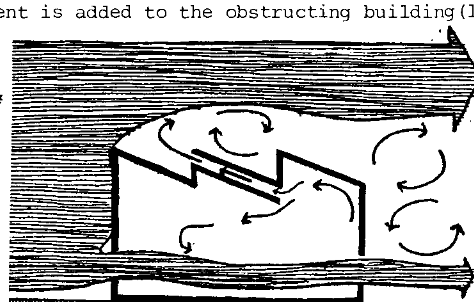




83. The airstream migrates towards the ridge of an obstructing building and an adjoining roof monitor (13).

84. This motion continues when a ridge vent is added to the obstructing building(13).



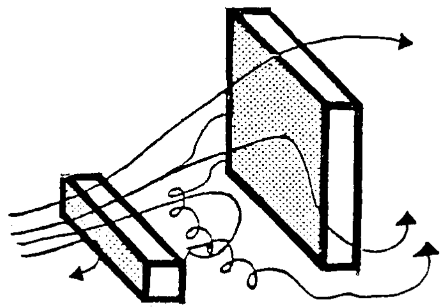


85 & 86. In a sawtooth roof, well defined ducts will suck air from the interior to the exterior, whether the exhaust is facing leeward (fig. 85) or windward (fig. 86) (24).

VOCABULARY

87, 88 & 89. Typical flow around a tall building with a low building to windward is illustrated in fig. 87 (32). Variations in wind speed or model scale have little effect upon such flow patterns. As it approaches the tall building, the wind gradually diverges until, at the windward wall, upward and downward flows occur. Some of the air deflected down forms a vortex, which then stretches out sideways and wraps around the building in a characteristic horseshoe shape. The resulting flow at ground level is typified by fig. 88 (32), where the horseshoe vortex is clearly shown. The effect of increasing the space to windward of the building is to elongate the vortex, as shown in fig. 89 (32), but at large spacings the stabilizing influence of the low building is lost, and the vortex becomes weak and variable in position. Wind speed at ground level in the vortex region are generally greater than on an open site away from a tall building with maxima in the positions shown in figs. 88 & 89 thus:

Fig. 87



——— approximate position of maximum speed in vortex flow.

- - - - approximate position of maximum speed in corner streams.

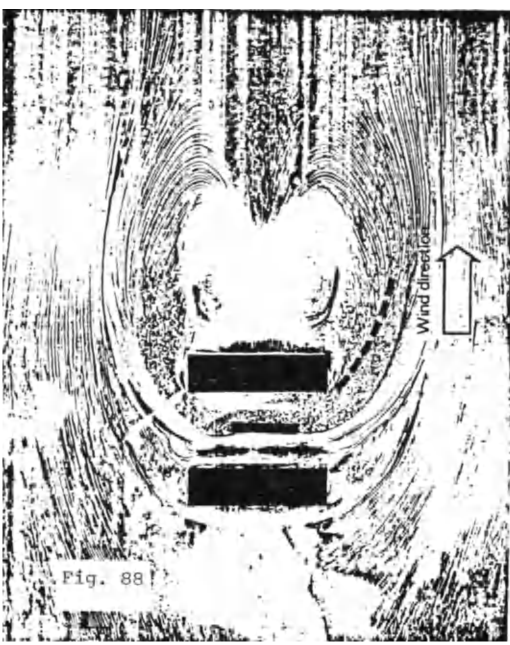


Fig. 88

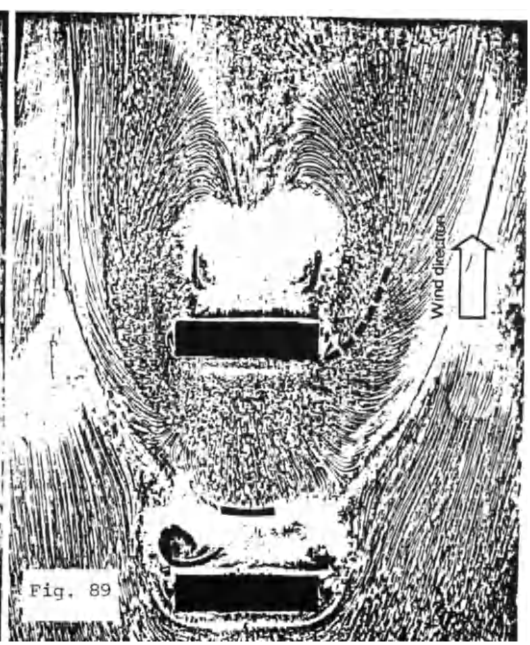
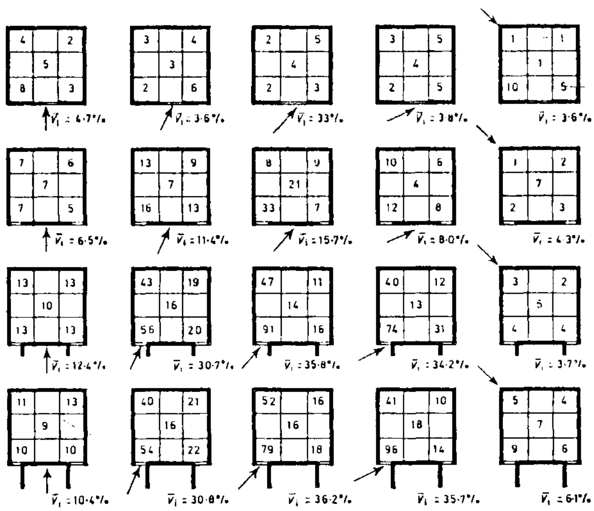


Fig. 89



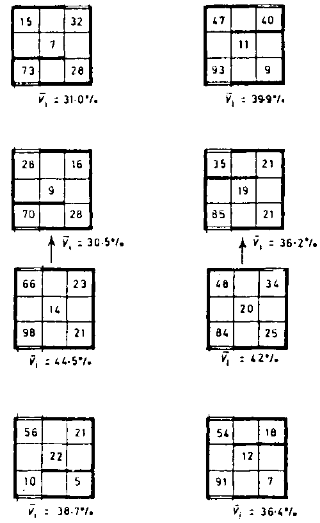


Fig. 91

Fig. 90
Internal air speeds in models with vertical projections of different depths, compared with values in models without projections. Window width 1/3 of wall width (8,9). Givoni, B.

Fig. 91
Effect of sub-division of the interior on the distribution of internal air speeds (8,9). Givoni, B.

CONCLUSION

This literature survey has revealed a small number of authentic sources. It would seem that all other writings on this subject matter have based their discussions on these original sources. The subject index identifies original research. Particular mention is made of work at the following:

1) Texas Engineering Station, Texas A&M College System, College, Texas, USA.
   -Evans, Holleman, Reed, Caudill, Crites & Smith

2) The Building Research Station, Haifa, Israel
   -Givoni, Paciuk and others

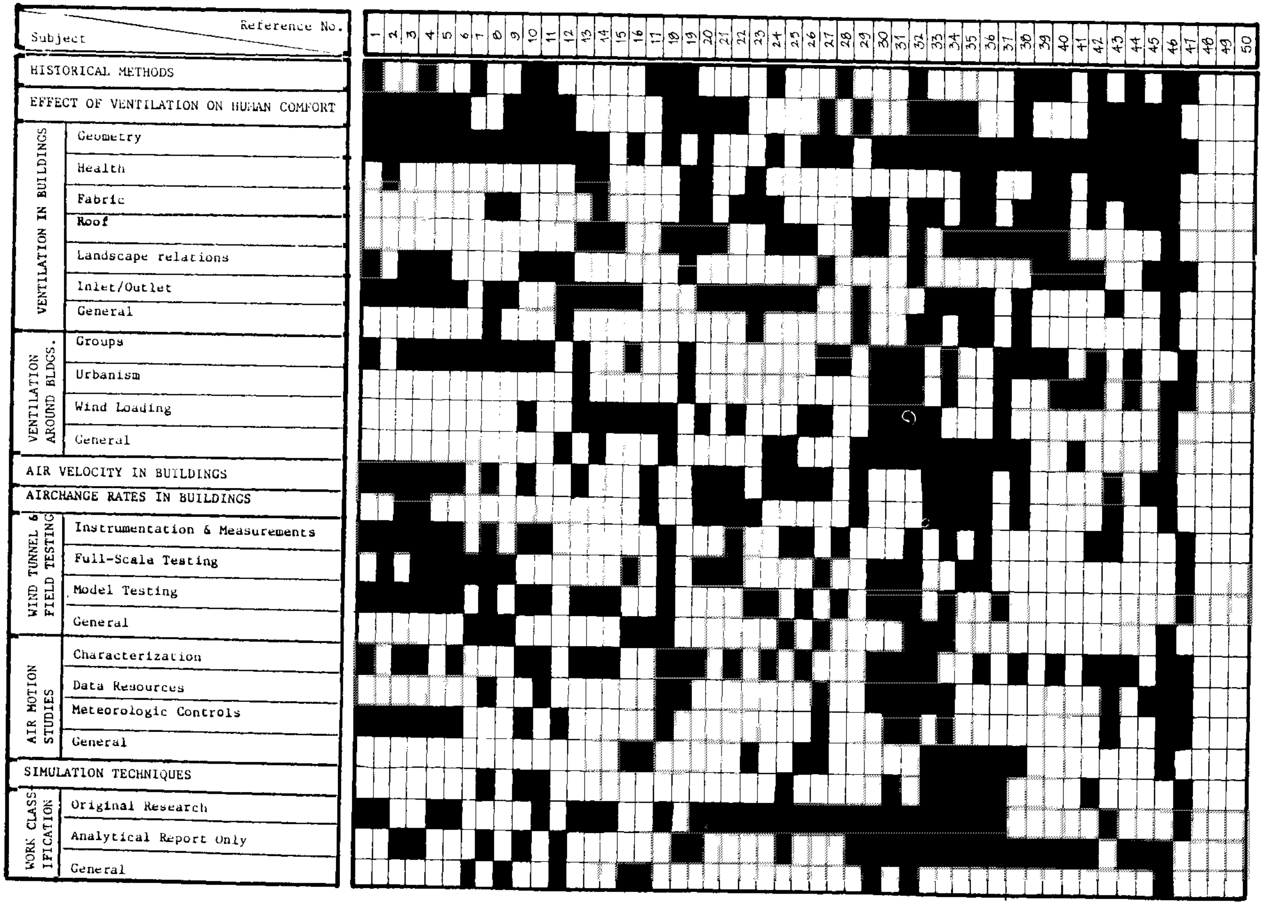
3) Building Research Establishment, Garston, England
   -Dick, Sexton, Wise, Penwarden, Newberry and Eaton

4) The Commonwealth Experimental Building Stations, CSIR, Sydney, Australia
   -Weston and Crane

5) The National Building Research Institute, CSIR, Pretoria, South Africa
   -Van Straaten, Richards, Roux, Olivier and Wannenburg

6) Swedish Council for Building Research, Stockholm, Sweden
   -Handa, Nylund, Bjerregaard and Nielsen

It will be gathered from the foregoing that while much is known on lateral motion, there is little accomplished in the way of a thorough documentation on vertical motion and movement in building envelopes. Work in these two areas are presently being investigated by Eureka Laboratories in California and the Florida Solar Energy Center, respectively.



SUBJECT MATRIX BY REFERENCED AUTHOR

SUBJECT MATRIX BY AUTHOR

No. Entry

1 Evans, Benjamin H., "Natural Air Flow Around Buildings", Texas Engineering Station, Research Report No. 59, Texas A&M College System, College Station, Texas, USA, March 1957.

2. Holleman, Theo R., "Air Flow Through Conventional Window Openings", Texas Engineering Station, Research Report No. 33, Texas A&M College System, College Station, Texas, USA, November 1951.

3. Reed, Robert H., "Design for Natural Ventilation in Hot Humid Weather", Reprinted from Housing and Building in Hot-Humid and Hot-Dry Climates, Building Research Institute, National Research Council, Washington, D.C., USA, 1953.

4. Caudill, William W. and Crites, Sherman E. and Smith, Elmer G., "Some General Considerations in the Natural Ventilation of Buildings", Texas Engineering Experiment Station, Research Report No. 22, Texas A&M College System, College Station, Texas, USA, February 1951.

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GLASS AND ITS ROLE IN SOLAR HEATING AND COOLING

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ABSTRACT

Glass is an essential component of virtually all solar heating and cooling systems and so its properties, its strengths and its limitations should be thoroughly understood by the designers of such systems. Recent advances in glass technology offer those designers new capabilities in dealing with the admission of solar heat and light into spaces where they are needed and in rejecting both heat and light when cooling and darkness are required.

KEYWORDS

solar-optical properties; solar radiation; longwave emittance; selective reflectance; physical properties; thermal conductivity; shading coefficients; solar heat gain factor;

INTRODUCTION

The purpose of this paper is to present as concisely as possible the current state of our knowledge of glass and particularly of those properties which affect its usefulness in solar heating and cooling. Because of its unique ability to transmit and reflect solar radiation without being adversely affected by the ultraviolet content of that radiation, glass is almost universally used throughout the world as the glazing material in all types of fenestration and as the transparent covers for flat plate collectors. Because glass never needs to be painted or otherwise maintained by any process other than occasional cleaning, it is widely used by architects as the weather surface of high-rise buildings. This has frequently led to overheating on sunny days and overcooling on winter nights. These problems can be overcome in many situations by proper choice of glass and shading systems.

Passive heating is largely dependent upon the admission of solar radiation through large areas of south-facing glass and new glazing materials are now available which can admit sunshine when it is needed while nocturnal heat losses can be minimized. Passive cooling is more difficult to accomplish and the primary role of glass in the cooling process is to minimize the cooling load while still admitting light.

THE PHYSICAL PROPERTIES OF GLASS

Window glass is classified as a non-crystalline transparent solid which is produced by melting together oxides of silicon (typically about 73%), calcium (9%), and sodium (13%) plus other miscellaneous oxides which are contained in the raw materials. The silicon comes from ordinary sand, the calcium comes from lime or calcium carbonate and the sodium comes from soda ash. The sand usually contains some unwanted iron oxide and the glass with the highest transmittance and the lowest absorptance is that which contains the least iron. The words "soda-lime" are often used to describe this type of glass although, in deference to its primary constituent, it should more properly be called "silica-soda-lime".

Many different processes have been developed during the past century for producing clear window glass of acceptable quality but the most recent development, Pilkington's "float" process, now dominates the field because it can produce very large sheets of glass with flat, parallel sides in any desired thickness from 1/8 inch (3mm) to 1 inch (25mm). High grade glass can now be produced in all industrialized countries.

The density of soda-lime glass is about 157 lb/ft^3 (2515 kg/m^3); the weight of 1.0 square feet of window glass is 1.64 lb for 1/8 inch thick and 3.28 lb for 1/4 inch thickness (8.01 kg/m^2 for 3mm; 16.02 kg/m^2 for 6mm). The coefficient of thermal expansion for soda-lime glass is about 6 x 10^{-6} in./in.F (10.8 x 10^{-6} mm/mm.°C). The metal or wooden frames in which glass is usually mounted have different coefficients of expansion, so the glass must always be installed with some freedom to change its dimensions as its temperature changes.

The specific heat of soda-lime glass is about 0.19 Btu/lb.F (0.796 kJ/kg.°C). The thermal conductivity varies somewhat with temperature, rising from 7.35 Btu.in./hr.ft^2.F at 68 F to 7.48 at 100 F and 7.68 at 150 F. (1.058 kJ/kg.°C at 20°C; 1.077 at 38°C; 1.1059 at 66°C). The hemispherical emittance for longwave radiation is 0.84 for uncoated glass, as determined by independent measurements made on identical samples of glass by laboratories at Pilkington Brothers in England, CSIRO in Australia and Corning Glass Works in the U. S., using spectrophotometers which covered the wavelength range from 5 to 50 micrometers (μm). Prior to World War II, the best available value for the emittance was 0.93 and this incorrect value is still found in many textbooks.

THE SOLAR-OPTICAL PROPERTIES OF GLASS

Of particular importance to solar designers are the optical properties (transmittance, reflectance and absorptance) in the shortwave solar spectrum from 0.3 to 3.0 μm. These vary with the incident angle at which the solar rays strike the glass surface, the wave length of those rays and the composition of the glass. Recently, surface treatments have been developed which can give either low or high reflectance or emittance to clear glasss and the importance of these developments will be discussed later in this paper.

Two types of glass are now in wide use; the first is clear glass which is used wherever maximum admission of solar radiation is desired. The thickness which must be used depends upon the wind loading and the unsupported area of the window. For small residential windows, 1/8 inch (3mm) glass is almost universally used while 1/4 inch (6mm) thickness is used for larger openings and higher wind loads. 1/2 inch thick glass (13mm) must be the choice for large windows where very high, typhoon-type winds may be encountered. The advice of glass manufacturers should be sought when unusual problems are encountered and tempered glass, four times as strong as ordinary annealed glass, should be used whenever breakage might result in danger to life or property.

The second widely used type of glass is tinted by the addition of suitable ingredients, primarily iron oxide, which cause the transmittance to decrease and the absorptance to increase. These are generally used to reduce the admission of solar radiation, thus reducing cooling loads and glare. Tinted glasses are rarely used when solar heating is needed, for obvious reasons, but they are widely used in commercial buildings to reduce air conditioning requirements. They are effective in excluding unwanted solar heat gain because about 75% of the absorbed energy is dissipated to the outdoor air while only 25% is admitted into the glazed space.

Metallic coatings can now be applied to clear glass which change its properties in both the visible (0.4 to 0.7 μm) and the invisible (0.7 to 3.0 μm) portions of the spectrum. The invisibly short ultraviolet radiation (0.3 to 0.4 μm) can also be excluded by applying appropriate coatings and this may well prove to be beneficial where fading of fabrics is likely to be encountered. The most recently perfected coatings are oxides of tin and indium which are highly transparent in the visible portion but highly reflective in the infrared. The beneficial effects of such coatings in particular circumstances will be explained later.

Solar Angles and Their Effect on Solar-Optical Properties

Since the direct beam radiation from the sun is a vector quantity, having both direction and magnitude, the angles between the earth-sun line and the glazed surface are extremely important. Fig. 1, presented at the end of this paper, shows the principal angles for a vertical surface, using the symbols which have been adopted by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). The solar position angles, the altitude β and the azimuth ϕ, vary rapidly with time because of the apparent motion of the sun across the sky and consequently the angle of incidence θ, between the earth-sun line, OQ, and the normal to the surface, OP, also varies. It is this incident angle which determines the numerical values of the solar-optical properties, as shown by Fig. 2. As the incident angle rises, the transmittance and the absorptance fall, reaching zero when θ = 90 deg, while the reflectance increases to reach 1.00 at θ = 90 deg. For diffuse radiation which has no specific direction, it is generally assumed that the solar-optical properties are the same as those for direct radiation for 0 = 60 deg.

Spectral Transmittance Variation for Window Glasses

The limited range of transmittance for window glasses is shown by Fig. 3 for 1/4 inch (6mm) clear glass and for two types of tinted glass. The first is the familiar grey glass which is frequently used by architects to reduce both glare and cooling loads. The 1/4 inch green glass is actually blue-green in color and it has the ability to transmit most of the visible radiation while it excludes much of the infrared. All three types transmit most of the solar ultraviolet which reaches the earth but none transmits any radiation longer than 4.5 μm in wavelength. This cut-off in transmittance at the end of the solar spectrum is a very significant property which glass possesses to a far greater extent than most of the transparent plastic materials which are frequently proposed for use in glazing.

The solar radiation which is transmitted into a glazed space warms its contents and they in turn emit longwave infrared radiation, with wavelengths which peak at about 10 μm. None of this radiant energy can be transmitted outward through the glass and this gives rise to the "greenhouse effect" which is so important in passive solar heating.

The blue-green glass shown in Fig. 3 was used in one of the first all-glass high-rise buildings in New York (Lever House, 1952) but its color rendition was considered to be unflattering and its primary use, until recently, has been in airport control towers where passive heating can attain unpleasant proportions. By using double glazing, with green-tinted glass as the outer pane and clear glass as the inner pane, the benefits of high outward visibility and comfort enhancement can both be enjoyed. Several very successful high-rise buildings have been erected in the U. S. in recent years, notable the Hooker Chemical Building in Niagara Falls, which makes good use of this combination.

HEAT GAINS AND LOSSES THROUGH WINDOWS

Nocturnal Heat Flows

When the sun is not shining, the rate of heat flow through glass is:

$$Q_{NS} = \text{Area} \times U \times (t_i - t_o) \quad \text{Btu/ft}^2\text{.hr or W/m}^2 \qquad (1)$$

The area involved here is the net area of the glass, exclusive of frames, mullions, etc. U is the overall coefficient of heat transfer from the indoor air through the glazing to the outdoor air. Its standard values, as given in the 1981 ASHRAE Handbook of Fundamentals are:

Table 1. U-Factors for Single, Double and Triple Glazing (1/2 inch or 13mm air Spaces) in Summer and Winter; Btu/hr.ft^2.F or W/m^2.^{o}C.

	Summer, 7.5 mph or 3.35 m/s		Winter, 15 mph or 6.7 m/s	
Type	I.P. Units	S.I. Units	I.P. Units	S. I. Units
Single	1.04	5.9	1.10	6.2
Double	0.49	2.8	0.56	3.2
Triple	0.39	2.2	0.31	1.8

Note that the conventional U. S. units are now called "Inch-Pound" (I.P.) units.

The indoor and outdoor temperatures are designated by t_i and t_o and their units are degrees Fahrenheit in I.P., or degrees Celsius in S. I.

In winter, the heat flow is normally outward from the warm indoor environment to the cold outdoor air, while in summer the outdoor air may well be warmer than the indoor air and so the heat flow will be inward. For multiple glazing, the width of the air-space has a significant bearing on the U-factor, which increases as the air-space falls below 1/2 inch (13mm).

One of the major developments in glazing technology has been the deposition of metallic coatings on the surfaces of the glass. The first successful application of this process came during World War II when thin and virtually transparent electrically conductive tin oxide coatings were deposited on aircraft windscreens to provide the heat needed for defrosting. It was later found that these coatings had very low longwave emittances, with beneficial results which will be described later.

The U-factor for any glazing system can be calculated when the thermal resistances of its components are known. For simplicity, consider a single glazing which has an outer surface combined coefficient h_o and a corresponding resistance R_o which is the reciprocal of h_o. The thermal resistance of the single glazing is L/k, where L is the thickness in inches or mm and k is the thermal conductivity in consistent units. The resistance of the glass is so low in comparison with the other resistances that it is often ignored. With double glazing this is not the case, since the existence of two lights of glass and the enclosed air space creates a significantly large resistance that cannot be ignored. The inner surface coefficient h_i and its corresponding reciprocal, the inner surface resistance R_i, are usually based on the assumption of still air and free convection, with the glass radiating at an emittance of 0.84 to the room which is considered to be a blackbody at the same temperature as the indoor air. The relation between U and these individual resistances is shown by:

$$U = 1.0/R_{total} = 1.0/(R_o + R_g + R_i) = 1.0/(1/h_o + L/k + 1/h_i) \quad (2)$$

Low U-factors are desirable in both winter and summer to reduce heat losses or gains. There is little that we can do to affect h_o or its reciprocal R_o, since they are largely determined by the wind. The conventional ASHRAE values for h_o are 4.0 Btu/hr.ft^2/F (22.7 W/m^2.^{o}C), so R_o becomes 0.25 in I.P. units and 0.044 in S.I. units. The wind speed is arbitrarily assumed to be 7.5 mph (3.35 m/s), but summer breezes are usually lower and h_o is often found to be about 3.0 in I.P. units (17.0 in S.I.), with comparable resistances of 0.33 in I.P. units and 0.059 in S.I.

The inner surface coefficient h_i is conventionally assumed to be 1.46 Btu/hr.ft^2.F (0.3 W/m^2.^{o}C) and the comparable resistance R_i is 0.68 deg F/Btu/hr.ft^2) or 0.120 ^{o}C/(W/m^2). The transfer of heat from a sun-heated window surface in summer or to a winter-cooled surface is accomplished by two separate processes, convection and radiation, which occur simultaneously but independently. The equations which govern these proceses are:

$$\text{Convection: } h_{Ci} = a \times (t_g - t_i)^{0.25} \quad (3)$$

where a = 0.27 in I.P. units and 1.77 in S.I.

t_g, t_i = temperatures of glass and indoor air, F or °C

Radiation: $h_{Ri} = e_g \times 0.1713 \times [(T_g/100)^4 - (T_a/100)^4] / (T_g - T_a)$ (4)

e_g = emittance of glass surface

T_g, T_a = absolute temperatures of glass and air, R or K

5.6697 = value of radiation constant for S.I. units in (4)

There is little that the designer can do about the convection heat flow but the emittance of the glass surface can be altered, as stated previously, by application of a thin, transparent metallic coating or by the use of film which possesses a low emittance inner surface.

To show the use of equations (3) and (4), consider a vertical glass window under summer day conditions, with t_g = 105 F, t_i = 75 F (40.55 and 23.89 °C). e_g = 0.84

$$h_{Ci} = 0.27 \times (105 - 75)^{0.25} = 0.27 \times 2.3403 = 0.6319$$

$$h_{Ri} = 0.1713 \times 0.84 \times (5.646^4 - 5.346^4)/30 \quad \underline{0.9562}$$

$$h_i = 1.588 \text{ Btu/hr.ft}^2.\text{F}$$

$$h_i = 9.018 \text{ W/m}^2.^\circ\text{C}$$

The overall coefficient of heat transfer, U, for the typical 1/4 in. (6mm) single glazing under summer conditions where h_o = Btu/hr.ft^2.F, is

$$U = 1.0/\ (1/4 + 0.25/7.5 + 1/1.588) = 1.095 \text{ Btu/hr.ft.}^2\text{F}$$

$$= 6.2174 \text{ W/m}^2.^\circ\text{C}$$

If the inner surface emittance is reduced from the conventional 0.84 to 0.20 by the application of a low emittance coating, h_{ri} will be reduced to 0.2277, h_i will fall to 0.8596, and U will become 0.8535, a reduction of 22%.

The temperature of a single-glazed window, in the absence of sunshine, can be found by using the equation:

$$t_g = (h_o \times t_o + h_i \times t_i)/(h_o + h_i) \text{ F or } ^\circ\text{C} \quad (5)$$

On a summer night, in a hot climate where t_o = 90 F (32.2°C) and t_i = 75 F (23.9°C), the glass temperature, for the uncoated glass will be:

t_g = (4.0 x 90 + 1.588 x 75)/(4.0 + 1.588) = 86.75 F = 29.8°C.F or the coated glass, where h_i is 0.8596, t_g will rise to 87.35 F (30.7°C).

On a cold winter night, where t_o = 0 F (-17.7°C) and t_i = 70 F (21.1°C), h_i for an uncoated glass will be found to be close to 1.46 Btu/ft^2.F. h_o

will be 6.0. t_g will fall to 13.6 F (-10.2°C). For the coated glass, h_i will be about 0.92 Btu/hr.ft^2.F and t_g will fall to 9.3 F (-12.6°C).

The rate of heat flow on the winter night will be:

$$q = U \times (t_o - t_i) \text{ Btu/hr.ft}^2 \text{ or } (W/m^2) \tag{6}$$

Neglecting the thermal resistance of the glass, for single glazing,

$$U = (h_o \times h_i)/(h_o + h_i) \tag{7}$$

For the uncoated glass, U in winter will be (6.0 x 1.46)/7.46 = 1.17 Btu/hr.ft^2.F (6.66 W/m^2.°C);for the coated glass, U = (6.0 x 0.92)/6.92 = 0.7977 Btu/hr.ft^2.F(4.5265 W/m^2.°C).. The rate of heat flow per unit area of glass surface will be:

$q = 1.17 \times (0 - 70) = -81.9$ Btu/hr.ft^2 $= -258.31$ W/m^2 for uncoated glass.

For the uncoated glass, $q = -55.14$ Btu/hr.ft^2 $= -173.9$ W/m^2

Heat Flow During Sunlit Days

For sunlit glazing, the situation becomes very different, since two new effects must be considered. First, the energy absorbed by the glass will raise its temperature until the absorbed energy can be dissipated by radiation and convection from the outer and inner glass surfaces. Second, the glass will transmit a substantial portion of the incident irradiation into the glazed space. In verbal form, for sunlit glass:

$$Q = A \times \left[\begin{matrix}\text{Transmitted}\\ \text{Solar}\\ \text{Radiation}\end{matrix} + \begin{matrix}\text{Inward Flow}\\ \text{of Absorbed}\\ \text{Solar Radiation}\end{matrix} + \begin{matrix}\text{Heat Flow}\\ \text{Due to}\\ (t_o - t_i)\end{matrix}\right] \tag{8}$$

Equation (8) can be restated to arrive at a numerical form:

$$Q = A \times \left(I_t \times \tau + h_i \times (t_g - t_i)\right) \tag{9}$$

It can be shown that, for sunlit glass with irradiance = I_t, the glass temperature is:

$$t_g = [h_o \times (\alpha \times I_t/h_o + h_i \times t_i]/(h_o + h_i) \tag{10}$$

Note that Equation (10) is very similar to Equation (5), with the major difference that the term $\alpha \times I_t/h_o$ is added to the outdoor temperature to give the equivalent of the sol-air temperature. By substituting the glass temperature from Eq. (10) into Eq. (9), and using the simplified relation between U and the surface coefficients, as given in Equation (7), we arrive at:

$$Q = A \times [I_t \times \tau + N_i \times I_t \times \alpha + U \times (t_o - t_i)] \tag{11}$$

$$\text{Where } N_i = \text{inward flow factor} = h_i/(h_i + h_o) \tag{12}$$

Using the standard summer values of h_i and h_o, N_i = 1.46/5.46 = 0.267 The irradiance I_t is expressed in Btu/hr.ft^2, the absorptance α and the transmittance τ are non-dimensional and the conductance term U x (t_o - t_i) may be expressed in either I.P. or S.I. units. Standard clear day values of I_t for North America are given in a number of ASHRAE publications. For engineering calculations of heat flow through sunlit windows, Equation (11) may be put into the following words:

$$\text{Total Heat Flow Through Sunlit Window, Btu/hr or W} = \text{Area, sq ft or } m^2 \times \left[\text{Solar Heat Gain, Btu/hr.ft}^2 \text{ or W/m}^2 + \text{Temperature Difference Heat Flux} \right] \quad (13)$$

It should be noted that the temperature difference heat flux can be either inward or outward, depending upon the relative values of t_o and t_i, but the solar heat flow is always inward. Passive solar heating depends upon the fact that the solar heat gain through sunlit glass, on clear days, is always positive, even when the outdoor air is many degrees colder that the indoor air.

In the U. S. the Solar Heat Gain is usually found by combining one term, the Solar Heat Gain Factor (SHGF), which depends upon location (latitude), date, time of day (solar time) orientation of the sunlit surface, and a second term, the Shading Coefficient, which is a unique property of the type of glazing system which is used. SHGF is the rate of heat gain through a clear reference glass (1/8 in. or 3mm) on a clear day for the specified location, date, time and orientation. Methods have recently been developed to estimate SHGF for average rather than clear days but they are beyond the scope of this paper. Tabulated values of the clear day SHGF for North America are given in the 1981 ASHRAE Handbook of Fundamentals for latitudes from 0 to 64 degrees north, by 8 degree increments, in both I. P. and S. I. units. Methods are also given for estimating clear day irradiance for the 21st day of each month for any time, and any orientation of glazing. Values of the Shading Coefficient are available for all combinations of glass and shading devices.

METHODS OF OPTIMIZING SOLAR HEAT GAINS FOR PASSIVE HEATING

Equation (11) gives us the key to methods of optimizing solar heat gains when passive heating is the objective of the design process. The designer seeks to maximize the transmittance of the glazing, to minimize the absorptance, since about 73% of the absorbed energy is dissipated to the outdoor atmosphere, and to minimize the conduction loss. It is this objective which leads us to the consideration of multiple glazing. When a second sheet of glass is added, providing an air space about 0.5 in. (13mm) wide, the thermal conductance of the glazing is reduced to about 50% of the value used for single glass. The transmittance for solar radiation is also reduced but there is usually a net gain in energy retained within the glazed space.

The transparent, low emittance coatings mentioned above can also be used to good advantage for double glazing, since they can make significant reductions in the U-value without seriously reducing the solar transmittance of the glazing. These coatings can also be applied to thin plastic films which can be suspended between the two sheets of glass, thus creating two air spaces where only one had existed before, with the added benefit of the low longwave emittance. Coated glass is now available which combines high solar transmittance with low longwave emittance while it retains the longevity which glass is known to possess.

Although the width of the air space in double glazing has no effect upon the solar transmittance, it does affect the thermal conductance. The convection component of the heat transfer from one glass to the other increases as the air space width is increased from 1/8 in. (3mm) to 1/2 in. (12mm), but there is little futher increase as the space is widened still more.

Most of the radiation-reducing coatings now available are relatively fragile and so they must be used within the air space where they are protected against damage. The tin oxide coating mentioned previously is quite rugged and so it can be used on the indoor surface of both single and double glazing. Attaining uniform thickness for the tin oxide has proved to be difficult and it is not yet commercially available for glazing applications.

Control of the incoming solar radiation must be carefully planned when high transmittance glazing is used, to avoid overheating during the months when outdoor temperatures are moderate and little additional warmth is needed indoors. Shades or blinds with reflective outer surfaces are effective in reducing solar heat gains by returning much of the incoming sunshine to the outdoor environment before the solar radiation can be absorbed and retained within the glazed space.

Tinted glass is often used to control solar heat gains; these are effective because they reduce transmittance and reject about 73% of the absorbed radiant energy to the outdoor environment. They are helpful in solar cooling because they can reduce the cooling load but they are not helpful in heating. Efforts are being made to develop glazing with controllable transmittance but no product with this property is yet available. Photochromic glasses which darken when exposed to ultraviolet radiation are currently in use for sun glassses, but the change in transmittance is primarily in the visible portion of the spectrum and there is little effect upon the infrared radiation which carries more than half of the solar energy.

CONCLUSION

Glass is primarily used in solar heating because of its ability to admit shortwave solar radiation and retain the longwave radiation which is emitted by sun-warmed surfaces. Clear glass in single or double form provides the best available means of utilizing solar energy for passive heating since it suffers no ill effects from the sun's ultraviolet radiation and it is impervious to wind and rain. Glass alone has little resistance to thermal conduction and so double glazing or the use of low emittance coatings must be used to decrease the U-value of single or double glazing. These coatings should have high transmittance for shortwave radiation and high reflectance (and hence low emittance) for longwave radiation. Both plastic films and glass with such coatings are now available commercially. One type of film has been developed which reduces reflectance to about 2% instead of the usual 8%, and this will be useful in creating multiple glazing which does not cause large reductions in transmittance.

For passive cooling, glazing materials are needed which have high transmittance in the atmospheric window region between 8 and 13 micrometers in wavelength. Several plastic films are available which have this property but they do not possess the necessary resistance to ultraviolet degradation which would enable them to be used alone as glazing materials. Glass continues to be the best choice for windows because its longevity has been proved by centuries of satisfactory use. Adapting this remarkable material to year-round energy control by electrical or other means continues to be the goal of research laboratories in the glass industry.

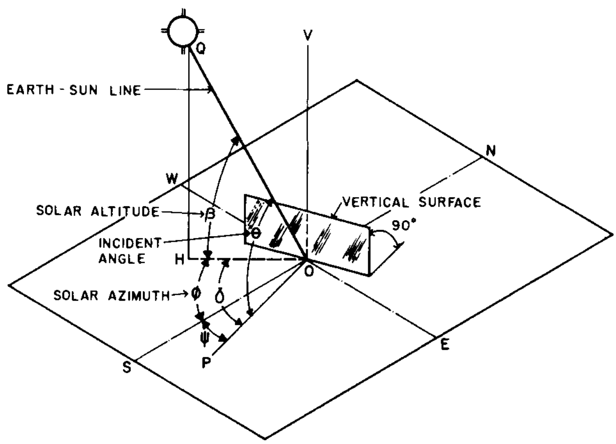

Fig. 1. Solar angles for a vertical surface.

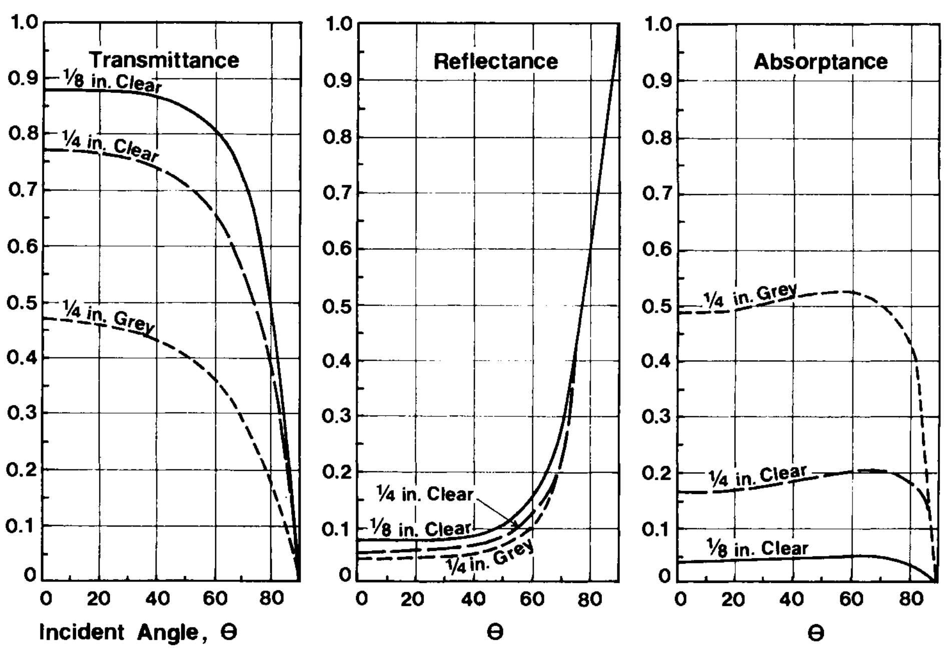

Fig. 2. Variation with incident angle of solar-optical properties of glass.

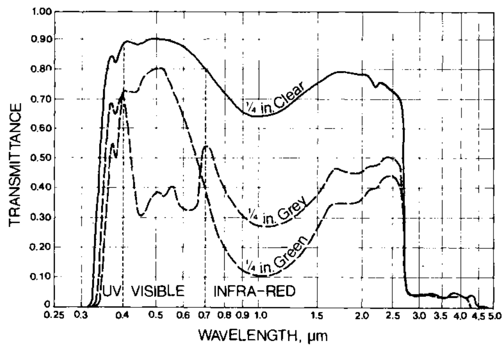

Fig. 3. Spectral transmittance for three types of window glass.

HEAT STORAGE AND DISTRIBUTION INSIDE PASSIVE SOLAR BUILDINGS*

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ABSTRACT

Passive solar buildings are investigated from the viewpoint of the storage of solar heat in materials of the building: walls, floors, ceilings, and furniture. The effects of the location, material, thickness, and orientation of each internal building surface are investigated. The concept of diurnal heat capacity is introduced and a method of using this parameter to estimate clear-day temperature swings is developed. Convective coupling to remote rooms within a building is discussed, including both convection through single doorways and convective loops that may exist involving a sunspace. Design guidelines are given.

KEYWORDS

Passive solar heating, heat storage, heat distribution, diurnal heat capacity, convection.

INTRODUCTION

Necessity for Heat Storage

There are three key physical processes that make passive solar heating possible: solar gain, heat storage, and heat distribution. A key difference between active and passive approaches to solar heating is that passive designs rely almost totally on natural processes for these phenomena. There is little, if any, exercise of control over the way they take place. The building works well or poorly, depending primarily on how it is designed; that is, it is the design that determines whether the natural processes will conform to the needs of the building at any particular time. Solar gains are controlled primarily by the location, orientation, and shading of the apertures (windows) in the building. Heat storage is in the normal materials of the building, and distribution is by radiation and convection.

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Heat storage becomes more essential as the dependence of the building on solar gains increases. If the building is only solar tempered, which means that the solar contribution is relatively small (usually less than about 40%), solar gains primarily offset the needs for daytime heating. Some heat storage will take place, but requirements for building heat at night and during cloudy periods are met primarily by auxiliary sources.

In a well-designed passive solar building the situation is quite different. Typically, no auxiliary heating is required in sunny winter weather. This means that all of the nighttime heating must come from heat stored within the building. Normally some auxiliary heat is still required, but it is needed only during cloudy periods when there has been less than full sun for one or more days. The need for auxiliary heat increases gradually as the heat stored in the building is gradually depleted. It is not very useful to talk in terms of a "heat storage carry-over time," as is often done, because of this gradual transition. Also, the carry-over time would depend on the particular heating requirements for the building. During mild, cloudy weather the carry-over time would be longer and during severe weather it would be shorter. For both reasons, carry-over time is not a particularly helpful concept.

In no small part, the economy of passive solar heating stems from the dual use of most of the construction and furnishing materials. Windows serve for light and view as well as for solar gain. Heat is stored in ordinary walls, floor, and, indeed, in all of the materials of the building. Although one may alter the construction techniques of the building to enhance the amount of heat storage available, in almost all cases heat storage serves multiple functions.

Natural convection within buildings is a very effective mechanism for heat distribution. Convective flow through doorways can be used to heat remote rooms if the heat loss of the space is not too large. A convective loop can also be set up within the building, greatly increasing the heat exchange. Such a loop may, for example, involve a sunspace, a doorway opening into the sunspace at the second level, upper rooms and hallways, a stairway, lower rooms and hallways, and a doorway opening at the lower level. Such loops have been shown to be very effective for heat distribution and make dual use of architectural features.

HEAT STORAGE IN PASSIVE SOLAR BUILDINGS

Direct Gain Situations

Direct gain is by far the most widely used passive solar strategy. It occurs to one extent or another in almost all passive solar buildings. It occurs with all windows, whether they are south facing or not, and storage of most of the heat associated with the solar gains occurs whether we plan for it or not. If the materials of the building interior are very lightweight, heat storage might be quite temporary, and transfer of the heat to the air in the room may take place quite soon. In more massive materials, the heat diffuses to the interior and is returned only at a later time when the room temperature drops somewhat, allowing for a reversal of temperature gradients so that the heat can rediffuse slowly to the surface.

The mechanisms of heat distribution within a direct gain room, after the short-wave solar radiation has entered the window, are very complex. Fortunately, we are not required to model all of these phenomena in great detail to obtain a reasonably good understanding of how heat storage takes place. Depending on sun angles, sunlight shines on a particular spot in the room with some energy being absorbed, some being converted to heat, and some being reflected, depending on the color of the surface. But if the surfaces are all light in color, the heat may be distributed rather uniformly around the room by short-wave solar radiation. If the angle of incidence of the sun at the light surface is acute, the sun may be reflected deep within the space, facilitating both natural lighting and heat distribution. If the surface is dark in color, there will be a concentration in conversion of light to heat at the region of first solar incidence.

Once the short-wave radiation is turned into heat at one or another of the building's internal surfaces, one of three actions occurs: (1) the heat migrates into the material, (2) the heat is transferred to the room air by convection, or (3) the heat is reradiated as infrared energy to all of the surfaces within the room that can be viewed from that location. Most of the energy that flows outward from the surface does so by infrared radiation with convection to room air being the smaller component. Thus, each surface in the room is continually bombarded by infrared radiation from every other surface within view. Except for surfaces that are in the direct sun, this inflow of infrared energy constitutes the major heat source. The fact that this infrared radiation transport within the space is so dominant is the primary reason that direct gain is a viable solar strategy. Understanding this fact is a great aid in direct gain design.

Only an area approximately the size of the window receives direct-beam solar radiation, depending on the angles. On a sunny day, the rate of energy inflow at this point is much greater than most masonry materials can accommodate for very long. Thus, most of the energy will be redistributed by convection and infrared radiation. Mazria (1979) has shown clearly that it is better to distribute the energy uniformly over a large surface area than to attempt to absorb it at the point of first incidence. This strategy results in much smaller temperature swings within the space. It is fortunate that infrared energy flow is such a good ally in accomplishing this redistribution. Although surfaces in the sun may be temporarily significantly warmer than other surfaces, the energy is quickly redistributed, and within a few hours most of the surfaces enclosing the space will be at similar temperatures.

Diffusion of heat into massive materials is a very slow process, affected little by the temporary shadows and other short-term variations in incident energy. We are more concerned with the gradual behavior of these materials over a period of a day or more than we are with the short-term effects occurring near the surface.

Convective Situations

It is usually better to maintain solar energy as radiant energy (either short wave or infrared) or stored heat as long as possible. Inevitably, however, some energy is transferred to the room air causing its temperature to increase. Air has a small heat capacity, typically about 1/1400th that of solid materials (on a volumetric basis). It is also quite mobile and tends to rise as heating decreases its density. This phenomenon displaces cooler air at some other location within the building and results in the establishment of convective loops. It is also possible for the hot air simply to collect at the top of the room, resulting in temperature stratification.

Usually about 1/3 of the solar gain entering the room results in heating of the room air. The warm air can then either convect to other spaces within the building that are cooler, flow out of the building by exfiltration (to be replaced by cooler infiltration air that dilutes its temperature), or rise in temperature until the energy flows balance. Controlling this temperature rise is a key factor in maintaining comfort in passive solar buildings. Normally the day/night temperature swing of the room is cited as a measure of the designer's success. Temperature swings above about 6°C are normally considered uncomfortable.

Distribution of heat by convection to cooler places within the building is a major mechanism of heat distribution during the day and a major source of energy for heat storage within the walls of those spaces. Because of the small thermal conductivity of air, the heat flux at these mass surfaces is substantially less than at surfaces within the direct gain space. Thus, it is convenient to distinguish between surfaces that are radiatively coupled to the source and those that are convectively coupled. Radiative coupling is much more effective and occurs at surfaces that are within the direct gain space. Convective coupling is the primary heat transport mechanism to remote spaces. Heat storage in materials in convectively coupled situations is usually less than in radiatively coupled situations. Nonetheless, convective coupling can constitute an important part of the heat storage in the building.

In the situation of a passive solar sunspace, convective coupling may be a major mechanism for energy transport. Temperature swings in the sunspace are large because the ratio of mass surface to glazing surface is small (typically 3:1). Thus, there are large temperature differences to drive convective exchange to the rest of the building. Because the living portions of the building have large interior surface areas, there can be extensive storage of heat in these rooms even though the heat fluxes at the surfaces are relatively small.

Importance of diurnal heat storage. It is convenient to distinguish between three time domains of heat storage: short-term heat storage, which lasts for a few hours; diurnal heat storage, which consists of heat stored during the day that is returned at night; and long-term heat storage, which refers to storage durations longer than one day. Of these phenomena, diurnal heat storage is the most significant to passive solar design. If one designs on the basis of diurnal storage, long-term storage will usually be adequate.

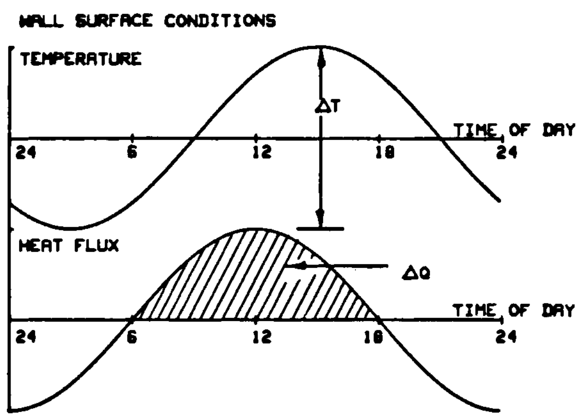

Fig. 1. Diurnal component of wall surface temperature and heat flux into the wall for a very thick wall. The crosshatched area is the heat stored during a half day (equal to the heat released during the other half day). The diurnal heat capacity is $\Delta Q/\Delta T$.

Diurnal heat capacity. Because of the importance of diurnal solar and outside temperature inputs, it is important to characterize the building's response at this 24-hour frequency. This has lead to the concept of a diurnal heat capacity, which, in simple terms, is the amount of heat that can be stored in building thermal mass during the first half of a 24-hour cycle and returned to the space during the second half of the cycle. This is shown in Fig. 1 for the case of a wall with a sinusoidal heat flux introduced into the wall surface. The curve shows that the typical response of the surface temperature to this sinusoidal input is also a sinusoid shifted 3 hours later. This time shift of 1/8 of a cycle (45^o phase shift) is characteristic of the response of very thick masonry walls. For thinner walls, the time shift is usually longer and may be up to 6 hours.

Diurnal heat capacity is the amount of heat that is stored per degree of temperature swing. This amount of heat is equal to the integral under the top half of the heat flux curve, which is marked ΔQ on the figure. The diurnal heat capacity is simply the ratio, $\Delta Q/\Delta T$. Diurnal heat capacity is given per unit of surface area and thus the units are $Wh/^oC\ m^2$ day. Because the day unit is implied in the term diurnal, it is usually omitted, and the units are given as $Wh/^oC\ m^2$. In this paper, diurnal heat capacity is referred to by the symbol dhc.

The dhc of a wall is a measure of the ability of the wall to absorb and store heat during one part of a periodic 24-hour cycle and then release the heat back through the same surface during the second part of the cycle. This 24-hour give-and-take at the wall surface is the most important heat storage that occurs in the passive solar building.

Diurnal heat capacities of various materials. Diurnal heat capacities of different materials can be tabulated as a function of the material thickness if the properties are known. Properties used for various materials are listed in Table 1.

TABLE 1 Properties of Materials

Material	Density	Specific Heat	Thermal Conductivity	dhc_∞*
	kg/m^3	$kCal/^oC\ kg$	$W/^oC\ m$	$Wh/^oC\ m^2$
Granite	2675	0.20	1.82	65.1
Concrete	2290	0.21	1.73	60.2
Concrete Masonry	2242	0.21	1.42	54.0
Limestone	2451	0.22	0.93	46.9
Builder Brick	1922	0.22	0.72	36.5
Adobe	1922	0.20	0.56	31.1
Hardwood	720	0.30	0.16	12.3
Softwood	512	0.33	0.12	7.8

*dhc of an infinitely thick wall.

Diurnal heat capacities for different wall thicknesses are shown in Fig. 2. Relationships needed to calculate the dhc of layered wall situations or situations with convective coupling from the room to the wall surface are given by Davies (1973) and Balcomb (1983).

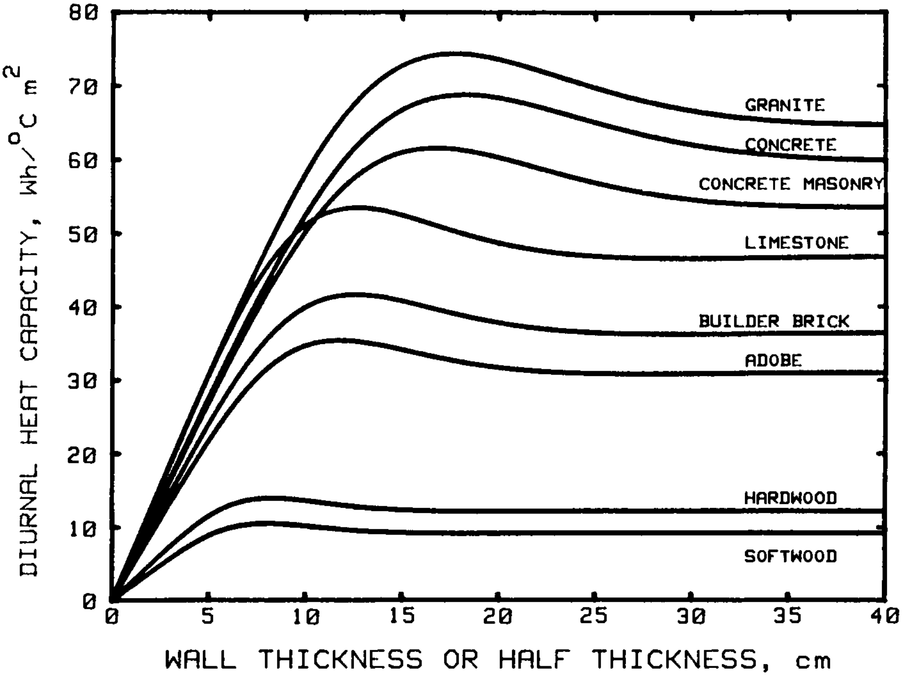

Fig. 2. Diurnal heat capacities of various materials as a function of thickness. Material properties used to generate these curves are given in Table 1. For interior partition walls, use 1/2 the total wall thickness to determine the diurnal heat capacity for each of the two surfaces. These curves apply to radiatively coupled mass.

Diurnal heat capacity of a whole room. The diurnal heat capacity of a whole room or a whole building can be determined by aggregating the effect of all surfaces acting in parallel. This will be called DHC. It is the vector sum of all the DHC values for all the various surfaces that enclose the room.

$$DHC = \sum_i A_i \; dhc_i \quad , \qquad (1)$$

where A_i is the area of the i^{th} surface, m^2, and
dhc_i is the dhc of the i^{th} surface, $Wh/^oC\ m^2$,

so that DHC has units of $Wh/^oC$.

It is first necessary to classify each inside surface of the building or room according to the coupling between the surface and the solar gain. It is useful to distinguish the following two major categories.

Radiation-coupled mass. Solar energy is transferred to the storage mass by either solar or thermal radiation. The mass must be either within the space that the sunshine enters or form an enclosing surface of the space. It is not necessary for the mass to be in the direct sun, but there must be a direct line of sight between the mass surface and absorbing or reflecting surfaces that are in direct sun.

Natural-convection-coupled mass. Solar energy is transferred to the storage mass by natural convection of warm air. Doorway or other convection openings must be provided with a total open area of at least 4% of the storage mass surface, or 2% of the storage mass surface if the openings are spaced more than 2 vertical meters apart.

Categorizing surfaces. We identify four types of surfaces as follows:

Type 1. Surfaces in the direct sun (radiation coupled),
Type 2. Other enclosing surfaces of a direct gain room (radiation coupled),
Type 3. Surfaces that are convectively coupled only, and
Type 4. Surfaces with zero coupling (zero dhc).

Exceptions are the following: (1) all ceilings, because of the excellent heat exchange with room air, are classified Type 2 even if they are in remote rooms, provided there is a suitable convective connection, and (2) floors not in the direct sun, because of the poor convective coupling and the lack of line-of-sight direct coupling, are downgraded one type number.

The following list gives further advice on assigning surface type:

Location	Type
The surface of any massive material that receives some direct sun, except covered floor.	1
Covered floor (or any covered surface).	4
Walls that enclose a direct gain room.	2
All ceilings, except in closed-off rooms (such as closets).	2
Walls that enclose other rooms that communicate by convection with direct gain rooms.	3
Uncovered floor in direct gain rooms (not directly sunlit).	3
Floors other than in direct gain rooms.	4
All surfaces in closed-off rooms.	4

In this listing, include gypsum-board surfaces and wood surfaces more than 1 cm thick. Do not include insulating materials such as fiber glass ceiling panels and walls or floors covered with heavy fabric, rugs, or other insulation. The next step is to estimate the area of each Type 1, Type 2, and Type 3 surface. For Type 1 surfaces, estimate the fraction of the solar day that the surface is sunlit, f, and the absorptance of the surface, α.

The estimates need not be very precise. Absorptance values can be estimated visually using the following guide:

Very dark surfaces	α = 0.8 to 0.9
Most surfaces	α = 0.5 to 0.6
Light colored surfaces	α = 0.3 to 0.4

Rough estimates are also adequate for f. Next determine the dhc of each surface using the following:

Type 1:	dhc = (radiation-coupled dhc) · $(1 + \alpha f)$
Type 2:	dhc = radiation-coupled dhc
Type 3:	dhc = convectively-coupled dhc
Type 4:	dhc = 0

By radiation-coupled dhc we mean dhc calculated in terms of surface temperature swing. By convectively-coupled dhc we mean dhc calculated in terms of room temperature swing using a convective coupling; a value of 0.26 $W/^{o}C\ m^2$ is normally used as the coupling coefficient.

Next calculate the DHC of the furniture and room air. This can be estimated as 11 $Wh/^{o}C$ for each m^2 of floor area for normal furnishings.

Next add the DHC = (A) · (dhc) for each surface to determine the whole building DHC. It is somewhat more accurate if this is a vector addition, accounting for the phase of each component, but the extra effort required is great and the improvement in accuracy is small.

Estimation of Room Temperature Swing

A major use of diurnal heat capacity is in estimating room temperature swing. This is relatively simple because DHC gives the amount of heat stored per degree of room temperature swing. It remains only to compute the amount of heat that is stored and divide this by the DHC to obtain the peak-to-peak amplitude of the 24-hour sinusoidal room temperature swing. A correction can then be made to account for higher harmonics.

The amount of heat that is stored in the building during clear winter days can be estimated knowing the direct gain glazing area, the solar penetration per square meter of glazing area, and the heat loss characteristics of the building. A heat balance is calculated over the 12-hour period from 0600 to 1800, accounting for solar gains plus internal heat minus heat losses. The heat losses are calculated based on the total heat loss coefficient of the building (TLC) and the difference between average inside temperature and average outside temperature.

The energy balance stated above in words can be put in equation form as follows:

$$\Delta T\ (\text{swing}) = \frac{Q_s \cdot A - (T_r - T_a)TLC/2 + Q_i/2}{DHC}, \qquad (2)$$

where ΔT(swing) = peak-to-peak room temperature swing,
T_r = daily average room temperature,
T_a = daily average ambient temperature,
Q_s = daily solar gains per unit area of direct gain glazing,
Q_i = daily internal heat (assumed uniform), and
A = direct gain glazing area.

Although one could account for the detailed structure of the inside and outside hourly temperature profiles in determining T_r and T_a, this is not done for this analysis. The primary reason is that we wish to keep the analysis fairly simple and little accuracy would be gained by the complication. A second reason is that both inside and outside temperatures will be higher than average during the daytime (both due to solar gains) so that there is a tendency for these effects to cancel one another. Whether they would cancel exactly, of course, depends on the exact magnitude of the two swings. If the building uses no auxiliary heat, then

$$Q_s \cdot A = (T_r - T_a)\ TLC - Q_i \quad , \tag{3}$$

$$\Delta T\ (swing) = \frac{Q_s \cdot A}{2\ DHC} \quad . \tag{4}$$

A factor can be used to account for higher harmonics. From study of typical profiles we find:

$$\Delta T\ (swing,\ actual) = 1.22 \cdot \Delta T\ (swing,\ diurnal) \quad . \tag{5}$$

$$\text{Thus, } \Delta T\ (swing) = 0.61\ Q_s \cdot A/DHC \quad . \tag{6}$$

Design Guidelines for Direct Gain

A design guideline can be determined based on limiting temperature swings in direct gain situations. This leads to a minimum required diurnal heat capacity per unit area of south-facing direct gain glazing. From Eq. (6) we obtain:

$$DHC/A \geq 0.61 \cdot Q_s/\Delta T\ (swing,\ maximum) \tag{7}$$

Other passive solar heating design guidelines for direct gain can be given.

- One should achieve an extensive distribution of heat storing mass within the building and use materials that have a high density. A rough rule is to make the surface area of mass located somewhere within the direct gain space at least 6 times larger than the direct gain window area.

- Surfaces within the room, with the exception of the floor, should be light in color. This refers to both lightweight elements, for which it is essential, and massive elements. One reason for this guideline is to aid in distribution of energy to all surfaces of the room; by making the surfaces light in color, short-wave solar radiation is more liberally scattered throughout the space. Another reason for this is to aid in balancing the daylight within the space. Light surfaces, and especially mat white surfaces, greatly aid in daylight distribution.

- One exception to the above consideration is the color of the floor. If the floor is massive, it should be dark in color (Mazria, 1979). This is to maintain heat storage at the lowest possible level within the space to counteract the inevitable tendency for stratification. Comfort is enhanced by keeping the radiant temperature near the floor, the space people occupy, as high as possible. However, if the floor is of low-mass construction or if it is covered with carpeting, it would undoubtedly be better to make it light in color to scatter the light to other locations where it can be better stored.

- The appropriate color of mass walls will depend somewhat on the total amount of heat storage in the room. If there is only one massive element, and all the rest are lightweight, it may be desirable to make this mass element darker in color to better absorb the energy. If all of the surfaces are massive, the use of light-colored surfaces greatly aids in distributing the energy to all of the mass.

- If mass added in construction increases the cost of the project, as is usually the case, there is a definite limit to the thickness that should economically be used. Although some long-term heat storage capacity is achieved by making the mass thicker, this is not of great importance to the overall performance of the building. There is little to be gained by increasing the thickness beyond the amount required by structural requirements or the thickness determined to give the maximum diurnal heat capacity, whichever is greater. The latter is typically about 10 cm for lower density masonry materials and about 18 cm for high-density materials.

All of the above guidelines lead strongly to one conclusion: if there is a limited amount of mass that can be put in a space, it is much better to spread that mass thinly to achieve as large a surface area as possible.

CONVECTION

Simple Doorway Convection

Convection through doorways can be estimated from the following relation (Weber and Kearney, 1980):

$$Q = 63.5\ w(d\Delta T)^{3/2} \quad . \tag{8}$$

where Q = heat flow, W,
w = doorway width, m,
d = doorway height, m, and
ΔT = room-to-room temperature difference, ^{o}C.

Based on this equation, we can develop a relationship for the steady-state temperature difference between one room and an adjacent room. Consider the simple case of a room that is heated only by convection through a doorway from an adjacent space at a steady temperature. The room loses heat to a steady outside temperature through a fixed loss coefficient. In this case the solution is very simple. The energy balance is as follows:

$$Q = 63.5\ w[d(T_d - T_r)]^{3/2} = LC\ (T_r - T_a) \quad , \tag{9}$$

LC = loss coefficient, W/^{o}C; T_d = driving temp., and

T_a = ambient temp.; T_r = room temp.

The solution to this equation gives the room-to-room temperature difference as a function of the room-to-outside temperature difference for different values of the load/door ratio (LDR).

$$\Delta T = T_d - T_r = \left\{[LDR\ (T_r - T_a)/63.5]^2/d\right\}^{1/3} \quad , \tag{10}$$

$LDR = LC/(wd)$, the load/door ratio (W/^{o}C m^2) .

If the door height is specified, the equation can be represented graphically as shown in Fig 3. This graph can be used as a design aid for determining the necessary door size for a particular given inside/outside temperature difference. Equation (10) is not very sensitive to door height.

Detailed numerical experiments were carried out to determine the validity of Eq. (10) under time-varying conditions. The conclusions (Balcomb, 1981) are as follows:

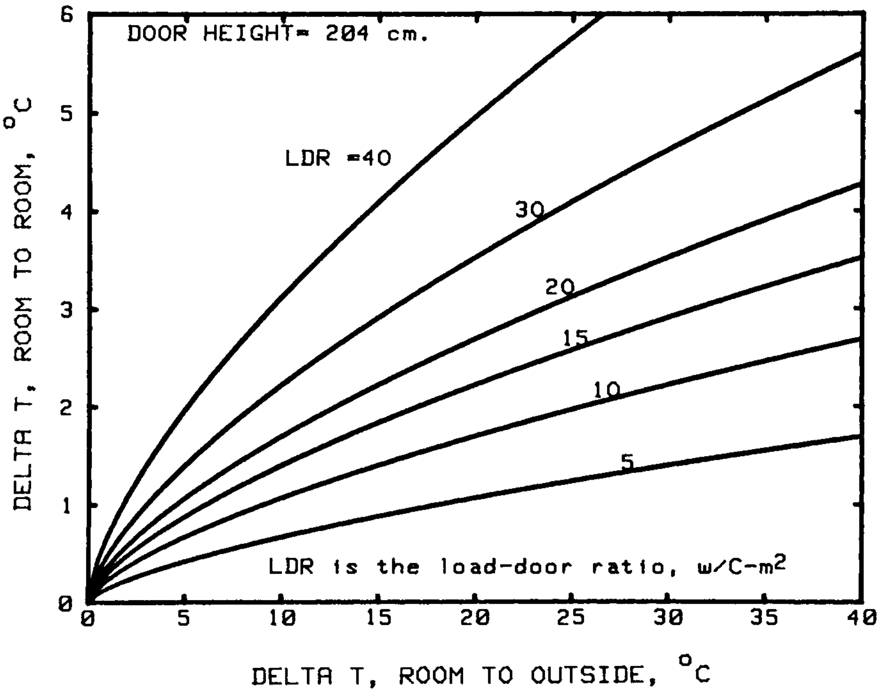

Fig. 3. Steady-state results for air flow through a doorway to a remote room. The curve shows the average temperature difference between the driving room and the remote room as a function of the average temperature difference between the remote room and the outside and the load/door ratio (LDR). The LDR is the ratio of the heat loss coefficient of the room to the door area. The curves are drawn for a standard height door.

- Convection through doorways is a very effective way of heating remote rooms. Quite reasonable temperature differences between the driving room and the remote room can be maintained.
- The steady-state solution given in Eq. (10) or Fig. 3 gives good indication of the 24-h average temperature differences that can be expected under most conditions.
- The effect of large variations in the driving temperature is advantageous, generally decreasing the difference between the average temperature in the driving room and in the remote room. Temperature swings in the remote room are always less than the driving room.
- If the temperature swing in the driving room is quite large, as in the case of an attached sunspace, properly operating the door can improve the situation, decreasing the ΔT. The door should be open during the day and closed at night.
- Heat storage in the remote room is quite important if the driving temperature swing is large. Insufficient mass will lead to excessive temperature swings.

Convective Loops

Discussion of Principles. Up to this point the discussion has concerned simple convection through doorways into rooms with a single opening. In this case, all of the air that enters the room through the top of the doorway must exit through the bottom of the same doorway.

Convective loops can also involve several rooms in the building. It is the purpose of this section to discuss this type of loop, especially in situations of multistory buildings with a sunspace.

A simple convective loop is shown in Fig. 4. In this example, a two-story sunspace is attached to a two-story house. The convective loop is made up of air that flows through openings into the sunspace at the upper level, down the stairway from the upper level to the lower level, and back into the sunspace at the lower level.

One way to describe such a loop is as a "heat engine." Figure 5 shows this schematically. Heat is added in the south side of the loop, and the same amount of heat is withdrawn on the north side. Air flows around the loop because of the difference in densities between the south leg and the north leg. In fact, we can calculate the flow rate based on the difference in average temperatures between the two legs. It is also possible for heat to be removed along the top leg of the loop; this is particularly effective in driving the loop because it increases

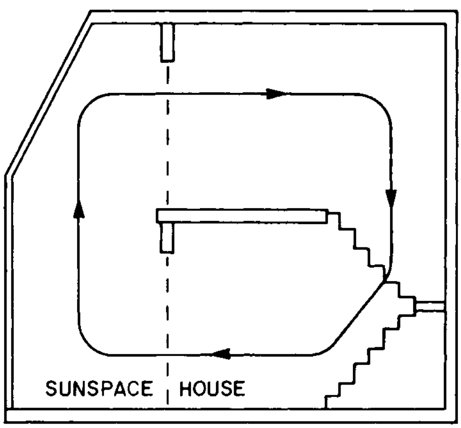

Fig. 4. Typical convective loop in a two-story house with a sunspace and stairway.

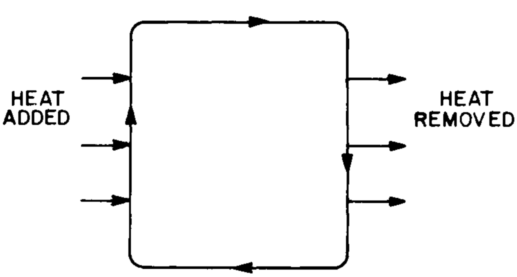

Fig. 5. "Heat engine" representation of a convective loop. The "engine" is the air motion and the mechanism driving the engine is heat added on one side and heat removed on the other side. Note that this heat engine is as dependent on the heat removal as on the heat addition.

the average density along the vertical north leg. Lastly, it is possible for heat to be removed along the bottom return leg; this is not very effective in driving the loop because it does not contribute to the increased density in the north vertical leg.

Although most convective loops that exist in present-day buildings are inadvertent (that is, they were not purposely designed into the building to cause convective heat exchange), it is certainly possible for the designer to consciously arrange the layout of internal spaces to aid in heat distribution. As in most design situations, this will probably result in a better functioning building than if the designer relies on luck.

The normal ingredients in a building convective loop are hallways, stairways, other rooms in the building, and doorways connecting these spaces. It is usually desirable to be able to stop the convective loop to prevent reverse flow at night. This is particularly true in sunspace situations; it is easily accomplished by providing a closable door in the openings at the top and bottom of the sunspace.

Convective loop results. Air velocity and temperature measurements have been made in six buildings that incorporate natural convective loops involving a sunspace and other architectural features. These measurements have been made near midday during relatively sunny weather. The results are still being analyzed and will be reported in detail in future Los Alamos reports. Balcomb (1983) shows the results from one building.

The results have been very encouraging, indicating large convective energy exchange. A summary of these results for a few houses is given in Table 2.

TABLE 2 Summary Convection Data

Sunspace Height	Sunspace Glazed Area	Sunspace-to-House			
		Connecting Doorway Area	Typical ΔT	Total Air Flow	Energy Transport by Convection
# of Stories	m^2	m^2	^oC	m^3/min	kW
2	37	7.4	3.3	47	5.18
1	17	2.9	1.7	19	0.17
2	38	10.6	2.8	63	4.54
2	53	4.5	5.6	47	6.18
1.5	29	5.9	2.2	29	1.50

Design Guidelines. Although the work described here is still in progress and certainly far from complete, certain design guidelines emerge clearly. It is evident that a major amount of heat can be stored inside a house resulting from convection from a sunspace. The major driving mechanism for this convection is the heat engine, driven by heat from the sun on one side and heat removed by the walls on the opposite side. If the designer is fully aware of the principles involved, the design can benefit most from effective convective exchange.

The key design factor is to lay out the building so that the convective loops can operate effectively. This can usually be done without architectural compromise.

In fact, in most cases studied, no conscious attempt to achieve a convective loop was made; it resulted, strictly in serendipitous fashion, from architectural considerations.

In designing for a convective loop within the building, the designer should try to use natural elements of the building as much as possible. Do not try to contrive a convective loop for its own sake but rather try to work it in with normal architectural considerations. The following list gives design hints for the convective loop, starting with the source of heat and moving around in the same direction as the air flow.

- A sunspace makes an excellent heat source to drive the convective loop. Because the flow velocity varies as the square root of the height, it is desirable to make the space as high as practical. A two-story building with a two-story sunspace has been found to work very effectively; even greater heights would probably work even better, although the tendency for temperature to stratify in the top of the building might be exacerbated. A dark-colored mass wall at the back of the greenhouse will aid in absorbing the sun and will heat the air as it rises.

- Provide a large opening at the top of the sunspace for the air to enter the upper story. Doors are excellent for this purpose, although large operable windows can also be used. Doors are preferable because they are larger and are more apt to be used. A shallow balcony opening out into the top level of the sunspace is excellent for this purpose. During sunny weather it will probably not be necessary to close these openings during the night because closing other openings at the return end will effectively shut off the convective loop.

- Provide for air flow across the upper level of the house from the south side to the north side of the building. This is most conveniently done using a hallway, although other rooms can also be used.

- Provide for downflow of air in the north part of the house. A stairwell serves this purpose ideally. The fact that the air may have to bend around corners to get across the building and down the stairs and into the lower portions of the building is of no great concern so long as the flow area is adequate. In fact, the scrubbing action of the air against the surfaces may increase the heat transfer. It is desirable for this path to be against the north wall of the house so that the convective loop can effectively supply the heat lost.

- Arrange for return of the air flow through the lower floor of the house and back into the solar heat source room. Again, this might be through a hallway or simply across a room. It is essential to provide an operable doorway or other opening that can be closed in this portion of the path. This prevents cool air from the sunspace from flowing back into the building, tending to reverse the loop at night.

- Provide one or more level changes at the ground floor, stepping down from the north side of the house toward the south. This makes the floor level of the solar gain room (sunspace) the lowest point in the ground-floor level of the building. One or two steps should be sufficient.

CONCLUSIONS

Diurnal heat capacity provides a useful measure of the heat storage capacity of a direct gain room during periodic clear-day weather. It can be used to estimate temperature swings yielding answers in good agreement with simulation analysis.

Closed-form solutions for the diurnal heat capacity of layered walls can be obtained. Methods of categorizing room internal wall surfaces and computing the diurnal heat capacity of an entire room are given.

Convection, either through single doorways or through interconnected building spaces, is a predictable and effective means of distributing heat to remote spaces. Mass within those spaces can be used effectively for storing this heat. However, air convection is nonlinear and, therefore, estimation of the diurnal heat capacity of remote spaces must be done cautiously; it may be that such estimation will require simulation analysis.

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A THERMAL MODEL FOR PREDICTION AND CONTROL OF AIR TEMPERATURE IN A DIRECT GAIN ROOM

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ABSTRACT

This paper presents results obtained from a passive solar heating numerical model. It points out the influence of the main parameters - glazing area and thermal mass- on the resulting ambient temperature, the system efficiency and the comfort. It shows the possibility of passive control of the air temperature, particularly to avoid overheating.

KEYWORDS

Passive solar heating ; thermal model ; thermal mass ; glazing ; comfort.

INTRODUCTION

Literature on thermal modelling of passive solar heating reveals two types of approach.

The first one is a lump approach which only allows to determine a simple energy balance but does not take into account shading, thermal mass and comfort aspects. A second technique uses much more sophisticated models which are too comprehensive to keep a sufficiently universal feature. Moreover these models require large computers and are time consuming which does not easily allow simulation of long periods.

Intermediate one-dimensional models fitted to elementary geometries and using classical thermal networks or finite-difference schemesmay be of interest in the way that they involve few parameters, the influence of which can be easily drawn.

This paper presents such an intermediate model able to provide quantitative results useful for passive solar system sizing. Using real weather data, it mainly points out the influence of glazing area and thermal mass on the system performances and comfort.

MODEL DESCRIPTION

This study is based on a direct gain room measuring 8 x 5 x 2,5 m^3. The only glazing is located on the south side. Thermal mass is distributed between the walls, the floor and ceiling.

In order to determine the air temperature evolution inside the room, we have to solve the unsteady flow through the different walls, the floor and the ceiling. A one-dimensional transient finite-difference scheme has been used which takes account, as boundary conditions, of insolation and convective heat transfer from surfaces to air.

Solar Radiation

In this work, we have used real weather data - direct and diffuse solar radiation, outside temperature - hourly recorded since 1971 at La Rochelle, France. Considering reflection and absorption of the glazing, shading due to directional and geometrical effects, reflection and reradiation of walls, we calculate the net flux absorbed on each surface along which it is then uniformly distributed.

Absorption factors have been taken equal to 0.6 for the floor and 0.3 for the walls and ceiling. Emissivity has been taken equal to 1.

Free Convection

Heat is transferred between the different surfaces and ambient air by free convection. Very few results are available concerning the corresponding heat transfer coefficients. For the study, we chose the data given by F. Bauman |1|.

Thermal Characteristics

Each wall, the floor and the ceiling are made of concrete and are insulated with 5 cm of glasswool. The glazing is insulated during the night with shutters.

The following values have been used to determine thermal losses, capacitances and conductances.

Wall, floor and ceiling :

$K = 1.74$ W/M°C
$\rho = 2300$ Kg/m^3
$C = 960$ J/Kg°C

Insulation : $K = 0.05$ W/m°C

Glazing :

Double glazing
$U = 3.19$ W/m^2°C (day)
$U = 1.80$ W/m^2°C (night)

Single glazing
$U = 6.20$ W/m^2°C (day)
$U = 2.33$ W/m^2°C (night)

A 0.5 air change per hour has been assumed in computing the ventilation and infiltration losses.

RESULTS

In order to determine the influence of the glazing nature and area as well as the thermal mass, this model has been run for the whole year of 1971. Particular results are presented for two typical clear sky days of January and October. The weather data characteristic of these two days are given on Fig. 1 and Fig. 2.

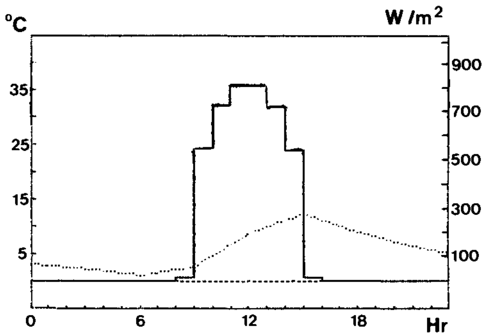

Fig. 1. Outside temperature and solar insolation on a vertical south facing surface. January 10, 1971.

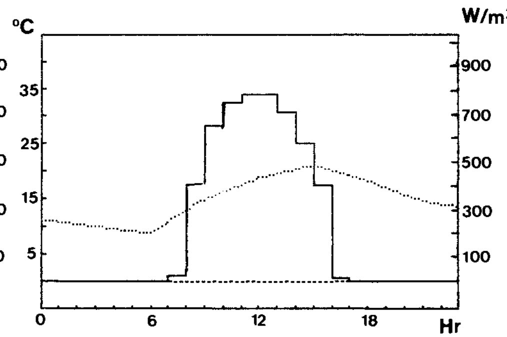

Fig. 2. Outside temperature and solar insolation on a vertical south facing surface. October 21, 1971.

Influence of the Glazing Nature

Four cases have been considered : single and double glazing with and without a night insulation. Results on Fig. 3 show that with a night insulation, in such a climate, a single or double glazing are equivalent. A similar result, not represented here, is obtained for the 21 of October 1971.

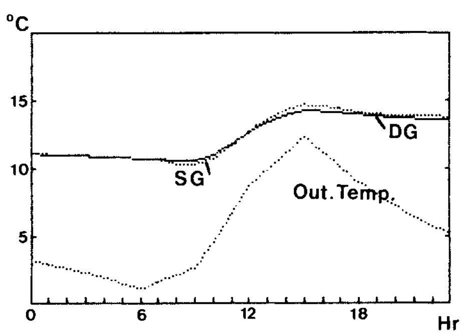

Fig. 3. Temperature fluctuations. January 10, 1971
Single glazing and double glazing with night insulation.
Glazing area : 6 m^2 . Uniform wall thickness : 15 cm.

Figures 4 and 5 show the double advantage of a single glazing for mild climates.

When combined with a night insulation in winter-time, it allows a saving of a few degrees, Fig. 4, and without a night insulation, it can limit appreciably overheating during cool seasons, Fig. 5.

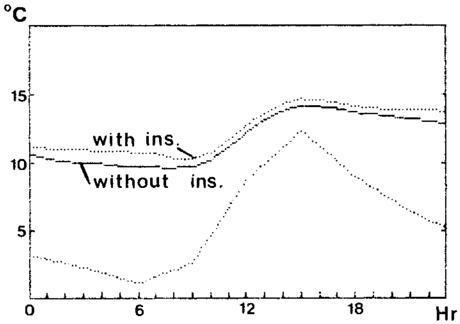

Fig. 4 Temperature fluctuations. January 10, 1971.
Single glazing with and without a night insulation
Glazing area : 6m^2. Uniform wall tickness 15 cm.

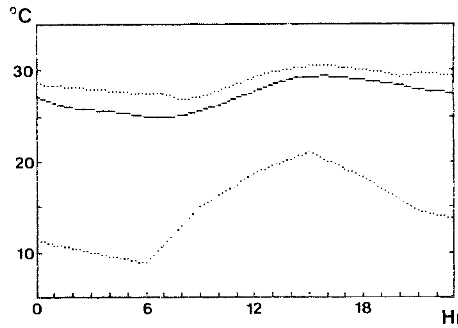

Fig. 5 Temperature fluctuations. October 21, 1971
Single glazing with and without a night insulation.
Glazing area : 6m^2. Uniform wall thickness 15 cm.

Influence of the Glazing Area

The choice of the glazing area in passive solar heating is critical. It results from a compromise to insure a sufficient solar insolation and to avoid overheating. The influence of the glazing area on the daily temperature fluctuations are given on Fig. 6 and Fig. 7 . Large differences in the temperature amplitudes can be observed. It can be noticed that the smaller the glazing, the smaller the fluctuations over the day.
To determine the optimal area, the model has been run over a ten year period(1971-1980). Results give the solar heating ratio and the overheating time ratio.

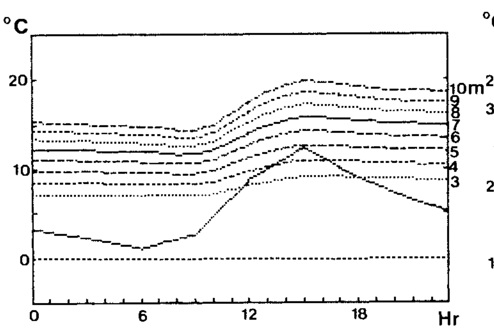

Fig. 6 Temperature fluctuations. January 10, 1971
Single glazing. Uniform wall thickness : 15 cm.

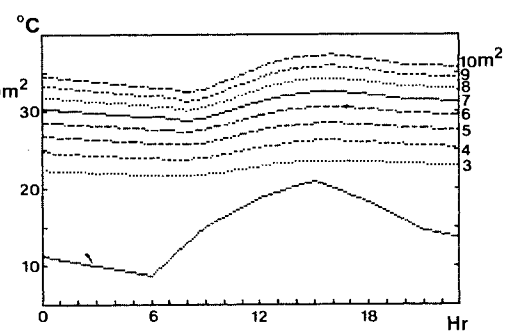

Fig. 7 Temperature fluctuations. October 21, 1971
Single glazing. Uniform wall thickness : 15 cm.

The solar heating ratio is the ratio between the solar insolation ahead of the glazing and the heating load (on the basis of 19°C inside the room). The overheating time ratio is the ratio between the time during which the inside temperature exceeds a given value (so called T_{over}) and the total time. Fig. 8 and Fig. 9 present monthly averaged results of this 10 year run.

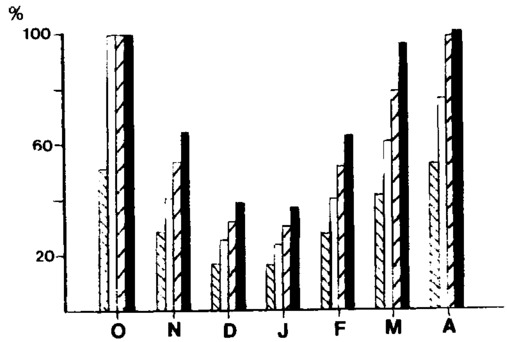

Fig. 8. Solar heating ratio. Monthly average over the 1971-1980 period. Uniform wall thickness : 15 cm.

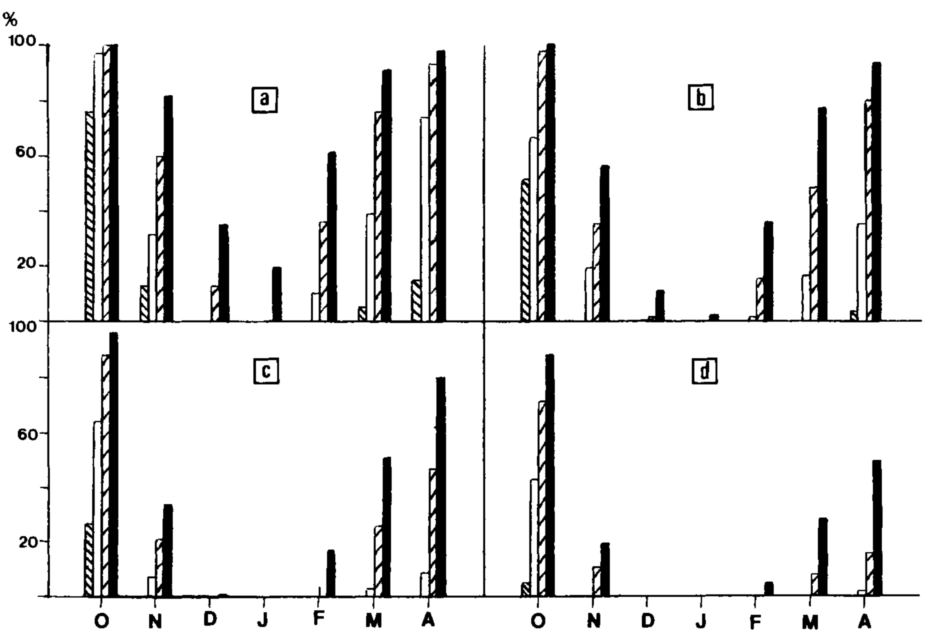

Fig. 9. Overheating time ratio. Monthly average over the 1971-1980 period. Uniform wall thickness : 15 cm.

(a) : T_{over} = 21°C (b) : T_{over} = 23°C

(c) : T_{over} = 25°C (d) : T_{over} = 27°C

Glazing area : 4m^2 6m^2 8m^2 10m^2

Influence of Thermal Mass

The influence of the wall thickness on the daily temperature fluctuations depends on the period of the year which is considered. The wall thickness has been successively taken equal to 5, 10, 15 and 20 cm. These values correspond to an overall thermal mass per unit of floor area respectively equal to 400, 800, 1200 and 1600 Kg/m^2 which characterizes a mid-heavy to heavy room range. In winter-time the influence of the wall thickness is weak and essentially affects the amplitude of fluctuations, Fig. 10. For cool seasons, the thermal mass affects both the fluctuations amplitude and the temperature level, Fig. 11.
When using an important wall thickness, it can be seen on Fig. 11. that if, as foreseen, the fluctuations are flattenned, on the other hand the temperature level is higher. This effect corresponds to a storage effect of the walls subsequent to several sunny days. When considering overheating, this effect has to be taken into account. This means that a heavy room is not the most appropriate solution and a mid-heavy structure must be preferred.

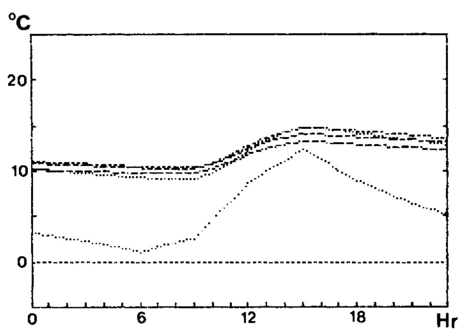

Fig. 10. Influence of thermal mass on temperature fluctuations.
January 10, 1971
Single glazing : 6m^2.

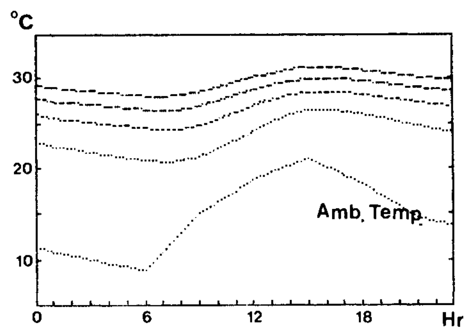

Fig. 11. Influence of thermal mass on temperature fluctuations.
October 21, 1971
Single glazing : 6m^2

5 cm
10
15
20

Influence of Thermal Mass Distribution

Under latitudes of 40°,the greater part of solar flux is absorbed by the floor. It is interesting to consider the influence of the relative distribution of the thermal mass between the floor and the walls on the inside temperature. In winter-time, as shown on Fig. 12, this influence is negligeable beyond the value of 30 %. But results of Fig. 13 show the relative importance this distribution may have during spring or autumn. As said before, the storage effect still operates here, and a heavy floor may contribute towards an increasing of the air temperature level. For the studied configuration, an ideal value of the relative thermal mass of the floor should be about 30 %.

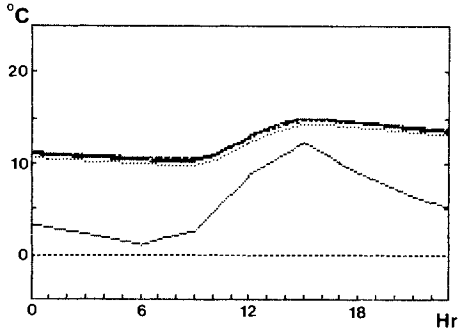

Fig. 12. Influence of the thermal mass distribution on temperature fluctuations. January 10, 1971. Single glazing : 6m^2 . Total mass : 3200 Kg.

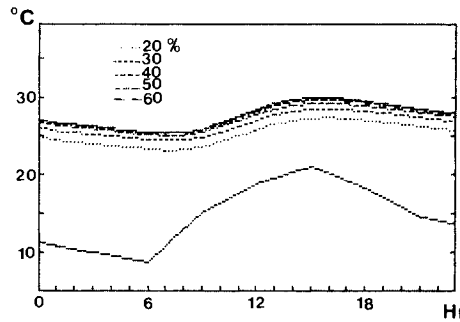

Fig. 13. Influence of the thermal mass distribution on temperature fluctuations. October 21, 1971. Single glazing : 6m^2. Total mass : 3200 Kg.

CONCLUSION

These results clearly show the importance of the choice of the glazing area and the thermal mass in the design of a direct gain room. For temperate climates, a large glazing area and an important thermal mass may give rise to frequent overheating.
In such climates, for medium insulated rooms, we suggest a glazing area of about 1/6 of the floor area and a thermal mass per unit of floor area of about 800 Kg/m^2, 30 % of which are distributed in the floor.

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USING THE BARRA-COSTANTINI SYSTEM FOR MULTISTOREY RESIDENTIAL BUILDING RETROFITTING

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ABSTRACT

For many situations whatever passive solution or energy conscious idea should be actually suitable for multistorey residential buildings as well as for retrofitting applications. The Barra-Costantini(BC) system is a passive tool which can be successfully applied to such dwellings, due to the ceiling floor used as thermal storage and the absorber disconnected from the south facing wall. This allows an uniform distribution of the air among several rooms, as the heat is conveyed trough ceiling channels. Anyway one of the most peculiar feature of such a device is that it may be used for multistorey buildings and for retrofitting. Through the results of the thermal transient analysis, by means of a computer simulation program, a methodology was carried out to foresee the performance of multistorey buildings retrofitted with BC system and which allows to predict the amount of the storage mass involved, the absorbing surface to be provided and the fraction of the thermal load met by such a device. The methodology is summarized in few diagrams for a quick computation on the basis of climatological data and thermophysical properties of the building. A number of study cases are investigated and the comparison of the results obtained by the proposed method and those arising from the SLR-SHF curves are greatly satisfactory.

1. INTRODUCTION

Wherever in the world the amount of the existing buildings which should be energetically improved is very high. The recovery and/or the conservation of energy may be of course attained by a careful design of heating or air conditioning facilities but probably a cheap solution may also be to retrofit buildings with a passive device. On the other hand passive systems today known, such as green-house, Trombe wall, solar chimney and so on, are unfortunately not generally suitable for multistorey buildings, whereas this is the most widespread typology of the existing architecture. The BC system, instead, may be succesfully used to this aim thanks to its peculiar features, which basically rely on the ceiling floor used as thermal storage and on the low mass absorber disconnected from the south facing wall.
The air conveyed through ceiling channels can reach the north areas of the house

and the whole dwelling can be therefore uniformly heated. Further no restriction arises against the architectural design of the interiors. The low mass absorber, as disconnected from the south wall, induces turbulence into the solar chimney and resultsin a very high system efficiency. In order to improve the thermal performance of the solar wall, a finned absorber was introduced which increases both the absorbing surface hitted by solar radiation and the heat transfert rate between fins and air. In previous papers a detailed study was carried out on the dynamics of the ~~solar wall~~ [1], [2], whose main aspects are summarized in sections 2. and 3. In this paper a simple procedure is developed based on the results of the previous work and allowing a quick assesment on the amount of energy collected, as a function of the absorbing surface and climatic conditions. Such a methodology does not require hand computations as it is presented in a graphical form whose results are consistent with those coming from the SLR-SHF method, obtained by Barra [3].

2. PERFORMANCE OF THE SOLAR CHIMNEY

The solar chimney basically consists of a finned absorber usually put in the gap between the glazing and the wall, as shown in fig.1.
Due to the fins, the convective heat transfert surface will be increased over the apparent surface of the wall S, by the factor:

$$S_a/S = (d/b) \cos i$$

and the surface "seen" from the sun, by the factor

$$S_i/S = (b/H) \; (\cos(q-i)/\mathrm{sen}\, q) + 1$$

where: b= fin length, d= distance between fins, H= wall highness, q= solar angle, i= slope of the fin with respect to a horizontal plane.
The flowdynamics of the solar wall was also investigated. By writing the Bernoulli theorem for the inlet and outlet section of the chimney, coupled with the mass conservation law, the mass flow rate can be expressed as follows:

$$1) \quad G = A\, d_u v_u = A\, d_u \left(\frac{2H(z - L)/dm}{1 + R_i \left(\frac{d_u}{d_i}\right)^2 + R_u} \right)^{0.5} \qquad (Kg/s)$$

where dm is the average air specific mass between the value in the inlet (d_i) and outlet (d_u) section; R_i and R_u the lumped resistances, z the driving head per meter due to the air density gradient, which depends on the temperature across the chimney; and L is the specific pressure loss. This latest may be expressed as a function of G and of the equivalent diameter, then coupled with the 1) in a "trial and error" procedure until the difference between an arbitrarly assumed L and the actual one becomes lower than a prefixed error. The net pressure gain across the chimney will be finally given by:

$$\Gamma = (V_u^2 / 2)\, d_m \qquad (Pa)$$

For the convective heat transfert coefficients, the following correlations were used respectively for the air-absorber convection [3] :

$$N_u = 4.35\; G_r^{0.22}$$

and for glazing-air or wall-air convection:

$$N_u = 0.071 \left(\frac{H}{b}\right)^{-1/9} (Gr\ Pr)^{1/3}$$

THE ENERGY BALANCE EQUATIONS

With reference to the fig.I, the energy balance equations are concerned with: 1) The glazing cover; 2) the absorber; 3) the wall; 4) the air in the glazing-absorber gap; 5) the air in the absorber-wall gap, and are as follows:

$$m_1 c_1 dT/dt = h_{1,e} S_1 (T_e - T_1) + F_{1,e} \sigma \varepsilon_{1,e} S_1 (T_e^4 - T_1^4) + h_{1,4} S_1 (T_4 - T_1) + + F_{1,2} \sigma \varepsilon_{2,1} S_1 (T_2^4 - T_1^4) \quad (1)$$

$$m_2 c_2 dT_2/dt = h_{2,4} S_2 (T_4 - T_2) + F_{3,2} \sigma \varepsilon_{3,2} S_1 (T_3^4 - T_2^4) + h_{2,5} S_2 (T_5 - T_2) + + F_{2,1} \sigma \varepsilon_{2,1} S_2 (T_1^4 - T_2^4) + (\alpha \tau) I S_2 \quad (2)$$

$$m_3 c_3 dT_3/dt = h_{3,5} S_3 (T_5 - T_3) + F_{3,2} S_3 (T_2^4 - T_3^4) + h_0 K_0/(h_0 + k_0) S_3 (T_0 - T_3) \quad (3)$$

$$m_4 c_4 dT_4/dt = h_{4,1} S_1 (T_1 - T_4) + h_{4,2} S_2 (T_2 - T_4) + 2 G_4 \rho c (T_0 - T_4) \quad (4)$$

$$m_5 c_5 dT_5/dt = h_{5,2} S_2 (T_2 - T_5) + h_{5,3} S_3 (T_3 - T_5) + 2 G_5 \rho c (T_0 - T_5) \quad (5)$$

To solve the equation set,let us write in the form :

$$[\dot{X}] = [A][X] + [B][U]$$

where $[X]$ is the temperature state vector, $[\dot{X}]$ its derivative, $[A]$ the state matrix $[B]$ and $[U]$ the input matrix and input matrix and input vector respectively. The meaning and the form of matrices $[A]$ and $[B]$ as well as the algorythm used to solve the given equations is discussed in detail in [1] and [2]. The performance of the solar chimney is shown in figures 2.and 3. which summarize the results of the computer simulations. The study case was a wall 3m high, 1m long, the wall-glazing was 0.09 m and the absorber put between glazing and wall. For a number of situations the solar wall efficiency was computed by means of the following expression:

$$\eta(t) = \frac{\int_t^{t+\Delta t} G(t) C (T_u(t) - T_0(t)) dt}{\int_t^{t+\Delta t} I(t)\, S\, dt}$$

On the basis of these results we are then able to carry out a simple procedure for a rough prediction of the concrete ceiling involved as storage mass and the fraction of the heating load covered by such a device.

3. DESIGN OF THE CEILING FLOOR AS THERMAL STORAGE

The use of the ceiling floor as thermal storage provides the building with a very high storage mass, usually much greater than any other passive system already known. Of course the amount of the energy stored is only that part of the gain which overcomes the thermal load directly covered during the morning; and, on the

other hand, not the whole ceiling floor is involved, but a relatively small amount around the channels; moreover a thermal transient exists degrading from the south to the north side of the ceiling.
In order to predict the behaviour of the storage mass, a diagram is shown in fig.4, which arises from a number of situations according to different climatic areas and building parameters. It allows to know the excess of energy "e" as a function of the building loss coefficient "d" (W/m^3 °C), and of the ratio "r" (m^{-1}) of the solar wall surface to the flat volume to be heated.
The term "e" is expressed as a percentage with respect to the average daily thermal load Q_d (Joule). Three families of curves are shown in the diagram which can be used respectively for very sunny areas (curves A) with a low temperature excursion between night and day, and with approximately less than 700 Degree-days (Dd); for relatively sunny areas (curve B) with $700 < Dd < 1200$; and for cool regions (curve C) with $Dd > 1200$, and low solar radiation.
The mass M involved in the storage process can be deduced from the following expression:

$$e \cdot Q_d = M\, c_s\ \Delta T_s$$

where c_s (J/Kg° C) is the specific heat of the ceiling material; and $\Delta T_s = 5 \div 7$ °C is the temperature rise in the storage.
The length "b" of the slab involved in the process may be computed by:

$$b = \frac{M}{n_c\ l\ s\ d_s} \qquad (m)$$

where n_c is the number of channels per flat, s(m) the thickness of the ceiling and d_s the specific mass (kg/m^3) of the storage. A number of cases are presented in tab.1

4. PREDICTION OF THE ENERGY GAIN AND USE OF THE FINAL DIAGRAM

In this section we develop a simple method for the "bookeeping" of energy monthly gained by a building (or a flat) provided with the B-C system.
To this aim, being Dd the monthy Degree-day value of the area where the building exists, let us express the mean daily temperature Te as follows:

$$T_e = 18 - Dd/30 \quad (°C)$$

The diurnal mean daily temperature (at least in Italy) may be roughly approximated by:

$$T_{ed} = 2 + T_e = 20 - Dd/30$$

whereas the mean absorber temperature may be cautiously assumed in winter:

$$T_p = 30\ °C$$

Known, from the meteorological statistics of the zone, the average daily sunshine hours H_i in the month and the solar energy availability I ($Wh/m^2 day$) on the vertical surface, let us write:

$$X = \frac{T_p - T_{ed}}{I/H_i} = \frac{(10+Dd/30)Hi}{I}$$

It is now possible, to compute with a good approximation the daily efficiency of the chimney, according to the following formula, wich comes from the best fit of a number of simulations.

$$\eta = -1.13\ X + 0.57$$

The daily energy gain will be therefore given by:

$$Q = I\ S\ \eta\ \ 10^{-3} \qquad (kWh/d)$$

On the other hand the daily energy load can be expressed in the form:

$$L = U\ \ V\ \ \frac{Dd}{30}\ \ 10^{-3} \qquad (kWh/d)$$

where U is the building loss coefficient "d" ($W/m^3\ °C$) times the hours of daily heating needed (h)

$$U = d\ .\ h \qquad (Wh/m^3\ °C)$$

All this procedure, though simple for hand computations, was finally converted in to the diagram of fig. 5. The diagram can be used also to compute the required S, given the fraction f, or to deduce the U value, given f and S.
To show the flexibility of the diagram three study cases will be faced.
Study case n.1: A flat to be retrofitted has a loss coefficient d = 1.25 $W/m^3 \cdot C$, volume V = 300 m^3, absorbing surface S = 15 m^2 and 8 hours of heating are requested. Find the average fraction of the thermal load covered by the BC system.
Solution: Following the procedure described in fig.5 , the table 2, can be filled In the right side of the table the output which results from the SLR-SHF are also shown, computed according to the SLR-SHF given by Barra [3]
Study case n.2: For the above mentioned flat, find the absorbing surface such as to obtain f = 0.8. Solution: the average input seasonal parameters are: Dd=262; I = 2500 (Wh/m^2d); H_i = 4.6 (h).
In this case the final point will be read in that frame where the S and the I curves are shown; the result is S = 18 m^2. Assuming this one as a trial value, the reader is able to set up a table just as previously done, and from which an average seasonal f will arise.
One should carry on the computation, trying with different S, until a satisfactory f results. In this case one should find S = 15 m^2.
Study case n.3: Given S = 20 m^2, find the loss coefficient d such as to have f = = 0.6 in December, when 8 hours of heating are requested. Solution: The final point lies in the right uppermost frame.
With the climatic data of December shown in tab.2, we find: U = 12.5 ($Wh/m^3\ °C$) and therefore d = 12.5/8 =1.5 $W/m^3 \cdot C$.

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Location: Rome, 41.8 north latitude

INPUT				OUTPUT				SLR-SHF Method [3]	
Month	Degree days	H_i (h)	I (wh/m^{2}d)	η	Q_u (Kwh/d)	L (Kwh/d)	f	SLR	SHF
Nov.	182	4,1	2400	0,54	19,4	16,3	1,19	2,20	0,08
Dec.	304	3,3	2100	0,53	16,6	27,3	0,60	1,15	0,71
Jan	337	4,3	2600	0,52	20,3	30,3	0,67	1,28	0,82
Feb	270	4,7	2700	0,52	21,0	24,3	0,86	1,67	0,88
Mar	221	6,6	2900	0,53	23,0	19,9	1,15	2,18	0,87
				TOTAL	100	118,5			
				AVERAGE	20	23,7	0,84		

TAB. 2

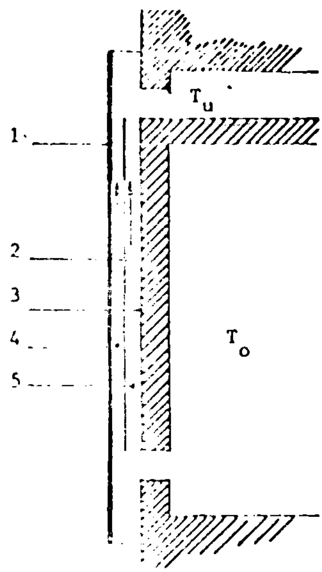

Fig. 1.

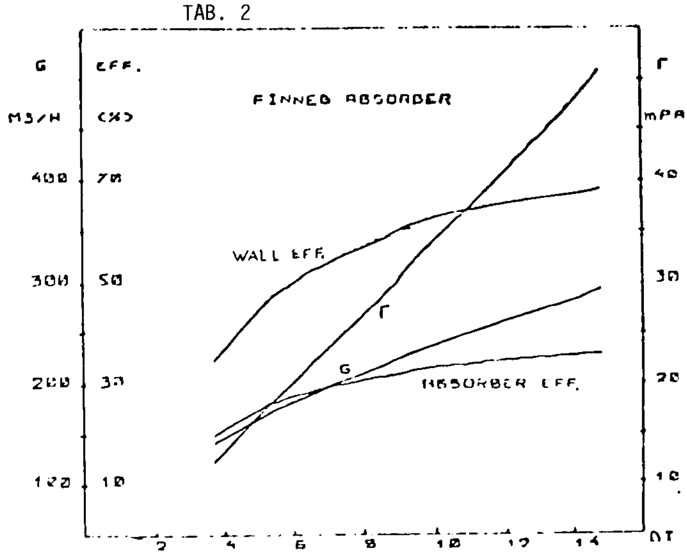

Fig. 2.

CON.			A			B			C		
Q (Kwh)			40			48			56		
S (m^2)	n_c	r_1 (m^{-1})	e	M (Kg)	b (m)	e	M (Kg)	b (m)	e	M (Kg)	b (m)
9	3	0.03	0.05	1630	0,27	0	/	/	0	/	/
18	4	0.06	0.25	8180	1.02	0.05	1960	0.25	0	/	/
27	6	0.09	0.55	18000	1.50	0.25	9820	0.82	0	/	/
36	9	0.12	0.90	29450	1.64	0.52	20400	1.13	0.12	5500	0.3

TAB. 1

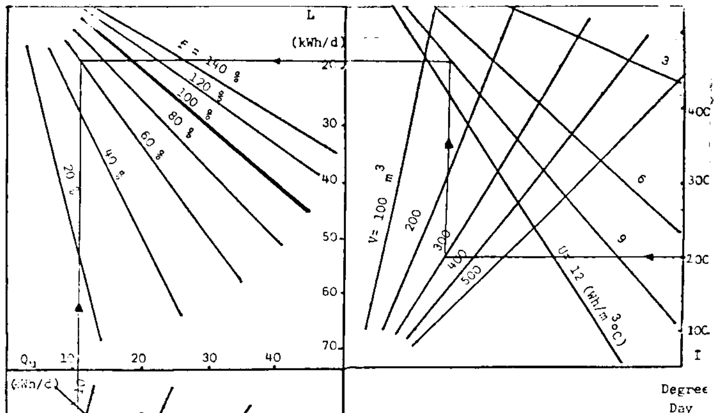
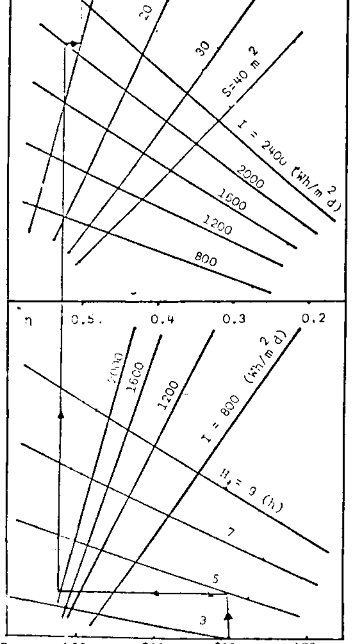

Fig. 5

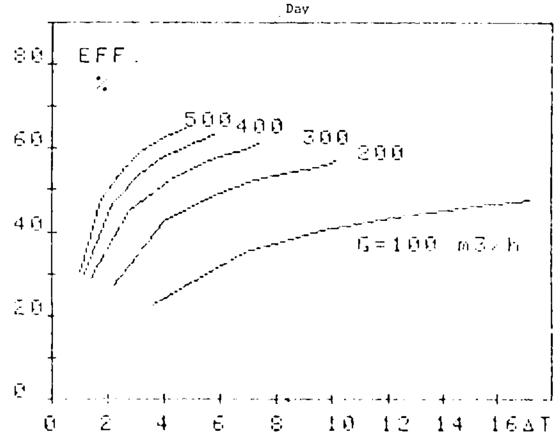

Fig. 3.

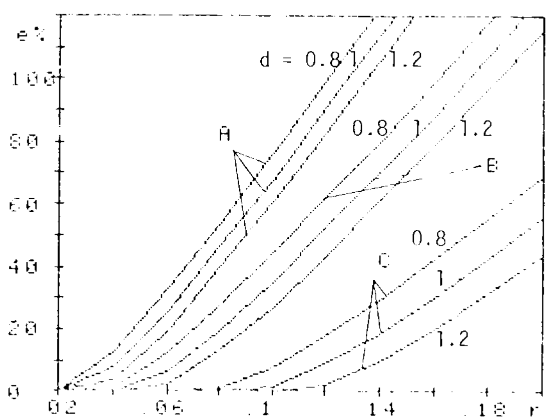

Fig. 4.

Mode of use:

Enter first the lowest frame of the diagram with the Dd value and intersect the H_i curve. From this point move horizontally towards the selected I curve; therefore go up, across the η axis where the monthly efficiency value of the solar wall can be read, as long as the vertical line reaches the I curve. Then move again horizontally towards the relevant S curve, and from this point upward passing through the Q_u axis. Here stop. Now restart from the right hand side of the diagram, and intersect firt the V and after the U curve.
The fraction f of the internal load covered by the BC system will be determined in the left uppermost frame of the diagram in the point of intersection of Q_u and L coordinates.

SOLAR CONTROL AND SHADING DEVICES FOR BUILDINGS IN GREECE

BIOCLIMATIC SHADING ANALYSIS

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ABSTRACT

This paper attempts to identify the times of year when shading is required in buildings located in three representative climatic regions of the country. The study is part of a PhD research on "Solar Control of Buildings in Greece by means of Shading" which the author is currently pursuing at the Architectural Association Graduate School, London.

KEYWORDS

Comfort zone bioclimatic chart, bioclimatic shading analysis, shading periods,

INTRODUCTION

Since the 1950's, architectural trends have been towards frame construction buildings with lightweight cladding and large areas of glazing. This trend has introduced new problems, among them the need to consider the internal thermal environment of buildings throughout the year. Numerous reports from all over the world have indicated that a large number of occupants of such buildings are uncomfortably hot during the days of high solar radiation intensities.

The problem of overheating has become more acute than the one of underheating in countries with high insolation, like Greece, where overheating conditions usually persist during 5 months of the year.

The provision of shading can contribute significantly in maximising the defence of building envelopes against excessive solar heat penetration and hence reduce the need for mechanical space cooling. The times of year when shading is required can be identified from the bioclimatic chart (1) using a procedure that can be called "bioclimatic shading analysis".

THERMAL COMFORT AND THE BIOCLIMATIC CHART

Man's energy and health depend to a great extent on the direct effects of his physical environment. Light, sound, climate and space all act directly upon the human body with favourable or unfavourable effects. The maintenance of thermal equilibrium between the human body and its physical environment is the basic requirement for thermal comfort. This is achieved by keeping the temperature of the core tissues of the body at an approximately constant level regardless of the variations in the outdoor environmental conditions.

Thermal comfort depends primarily on four climatic variables: air temperature, humidity, air movement and solar radiation. It also depends on the combined effect of other factors such as the involuntary physiological mechanisms of shivering, sweating and control of blood flow, the use of clothing, the variation of physical activity, acclimatisation, age and sex, state of health, skin colour, food and drinks, body shape and subcutaneous fat.

The range of climatic conditions under which a human being keeps its body temperature approximately constant with minimum expenditure of energy is called the "comfort zone". Within this range most of a person's energy is freed for productivity. Thermal comfort conditions can be graphically represented in a single chart, so called "Bioclimatic Chart" first developed by A. and V. Olgyay of Princeton University (1, 2). The original chart has been widely used by architects as the basis for designing buildings in which climatic elements are exploited to the maximum in order to maintain a comfortable indoor thermal environment. The chart was revised by E. Arens et al (3, 4) to incorporate recent research results. Examples of the revised chart are presented in both the original format and in the format of the psychrometric chart. This is a cartesian plot of dry bulb temperature versus relative humidity on which thermal comfort lies in the middle. Also shown on the chart are the elements (shading, solar radiation, air movement, moisture) which may be used to restore a person's thermal sensation to the nearest boundary of the comfort zone.

BIOCLIMATIC SHADING ANALYSIS

The lower edge of the comfort zone has special importance as it designates the "shading line". Air termperatures below this line are cold for human beings causing discomfort and this area may be called "underheated zone". Above the shading line are the areas of thermal comfort and over-heated conditions, both requiring shade and this area is termed the "shading zone". Plotting the climatic conditions for any time on the chart, one can easily identify which zone they belong to. The times of the year that belong to the shading zone may be called the "shading period".

Shading periods in Greece vary from location to location due to the different distribution of climatic elements throughout the country. Using a study prepared by the national Meteorological Service (5), Greece is divided into three representative climatic regions and three cities are selected (Chania, Athens, Thessaloniki) one from each region, to represent the country in the following stages of this paper. A shading analysis is then carried out for each city to identify the shading periods. The example shown in fig.1 illustrates the bioclimatic shading analysis for Athens in May, June and July, i.e. plotting on the bioclimatic chart the mean monthly values of hourly dry bulb temperature and relative humidity data (6, 7). Identical analyses have been carried out for the three cities during April, May, June, July, August, September and October. The results have been represented in yearly charts indicating the times of year when shading is required (Tables 1 - 3).

Shading periods for each location can be plotted on sun path diagrams, with months and hours as coordinates. The diagrams will then not only show the positions of the sun but also indicate whether shading is desirable or not at a given time (figs. 2 - 4). The plotted shading periods in dark tone show that shading is required on both the corresponding dates. Other areas in lighter tone indicate that shading is needed on only one of them, usually the autumn date.

CONCLUSIONS

The bioclimatic chart and the Olgyay's proposed design methods and techniques are most useful for buildings with an interior environment responding to outdoor climatic conditions. As a result of the increase in energy costs, there are now trends towards designing buildings that incorporate passive solar systems and techniques. The thermal environment in passive solar spaces responds much quicker to outdoor climatic conditions and is inherently more changeable than in mechanically controlled spaces. Passive solar spaces have the following features: direct solar gain into occupied rooms, more natural ventilation through windows resulting in higher air movement indoors, high radiant temperature differences resulting from solar heated components such as Trombe walls and floor slabs, localised radiant heating and fan cooling, and evaporative cooling. These features increase THE UTILITY OF THE BIOCLIMATIC CHART and its associated climatic design procedures such as shading periods for buildings throughout the year. More specifically in the case of Greece, with an acute overheating problem in buildings, designers of passive solar spaces must take into account the difference in shading periods from location to location. They should also understand human comfort under a wider range of climatic conditions than has been necessary in the past; where temperature alone, or temperature and humidity, were considered sufficient.

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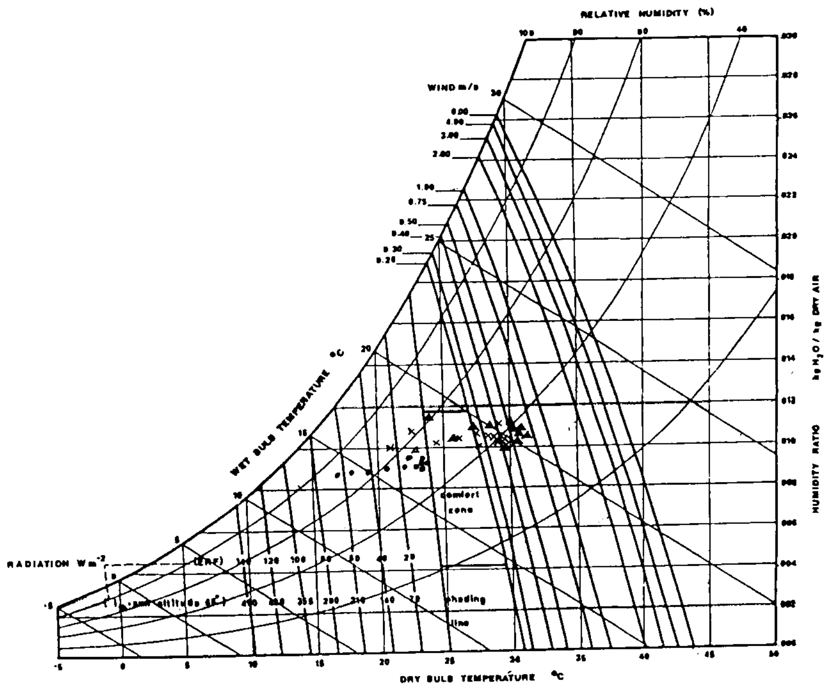

fig. 1 Shading analysis of May (.), June (x) July ( ) for Athens

Source: Vastardis, P. "Solar Control of Buildings in Greece by means of Shading" (6)

Table 1 Annual shading period for Chania

Source: Vastardis, P. "Solar Control of Buildings in Greece by means of Shading"

Table 2 Annual Shading Period for Athens

Table 3 Annual Shading Period for Thessaloniki

Annual daytime hours	Annual shading period (hours)	Percentage
3,772	858	22.7

Source: Vastardis, P. "Solar Control of Buildings in Greece by means of Shading" (6)

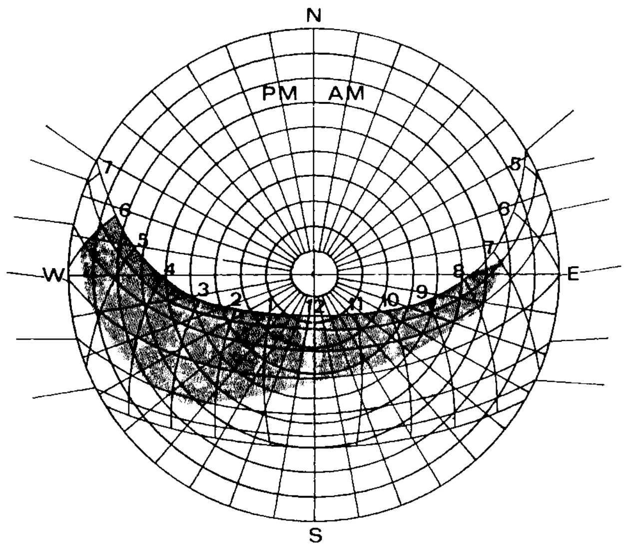

Fig 2 Sun path diagram with transferred shading period for Chania (35° 30 N)

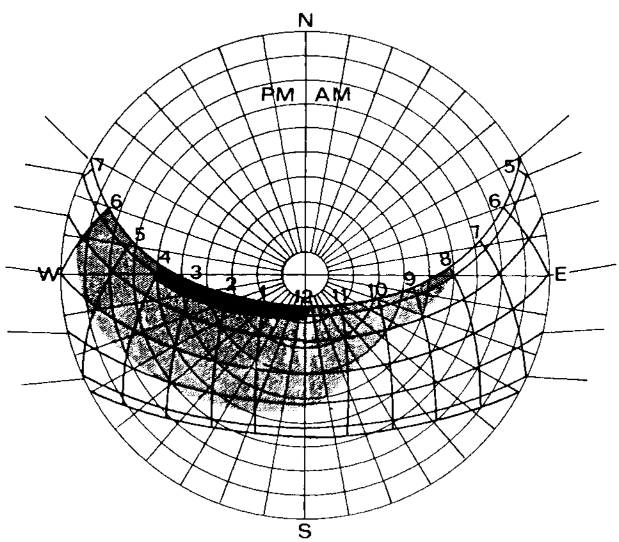

Fig 3 Sun path diagram with transferred shading period for Athens (37° 58 N)

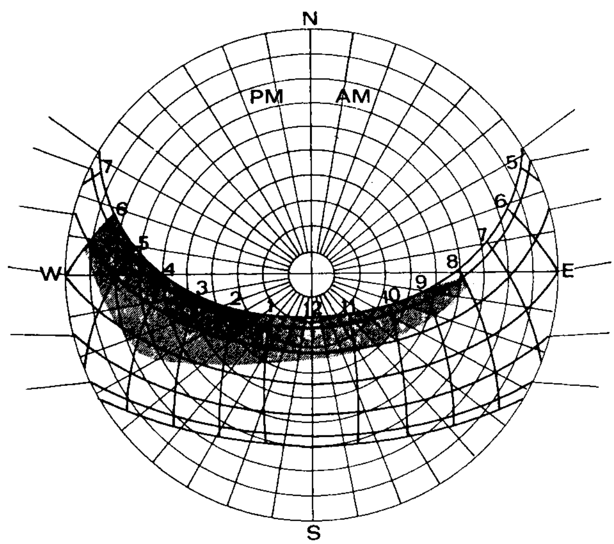

fig. 4 Sun path with transferred overheated period for Thessaloniki (40°40°N)

OPTIMISING THE DESIGN OF NATURAL-CIRCULATION SOLAR-ENERGY WATER HEATERS

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ABSTRACT

A simple, but rigorous, model has been developed which enables the minimum area of a flat-plate solar-energy collector, required to satisfy a specified hot-water requirement, to be predicted. The procedure can accommodate any flat-plate collector design and the recommendations emerging therefrom can be presented as a sizing graph for a particular system.

KEYWORDS

Thermosyphon; water-heater; flat-plate collectors; solar energy.

Abbreviations

n.c.	natural circulation
s.e.	solar energy
w.h.	water heater

Nomenclature

A	Area	(m^2)
B	Thermal conductivity of the mechanical bond between the collector fluid channel and plate	($Wm^{-1}K^{-1}$)
C	Parameter in equation (9)	
c	Mean specific heat capacity	($J\ kg^{-1}K^{-1}$)
D	Diameter of collector flow channel	(m)
F	Collector efficiency factor	
f	Parameter in equation (9)	
Gz	Graetz number	
H	Height	(m)
h	Heat transfer co-efficient	($Wm^{-2}K^{-1}$)
I	Global insolation upon the plane of collector	(Wm^{-2})
k	Thermal conductivity	($Wm^{-1}K^{-1}$)
ℓ	Length of flow channel	(m)
M	Mass of water	(kg)

m	Mean daily thermosyphon mass flow rate	(kg s^{-1})
n	Number of collector covers	
Q	Mean rate of heat gain of the collector during insolation period	(W)
s	Collector tilt angle	(degrees)
T	Temperature	(K)
U	Overall heat loss co-efficient	($Wm^{-2}K^{-1}$)
V	Volume	(m^3)
v	velocity	(ms^{-1})
W	Spacing between collector flow channels	(m)
Y	Parameter defined in equation (17)	(m K W^{-1})
α	Absorptivity	
δ	Thickness of collector plate	(m)
ε	Emissivity	
η	Efficiency	
θ	Duration of insolation period	(s)
ρ	Mean density	(kg m^{-3})
σ	Stefan-Boltzmann constant	(5.67×10^{-8} $Wm^{-2}K^{-4}$)
τ	Transmissivity	

Subscripts

a	ambient
c	collector
f	heat transfer fluid
g	collector glazing
i	inlet to the solar-energy collector
o	outlet from the solar-energy collector
p	collector plate
R	heat removal factor
s	refers to the system as a whole
T	hot-water store
W	wind
z	the volume of water to be heated
1	refers to fully-mixed store immediately prior to the insolation period
< >	denotes a time-averaged value for the contained parameter
–	denotes a space-averaged value of the variable

Economic Solar-Energy Water-Heating

The prediction of the performance of solar-energy water-heaters with pumped circulation can now be accomplished using several techniques of varying degrees of sophistication (Barley and Winn, 1978, Klein and co-workers, 1976; Kenna, 1982). These methods require the mass flow rate to be specified and are thus inapplicable to n.c. systems in which the flow rate is a function of the system design. Previous design methods for n.c.s.e.w.h's have involved the solution of the coupled momentum and energy equations that describe the behaviour of the system (Norton and Probert, 1982; Norton and Probert, 1983 b). This generally requires a large-store computer. An alternative approach is to use experimentally-derived correlations for a particular system in a specified locality (Song and Zhang, 1982): as expected this method has inherent limitations.

It has been observed experimentally in studies of different systems that the temperature difference, ΔT_p, between the inlet and outlet of the collector of an n.c.s.e.w.h., remains almost invariant during the insolation period (Close, 1962; Shitzer and co-workers, 1979; Gupta and Garg, 1968; Parker, 1981; Norton and

Probert, 1983 c), i.e. it is not very sensitive to insolation level. It is, however, dependent upon vertical difference in the positions of the collector and hot-water store. This vertical difference or the insertion of a check-valve in the flow-circuit, is necessary so that noctural reverse circulation is prevented (Norton and Probert, 1983 a). Thus the collector area and store volume can be varied without significantly affecting ΔT_p if the vertical positions of the system components are unaltered. This remains valid until either with increasing collector area appreciable additional fluid flow resistance has been introduced or with increasing hot-water store volume, the aspect ratio of the cylindrical hot-water store (i.e. its height to radius) has decreased to such an extent that the thermal storage characteristics have been significantly altered. The exact limits within which both the collector area and the store volume may be varied depend on their shapes and dimensions. Within those limits, with a known value of ΔT_p the minimum required collector area for a particular hot-water requirement can be determined for any location by the method to be presented. This technique will not permit one to predict the economic optimal domestic hot-water solar fraction. However, it will allow the capital costs of providing various solar fractions to be determined. This information may be assessed using a life-cycle costing technique (Manning, 1982), and compared with auxiliary fuel costs to determine the economic optimal solar fraction (Tybout and Lof, 1970).

Mathematical Model of the Performance of a Multi-Pass s.e.w.h.

Let us assume we have a direct n.c.s.e.w.h. which at the start of the insolation period has a fully-mixed store at a temperature, T_1. Let the system be required to raise the temperature of a mass of fluid, M_z, to a temperature T_z by the end of the insolation period. If it is assumed that the mean temperature of the tank increases linearly with time during the insolation period and that no water is drawn off during that period, then the daily mean fluid temperature at the collector inlet is given by:-

$$\langle T_{f,i} \rangle = T_1 + \frac{T_z - T_1}{2} \tag{1}$$

thus $$\langle T_{f,i} \rangle = \frac{T_1 + T_z}{2} \tag{2}$$

In the following analysis it is assumed that:-

(i) heat losses from the up-riser and down-comer are negligible;
(ii) transient effects do not have a significant effect on the daily system performance;
(iii) no hot-water is drawn off during the insolation period;
and (iv) the effects of thermal diffusion and mixing on the hot-water store are negligible.

The energy balance of a flat-plate solar collector is represented by the Hottel-Whillier-Bliss equation:-

$$\dot{Q} = A_c F_R \left[\langle I \rangle \tau_g \alpha_p - U_c \left(T_{f,i} - T_a \right) \right] \tag{3}$$

The use of $\langle I \rangle$, the mean daily global insolation in the plane of the collector, in equation (3) has been shown not to introduce a significant error in the calculation of the net daily heat gain, $\dot{Q}$, for most designs of n.c.s.e.w.h. (Gordon and Zarmi, 1981).

The heat removal factor F is:-

$$F_R = \frac{\dot{m}c_f}{A_cU_c}\left[1 - \exp\left(-\frac{U_cA_cF_p}{\dot{m}c_f}\right)\right] \quad (4)$$

The energy collected by a solar-energy collector can also be expressed in terms of the mass flow rate, $\dot{m}$, and the temperature difference between the inlet and outlet of the panel by the relation

$$\dot{Q} = \dot{m}c_f\,(T_o - T_i) \quad (5)$$

Let us use the experimental observation that $(T_o - T_i)$ remains almost invariant. Thus

$$\Delta T_p = T_o - T_i \quad (6)$$

then $$\dot{Q} = \dot{m}c_f\,\Delta T_p \quad (7)$$

Substituting from equations (2), (4) and (7) into equation (3), and solving for $\left(\frac{A_c}{\dot{m}}\right)$ reveals that

$$\frac{A_c}{\dot{m}} = -\frac{c_f}{U_cF_p}\,\ell n\left[1 - \frac{U_c\Delta T_p}{\langle I\rangle\tau_g\alpha_p - U_c\left[\left(\frac{T_1 + T_z}{2}\right) - T_a\right]}\right] \quad (8)$$

where U_c can be determined to within an accuracy of $\pm$ 0.25 $Wm^{-2}K^{-1}$ for all angles of tilt in the range zero to 90^0 (Agarwal and Larson, 1981) by the relation

$$U_c = U_{back} + U_{edge} + \left[\frac{n}{\left(\frac{C}{\langle T_p\rangle}\right)\left(\frac{\langle T_p\rangle - \langle T_a\rangle}{n+f}\right)^{0.33}} + \frac{1}{h_w}\right]^{-1}$$

$$+ \frac{\sigma\left(\langle T_p\rangle + \langle T_a\rangle\right)\left(\langle T_p\rangle^2 + \langle T_a\rangle^2\right)}{\left[\varepsilon_p + 0.05n\,(1-\varepsilon_p)\right] + \left[\frac{2n + f-1}{\varepsilon_g}\right] - n} \quad (9)$$

where $f = (1 + 0.04h_w + 0.055\,h_w^2)\,(1 + 0.091\,n)$ (10)

and $C = 250\left[1 - 0.0044\,(s - 90)\right]$ (11)

Several correlations for the wind heat loss co-efficient h_w in equation (10) (McAdams, 1954; Drake, 1949; Sparrow and Tien, 1977; Sogin, 1964; Raghuraman and Kon, 1981) are available. The following correlations (Onur and Hewitt, 1980) will be used:-

$$h_w = -0.685 + 11.8\sqrt{V_w} \quad (12)$$

for a wind blowing from any part of the southern quadrant, and

$$h_w = -2.27 + 9.94\sqrt{V_w} \qquad (13)$$

for a wind blowing from any part of the northern quadrant. The variation of U_c with $\langle T_p \rangle$ for different windspeeds from the southern quadrant is given in Fig. 1.

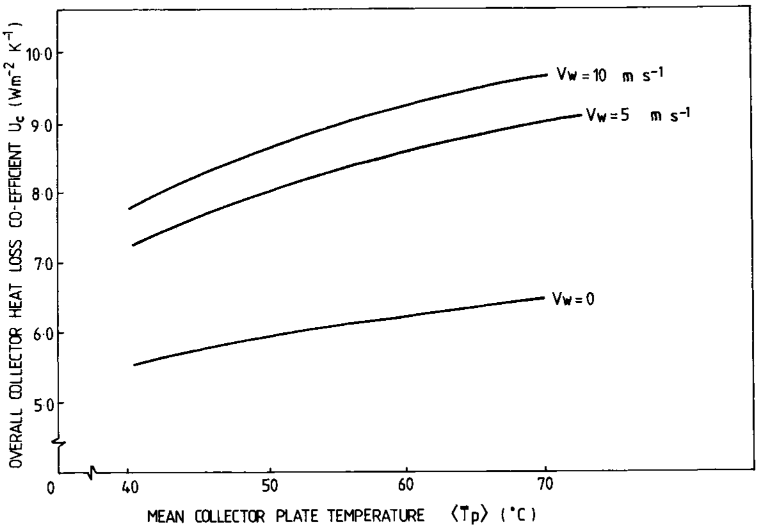

Fig. 1. Variation of U_c with $\langle T_p \rangle$ for a south-facing collector subjected to winds from the south at the three stated speeds. ($T_a = 26^0C$, $s = 60^0$, $U_{back} = 0.27\ Wm^{-2}K^{-1}$, $U_{edge} = 0.27\ Wm^{-2}K^{-1}$, $\varepsilon_p = 0.3$ and n=1)

The rate of heat gained by the collector plate is

$$\dot{Q} = A_c\left(\langle I \rangle \tau_g \alpha_p - U_c\left(\langle T_p \rangle - \langle T_a \rangle\right)\right) \qquad (14)$$

If it is assumed that all this heat is transferred to the fluid, then $\dot{Q}$ can be eliminated between equations (3) and (14). By substitutions from equations (2) and (4), an expression for the mean plate temperature is obtained, namely

$$\langle T_p \rangle = \frac{T_1 + T_z}{2} + \frac{\langle I \rangle \tau_g \alpha_p}{U_c}\left(1 - \frac{\dot{m}c_f}{A_c U_c}\left[1 - \exp\left(-\frac{U_c A_c F_p}{\dot{m}c_f}\right)\right]\right) \qquad (15)$$

The collector plate efficiency factor F_p, (Gillet, 1980) which appears in equations (4), (8) and (15) can be determined from:-

$$\frac{1}{F_p} = W\left\{\frac{1}{\left[D+2\left(\frac{k_p\delta}{U_c}\right)^{\frac{1}{2}}\tanh\left(\frac{(W-D)}{2}\sqrt{\frac{U_c}{k_p\delta}}\right)\right]} + U_cY\right\} \tag{16}$$

$$\text{where } Y = {}^{1}/_{B} + {}^{1}/_{\pi Dh_f} \tag{17}$$

Laminar flow prevails in the conduits of most natural-circulation solar-energy water-heaters operating under typical conditions (Norton and Probert, 1982). If such a flow regime can be described by a low to moderate value of the Graetz number, the heat transfer co-efficient, h_f, between the fluid and the inner wall of the collector flow channel tends to the asymptopic value for fully-developed uniformly-laminar flow (Knudsen and Katz, 1958). Thus

$$h_f = \frac{4.364\ k_f}{D} \tag{18}$$

$$\text{provided, } Gz = \frac{D\rho_f\ v_f c_f}{2\ell_c k_f} \leqslant 4$$

If $Gz > 4$, the heat transfer co-efficient, h_f, varies along the collector according to the local Graetz number (Mertol and co-workers, 1982).

The energy balance for the whole system, over the full insolation period, can be represented by

$$M_z\ c_f\ (T_z - T_1) = \dot{Q}\theta - U_TA_T\theta\left\{\left(\frac{T_1 + T_z}{2}\right) - \langle T_a\rangle\right\} \tag{19}$$

for which it is assumed that the heat losses from the up-riser and down-comer are negligible.

The minimum capacity of tank, V_T, necessary to accommodate the mass M_z will be

$$V_T = \frac{M_z}{\bar{\rho}_f} \tag{20}$$

The actual tank capacity installed should, however, exceed this, because the system needs to be designed to satisfy the hot-water requirement during typical rather than peak insolation conditions. Thus, the tank should have sufficient capacity for the larger volumes of hot-water produced during peak insolation periods. The optimal storage tank capacity is a function of the solar fraction and the diurnal pattern of hot-water consumption (Dutré and co-workers, 1978).

Substituting from equation (7) into equation (19) gives

$$\dot{m} = \frac{M_zc_f\ (T_z - T_1) + U_TA_T\theta\left(\left(\frac{T_1 + T_z}{2}\right) - \langle T_a\rangle\right)}{\theta\ c_f\ \Delta T_p} \tag{21}$$

where the minimum storage tank surface area for a tank of fixed height H can be shown, by considering the tank geometry, to be

$$A_T = \frac{2M_z}{\rho_f H_T}\left(1 + \left(\frac{\rho_f \pi}{M_z}\right)^{\frac{1}{2}}\left(H_T\right)^{\frac{2}{3}}\right) \quad (22)$$

The system heat gain efficiency is defined as

$$\eta_s = \frac{M_z c_f \ (T_z - T_1)}{\langle I \rangle \theta \ A_c} \quad (23)$$

Design Methodology

The steps necessary to design a n.c.s.e.w.h. using the analytical framework described are illustrated in Fig. 3. The procedure was undertaken for a system of the specification shown in Table 1 for required hot-water temperatures in the range $10^0C < (T_z - T_1) < 30^0C$.

TABLE 1 Design Information Used in Deriving the Data for Fig. 1

SPECIFIED NEED	$M_z = 100$ kg ($\equiv 0.1$ m^3 at 20^0C)
Typical of "worst" conditions under which specified hot-water requirement is to be met	$\langle I \rangle = 500$ Wm^{-2}, $\theta = 28.8 \times 10^3$s, $\langle T_a \rangle = T_1 = 26^0C$, $v_w = 5.0$ ms^{-1}
Parameters characteristic of solar-energy system	$\Delta T_p = 12^0C$, $U_T = 0.04$ Wm^{-2}K^{-1}, $H_T = 1.6$ m $U_{back} = U_{edge} = 0.02$ Wm^{-2}K^{-1}, $\tau_g \alpha_p = 0.8$ $\varepsilon_p = 0.9$, $\varepsilon_g = 0.8$, $n = 1$, $s = 60^0$ $W = 0.09$ m, $D = 0.015$ m, $\delta = 0.001$ m, $Y = 0.045$ m K W^{-1} and $k_p = 236$ Wm^{-2}K^{-1}

The calculated values of A_c for that range of T_z are shown in Fig. 3. Generally only one or two iterations are required to achieve a satisfactory convergence of the iterative process.

It has been shown that the rate of heat gain is not very sensitive to variations in ΔT_p (Duffie and Beckman, 1980), e.g. a 17% change in ΔT_p will typically only cause approximately a 1% change in $\dot{Q}$. Thus the efficacy of the design method is not significantly affected by inaccurate determinations of ΔT_p for most collector designs.

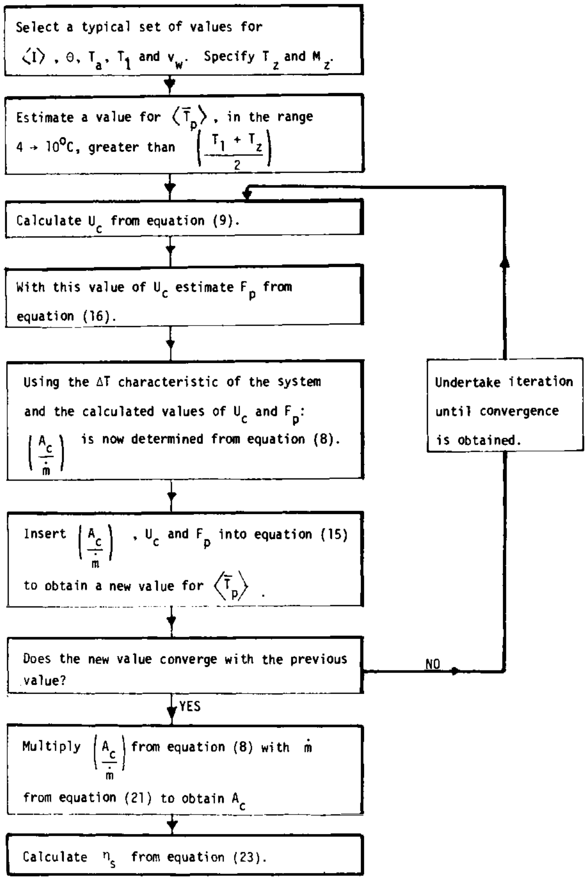

Fig. 2. Design procedure

It is important to note that the minimum collector area required to raise the temperature of 100 kg of water by 30°C is not equivalent to that required to heat 200 kg through 15°C under the same conditions, even though the amount of heat is the same in both cases. This is because to obtain the higher specified temperature, the mean collector inlet temperature will be higher and the system will thus operate at a lower efficiency. In the former case, therefore, the minimum collector area will be greater.

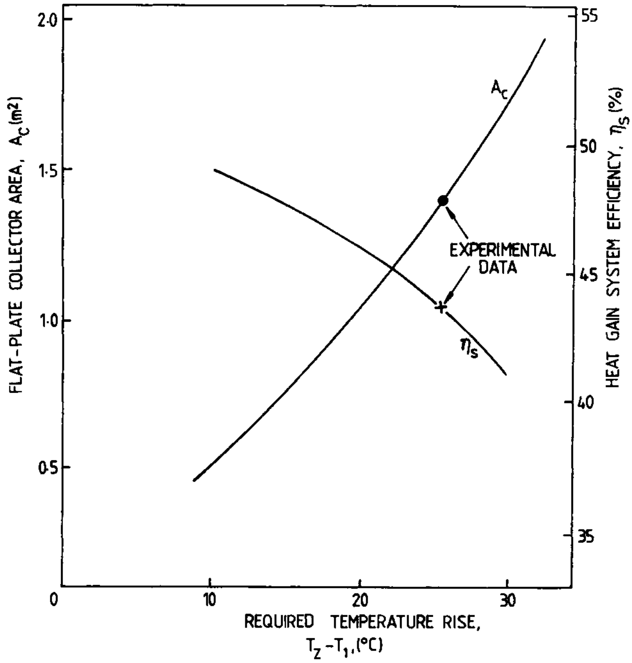

Fig.3 Minimum flat-plate collector area required to raise 100 kg of water through a temperature increment of (T_z - T_1) and the variation with (T_z - T_1) of the heat-gain system efficiency for minimum A_c. The collector parameters and applied conditions are listed in Table 1.

CONCLUSIONS

The underlying theory and the procedure to be adopted for a straightforward method of predicting the performances of n.c.s.e.w.h.'s has been described. Thus optimised designs can be deduced. A thermosyphon s.e.w.h. of 1.4 m^2 collector area has been constructed: this system possessed the characteristics shown in Table 1. When operating under the conditions also shown in that table (which occurred on 27th August 1981 at Cranfield, England), the temperature of 100 kg of water rose through 26^{0}C giving a system heat gain efficiency of 43.5% as predicted by the present theory (see Fig. 3).

With sufficient information concerning the local insolation and meteorological conditions, curves in the manner of Fig. 3 can be derived for any given location and enable the straight-forward sizing of a n.c.s.e.w.h. for each particular collector type to be achieved.

ACKNOWLEDGEMENTS

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COMPARISON OF PASSIVE SOLAR DESIGN METHODS

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ABSTRACT

Participants from eight European countries gathered details of models and calculation methods for the prediction of passive solar performance.

Practical constraints reduced the large number of models to a small number which were subjected to various kinds of test, each carried out on one model by more than one participant.

A comparison is presented of annual simulations on a $1m^3$ cell and a Los Alamos cell, and of the response following an external temperature jump.

KEYWORDS

Passive, solar, computer, simulation, design, models.

INTRODUCTION

In 1981 the Passive Solar Modelling Group of the Commission of European Communities was formed to make a comparison of main frame, mini, micro, calculator and manual methods for estimating the thermal performance of passive solar houses. This Report is a personal view of the U.K. participant and does not necessarily reflect the opinions of the Group. Since the study does not finish until mid-1983, the conclusions are not final.

Dupagne has reported on some of the principles governing the choice of models, and some of the Group's general conclusions, in the Draft Passive Solar Handbook (CEC 1983).

The aim of the Modelling Group was not to make firm recommendations concerning the choice of models; but rather to eliminate from the large list those which could not at the time be strongly recommended. In the end choices *were* made at either end of the scale of complexity. A *manual* method was selected so that a complete technique could be reprinted in the CEC Passive Solar Handbook since some manual methods are excellent vehicles for conveying principles of design to the archtechtural profession. A particular *main-frame* method (ESP) was selected because it was European and thus more easily serviced than those from the U.S., because it is the subject of continuing investment, and because it is a priori one of the world leaders in assessing building thermal response.

The participants are listed in Table 1 so that interested readers may consult further with a participant from their own country.

TABLE 1 European Commission Modelling Group

Denmark	H.Lund	Thermal Insulation Laboratory	Lyngby
France	M.Raoust	Claux-Pesso-Raoust	Paris
W.Germany	C.Kupke	Fraunhofer Institute	Stuttgart
Ireland	J.Cash	Dublin Institute of Technology	Dublin
Italy	F.Rubini	Advanced Consulting Technologies,srl	Torino
Netherlands	C.Pernot	Samenwerkingsverband FAGO/TPD	Eindhoven
Belgium	A.Dupagne	Lab.Phys.Batiment, Univ.Liege	Liege
U.K.	J. Clarke	University of Strathclyde	Glasgow
U.K.	J. Littler	Polytechnic of Central London	London
CEC	T. Steemers	The European Commission	Brussels
CEC	R. Lebens	Ralph Lebens Associates	London

MODEL ELIMINATION

In January 1982, Littler summarised conclusions about main frame models available in 1981. It was suggested that the short list of large programs which should be considered was limited to BLAST, DEROB, ESP, SUNCODE and their future developments.

As a result partly of this study, the U.K. Department of Energy elected to use SUNCODE within its Passive Solar Programme, primarily for its intermediate size (which reduced the costs of repeated use); because it contains treatments of all the passive solar techniques suitable for the U.K. (i.e. direct gain, mass walls, Trombe-walls, conservatories and thermosiphon systems); and because it was written with these techniques constantly in mind, as opposed to models such as DOE-2 written mainly for heavily serviced commercial buildings.

Each participant in the CEC study was asked to list all the models available to his country (large, small and manual). Many models were eliminated because they were not readily available (i.e. they could be used only via a bureau service or their codes were not open to inspection or they could not be transported to other host machines); or because they were not clearly documented; or because software support in the event of problems was not likely to be provided. If participants had already experienced difficulty in mounting a model from elsewhere on their own (apparently suitable) computing facilities, the model was not considered further. Table 2 indicates the list of 'large' models considered.

When the constraints outlined above had been applied, only five large programs survived: LPB-1, MORE, ESP, SUNCODE and DEROB. In depth investigation suggested that the first two were not completely documented and were not ready for transportation to other host machines. Some problems had been reported in the use of DEROB by Hastings (1981) and thus the two models used for subsequent examination were ESP and SUNCODE.

TABLE 2 Large Models considered initially

Program	Author	Country	Program	Author	Country
LPB-1	Lab.Phys.Bat. Liege	Belgium	KLIPAS	Pernot	Netherlands
			ATKOOL	Atkins	U.K.
CEN	Vandenplas	Belgium	BEEP	CEGB	U.K.
Masuch	Masuch	W.Germany	THERM	Sharman	U.K.
Philips	Philips	W.Germany	BUILD	Jones	U.K.
BA4	Lund	Denmark	ESP	Clarke	U.K.
OPT	Gilles	France	HOUSE	Basnett	U.K.
Lyons	Lyons	Ireland	PASOLE	Balcomb	U.S.
Admittance	Cowan	Ireland	DEROB	Arumi-Noe	U.S.
MORE	Alpa	Italy	DOE 2	LBL	U.S.
KLIMASIM	Seeleman	Netherlands	BLAST	Hittel	U.S.
DYWON	Van Dijk	Netherlands	SUNCODE	Palmitor	U.S.

Table 3 lists the models reported by participants and which fit on micros, together with the passive designs which they address.

TABLE 3 Micro-computer Models

		Direct gain	Sunspace	Trombe wall	Mass wall	Water wall	Thermosiphon	Roof pond
LPB2-3-4	Lab. Phys.Bat., Liege	*	*					
SOLPA	Gratia	*						
BA4	Lund	*						
EFP 1-2-3	Nielsen	*						
CASAMO	Ecole des Mines	*	*	*	*	*		
Cash	Cash			*				
Fuller	Fuller	*						
FRED 10	Baker	*	*	*	*	*		*
SPIEL	Green	*	*	*	*	*	*	*
SUNPAS	Balcomb	*	*	*	*			

When constraints similar to those mentioned above were applied, the micro-models selected for further comparison were SPIEL, CASAMO and SUNPAS.

Thirteen potentially useful methods were located running on calculators, however, given their purchase cost and the falling price of micros, it was felt that such tools might become quickly redundant and what was needed was a *transparent* manual method. The only manual methods which passed the "constraints" test were Los Alamos III and Method 5000 (from the Los Alamos Laboratories U.S., and Claux--Pesso-Raoust, Paris, respectively). The main objection to LASL III was that students using it had great difficulty in seeing through the equations and under-

-standing what was actually being calculated, and thus Method 5000 was chosen for further study.

MODEL COMPARISONS

The tests shown in Table 4 were applied by at least two participants to each model.

TABLE 4   Tests applied to the Models

Ambient temperature jump, applied to the lightweight Liege $1m^3$ cell.
Monthly values of auxiliary heating for the lightweight Liege cell.
Monthly values of auxiliary heating of a heavyweight LASL test cell.
Hourly internal temperatures for 10 days in January and June for the Liege cell.
Hourly internal temperatures for 10 days in January and June for the LASL cell.

The models under consideration are ESP, SUNCODE, SPIEL, CASAMO, SUNPAS and Method 5000. Figure 1 indicates the behaviour of those which aim to predict hourly temperatures. For this test, the window in the lightweight Liege cube (detailed in Table 5) was assumed to be insulated as the walls. After equilibration without sun at $0^{\circ}C$, the ambient temperature was assumed suddenly to rise to $10^{\circ}C$. The results were taken as an indication that ESP, SUNCODE and SPIEL handle dynamic heat loss acceptably.

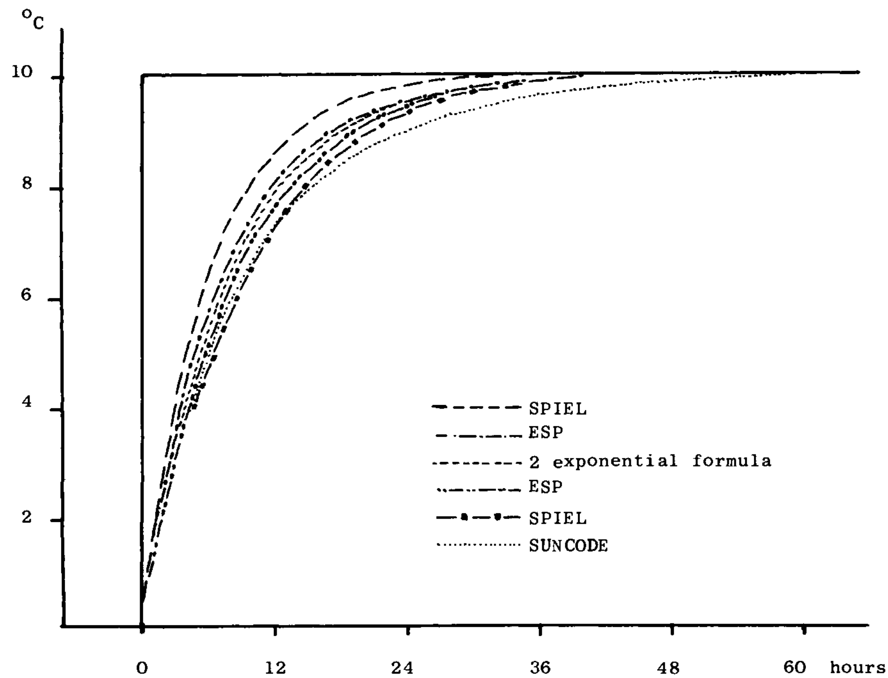

Fig. 1. Model response to an external temperature jump.

TABLE 5 Outline of the Liege Cube

External length 1m; height 1m; width 1m.
Walls U=0.76; floor U=0.37; roof U=0.76 W/m^2K.
South window double glazed 0.36 m^2.
Raised off ground.
Thermal mass restricted to plasterboard (total=50 Wh/K)

Table 6 summarises the annual auxiliary energy required to heat the Liege cell to 18.3^{o}C (24 hrs/day, no venting and no internal gains) with the window exposed to the sun.

TABLE 6 Annual Auxiliary Heating Demand for the Liege Cube in kWh

Model	Participant	Energy	Model	Participant	Energy
5000	Lebens	347	CASAMO	Raoust	311
5000	Pernot	313	CASAMO	Dupagne	357
5000	Raoust	339			
5000	Rubini	338	SPIEL	Cash	377
5000	Dupagne	366	SPIEL	Littler	371
5000	Cash	348	SPIEL	Dupagne	416
LASL III	Rubini	322	SUNCODE	Littler	325
LASL III	Kupke	439	SUNCODE	Kupke	325
LASL III	Pernot	327	SUNCODE	Lebens	380
LASL III	Lebens	408			
ESP	Clarke	241			

It was very encouraging to find such self-consistency amongst usersof Method 5000, on the other hand the direct gain system is the most easy to calculate using this procedure. Subsequent work by the author with a group of architects has shown that at least 4 hours is needed for a calculation using "5000" on a realistic house with buffer spaces and a conservatory, and it is not clear how to deal with ventilation preheating in a sunspace.

It was discouraging to find an overall lack of agreement. However, the internal consistency of the ESP and SUNCODE results show that for these models different users on different computers obtained similar results with the same model, in other words the fault is not with the implementations on alien machines. Similar data for the heavyweight Los Alamos cell (summary description in Table 7) are shown in Table 8.

TABLE 7 Outline of the Los Alamos Cell

Internal length 2.3m; height 2.8m; width 1.4m.
Walls U=0.34(north); 0.34(east);0.0.(west);0.39 (south opaque)
Roof U=0.27; floor U=0.21 W/m^2K
South window double glazed 4.1m^2.
Cell in contact with the ground.
Thermal mass 1230 Wh/K.

TABLE 8 Annual Auxiliary Heating Demand for the LASL Cell

Model	Participant	Energy	Model	Participant	Energy
5000	Cash	1393	CASAMO	Raoust	1074
5000	Lebens	803	CASAMO	Dupagne	1014
5000	Pernot	1024			
5000	Raoust	835	SPIEL	Cash	1132
5000	Dupagne	833	SPIEL	Littler	873
			SPIEL	Raoust	1146
LASL III	Kupke	1505			
LASL III	Lebens	1208	SUNCODE	Lebens	922
LASL III	Pernot	1109	SUNCODE	Littler	867
ESP	Clarke	1100	ESP	Lebens	1100
ESP	Littler	1157			

The results of Table 8 are more indicative of how models might respond to a real house with appreciable thermal mass. It should be noted that the values quoted are "first round" ones, and much of the disparity may be due to differences in the assumptions made by participants when inputting building descriptions. Except for ESP the models require the specification of surface heat transfer coefficients, and the data chosen can greatly affect the output.

CONCLUSIONS

- On light weight structures the manual method showed good self-consistency amongst various users.
- On both light and heavy weight cells, the large models SUNCODE and ESP showed internal self consistency, but did not compare well one with another.
- Such "round robin" tests need very careful attention to input detail.
- Comparisons of this type warn us dramatically about user induced errors and should persuade modellers to make input simpler and less prone to mistakes.

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A COMPUTER CODE FOR DETERMINING THE EFFECT OF SHADOWS ON THE AVAILABILITY OF SOLAR RADIATION ON FACADES OF BUILDINGS

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ABSTRACT

The computer code presented in this paper determines the shadows cast on a building's facade by surrounding obstacles and external structures as a function of site and time. Shadows cast by a building on the ground can also be determined. Code outputs are both numerical and graphical, executed by plotter. The code is intended as an input stage for large codes, simulating buildings' thermal behaviour.

KEYWORDS

Shadows; numerical simulation; computer graphics; solar energy availability, passive solar systems.

INTRODUCTION

Solar radiation availability on a building's envelope is a very important information for evaluating energy balances. This is particularly true for buildings with relevant passive solar features, such as large south-facing glazed surfaces.

In order to estimate the effect of shadows cast either by obstructions - such as other buildings - or by external structures - such as vertical fins, or overhangs - in reducing solar gains, a computer code has been developed. The code allows the analysis of the simultaneous, combined effect of many obstructions, and it is intended as a routine for larger codes providing thermal performance evaluations of a building.

The code has been developed for a HP-85 personal computer, with 1 Mbyte floppy-disk drivers, a TA22Y printer and a HP-7225A plotter.

SUN ANGLES

As a first step the code determines the sun's position, for the given location - that is, latitude - as a function of time. The sun's position is defined by the two angles: γ, azimuth angle, and α, solar altitude, given by:

$$\sin\alpha = \cos\delta \cos\varphi \cos\omega + \sin\varphi \sin\delta \quad (1)$$

$$\sin\gamma = \cos\delta \sin\omega / \cos\alpha \quad (2)$$

where ω is the hour angle, δ is the declination, φ is the latitude.

The code automatically computes α and γ, hour by hour, from sunrise to sunset, for the 21st day of each month. As an example, Table 1 shows a printout of sun angles for January - or November - 21st in Naples, i.e. for a 40.5° N latitude, while Fig. 1 shows the sun path diagram, plotted for the same latitude.

TABLE 1 Sun Angles Printout

POSIZIONE DEL SOLE-LATITUDINE 40 5'N

MESE= 1 ALBA= 7:13 TRAMONTO= 16:46

ORA	ALTEZZA	AZIMUT
7.13	0	-62.935
8	7.4754	-55.09
9	16.095	-43.706
10	22.962	-30.653
11	27.457	-15.893
12	29.032	0
13	27.457	15.893
14	22.962	30.653
15	16.095	43.706
16	7.4754	55.09
16.46	0	62.935

INPUT DATA

The program then requires data relative to the building. More specifically, facade data have to be specified, a facade being any vertical or tilted surface belonging to the building's envelope. For each facade, i, the following data are necessary:

$\beta(i)$ orientation, or angle between the normal to the facade and the south vertical plane, positive towards West;

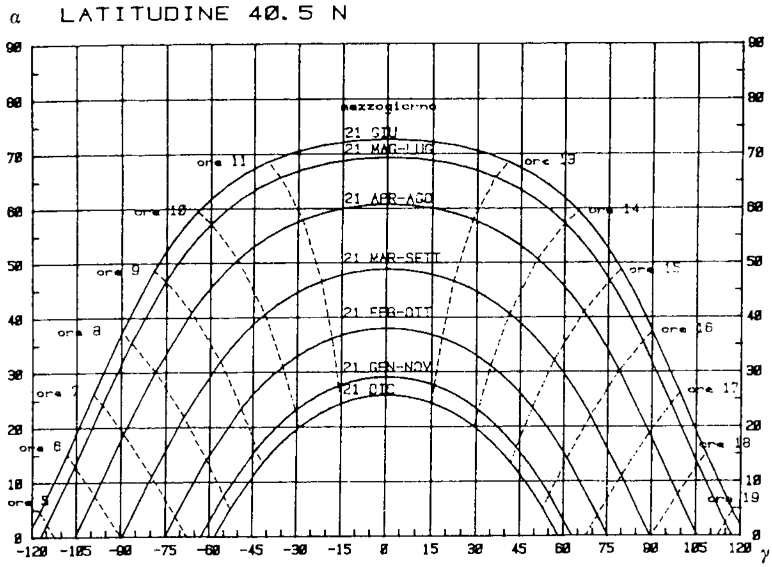


Fig. 1. Sun-path diagram

L(i) and H(i) dimensions

ξ(i) tilt angle with respect to the horizontal plane

$N_o(i)$ number of obstructions seen by the facade.

The code then asks if an overhang is present and, in case, its dimensions and angle formed with the facade.

Solar radiation data are also required, unless the location is among the ones already on file. It is sufficient to input monthly average daily global radiation data on the horizontal plane: hourly direct, diffuse and reflected data are computed, based on the Liu&Jordan correlation, for each orientation and tilt angle. Table 2 shows an example of hourly solar radiation data printouts, relative to a south-east-facing (β=-45°) vertical surface in Naples, for January.

Each of the $N_o(i)$ obstructions seen by the i facade, that is all obstructions belonging, entirely or partially to the semi-space defined by the plane containing the facade, has to be described. This is done, in the general case, by providing the following data:

$N_V(i,j)$ number of vertices of obstruction j

$X_V(i,j)$, $Y_V(i,j)$, $Z_V(i,j)$ coordinates of each vertex, in the space defined by the three axes shown in Fig. 2a

A(l,k) with l,k=1,...,$N_V(i,j)$; A(l,k) is a matrix with elements equal either to 0 or to 1, and expresses whether

TABLE 2 Hourly Solar Radiation Data

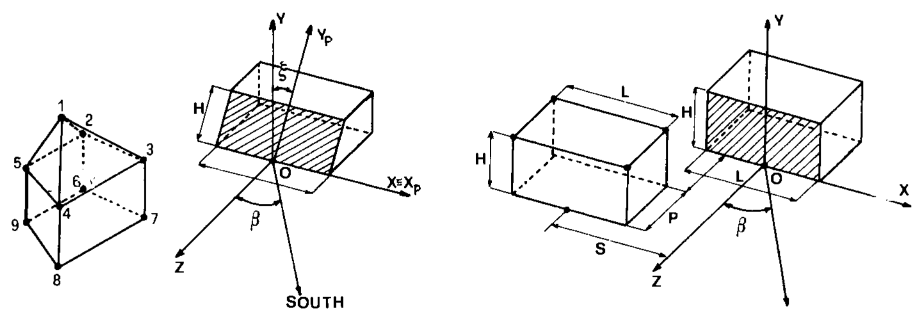
MESE= 1 ALBA=7:13 TRAMONTO=16:46

ORA	RAD.DIR.	RAD.DIFF.	ALBEDO	RAD.GLOB
8	.221	.017	.006	.244
9	.287	.036	.015	.338
10	.316	.051	.024	.390
11	.301	.060	.030	.391
12	.247	.063	.032	.343
13	.168	.060	.030	.258
14	.081	.051	.024	.155
15	.006	.036	.015	.058
16	0.000	.017	.006	.023
TOT.GN.	1.627	.391	.183	2.201

Figures are kW/m^2, for hourly values, and kWh/ m^{2}day, for daily values. South-east vertical surface, in Naples.

the two vertices, l and k, are connected or not. This is important for convex obstructions.

If all obstructions areparallelepiped in shape, with sides parallel - or perpendicular - to the facade ground line, instead of the vertices coordinates, the much simpler data shown in Fig. 2b are sufficient.



a. b.

Fig. 2. Description of an obstruction with respect to a facade: a. general case; b. parallelepipeds

SHADOW CAST BY AN OBSTRUCTION

The shadow that an obstruction casts on the facade is defined by the vertices' projection on the plane containing the facade, from the direction given by the sun angles at that hour. The coordinates of one of these projections, with respect to the axes X_p and Y_p of Fig. 2a, are given, omitting the notation (i,j), by:

$$X_p = X - Y \frac{\sin\gamma}{tg\xi \cos\gamma + tg\alpha} \tag{3}$$

$$Y_p = Y \frac{\cos\gamma}{\cos\xi\,(tg\xi \cos\gamma + tg\alpha)} \tag{4}$$

where X and Y are the coordinates of the projection on the vertical plane, given by:

$$X = X_v + Y_v tg(\gamma - \beta) \tag{5}$$

$$Y = Y_v - Z_v tg\alpha / \cos(\gamma - \beta) \tag{6}$$

The same procedure is followed for all vertices of all N_o obstructions. Links between projection points are given by the A matrix values.

SHADOWS RESULTING FROM SEVERAL OBSTRUCTIONS

The code has now to proceed to determine the shaded portion of the facade, resulting from the summation - with possible overlaps - of the shadows cast by all obstructions at the same time. The procedure is shown in Fig. 3, which is relative to four obstructions. The code finds the four separate shadows, as said before (Fig. 3a), then their summation, taking into account overlapping areas (Fig. 3b), and finally, it delimits the analysis to the portion interfering with the facade (Fig. 3c).

This result is obtained by exploring each interval of the X-axis defined by two adjacent projection points, regardless of the obstruction from which they come, and determining the uppermost line - or lines.

This is shown in Fig. 4, where in the A-B interval, only the A'-B' line has to be saved, out of the four appearing in the interval. In order to do that, comparisons are made between the highest horizontal line and the sloped lines, expressed by means of equations of straight lines through two points. If the intersection points are internal to the interval, then they are added to the points to be saved, as in the case of point C' of Fig. 5.

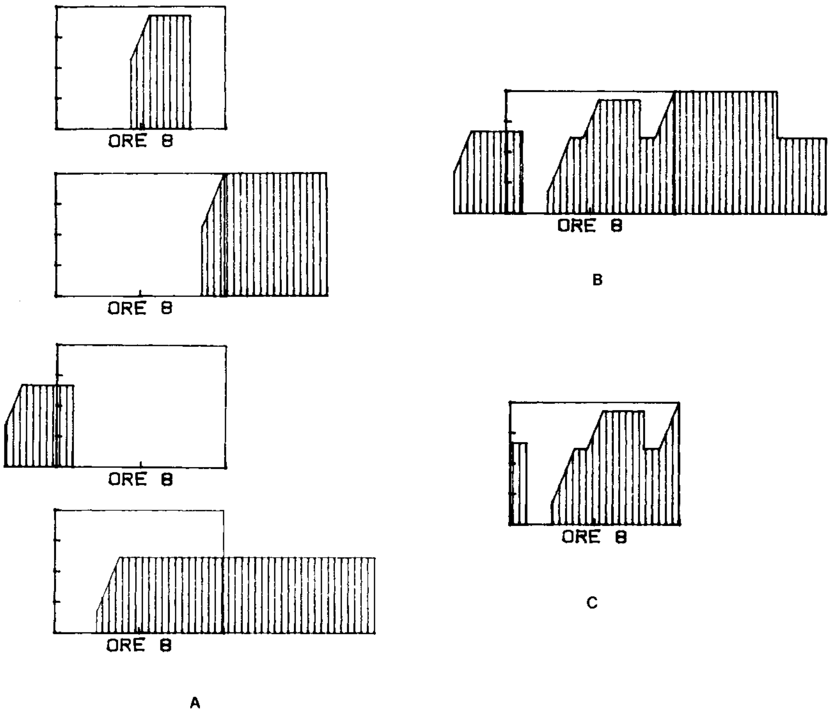


Fig. 3. Shadow cast by four obstructions

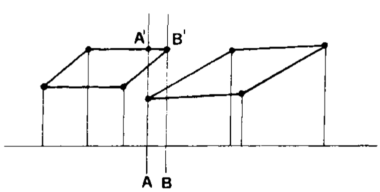


Fig. 4. Interval with four lines

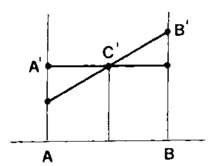


Fig. 5. Intersection between lines

At the end of this stage, the code has generated two vectors, $X_s(n)$ and $Y_s(n)$, containing the coordinates, on the X_p-Y_p plane, of all points defining the shaded area contour.

Finally, comparisons are made with the facade's dimensions and position, as to determine its shaded portion. Shadows cast by overhangs are then compared with it, eliminating possible overlaps.

SOLAR ENERGY AVAILABILITY

Once the shaded portion has been determined, the amount of solar radiation reaching the facade has to be evaluated, as it is not accurate to assume that the only result of shadows is the exclusion of direct sunlight. Hourly data, such as the ones seen in Table 2, refer to totally unobstructed configurations, where a vertical surface is assumed to see one half of the sky. This is not true for obstructed configurations, where portions of the sky are occupied by occlusions, thus reducing diffuse and reflected components, too.

A more accurate study is under way, to introduce into the code the capability of determining this multiple effect. The code will automatically compute the fraction of the total sky area that is occupied by obstructions, as seen from one or more points on the facade, and from points on the horizontal surface in front of the building, thus determining two reduction coefficients, c_d and c_a, for the diffuse and reflected components, respectively. c_d and c_a are functions of obstructed sky areas and of obstructions' luminances. Therefore, hourly global radiation values are given, for the unshaded area, A_e, by:

$$E_e = A_e(I_b(h)+c_d I_d(h)+c_a I_g(h)) \qquad (7)$$

and, for the shaded area, A_s, by:

$$E_s = A_s(c_d I_d(h)+c_a I_g(h)) \qquad (8)$$

where $I_b(h)$, $I_d(h)$ and $I_g(h)$ are the beam, diffuse and reflected components on the facade unit area, in the h hour.

OUTPUTS

The code provides two kinds of printouts. The first one provides the coordinates, X_s and Y_s, of all points defining the shaded area contour, hour by hour. The second one (see Table 3), provides hourly values of the shaded area, both in absolute value and as a fraction of the total area;it also shows the amount of energy that would reach the facade if it were totally unobstructed (E.TEO), the actual value (E.EFF), and their ratio. The bottom line shows daily values of the same quantities. Finally, among other gaphical outputs, the code plots the diagram shown in Fig. 6, describing the shadows on the facade in a day of a month.

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TABLE 3 Energy Availability Printout

FACCIATA: 1	SUP.FACC.: 1320 mq	ORIENTAM.:-45
MESE 3	ALBA 6:01	TRAMONTO 17.58
ORA: 7	AREA OMBRA: 1315	FRAZ.OMBRA: 100
E.TEO.= 324.75	E.EFF.= 44.38	E.EFF./E.TEO.= .14
ORA: 8	AREA OMBRA: 989	FRAZ.OMBRA: 75
E.TEO.= 462.26	E.EFF.= 181.11	E.EFF./E.TEO.= .39
ORA: 9	AREA OMBRA: 546	FRAZ.OMBRA: 41
E.TEO.= 562.21	E.EFF.= 382.43	E.EFF./E.TEO.= .68
ORA: 10	AREA OMBRA: 358	FRAZ.OMBRA: 27
E.TEO.= 604.15	E.EFF.= 480.36	E.EFF./E.TEO.= .80
ORA: 11	AREA OMBRA: 339	FRAZ.OMBRA: 26
E.TEO.= 578.60	E.EFF.= 472.73	E.EFF./E.TEO.= .82
ORA: 12	AREA OMBRA: 328	FRAZ.OMBRA: 25
E.TEO.= 489.67	E.EFF.= 410.83	E.EFF./E.TEO.= .84
ORA: 13	AREA OMBRA: 429	FRAZ.OMBRA: 33
E.TEO.= 353.98	E.EFF.= 294.61	E.EFF./E.TEO.= .83
ORA: 14	AREA OMBRA: 1115	FRAZ.OMBRA: 84
E.TEO.= 196.86	E.EFF.= 166.82	E.EFF./E.TEO.= .85
ORA: 15	NON ESPOSTA	
E.TEO.= 133.54	E.EFF.= 129.12	E.EFF./E.TEO.= .97
ORA: 16	NON ESPOSTA	
E.TEO.= 91.18	E.EFF.= 88.06	E.EFF./E.TEO.= .97
ORA: 17	NON ESPOSTA	
E.TEO.= 44.91	E.EFF.= 43.32	E.EFF./E.TEO.= .96
E.TEO.GIOR.= 3842	E.EFF.GIOR.= 2694	E.EFF./E.TEO.= .70

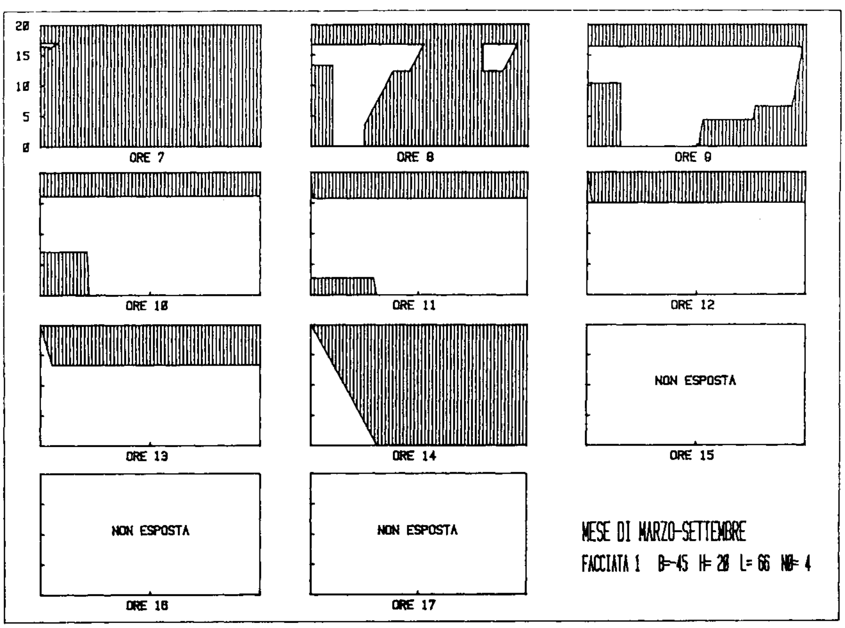

Fig. 6. Plotted diagram of shadows in a month; NON ESPOSTA means sun behind the facade plane

A SIMPLE COMPUTER AIDED DESIGN METHOD FOR ROW HOUSES ENERGY OPTIMISATION

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ABSTRACT

The problem of designing row-house aggregations to get maximum winter insulation and summer shade.
A program for lowcost personal computer that evaluates the percentage of sunny surface of each wall and roof of the tested block unit has been set up.
Two basic row-house aggregations for three different orientations are shown as examples of the computer program application.

KEYWORDS

Design tool; bioclimatic alternative solutions; computer code.

INTRODUCTION

Lately there has been a lot of discussion about the fact that solar architecture is not widely accepted by practising architects. In fact the energy conscious building design creates quite a few constraints for a normal housing design process. The architects need practical and simple design tools, therefore we believe that this type of research should be developed urgently.
First we start by analyzing different residential types of buildings and the shapes most commonly used. The shape of the building is an important factor for the architectural design and equally important for the use of passive climatization.
The row-house type of housing is very frequent in our region, so it was decided to examine it in detail. Often in Tuscany dwelling units are placed one upon another creating three or four floor aggregations. The housing unit blocks of older row-house type are strung along the street to form a compact main front. The present trend of the design approach is to create more volumetric variety, so the block units are shifted forwards or backwards following either vertical or horizontal plans. These solutions also create greater privacy for garden spaces.

In the energy conscious design, one of main factor that must be considered is orientation. Often the available site creates difficulties in this regard, so the sliding of the block units offers more possibilities to solve the problem of orientation, that is to create large south fronts.
For these reasons we have chosen to examine the row-house aggregations with shifted block units, which offer the oppurtunity to fit independent passive solar systems in each flat, but also one may consider to realize a front that overshadows itself on summer afternoon to prevent the house from overheating.
We consider that it should be useful to have a method to evaluate energy and comfort performances of different aggregation models and to control the shading effect of different staggering positions of the buildings. The computer code that evaluates and plots reciprocal shadows of buildings has been developed by Prof.Colajanni and others, it works on the Hewlett Packard personal computer in HP-BASIC language. We adapted this code with some changes to the Texas Instrument TI-99/A personal computer, to verify the operation also with a low cost computer but which is able to plot a coloured video-output. Its versatility enables us to evaluate the shadows of several row-house aggregations frequently used, and to evaluate their sun-catching frontage.

THE COMPUTER CODE

The program evaluates the percentage of sunny surface of each wall and roof of the tested buildings, and visualizes the result.
As imput the program require the following data.
For tested block unit:
floor plan and cross section dimensions of the building, its orientation in relation to the azimuth angle with an E-W axis, eventual volume variations along the front.
For neighbouring blocks:
floor plans and cross section dimensions, their orientations to azimuth angle with the tested buildings.
Beside that it requires the following data:
latitude and longitude of the site, meridian longitude in relation to local time, day and hour of the test.
In running the program the tested wall or roof is divided into successively ordered elements in a matrix. In each element a line is considered as having the same direction as the sun ray for any successive hour, and the program verifies which element interupts the line. A matrix of shadowed or sunny elements is generated and plotted on the video or printed.
As output for any of the four walls and roof the program gives the percentage of sunny surface, and beside it plots the wall with two areas, sunny and shadowed, in two colours with graphic accuracy varying according to choice.

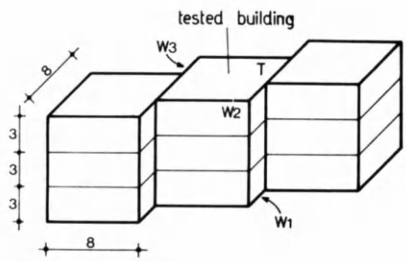
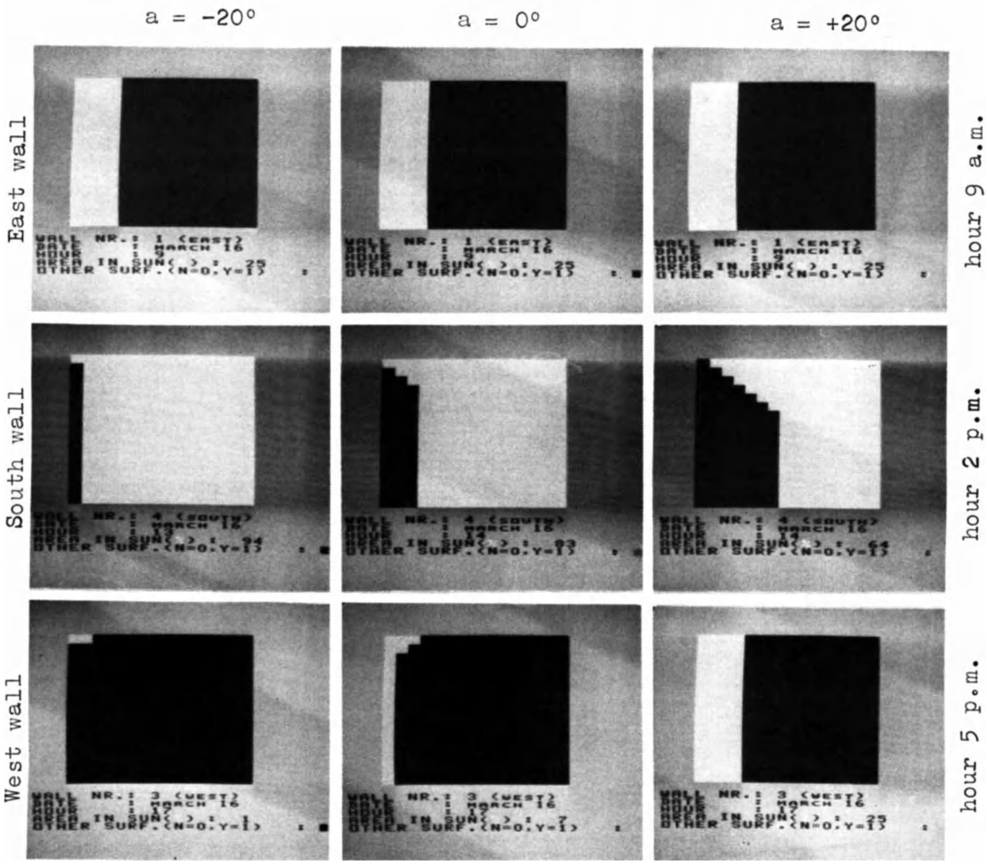


Fig. 1

VIDEO-OUTPUT OF COMPUTER PROGRAM FOR ROW-HOUSES

Aggregation of three blocks same height.
Test data:
Day 16 March
Hour 9 a.m., 2 p.m., 5 p.m.
Orientation angle -20°,0°,+20°



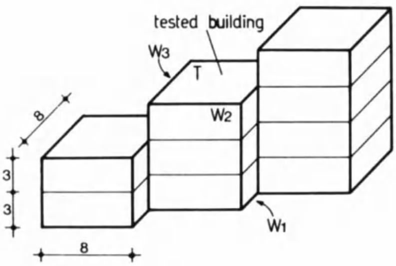
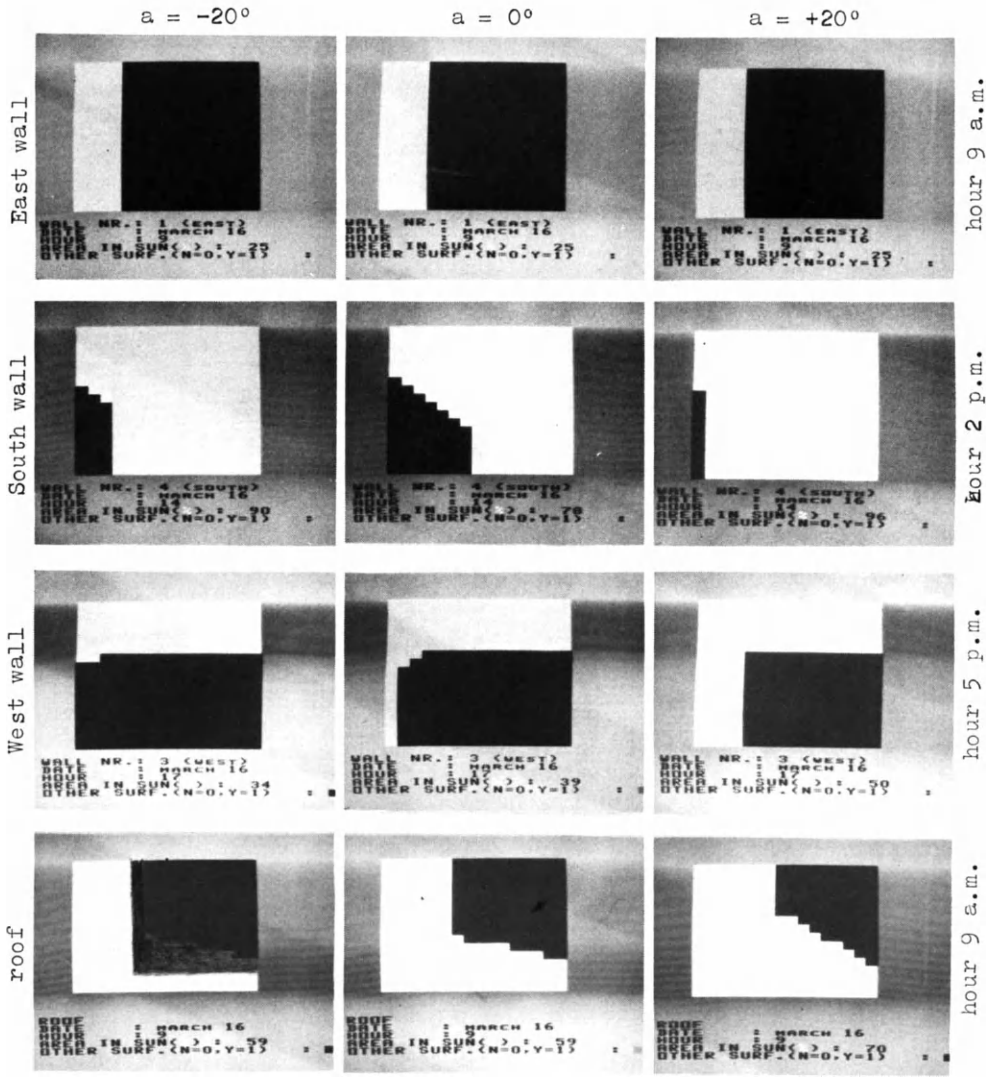


Fig. 2

VIDEO-OUTPUT OF COMPUTER PROGRAM FOR ROW-HOUSES

Aggregation of three blocks of different height.
Test data:
Day 16 March
Hour 9 a.m., 2 p.m., 5 p.m.
Orientation angle -20°, 0°, +20°



EXAMPLES OF APPLICATIONS OF THE METHOD TO ROW-HOUSE AGGREGATION

We ran a first phase of analysis of the mutual shadows of various aggregation types and we showed in this paper some examples of the application of the method described above.
First we examined a basic dwelling unit dimensioned for a nuclear family of four members according to the existing building code regulations.
The basic dwelling unit is 8x8 mt. size floor plan 3 mt. high.
We show two types of aggregations. The first one consists of a block of three basic dwelling units placed one over the other adjoining two similar blocks on either side. All blocks are in staggered positions and have the same height (Fig. 1).
In the second aggregation type the height of the two adjoining blocks is two floors and four floors respectively on west side and East side of the central block wich remains three floor high (Fig. 2).
In both cases the shadow test has been run over the central block three floors high in order to verify the shadow effect on it of the adjoining blocks.
One example of the shadow-tests is on the East, South and West walls respectively at 9 a.m., 2 p.m., 5 p.m. of 16 March, shown in Fig. 1 and Fig. 2. Besides, the effects of three different orientations 20°, 0°, -20° in relation to an E-W axis are verified and shown. The accuracy of plotting has been chosen 0,5 m . size of every shown element. In this case the RAM computer space required is 15 Kbytes.

NEW DEVELOPMENTS AND CONCLUSIONS

The first results of research have shown the aptitude of the program to test different row-house aggregation types. In the next development of research the shadows of more complex building will be tested and also the architectural front elements, as window or loggias, will be represented to verify which areas can be used eventually to fit passive solar systems. This operation requires more RAM space in the computer TI 99/A, whose peculiarities also allow one to represent differently coloured areas. Besides, the solar radiation incidence on each element can be evaluated at any step so that technical and economic evaluations can be made
The research is supported by fund from Ministry of Public Education in an interuniversity coordinated research program.

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SIMULATING PASSIVE SOLAR PERFORMANCE USING INDUSTRIAL DYNAMICS MODELS

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ABSTRACT

Industrial Dynamics as a tool for simulating the performance of Passive Solar Systems has been demonstrated. A model has been developed, parametrically tested, and applied to a test array currently under study. The application of Industrial Dynamics to the field of solar analysis is particularly effective as a pedagogical tool and can be used in predicting passive component performance. This methodology and sample runs will be discussed.

KEYWORDS

Solar, Thermal, Industrial Dynamics, Passive Design

INTRODUCTION

Industrial Dynamics, introduced and developed by J. Forrester (1968) and co-workers as a tool for modeling industrial processes, has found applicability in recent years in the simulation of complex socio economic systems. This paper introduces Industrial Dynamics (or Forrester Models as they are sometimes called) as a tool for modeling thermal heat transfer and solar design.

The model introduced herein takes into account first order processes and is useful principally as a pedagogical tool. The models are easy to construct, formulate, manipulate, and execute and the logical refinements required to simulate real systems are apparent.

This paper will briefly outline the framework of Industrial Dynamics modelling, present a simple example (Newton Cooling), define the basic passive model the authors developed to introduce this application, and show the results and implications of the parametric runs on this test model.

INDUSTRIAL DYNAMICS FRAMEWORK

Industrial Dynamics is a technique generically related to the state approach wherein an n-order differential equation is reduced to n simultaneous first order differential equations. The major elements in an industrial dynamics model are levels, rates, and parameters. The symbols are depicted in Fig. 1.

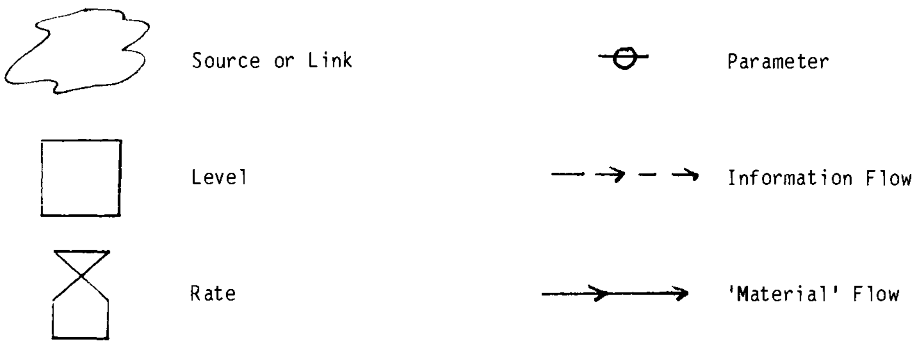

Fig. 1. Industrial Dynamics Model Symbols

In this scheme levels are controlled by rates which in turn are set by levels and parameters. The model equations for the levels and rates are iteratively solved providing a simulation of the system over elemental time increments.

To illustrate this procedure, consider the simple process shown in Fig. 2 known as Newton Cooling. The container at temperature, T, is conducting heat to its environment which is held at temperature TO. The equation governing the heat loss, dQ/dt is

$$dQ/dt = -k\ (T-TO)$$

where k represents the physical parameters governing the conduction of the container. One can rewrite this equation using the heat capacity and mass to change dQ/dt to dT/dt as follows:

$$C\ m\ dT/dt = -k\ (T-TO)$$

or

$$dT/dt = -K\ (T-TO)$$

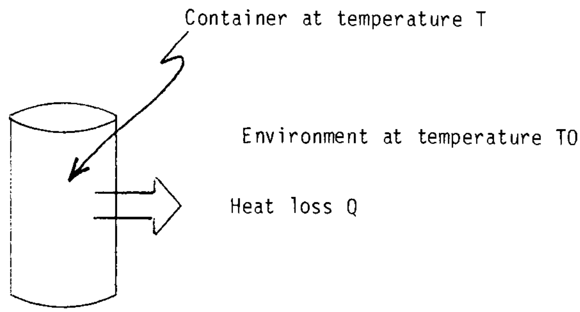

Fig. 2. Newton Cooling

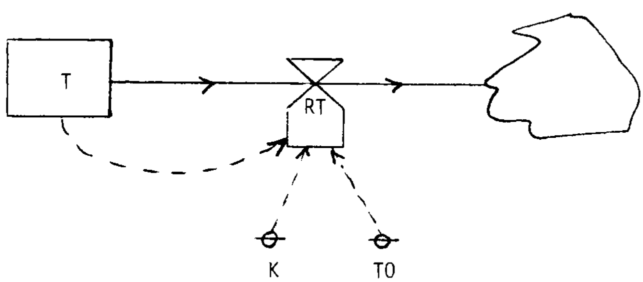

Fig. 3. Industrial Dynamics Model for Newton Cooling

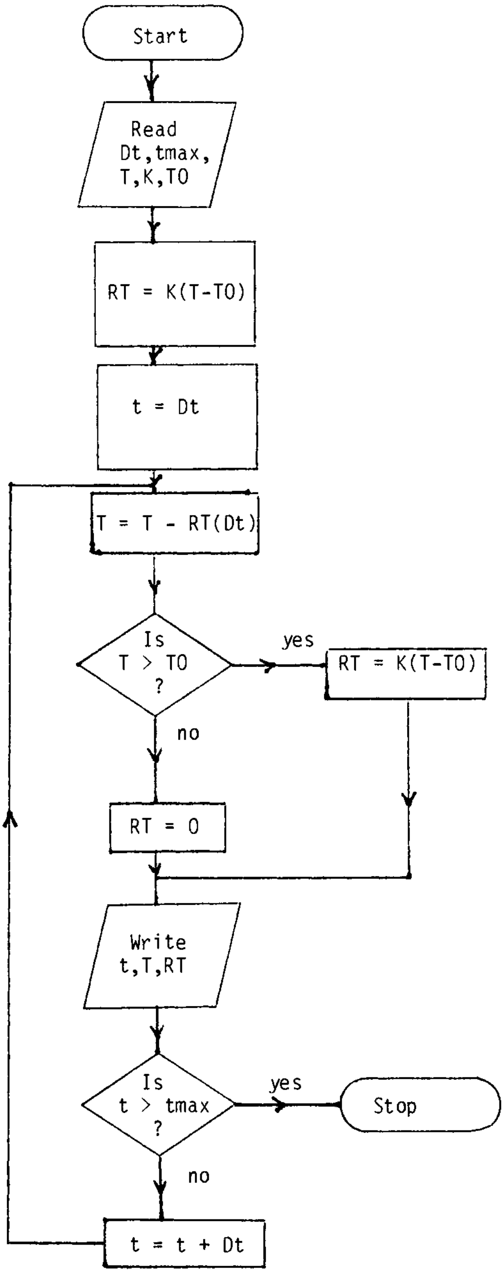

Fig. 4. Flowchart for the numerical execution of the Newton Cooling model

where K represents a combination of physical parameters for the container. The above equation can be solved analytically for T(t) giving the usual exponential cooling curve known as Newton Cooling. In an Industrial Dynamics framework, this system could be represented by a level, T, a rate RT, and parameters K and TO as shown in Fig. 3. The level, T, is reduced by the rate, RT, which in turn is adjusted by the parameters K and TO and the level T. The level and rate equations for this system are shown as the repeated process in the algorithm of Fig. 4. In this flowchart the parameters and initial value of level T is defined and the system is simulated over a finite time element, Dt. Of course, the smaller this time element, the more closely the numerical procedure will follow the analytical one.

A PASSIVE DESIGN MODEL

This methodology can be applied to a simple system abstractly defined in Fig. 5 wherein insolation impinges on a conditioned space and on a mass within that space. Energy exchanges take place between the system mass and the conditioned space and between the conditioned space and its environment. An Industrial Dynamics diagram depicting this simple model with first order effects is shown in Fig. 6. It sould be noted that, while a formulation can be made using energy contents as levels, the formulation becomes much simpler when temperatures are treated as levels. In the simple model described herein, outside temperatures were held fixed and the principal levels are the temperature of the conditioned space (air) and the temperature of the system mass. The model permits conductive gains and losses to and from the conditioned space and thermal energy exchanges between the mass and the conditioned space.

The equations corresponding to the above model were programmed using an iterative procedure similar to the one described in the example of the previous section. Parametric analyses were carried out to test isolated features of the model. The results of these runs are shown in Figures 7 through 11. Figure 7 shows the results for a set of conditions with zero solar gain and zero thermal mass. The temperature of the conditioned space falls exponentially as one would expect. Figure 8 shows the effect of a change in thermal mass, holding other parameters constant. These results were run for winter conditions holding constant outdoor temperature and a hypothetical insolation rate shown in Fig. 9. The usual time delay for peak temperatures and a reduction of temperature swings, when thermal mass is increased, are noted in Fig. 8. The effects of mass for summer conditions are depicted in Fig. 10 where outdoor temperatures were held constant at 70 deg. F and the moderating effects of mass are apparent. Parametric analyses were also carried out varying the absorbtance of thermal mass, glazing area, and exposed mass area. The effects noted were not unexpected. For example, average conditioned space temperature increased evenly with glazing area and the beneficial effects of spreading the thermal mass over a large exposed area were apparent. These effects in our simple model are consistent with the detailed results found in the works of Balcolm (1980) and Mazria (1979).

The effects of varying the mass to air transfer coefficient are shown in Fig. 11. For low values of the mass to air transfer coefficient, the mass is ineffective in heating the conditioned space. (If it is zero, the limiting case, the mass is of no value in heating the conditioned space.) Coefficients above 1.5 can only be reached through forced ventillation (active technology). This is discussed in Balcolm (1980). It is interesting, nonetheless, to see the improvement in physical performance as one increases this transfer coefficient. For extreme values, 999, shown in Fig. 12C, the temperature oscillates and the behavior becomes unstable. It should be pointed out, however, that no optimum value was predicted in the range from 1 to 100 in this simple model.

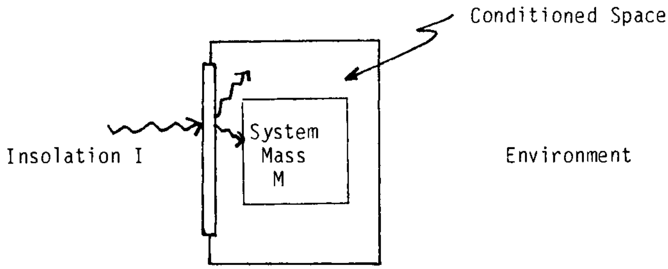

Fig. 5. Conceptual system for passive model

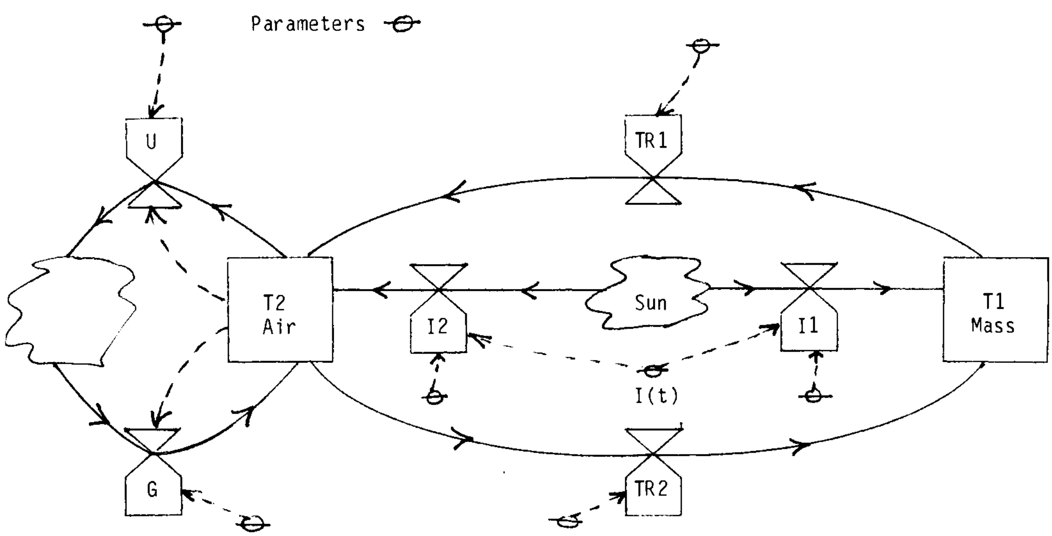

Fig. 6. System model

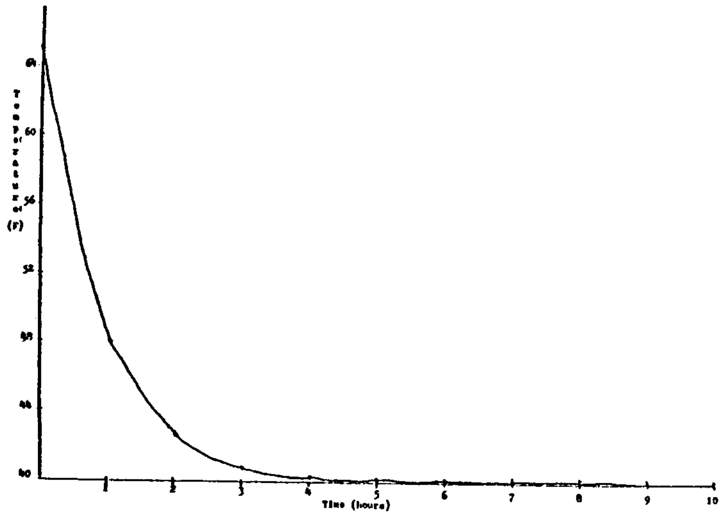

Fig. 7 Results with no solar gain (Newton Cooling)

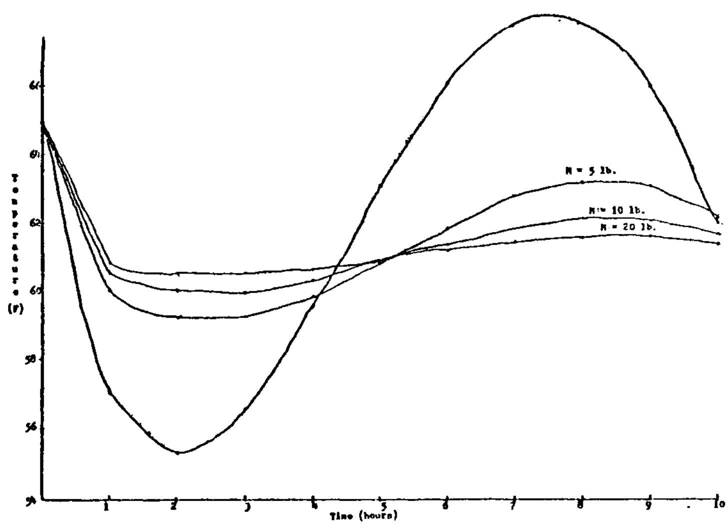

Fig. 8. Effects of system mass under winter conditions

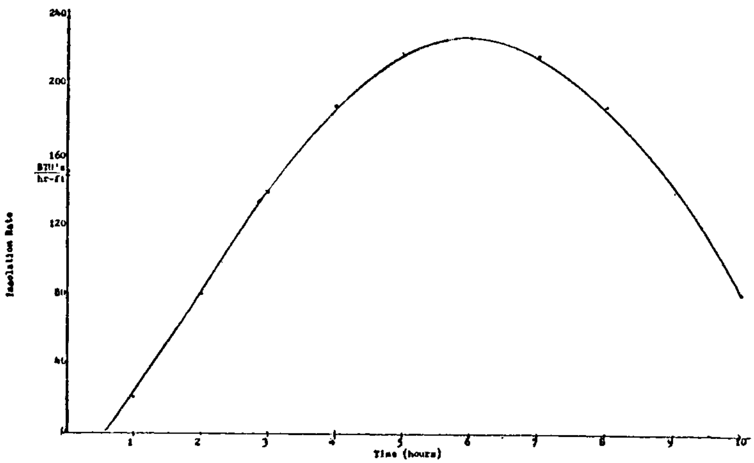

Fig. 9 Assumed insolation rate

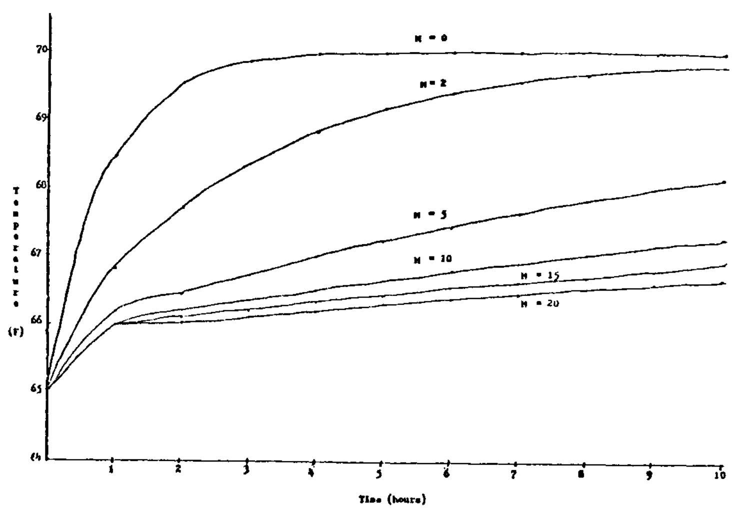

Fig. 10. Effects of system mass under summer conditions

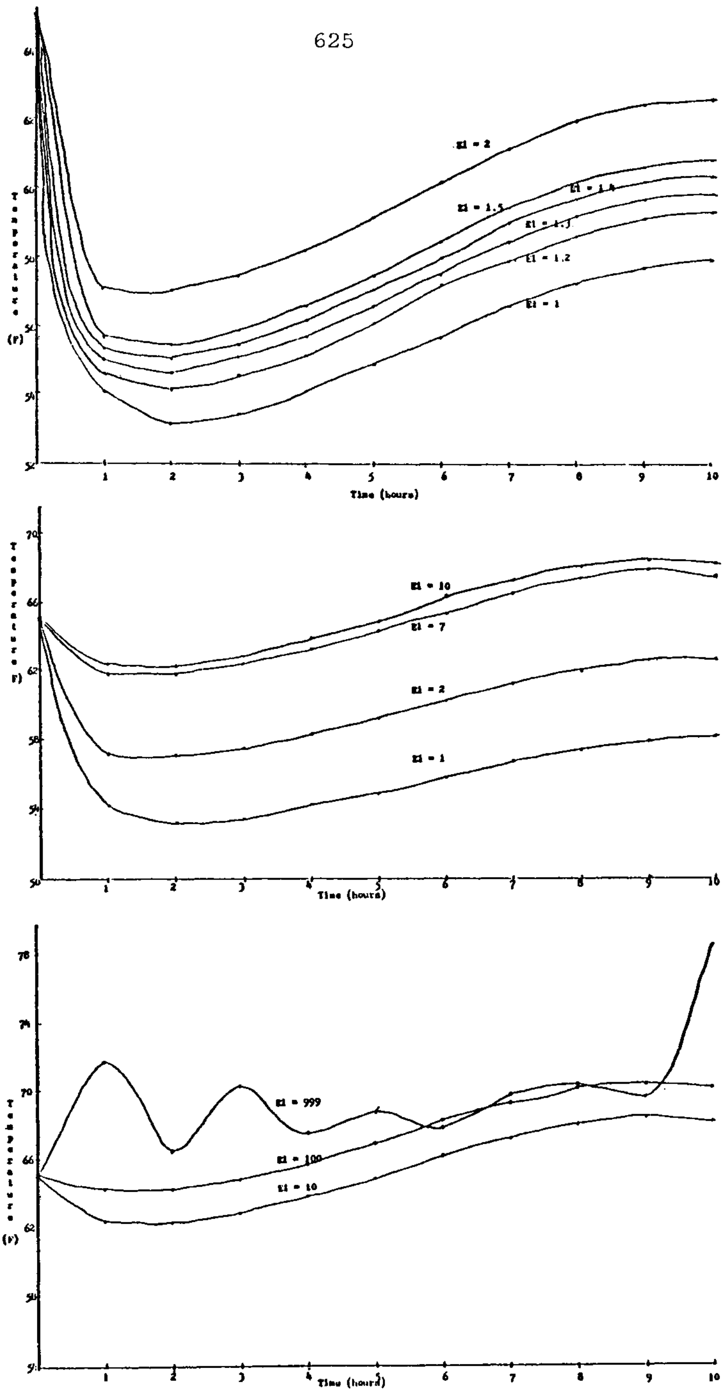

Fig. 11a,b,c. Effects of mass to air transfer coefficient, El

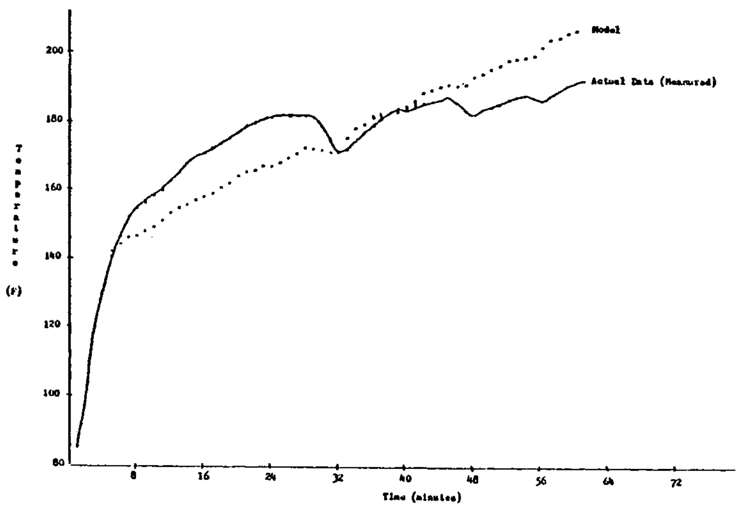

Fig. 12. Real system results

Simulations were performed to test the effects of varying the outdoor temperature and the thermal integrity of the structure and the results are consistent with what one would expect.

CONCLUSIONS

Industrial Dynamics is a framework which can well represent the essential features of a passive system. The model has pedagogical appeal and is rather simple to construct, manipulate, and execute. The model described in the previous section was executed on a stand-alone microcomputer system utilizing a BASIC language interpreter.

In order to capture subtle effects that are important in system design and operation, it will be necessary to extend the model. However, Industrial Dynamics appears to have the capability for the kinds of extensions one must envision in design including geometry, shading, diurnal and seasonal changes, etc.

Our laboratory is not currently equipped with a suitable test facility and the simple model described above includes only major first-order effects. Nevertheless, we attempted to simulate conditions for a real system, a thermally light solar collector that is being tested in another study at Providence College. The results of this simulation and the actual data are shown in Fig. 12 for a test period of one hour. A Least Squares analysis of these data reveals the probability of a Type II error (saying that there is a correlation between the distributions when there is not) is less than one percent. The model well predicts the subtle changes in temperature and the largest differences between the actual and simulated results is about 5 degrees. Considering the experimental errors and the fact that only first order effects are included in the model, the results are suggestive that Industrial Dynamics holds promise as a design-simulation tool in solar architecture.

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EXPERIMENTAL VALIDATION OF A FINITE DIFFERENCES TROMBE WALL MODEL

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ABSTRACT

The paper describes a finite differences Trombe wall model validation, based on experimental data recorded at a passive systems test station in Central Italy. The computer code has been checked step by step, due to the different reliability of the data and to the various algorithms used in the code. Thus, cloudy and clear nights with no thermocirculation were simulated and compared with experimental data, then evening hours with thermocirculation, but no sun and, finally, a full day was simulated and compared. Some inaccuracy has been found in the simulation of wind effect on outer glass convective heat transfer coefficient. The code, however, has been found to provide data in reasonable good agreement with experiments. Thus, allowing for some uncertainties about input data used and for some measurements unreliability, the overall performance of the simulation model may be considered satisfactory.

KEYWORDS

Trombe wall; simulation; test facility; validation; convection.

INTRODUCTION

In the following pages both the experimental facility where the data have been gathered and the numerical simulation computer code will be briefly described.
The research groups involved in this joint effort consider the activity developed so far as a preliminary stage for the development of simple and reliable design tools. In fact, both the experimental data and the computer code are far too complex to be usable by designers; on the other hand, cooperation between university researchers and professional designers is possible and very productive, but it has to be restricted to few projects, requiring detailed analyses.
In order to develop reliable design tools, ranging from the very simple ones, such as diagrams and graphs, to more complex instruments, such as personal computer codes, a highly reliable large computer code is necessary.
This sort of concerns and objectives leads to the activity discussed here: the comparison of experimental data with simulation, so as to test and modify, when necessary, the different assumptions and algorithms used in the code. Since not all experimental data have the same reliability, this exercise also helped in pointing out deficiencies in the data acquisition system, which will be corrected in the future.

THE EXPERIMENTAL FACILITY

An existing, two-storey building, located near Urbino, in Central Italy, latitude 43° 43' N, with heavy brick and stone walls, has been transformed as to accomodate a passive solar systems test facility (Fanchiotti, 1980, 1981).
Six Trombe wall test cells - three on each floor - were obtained by double-glazing a portion of the south-facing facade, that was partly made of 40 cm thick brick walls, and partly of 50 cm thick stone and brick walls (fig.1). The two central cells walls were built with concrete blocks, 35 cm thick. The glass panes are easily removable for maintenance and inspection; the concrete blocks can be replaced with other types of walls, for comparison.
The instrumentation consists of more than 200 sensors, measuring :

a. climatic data: air temperature, humidity; wind velocity and direction; solar radiation on the horizontal and on the vertical south-facing panes;
b. heat losses: these are evaluated by means of temperature measurements: glass, wall surfaces, internal air, etc.;
c. thermal comfort: surface and air temperatures, as well as globe temperatures, are measured in each cell.

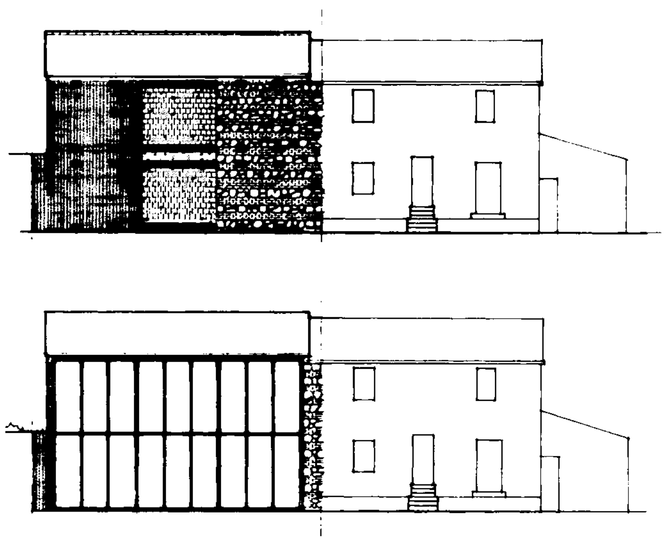

Fig. 1. The passive solar systems test facility.

The type and position of the sensors in each of the six cells is shown in fig.2. In addition to temperature sensors, three air velocity sensors are placed in one of the upper vents.
There are 32 sensors per cells, plus about 30 additional sensors for measuring temperatures in other parts of the building and for climatic data.
Temperature sensors are thermistors, solar radiation sensors are Eppley PSP pyranometers, air velocity sensors are hot wire anemometers, developed for this purpose: unfortunately they did not provide reliable data.
The data acquisition system consists of a central unit - a microprocessor computer - acting either as a data-logger, or as an off-line computer. The computer has 32k bytes memory for programming. The central unit is connected to 15 satellite units, each connected to 16 sensors. Measured data are recorded on magnetic

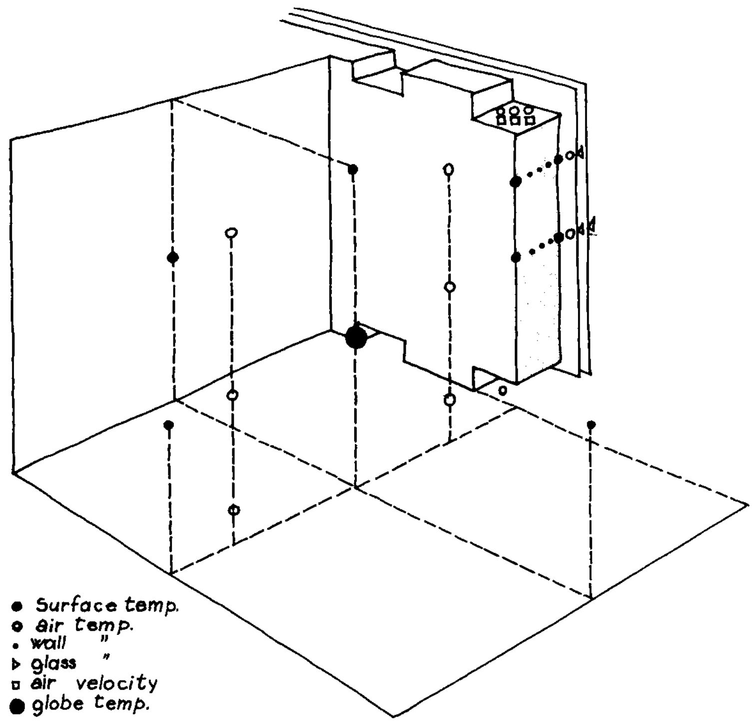

Fig. 2. Position of main sensors.

cassettes. Data used for the validation exercise are relative to the upper floor concrete blocks cell.

THE SIMULATION MODEL

The Trombe wall simulation model, the reliability of which is analysed in this paper, is a sub-routine of a larger model (SMP, Simulazione Moduli Passivi) developed for the simulation of building modules equipped with passive components, and based on monodimensional explicit finite difference method (Butera and co-workers, 1983).
The sub-routine "Trombe" is able to simulate the thermal behaviour of a system composed by a single or multi layer wall, with an outside single or double glass cover and optional night insulation. It is possible to choose between vented or unvented wall; reverse thermocirculation may be allowed or not.
As a consequence of the monodimensional finite difference method, no allowance is made for vertical thermal gradient in the wall and in the glass; outlet temperature of the air flowing in the air space, viceversa, is calculated taking into account an exponential trend (Utzinger, Klein and Mitchell, 1980).
The algorithm used for the calculation of glass-air and wall-air convective coefficients when thermocirculation is off, is based on the following empirical formulae (Gebhart, 1979) :

$$Nu = 0.233 \left(Ra \cdot \frac{W}{h}\right)^{1/4} \qquad \text{for} \quad 2.10^4 < Gr < 2.10^5 \qquad 1)$$

$$Nu = 0.0512 \, (Ra)^{1/3} \qquad \text{for} \quad 2.10^5 < Gr < 10^7 \qquad 2)$$

where Nu, Ra and Gr are the adimensional Nusselt, Rayleigh and Grashof numbers, function of surface temperature; W and h are the air space width and height.
When thermocirculation is on, convective coefficients in the glass-wall air space are calculated by means of an algorithm based on the empirical formulae (Gebhart, 1979) :

$$Nu = 0.59 \, (Ra)^{1/4} \qquad \text{for} \quad 10^4 < Ra < 10^8 \qquad 3)$$

$$Nu = 0.13 \, (Ra)^{1/3} \qquad \text{for} \quad Ra > 10^8 \qquad 4)$$

Glass-air external convective coefficient h_e, is calculated with the following empirical formula (ASHRAE, 1975) :

$$h_e = - 0.0355 \, v^2 + 3.328 \, v + 8.233 \qquad \text{for} \quad v > 1 \text{ m/sec} \qquad 5)$$

where v is the wind speed. For $0 < v < 1$ an interpolation is made between values obtained with natural and forced convection.
Natural circulation flow in the channel is calculated with the expression proposed by Varcolik (1979), adjusted (Butera and co-workers, 1983) to allow for air temperature stratification in the room :

$$\dot{m}^2 \{ T_o K_o/A_o^2 + T_i K_i/A_i^2 + (T_o + T_i) \, b \, h/E^2 D_e \} +$$
$$+ \dot{m} \, (a \, h \, \nu/D_e^2 E) + g \, h \, c^2 \{ (T_i T_a + T_o T_a - 2 T_o T_i)/(2 T_o T_i T_a) \} = 0 \qquad 6)$$

where
$\dot{m}$ = mass flow rate per unit wall area
T = air temperature (°K)
K = vents head loss
A = vent area
a,b = coefficients to allow for friction effects
c = coefficient to allow for barometric pressure
D_e = equivalent hydraulic diameter of the glass-wall air duct
E = air duct cross section area
g = gravity acceleration
h = distance between upper and lower vent
ν = air kinematic viscosity
subscripts : o = outlet, i = inlet, a = average air temperature in the room.
The net longwave radiative loss of the outer glass, Q_r, is calculated with an algorithm based on the following empirical formula (Cole, 1979) :

$$Q_r = \varepsilon_v \{ \sigma T_v^4 - R_A(\alpha) - R_G(\alpha) \} \qquad 7)$$

where :
ε_v = glass emittance
σ = Boltzmann's constant
T_v = glass temperature (°K)
$R_A(\alpha) = R_{AO} K_1 + K_2 b' \sigma T_a^4$ = atmospheric longwave radiation incident upon a surface inclined at an angle, α, to horizontal
$R_{AO} = \sigma T_a^4 \{ a' + b' (0.5 + \ln u) \}$

a' = 0.7 + 0.3 n c

b' = 0.09 (1 - n c)

n = $0.7067 + 0.00822\, t_a$

t_a = $T_a - 273$ = external air temperature (screen height)

c = fractional cloud amount

u = 12.5 exp (0.295 p - 0.803) = optical path depth (Cole, 1979)

p = saturation water pressure, calculated as a function of relative humidity (IHVE, 1970)

K_1 = view factor glass-sky = $\cos^2 \alpha/2$

K_2 = coefficient function of α

$R_G(\alpha)$ = $K_3\, \sigma\, T_a^4$ = ground longwave radiation incident upon a surface inclined at an angle, α, to horizontal

K_3 = view factor glass-ground = $\sin^2 \alpha/2$

VALIDATION METHODOLOGY AND DATA USED

In order to be able to evaluate the accuracy of each algorithm used in the model, a step by step validation methodology has been adopted. Four steps were judged to be sufficient for obtaining the required information :

a) simulation of conduction heat transfer in the wall.

b) simulation of convective and radiative losses of outer glass in overcast sky condition, and no thermocirculation;

c) as above, but in clear sky condition;

d) simulation of convective and radiative losses of glass cover in presence of thermocirculation;

e) simulation of the whole Trombe system.

Because of the limited reliability of glass temperature measurements in sunshine, the validation of convective and radiative heat transfer algorithms has been executed selecting suitable data sequences recorded during night time. The sequences selected are four, with the following characteristics :

- sequence n. 1 : it has been assumed that during these hours there is no natural circulation in the Trombe wall, because mid-height air temperature in the air space is lower than mid-eight air temperature in the room (reverse circulation is not allowed); it has also been assumed fully overcast sky (c = 1) because this night is between two days with very low solar radiation.
- sequence n. 2 : also in this sequence it has been assumed no thermocirculation, for the same reasons as in sequence n. 1; the sky, viceversa, it has been assumed either fairly clear (c = 0.3) and fully clear (c = 0), estimating that from the trend of solar radiation the day before and the day after.
- sequence n. 3: it has been assumed that during these hours there is natural air circulation in the Trombe wall, because mid-height air temperature in the air space is higher than mid-height temperature in the room; it is also been assumed fully clear sky (c = O), because the night is between two fully clear days.
- sequence n. 4 : it has been chosen as representative of a day partly clear and partly overcast, rather windy, for testing the behaviour of the whole simulated system.

The simulation time step used was 5 minutes.

EVALUATION OF UNAVAILABLE DATA

Before executing simulation runs it was necessary to estimate some not measured input data, like the thermal diffusivity of the wall, the absorption coefficient of its outer surface,the values of head loss coefficient in upper and lower vent.

Thermal diffusivity of the wall was calculated by means of an iterative procedure based on the comparison between measured temperature data inside the wall and corresponding temperature values calculated with the finite difference method, varying the diffusivity value. Experimental and computed values were then treated with the minimum square root method for determining the most appropriate value of thermal diffusivity. The value obtained was $0.657 \cdot 10^{-6}\ m^2/s$.
Absorbtion coefficient of outer wall surface was assumed 0.9.
Head loss coefficients in upper and lower vent were estimated by solving the system of equations formed by eqn. 6 and :

$$c_p \dot{m} (T_o - T_i) = h_g (T_g - T_m) + h_w (T_w - T_m) \qquad 8)$$

where :
c_p = air specific heat
h_g, h_w = convective heat transfer coefficients, calculated with eqns. 3) and 4)
T_m = logarithmic mean air temperature in the air space
subcripts : g = glass; w = wall.

RESULTS OF SIMULATIONS AND COMPARISON WITH EXPERIMENTAL DATA

According to the validation steps previously described, the first analysis carried out was for checking the reliability of the estimated value of wall thermal diffusivity. In fig. 3 is shown the comparison between experimental data and the results of a simulation run executed by imposing, as boundary conditions, measu-

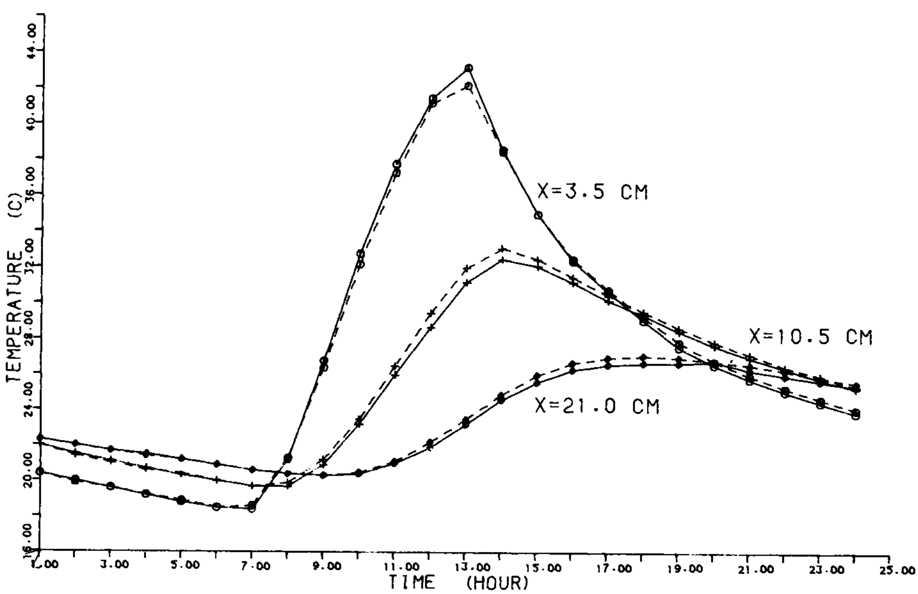

Fig. 3. Simulated (dotted lines) and measured temperatures in the wall at three distances from outer surface.

red values of wall surfaces; computed and measured temperatures at three distances from outer wall surfaces are given. The agreement between experimental and computed data may be considered reasonably good, expecially if the unavoidable measurement inaccuracies are allowed for.
The second step was the simulation of the thermal behaviour of the cover system in a cloudy night, without thermocirculation. Data sequence n. 1 was used for metereological inputs. Measured temperature data at 3.5 cm from outer wall surface were used as boundary condition in the simulation; initialization temperature values were the measured ones.
The comparison between calculated and measured temperatures of cover system components is shown in fig. 4.
The maximum difference between calculated and measured outer glass temperatures is about 1 ^{o}C. This difference cannot be attributed entirely to modeling inaccuracies, for two reasons :
i) the input value of cloud cover (c=1.0) is estimated, and it could have been somewhat different during that night;
ii) temperature sensors in the glass are protected by a small piece of aluminium foil, the emissivity of which is lower than that of glass; some degree of inaccuracy in glass temperature measurements must be allowed for.
Calculated inner glass temperature at mid-eight is almost identical to the measured one in the last two hours. It should be noted that - because of a malfunction of the mid-eight sensor - inner glass temperatures plotted in fig. 4 are measured in the upper part of the glass (see fig. 2). Mid-eight temperatures probably would have been slightly lower.
In the clear sky night - sequence n. 2 - the comparison between calculated and measured temperature values (fig. 5) shows that measured temperature values are - both in outer and inner glass - higher than calculated.
Because of the aluminium foil protecting the sensor, however, it is reasonable to suppose that actual outer glass temperature would have been slightly lower than measured. Also inner glass temperature, if it had been measured at midnight, probably would have been slightly lower.
In the same fig. 5 is shown the simulated effect of cloud cover on glass temperatures. The importance of the exact knowledge of the actual value of c during the simulated night is clearly enlightened.
Sequence n. 3 (clear night) was used for testing thermocirculation algorithms. Unfortunately the test could not be complete for lack of reliable experimental information about air flow rate in the duct.

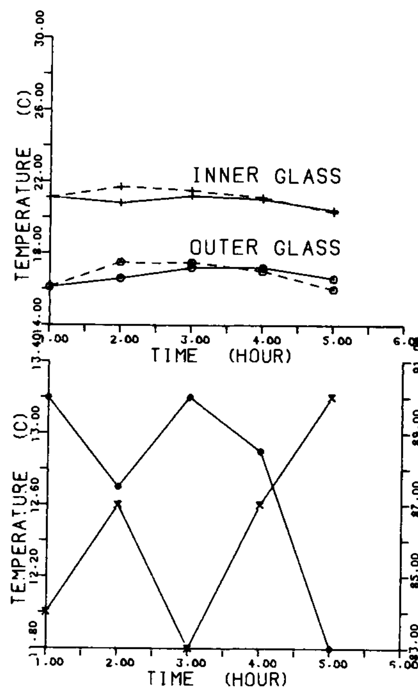

Fig. 4. Top: calculated (dotted lines) and measured glass temperatures in a cloudy night; no thermocirculation.
Bottom: temperature and relative humidity data used as input.

Results of simulations, executed imposing experimental values of wall temperature at a distance of 3.5 cm from the outer wall surface, are shown in fig. 6. Calculated values of outlet air temperature are very close to measured values, but always slightly lower, and lower than measured are also inner and outer glass calculated temperatures : this is probably due to the inaccuracy of the algorithm used, that over-estimates the convection heat transfer coefficient. Also wind data treatment may cause error : they are the instantaneous values measured each hour, but in the simulation they have been treated as average hourly data and a linear interpolation between successive values was made.
A final simulation run was executed with the 24 hours sequence n. 4.
The simulation was extended to the whole Trombe wall system : boundary conditions were the measured values of room air temperature and surface temperatures of room walls. Results are compared with measured data in fig. 7. Lower calculated temperatures of thermocirculation air and of inner wall surface confirm that glass heat losses are overestimated.
As shown in the same fig. 7, calculated and measured values of solar radiation incident on the glass surface are fairly consistent, and further runs executed increasing wall surface absorbtion coefficient from 0.85 to 0.95 did not show substantial improvements.
It may be concluded that the Trombe wall model, in windy environment, slightly under-estimates the efficiency of the Trombe system.

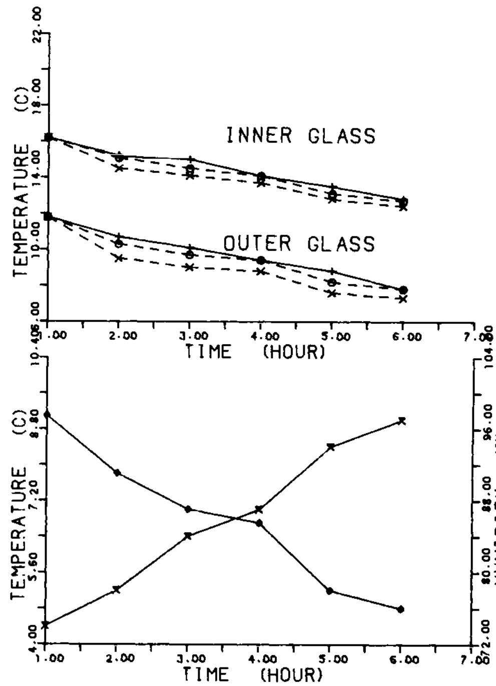

Fig. 5. Top: calculated (dotted lines) and measured glass temperatures in a clear night; no thermocirculation. Higher calculated values are for c = 0.3, lower for c = 0. Bottom: temperature and r. h. data used as input.

CONCLUSIONS

The methodology used for the validation enabled us to identify in the external convective heat transfer algorithm a critical part of the sub-routine Trombe. The lack of experimental data on air flow rate in the channel did not allow us to test accurately the thermocirculation algorithms. Other areas of uncertainty derives from the unavalability of experimental data on thermal properties of the wall and on optical properties of the glass cover. Measurements of solar radiation behind the glass cover would have been very helpful.

It has been shown that the limited accuracy of the external convective heat tranfer algorithm in windy environment has little effects on the overall thermal behaviour of the Trombe wall; the sub-routine "Trombe" may be, therefore, considered since now as a reliable tool for passive building design. Further tests, however, are being carried out in order to validate more accuratly thermocirculation simulation and to identify more accurate wind sensitive heat transfer algorithms.

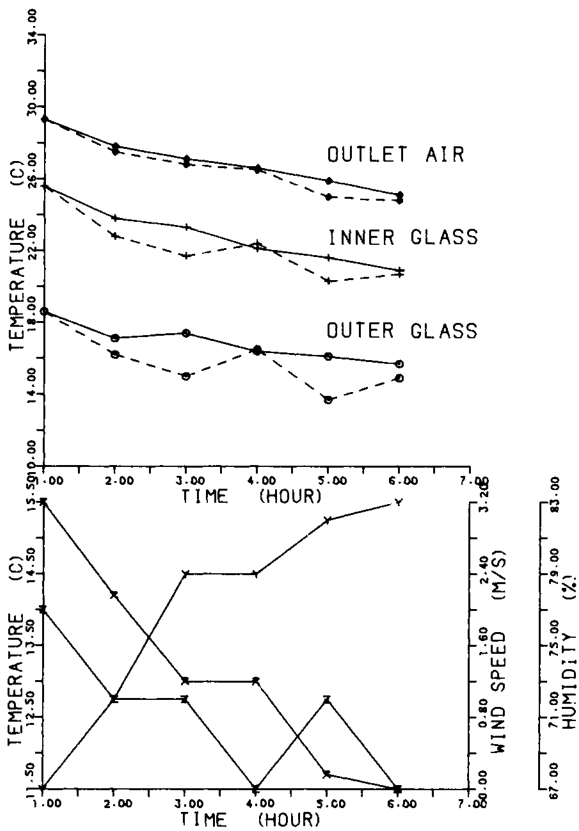

Fig. 6. Top: calculated (dotted lines) and measured glass and outlet air temperatures in a clear and windy night; thermocirculation on.
Bottom: temperature, relative humidity and wind speed data used as input.

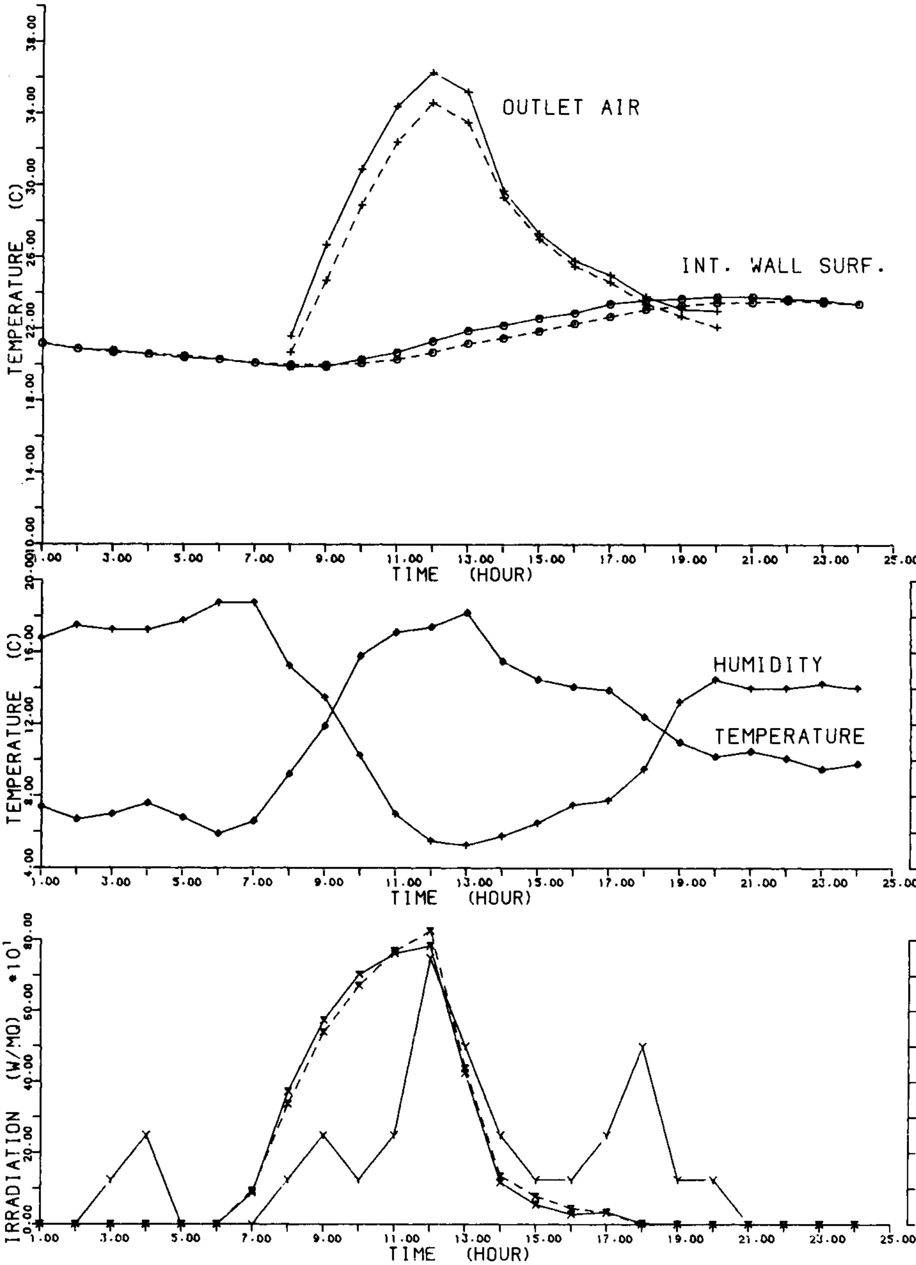

Fig. 7. Top: calculated (dotted lines) and measured air and wall temperatures. Bottom: calculated (dotted line) and measured solar radiation incident on glass panes; wind speed.

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COMPARISON OF COMPUTER SIMULATIONS AND BILLING DATA ENERGY USE IN SIXTY-THREE PASSIVE SOLAR HOMES IN CALIFORNIA

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ABSTRACT

Detailed building parameters including house plans and billing data were collected during visits to sixty-three passive solar houses located throughout California. These data were collected using the Solar Energy Research Institute (SERI) Class C questionnaire forms. Using these data, inputs for DOE 2.1 and CALPAS 3.01 Computer Codes were prepared and the predicted monthly energy use and indoor temperatures were obtained. The energy use predicted by the codes was compared to the energy use obtained from the billing data. The observed and predicted Building Performance Index (BPI) for each house was calculated using the billing data and the simulated performance.

The DOE 2.1 results were generally closer to the billing data results. The data were also analyzed to see if there were systematic indications of the suitability of various passive system type for different climates. The preliminary analyses show no correlation between the system type and climate.

KEYWORDS

Passive solar houses; billing data; computer simulations; Class C houses; Building Performance Index; DOE; CALPAS.

INTRODUCTION

During the last decade a great deal of research has been done in the field of solar energy. Side by side, with, and many times proceeding, this research, a great variety of solar energy utilization technologies have been developed. Many of these technologies were aimed at using solar energy for residential space and water heating. There is a twofold reason behind the motivation for the great push of solar applications to space and water heating in the U.S.A. Firstly these applications have been used since the time of ancient civilization (Aristotle used solar energy around 2300 years ago) and secondly a significant portion of the total energy consumption in the U.S.A. is for space and water heating. To further encourage the utilization of solar energy in homes, federal government and many state governments gave tax incentives. The State of California leads the nation in clearly formulating a solar energy tax credit policy for space and water heating. Computer codes such as DOE and CALPAS were extensively used for simulations in order to generate the information required for policy making decisions. Computer codes have also been extensively used for house design. It has been realized from the start that these computer codes should be "validated" using field data, however, this has proved to be an extremely difficult and costly undertaking. The problems are exacerbated by the different approaches that can be taken. A detailed treatment of this subject is given by Mahajan and co-workers (1980). For the present paper by validation of the computer code we shall mean the bottomline comparisons of the computer predictions and field data values for the auxiliary energy and the range of indoor temperatures. The present study is limited to only passive solar houses in the State of California.

In the following sections the methodology used for validation and the findings are discussed in detail.

DATA COLLECTION

There are four major steps involved in the collection of field data required for this study. These are

Site Selection

Geographic location and solar system type were two of the main criteria for inclusion in the study. A telephone survey of more than 300 solar houses located throughout California was conducted. On the basis of this preliminary survey 63 sites were chosen for inclusion in the final survey. Most of the houses surveyed by telephone had wood burning stoves for backup heating. This kind of backup can introduce a large source of inaccuracy. However it was not possible to completely leave out from the final site list houses using wood burning stoves.

Even though 63 sites were surveyed, data from only 51 sites were found to be reliable and complete enough for the present analysis.

Survey and Site Visits

The survey forms used were developed by the Solar Energy Research Institute (1980), Golden, Colorado. These forms (Class-C data) have two questionnaires - one dealing with the marketing information and the other dealing with thermal performance information. The analysis presented here uses only thermal performance information. At the time of the site visit extensive house drawings, pictures, name plate information, orientation, insulation levels, system type, range of thermostat setting, backup for water and space heating etc. were obtained. These data were then used to prepare inputs for CALPAS 3.01 and DOE 2.1 Computer Codes. Two main reasons for using these codes are

- the widespread use by designers and
- extensive use by the California Energy Commission in formulating solar energy policy making decision.

Billing Data

Monthly billing data for a one year period was obtained from the utility companies. In addition the amount and type of wood used was estimated during the site visit.

Weather

Data from 450 weather stations throughout California is compiled by the National Oceanic and Atmospheric Administration (NOAA). Monthly heating degree days (HDD) data, based on 65°F set point, is consistent with the HDD data derived from weather tapes used for DOE 2.1 and CALPAS 3.01 Computer Codes. The weather station selected for each of the 51 sites was based on the following criterion

- one of the 300 stations for which NOAA has computed monthly HDD
- geographically reasonably close to the site
- at about the same elevation as the site.

An example of the summary prepared for each house is presented in Table 1.

TABLE 1 Class-C Site Summary

LOCATION: Inverness, California, USA

LATITUDE: 37

LONGITUDE: 122

ELEVATION: 600 ft

CLIMATE ZONE: 3

INSULATION:
1) Walls: R-11
2) Ceiling: 1-1/2" technifoam over 5/8" plywood.
3) Floor: R-11 underneath floor above crawlspace.

NEAREST WEATHER STATION: Kentfield

CONSTRUCTION TYPE: Single family detached. 2x4x16 wood frame with basement. Unheated crawlspace (2134 ft^2). Two floors.

HEATING: Passive
1) Direct Gain/Misc. Exposed Mass.

COOLING: Night ventilation.

BACKUP: Fireplace, 3KW electric heater.

FLOOR AREA: 2134 ft^2 VOLUME: 20540 ft^3

APERTURE AREA: 328 ft^2 double glazed glass.

SHADING OF APERTURE: Trees to SE and SW. Second floor windows shaded from above by 2 ft overhang. SE windows shaded by 4-1/2 ft balcony.

USE OF THERMAL DRAPES ETC FOR WINDOWS: Sunscreens for south windows.

OCCUPANT ESTIMATED TEMPERATURE RANGE: 68°F night. Manual thermostat set-back.

THERMAL MASS TYPE: 4" unexposed concrete slab (711 ft^3). 8" brick around fireplace (20 ft^3).

NON-APERTURE U (BTU/Hr°F): 806

TOTAL U (BTU/Hr°F): 996

DATA ANALYSIS

Once the data were collected, the first step was to choose a measure of performance which would adequately compare the survey data and computer simulations. Some of the difficulties encountered were:

- The weather at the site is often different, sometimes drastically different than that used in simulations.

- The energy used by the water heaters is usually a significant fraction of the purchased energy. It may or may not end up in the house depending upon the location of the water heater. The fact that many of these sites had solar water heaters made the estimation of purchased energy for water heating even more difficult.
- The billing and wood use data from Class-C give a measure of total purchased energy. The simulations predict heat energy delivered to the space. These quantities are not comparable.
- The uncertainty of the energy delivered by wood stoves and fireplaces is quite serious.
- Since only the heating season data is used for validation, the duration of the heating season had to be defined separately for each house since they are in widely different climates.

The difference between the climate at the site and simulation climate is to some extent taken into account by using a Building Performance Index (BPI) as a performance measure. The BPI is defined as energy/HDD/floor area. The division by degree day and floor area partially "normalizes" the energy use and removes the effects of weather and house size. The appropriate energy to use for the numerator of this expression must be chosen carefully to reflect both the data available and the intended use to be made of the index. If one is using billing data a BPI based on total purchased energy is clearly the easiest to calculate but is not necessarily an accurate indicator of heating performance. If one is working from simulation results, however, a BPI based on delivered energy ($Q_{aux} + Q_{int}$) is both the easiest to obtain and is also the most direct measure of heating performance. In this study BPI's based on both approaches are presented.

Uncorrected BPI = Purchased energy/HDD/floor area

Corrected BPI = $(Q_{aux} + Q_{int})$/HDD/floor area

The $Q_{aux} + Q_{int}$ are estimated from the billing data as follows:

$Q_{aux} + Q_{int}$ = (Purchased gas energy - Energy used by gas water heater) x efficiency

+ (Purchased electric energy - electric energy used by water heater and other appliances outside the living space) + wood energy x efficiency

The wood use efficiency was taken to be 50% for wood stoves and 5% for fireplaces. The purchased DHW energy which does not enter the living space was estimated on a case-by-case basis. The location of the water heater, the form of energy used to heat water, the ground water temperature, the thermostat setting of the water heater, thermal efficiency and estimated hot water consumption were taken into consideration for estimation of energy used by DHW heaters.

SIMULATIONS

The Class-C data collected during the present study were used as inputs for DOE 2.1 and CALPAS 3.01 Computer Codes. The outputs were compared to each other and to the field data. Caution has to be used in drawing conclusions because of the inadequacies in the Class-C data and possible inconsistencies between the assumptions on which the simulations are based and the actual house operation. In particular the weather tapes used for the simulations do not necessarily accurately represent the conditions at the sites.

Table 2 gives the simulation results for a sample of the houses. Table 3 gives general trends. As seen from this table CALPAS 3.01 predicts more required heating energy than DOE 2.1. The cooling energy requirements predicted by the two models are surprisingly close, especially when venting and air conditioning are aggregated.

TABLE 2 Sample of Class-C Simulation Results

Location in California	DOE 2.1 Heating (MBTU)	DOE 2.1 Cooling (MBTU)	DOE 2.1 Venting (MBTU)	CALPAS 3.01 Heating (MBTU)	CALPAS 3.01 Cooling (MBTU)	CALPAS 3.01 Venting (MBTU)
Suisun	3.5	8.7	30.0	14.3	18.4	37.6
Inverness	11.2	15.6	17.0	10.8	0.8	31.3
Berkeley	1.1	5.2	26.4	1.9	1.8	43.4
Shingle Springs	7.7	17.2	31.8	8.3	11.6	43.6
Point Reyes	3.3	6.2	31.8	10.4	28.3	37.9
La Honda	1.3	3.7	34.9	1.9	0.4	24.6
Inverness	4.2	18.7	25.5	11.3	5.7	54.6
Chico	18.6	30.2	22.1	11.2	19.6	30.0
Sonora	10.0	2.9	32.2	12.2	16.7	31.5
McKinleyville	16.4	2.6	7.7	21.3	0.0	7.9
Sebastopol	7.7	2.8	31.7	12.5	8.8	20.8
Santa Barbara	11.4	0.3	31.3	10.5	2.1	29.2
Rio Linda	2.2	7.0	25.6	2.4	7.2	27.2
Davis	0.8	10.4	40.6	4.0	9.6	32.4
Woodland	10.8	16.4	36.3	9.9	7.4	33.5
Pleasanton	7.9	0.1	16.3	0.7	4.0	28.0
Running Springs	4.5	32.5	31.5	12.8	26.4	24.1
Oakland	11.3	2.3	43.8	9.9	1.1	36.0
Whittier	6.9	12.5	48.2	12.9	10.9	43.0

TABLE 3 General Simulation Trends

Means and Standard Deviations of Simulations[2]
(Energies in MBTU)

	Heating mean	Heating σ	Air Conditioning mean	Air Conditioning σ	Venting mean	Venting σ	Total Cooling[1] mean	Total Cooling[1] σ
DOE 2.1	7.81	7.79	11.4	13.6	27.1	11.3	38.5	17.0
CALPAS 3.01	9.05	6.83	9.40	8.96	30.8	11.8	40.2	14.6

Extremes of Simulation Results
(Energies in MBTU)

	Heating min	Heating max	Air Conditioning min	Air Conditioning max	Venting min	Venting max	Total Cooling min	Total Cooling max
DOE 2.1	0.00	39.9	0.00	55.0	6.00	56.6	6.00	80.3
CALPAS 3.01	0.00	33.1	0.00	37.2	5.90	58.0	6.20	95.2

1) Total Cooling = Air Conditioning + Venting
2) Data for the 50 houses simulated with both models

COMPARISONS BETWEEN MODELS AND BILLING DATA

Another useful comparison is between the simulation results and the actual energy use. The corrected BPI values obtained from the Class-C billing data discussed above give an estimate of thermal performance. The mean, standard deviation, and extremes of the BPI for the models and billing data are given in Table 4. Since figures for cooling could not be obtained from billing data, comparisons in cooling will not be made. CALPAS 3.01 predicts more heating energy than was actually used. This is seen graphically in Fig. 1, which shows the percentage of houses with BPI's

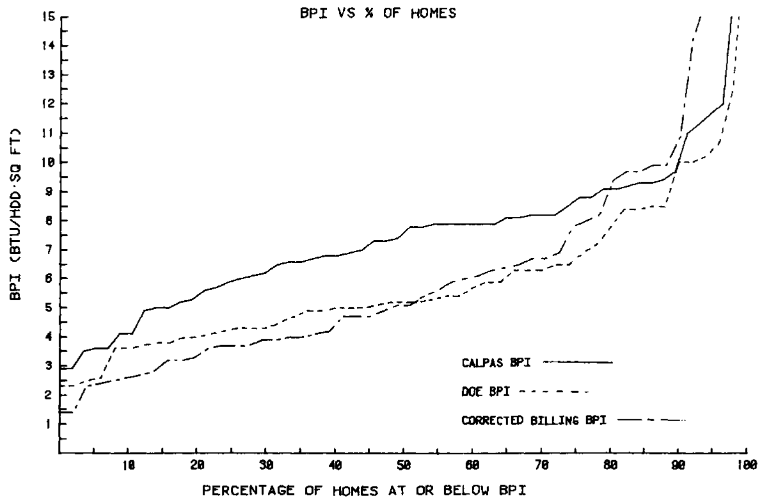

Fig. 1. BPI vs percentage of homes at or below the corresponding BPI for both computer simulations and the billing data.

at or below a given BPI. Note that for the 90% of houses with the lowest corrected BPI (<10), the graphs for DOE 2.1 and the billing data compare very well. However, the predicted energy use for houses with a corrected BPI greater than 10 is nearly the same for both models and is considerably smaller than that shown by the billing data. Both models predict few houses to have a corrected BPI greater than 13 (3% for DOE 2.1, 4% for CALPAS 3.01), while the billing data results indicate 12% of the houses have a BPI greater than 13. A possible cause of this discrepancy is that some houses may be poorly managed and not perform up to their theoretical potential. Since all houses were simulated as if they were managed well, the houses that weren't would have larger BPI's than predicted. Ignoring those houses with BPI's greater than 18.0, larger than the largest BPI of either model, the mean corrected BPI for billing data of the remaining 50 houses is 6.16, quite close to the mean corrected BPI of 6.04 for DOE 2.1.

Another comparison between DOE 2.1, CALPAS 3.01 and the Class-C data is from the ratio (field BPI/simulation BPI) for each house. These are given in Fig. 2 and Fig. 3. Unlike the graphs of Fig. 1 where house identities are lost this compares the simulation results to the Class-C data for the same house. With this display the systematics of the comparisons can also be seen. If the most extreme 5% or so of the data is disregarded the DOE 2.1 ratios seem to be relatively close to unity while those for CALPAS 3.01 seem significantly higher.

TABLE 4 Mean, Standard Deviation and Extremes of BPI

	$\bar{x}$	σ	Smallest	Largest
DOE 2.1	6.04	2.79	2.28	17.7
CALPAS 3.01	7.57	2.61	2.87	16.1
BILLING DATA	6.48	4.23	1.42	22.5

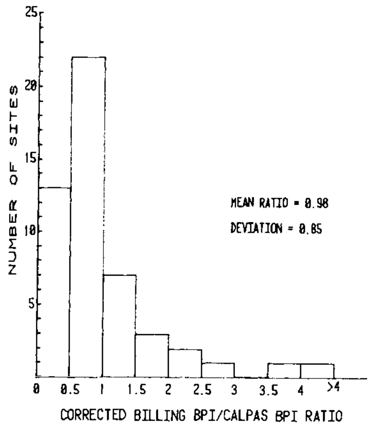

Fig. 2. Histogram of number of sites for a given billing to CALPAS BPI ratio.

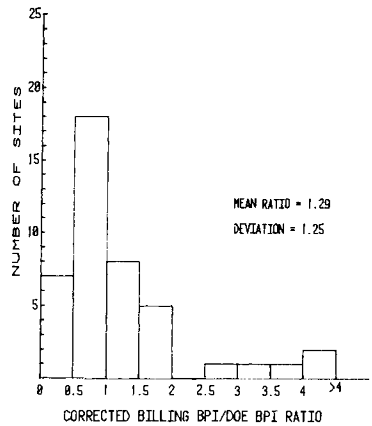

Fig 3. Histogram of number of sites for a given billing to DOE BPI ratio.

The corrected billing BPI are plotted in Fig. 4a and 4b. The houses are marked according to kind of auxiliary used. Also indicated by x's in Fig. 4 are data from eleven houses which were also instrumented at the SERI Class-B level (Solar Energy Research Institute, 1980). It is interesting to note that the scatter for these cases, where much more detailed and precise information on house performance is available, is not markedly better than for the Class-C sites. This may indicate that for comparisons such as this, the Class-B data does not provide significant increases in accuracy over Class-C.

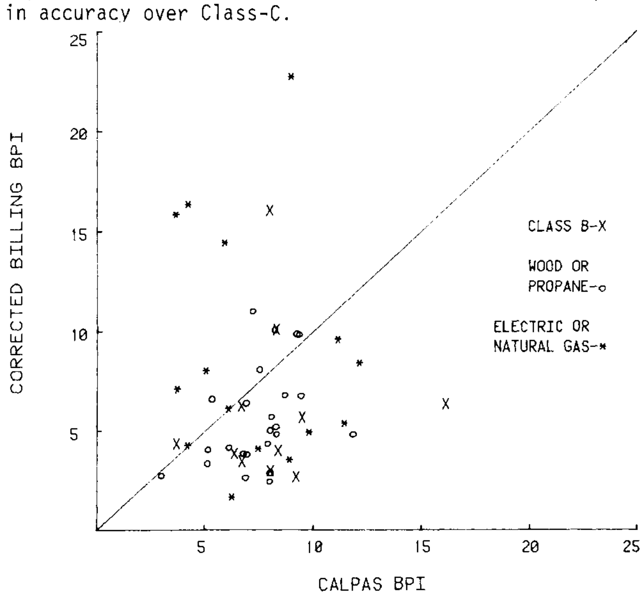

Fig. 4a. Scatter plot of corrected billing BPI vs. CALPAS BPI presenting type of primary space heating for the site.

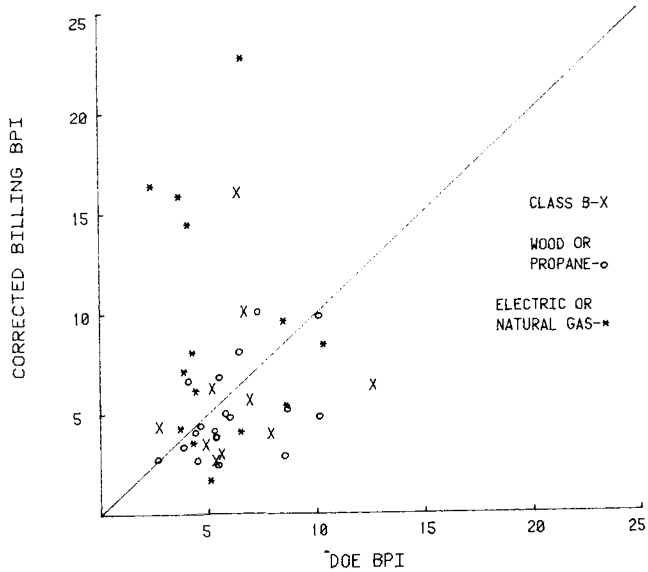

Fig. 4b. Scatter plot of corrected billing BPI vs. DOE BPI presenting type of primary space heating for the site.

CONCLUSIONS

The Class-C data analysis indicates that DOE 2.1 for a large percent of the time predicts energy use closer to the field data. In order to put this conclusion on firmer footing one needs an extended data base. However, we feel this kind of validation is useful to designers and policy makers as a test of how well the models are doing and should be expanded.

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SIMULATION OF A COMBINED SOLAR HEATING AND COOLING SYSTEM FOR A MIDDLE SIZE BUILDING IN GREECE

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ABSTRACT

The performance of a combined solar heating and cooling system was studied for Mediterranean climatic conditions, using a detailed computer model and hourly weather data. The TRNSYS-CODE was used to model the solar system and the building. The weather data used are from Athens. A reference year based on long term averages was developed. The system consists of flat plate collectors, a $LiBr/H_2O$ chiller and two heat storage devices, installed in a building with a floor area of 540 m^2. Also the performance of evacuated tube collectors was studied for such systems. The results of the simulation show that high yearly useful collector output (more than 500 KwH/M^2) is possible with flat plate collectors. With evacuated tube collectors about 40% more. A rough economic analysis shows that one can expect fuel savings of about 19 USD/m^2 for flat plate collectors, with a solar fraction of 80%.

1. INTRODUCTION

A fundamental problem for the use of solar energy is to find applications where the energy produced by the solar system can be used the whole year round. The combination of active space heating, cooling and DHW could be a valid way to use solar energy, since the yearly energy yield per m^2 of collector surface can be high. Some Mediterranean climates are such that airconditioning is needed in summertime and heating is needed in winter. This is particularly true for those buildings where a good indoor climate is needed, e.g. hospitals, offices, hotels, etc. On the other hand, a combined solar heating and cooling system is not very adapted for installation in single family houses, since they are rather complicated and they need to be of a certain size for economic reasons. For these two reasons it was decided to study a system for small medical centre. This study is related to and based on the solar heating and cooling experiments which have been carried out at the Solar Laboratory of the Joint Research Centre in Ispra for several years /1,2/.

2. WEATHER DATA

The weather data used in this study are those from Athens (latitude 37.97 N). The

PLE-V*

main climatic data are given in Table 1. The yearly solar irradiation on a horizontal plane is about 1600 kWh/m^2 for Athens. For this study, a reference year has been composed in the following manner: From several years of data, the month with the solar irradiation and ambient temperature closest to the average over 19 years for that month, was chosen. The advantage of this procedure is that one obtains correct average values for the most important climatic data, and at the same time realistic data with a more realistic sequence, for the system simulation. Hourly data have been used.

TABLE 1 - Climatic data for Athens (1960-1978)

Month	Global horiz. solar irrad. kWh/m^2	Temperature degr. C	Humidity %	Windspeed m/s
Jan.	59	9.4	73	2.6
Feb.	75	10.2	70	2.7
Mar.	118	11.6	67	2.6
April	157	15.3	62	2.2
May	197	20.1	59	1.8
June	210	24.6	51	2.1
July	217	27.1	47	2.7
August	197	27.0	48	2.6
Sept.	150	23.2	56	2.4
Oct.	107	18.3	66	2.5
Nov.	70	14.7	73	2.0
Dec.	53	11.2	73	2.4

3. SOLAR SYSTEM

The system isschematically shown in Fig. 1. It consists essentially of:

- solar collectors
- storage tank for hot water (12 m^3)
- storage tank for chilled water (20 m^3)
- LiBr/H_2O absorption chiller
- heat/cold distribution devices in the building

Solar collectors: Two types of solar collectors have been used for this study, a selective flat plate collector and an evacuated tube collector. The flat plate collector, made in Greece, has a steel absorber with a black-chrome selective layer and one glass cover. The measured efficiency is given by:

$$\eta = .78 - 4.04 * T^* \quad (1)$$

η = instantaneous efficiency
T^* = reduced temperature (C. m^2/W)

The efficiency of the evacuated collector is:

$$\eta = .65 - 1.4 * T^* \quad (2)$$

This efficiency is not related to a particular collector but is considered representative of this type of collectors. The inclination of the collectors is 38 degr. (= latitude).

Absorption chiller: The absorption chiller considered here is the Arkla WF 36 solaire. The key parameters are:

. cooling capacity	10 kW
. generator inlet temp.	76-96 °C
. cooling water inlet temp.	23-32 °C
. C.O.P.	.72

An identical chiller is in operation in the Solar Laboratory of the JRC in Ispra for more than a year. The data obtained with this chiller have been used to validate the results of the computer simulation.

Storage: The system has two heat storage devices. The reason for this is the high costs of absorption chillers. By using a storage for hot water and a storage for chilled water, one can operate the chiller many hours per day. In this way a relatively small chiller can satisfy a considerable cooling load. The storage for hot water is a steel tank of 12 m^3 with 15 cm of insulation (K = .27 W/C. m^2). The chilled water storage is also a steel tank with 15 cm of insulation. Its volume is 20 m^3. This rather large volume is necessary since the temperature range over which the storage can operate is limited. At the one hand the outlet temperature of the chiller should not be lower than about 10°C, in order to maintain a high C. O. P. of the chiller, at the other hand is is difficult to cool a building with water temperatures above 16°C. This means that the effective range of the cold store is only in the order of 6°C. The chilled water tank is located in the cellar of the building and the hot water tank on the roof.

Building: The building chosen for this simulation has been designed so that it is as close as possible to a typical building of this size in Greece. The main parameters are:

. floor area (2 floors)	537 m^2
. volume	2985 m^3
. ventilation rate	.6 per hr
. number of occupants	25
Windows:	
. south	50.7 m^2
. east	12.5 m^2
. north	48 m^2
. west	12.5 m^2
Heat transfer coefficients:	
. windows (double glazed)	3.4 W/C. m^2
. walls	0.62 "
. floor	0.66 "
. roof	0.5 "
. overall heat loss coeff.	1950 W/C
. thermal capacitance	554 MJ/C
Internal heat generation:	
. winter	4.3 kW
. summer	2.3 kW

The walls are made of two layers of bricks, 10 cm thick, with 5 cm of insulation in between. This corresponds to the actual local norms. The windows are equipped with movable shutters which are supposed to be open during the winter and closed during the summer. The shutters are only used as a protection against penetrating sunlight and not for insulation purposes. During the interseasons the shutters are for two third closed. The building given its size, could be a medical centre in a village or a small town. The heating and cooling of the building is done with thermal convectors.

Warm tapwater: The tapwater load assumed here is 1250 litre per day at a temperature of 50°C. In reality also tapwater at higher temperatures is needed. This is not taken into consideration here. The solar hot water system operates for this part of the load only as a pre-heating system.

4. SYSTEM OPERATION

For the system operation the year is divided into two parts: summer and winter. The winter starts end October and lasts until the end of March. The summer months are May, June, July, August and September.

Winter operation: During the winter the building is heated with the thermoconvectors which are directly connected to the heat storage on the roof. When the temperature in the storage is lower than 40°C, the auxiliary takes over. The cold storage tank is not used in winter. The tap water is as far as possible prepared by preheating.

Summer operation: During the summer the chiller is automatically put into operation as soon as the temperature in the hot water storage exceeds 78°C. The chiller stops when the storage temperature drops below 76°C. The chiller stops also when the evaporator inlet temperature drops below 10°C. Normally the chiller cools the cold water storage, which, in turn, provides the space cooling to the building. The chiller can be directly connected to the building in the case that the temperature of the cold storage is too high to cool the building, but the chiller can operate with heat from the hot storage. When both the hot and cold storage are exhausted, an auxiliary heater runs the chiller. In this case the chiller is directly connected to the thermoconvectors.

5. MODEL

The system was modelled with the TRNSYS-code /3/ version 11.1. This program has been developed at the Solar Laboratory of the University of Wisconsin. It is a modular code in which all the system components are described with separate subroutines. This gives an enormous flexibility, almost every solar system can be modelled with TRNSYS. For this system all the components were modelled with the component modules available in TRNSYS, sometimes with some minor modifications. Only for the system control a new subroutine was written and inserted in the code.

The modification concerns the building model. In this model the shading factor of the windows was entered as a monthly input data instead of a fixed parameter. This enables to take into account that one will keep the shutters closed in summer to content the cooling requirements without losing the possibility to use direct solar gain in wintertime. The D.H.W. routine accepts the temperature of the fresh water as an input variable. The monthly average of the ground temperature was taken as the temperature of the incoming fresh water for each month. Also some modifications were necessary for the chiller routine in order to simulate the operation with the cold storage. However, the model of the chiller itself was not modified. The operational data obtained in Ispra with the same type of chiller were in good agreement with those used in the TRNSYS model.

6. RESULTS

System performance: The system of which the results are presented here has not been optimized in a systematic way. It has been designed using the experimental results obtained in the Solar Laboratory in Ispra and the results of this model. Careful optimization could bring further performance improvements. The yearly performance of the system is given in Table 2. The data in this table refer to the system operating with 90 m^2 of flat plate collectors.

TABLE 2 - System performance

Solar irradiation on collectors	562700 MJ
Collector efficiency	32%
Useful collector output per m^2	1862 MJ/m^2
Solar energy for heating	32 GJ
Auxiliary for heating	5 GJ
Solar energy for cooling	74 GJ
Auxiliary for cooling	28 GJ
Solar energy for D. H. W.	60 GJ
Auxiliary for D. H. W.	10 GJ
Solar fraction	80%

The yearly energy requirements of the building were found to be:

. Heating:		
	Active solar heating	32 GJ (22%)
	Passive solar heating	72 GJ (50%)
	Auxiliary energy	5 GJ (3%)
	People and lights	37 GJ (25%)
	Total heating load	146 GJ
. Cooling:		
	Building load	56 GJ (74%)
	People and lights	20 GJ (2´%)
	Total cooling load	76 GJ
. D. H. W. :	Total load	70 GJ

In Fig. 2 the heating and cooling load of the building are shown on a weekly basis. The auxiliary energy used by the building is given in Fig. 3.

Collectors:

a) Flat plate collectors

The weekly collector efficiency (for 90 m^2) is given in Fig. 4. This figure demonstrates clearly that during the periods of heating or cooling the collector efficiencies are much higher than in the intermediate periods. This is obviously due to the fact that the load is too small in these periods. In Fig. 5 the amount of useful solar energy per unit collector is given for different array sizes, together with the solar fraction.

b) Evacuated tube collectors

In order to get an idea of the performance of evacuated tube collectors in such systems, the model was run for this type of collectors. The results are also shown in Fig. 5. From this figure it can be seen that the difference in performance of the two collector types does depend strongly on the solar fraction. For a solar fraction of 80% one needs 90 m^2 of flat plate collectors or 66 m^2 of evacuated tube collectors, i.e. 27% less. For a solar fraction of 70% one needs 31% less evacuated collectors. However, one should realize that this is a result that refers to a particular case, and the difference in performance can change from case to case.

Chiller: The average C. O. P. of the chiller was found to be .75.

7. ECONOMICS

A detailed economic analysis is beyond the scope of this study, however, a few general considerations can be given. The results of Table 2 show that the solar system can, in the considered climate, deliver 92 GJ of heat and 55.5 GJ of cooling capacity. With the actual local fuel and electricity prices one can estimate that the yearly savings are in the order of 1720 USD (19 USD/m^2).

8. CONCLUSIONS

The simulation of a combined solar heating and cooling system showed that for the considered location (Athens, Greece) such a system can deliver considerable amounts of useful energy per unit collector area. A rough economic assessment indicates that combined solar heating and cooling could become an interesting option in this kind of climate, provided that the overcost for the solar system can be kept lower than about 160 USD/m^2, for flat plate collectors. For a more precise assessment of the potential of these systems it is necessary, however, to make a careful system optimization based on the economic performance. It is also demonstrated that even with very simple means, the passive solar heating can give a very significant contribution for house heating.

The TRNSYS-code proved to be a useful and flexible tool for the system simulation. However, for the system optimization, more simplified models are required. One of the applications of this detailed TRNSYS model is the validation of these simplified models.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to the METEOROLOGICAL INSTITUTE of the NATIONAL OBSERVATORY OF ATHENS in Greece, for providing the meteorological data.

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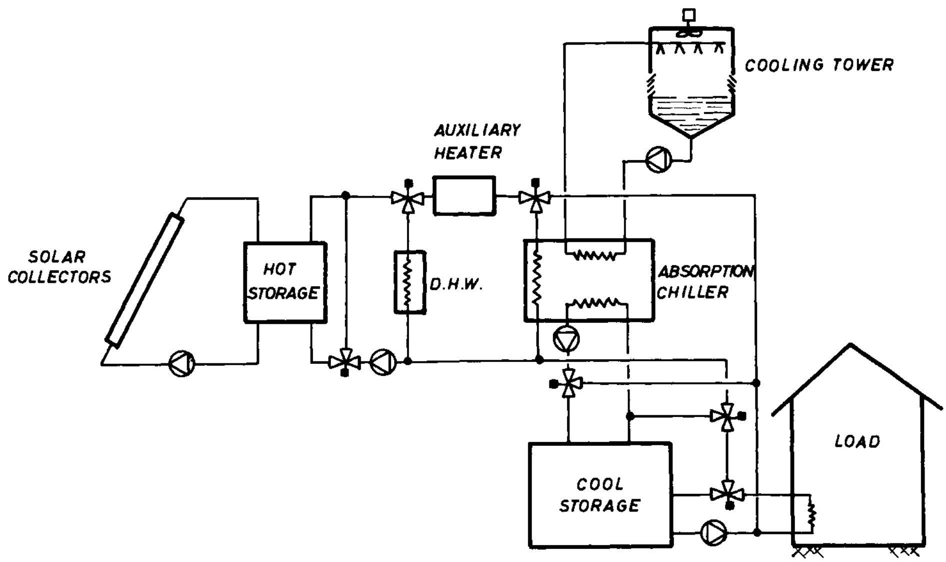

Fig. 1. Schematic diagram of a combined solar heating and cooling system.

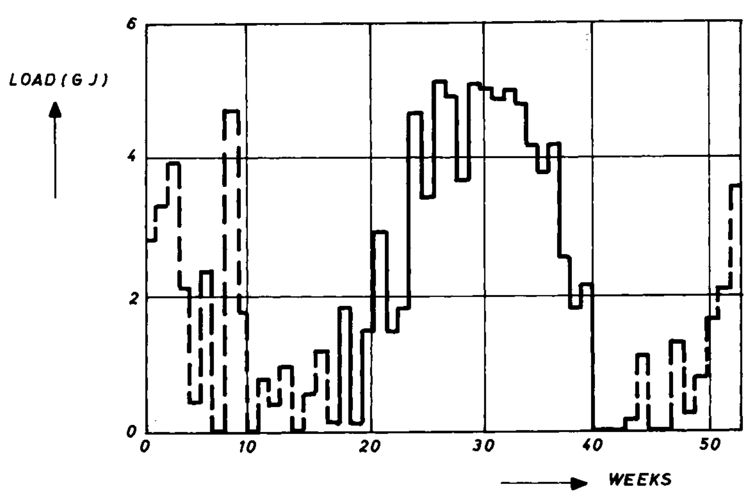

Fig. 2. Heating and cooling load of the reference building.

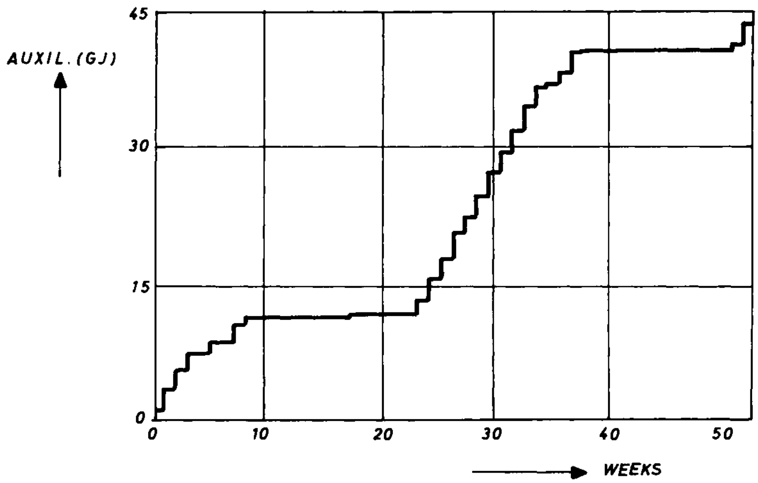

Fig. 3. Cumulative auxiliary energy.

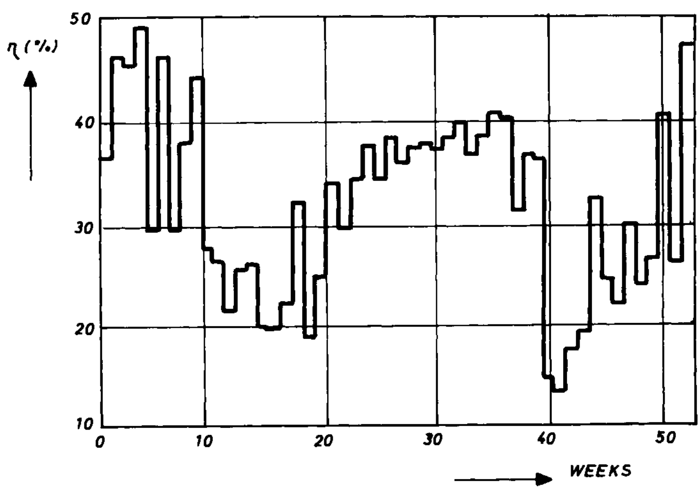

Fig. 4. Weekly average value of the collector efficiency.

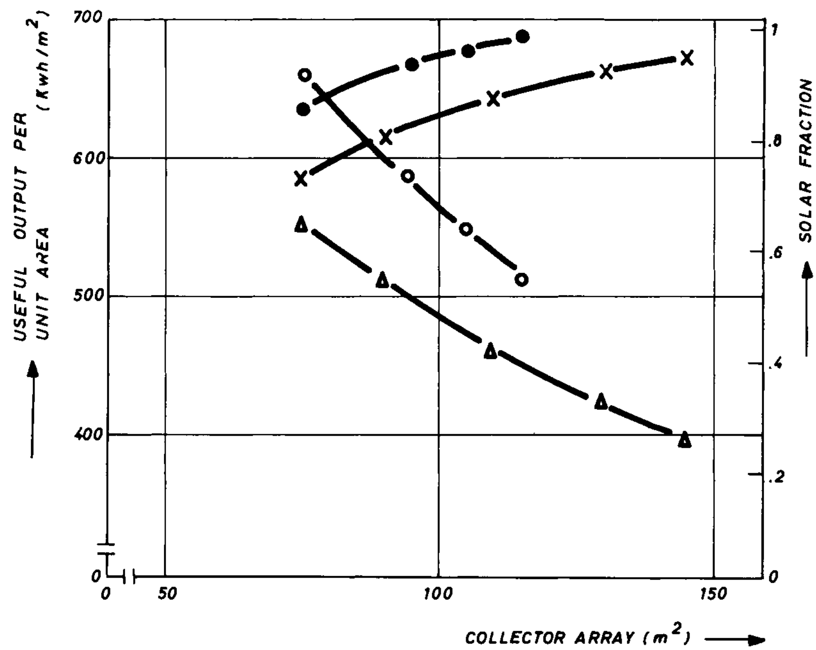

Fig. 5. The useful solar energy per m^2 of collector area and the solar fraction for different array sizes.

x △ Flat-plate collector
● o Evacuated tube collector

SUMMER PERFORMANCE ANALYSIS OF TYPICAL SETTLEMENTS IN THE ETNA AREA

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ABSTRACT

Continuing a programme in progress, which was partially referred about in Catania (February 1981) and in Miami (November 1981), the present research develops a study on the behaviour, during the stabilized thermal transient, of typical settlements in the Etna area.
In particular the thermal analysis of building types is presented with respect to local climatic conditions, which are characterized by high daily average temperature (about 28° C) and strong daily thermal variations (about 10° C).
The analysis aims to propose building methods and techniques closer to the correct bioclimatic principles, indicating building types suitable to Etna and Etna-similar areas. The type called "masseria" (farm-house) is described in this report.
The bioclimatic systems utilized to optimize the considered building types will be: Trombe wall, solar chimney and attached greenhouse.
The thermal analysis is carried out through a mathematical model, which now is ready to take into account only the solar chimney effect.

NOMENCLATURE

m	mass (Kg)
c	specific heat (J/Kg °C)
h	film coefficient (W/m^2 °C)
S	surface area (m^2)
T	temperature (°C)
f	shading coefficient
a	absorbance coefficient
k	wall trasmittance (W/m^2 °C)
$\dot{V}$	air mass flow rate (m^3/sec)
d	air density (Kg/m^3)
n	rate of air renewal (sec^{-1})
Q_{in}	internal heat generation (W)

SUBSCRIPTS

1-6	room walls
1'-4'	chimney walls
a	air inside the chimney
am	ambient air
e	external air
i = 1-6	counter
p	opaque surface
v	glazing surface

KEYWORDS

Mathematical model;solar chimney;sicilian farm-house.

1. INTRODUCTION

By continuing with the implementation of a research project completed with the identification of bioclimatic parameters to be used on the basis of a mathematical model, both in testing retrofitting on existing settlements and in the planning of new buildings, the Research Group associated with the "Center for Bioclimatic Studies" of Catania has further perfected the methodology of analysis and the calculation programme expounded in Catania and in Miami.

2. MATHEMATICAL MODEL

With the BIOCLI calculation routine, previously presented, the following parameters could be determined:

a) the temperatures of the walls (both internal and external);
b) the air temperature in each room, with external conditions (temperature and irradiation) varying anyhow and, in particular, with historical data.

The algorhythm used is that of the state trajectory, which is based on the following system of equations, in canonical form:

$$[\dot{x}] = [A]\cdot[x] + [B]\cdot[W] \tag{1}$$

whose solution is as follows:

$$[X((k+1)T)] = [F(T)]\cdot[X(kT)] + [D(T)]\cdot[W(kT)] \tag{2}$$

where:

- T is the elaboration period, which must be such as to engender no calculation fluctuations; in practice T is chosen in such a way as not to have non-negative eigen-values of the state matrix (A);
- k is a counter,

$$- \ [F(T)] = e^{[A]T} = [I] + [A]T + [A]^2\frac{T^2}{2!} + \cdots + [A]^n\frac{T^n}{n!} + \cdots \tag{3}$$

$$- \ [D(T)] = e^{[A]T}\int_0^T e^{-[A]t}\,dt\,[B] = \left[[I]\cdot T + [A]\frac{T^2}{2!} + \cdots + [A]^n\frac{T^{n+1}}{(n+1)!} + \cdots\right][B] \tag{4}$$

Matrices (A), (B), (W) and (X) are called respectively: (A) state matrix, (B) input matrix, (W) input vector, (X) state vector. Their definitions are given in detail in the paper presented at Catania (see the proceedings of the Catania Seminar).

Since the model provides for time invariant matrices with lumped parameters, there is a limit to its practical applications, due to the fact that the room parameters (which define the therms "A" and "B") may change during the simulation period and therefore the matrices "F" and "D" must also be accordingly calculated. It is possible to simulate the trasmittance variations of glass surfaces caused by the drawing and shutting of curtains, blinds, etc. during the day. Similarly it can be taken into account the opening of windows (which usually happens during the cooler hours in summer evenings), that produces a variation in the inflow of external air. The three instants of updating can be preset at the beginning of simulation so as to adjust the calculation to the real state of the thermal transient.

The simulations carried out with these variations were fully consistent with the

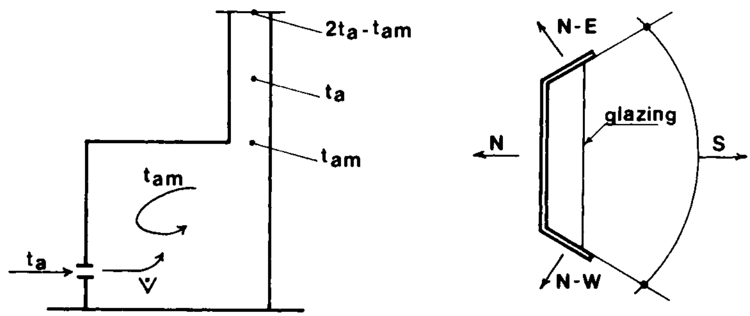

Fig. 1. Solar chimney: scheme

$$m_1 c_1 \frac{dT_1}{dt} = h_{e1} S_1 \left(T_e + \frac{I_1 a_{e1} C_1}{h_{e1}} - T_1\right) + \frac{a_{i1} S_1}{\Sigma a_{ii} S_i} \Sigma I_i f_i S_{vi} - \frac{h_{i1} S_1 k_1}{h_{i1} + k_1} (T_1 - T_{am})$$

$$m_2 c_2 \frac{dT_2}{dt} = h_{e2} S_2 \left(T_e + \frac{I_2 a_{e2} C_2}{h_{e2}} - T_2\right) + \frac{a_{i2} S_2}{\Sigma a_{ii} S_i} \Sigma I_i f_i S_{vi} - \frac{h_{i2} S_2 k_2}{h_{i2} + k_2} (T_2 - T_{am})$$

$$m_3 c_3 \frac{dT_3}{dt} = h_{e3} S_3 \left(T_e + \frac{I_3 a_{e3} C_3}{h_{e3}} - T_3\right) + \frac{a_{i3} S_3}{\Sigma a_{ii} S_i} \Sigma I_i f_i S_{vi} - \frac{h_{i3} S_3 k_3}{h_{i3} + k_3} (T_3 - T_{am})$$

$$m_4 c_4 \frac{dT_4}{dt} = h_{e4} S_4 \left(T_e + \frac{I_4 a_{e4} C_4}{h_{e4}} - T_4\right) + \frac{a_{i4} S_4}{\Sigma a_{ii} S_i} \Sigma I_i f_i S_{vi} - \frac{h_{i4} S_4 k_4}{h_{i4} + k_4} (T_4 - T_{am})$$

$$m_5 c_5 \frac{dT_5}{dt} = h_{e5} S_5 \left(T_e + \frac{I_5 a_{e5} C_5}{h_{e5}} - T_5\right) + \frac{a_{i5} S_5}{\Sigma a_{ii} S_i} \Sigma I_i f_i S_{vi} - \frac{h_{i5} S_5 k_5}{h_{i5} + k_5} (T_5 - T_{am})$$

room walls

$$m_6 c_6 \frac{dT_6}{dt} = \frac{a_{i6} S_6}{\Sigma a_{ii} S_i} \Sigma I_i f_i S_{vi} - \frac{h_{i6} S_6 k_6}{h_{i6} + k_6} (T_e - T_{am}) - k_{t6} S_6 (T_6 - T_t)$$

room floor

$$m_{am} c_{am} \frac{dT_{am}}{dt} = \Sigma \frac{h_{ii} S_i k_i}{h_{ii} + k_i} (T_i - T_{am}) + \dot{V} d c_a (T_e - T_{am}) + nVdc (T_e - T_{am}) + - \Sigma k_{pi} S_{pi} (T_{am} - T_e) + Q_{in}$$

ambient air

$$m'_1 c'_1 \frac{dT'_1}{dt} = h'_{e1} S'_1 \left(T_e + \frac{I'_1 a'_{e1} C'_1}{h'_{e1}} - T'_1\right) + \frac{a'_{i1} S'_1}{\Sigma a'_{ii} S'_i} \Sigma I'_i f'_i S'_{vi} - \frac{h'_{i1} S'_1 k'_1}{h'_{i1} + k'_1} (T'_1 - T_a)$$

$$m'_2 c'_2 \frac{dT'_2}{dt} = h'_{e2} S'_2 \left(T_e + \frac{I'_2 a'_{e2} C'_2}{h'_{e2}} - T'_2\right) + \frac{a'_2 S'_2}{\Sigma a'_{ii} S'_i} \Sigma I'_i f'_i S'_{vi} - \frac{h'_{i2} S'_2 k'_2}{h'_{i2} + k'_2} (T'_2 - T_a)$$

$$m'_3 c'_3 \frac{dT'_3}{dt} = h'_{e3} S'_3 \left(T_e + \frac{I'_3 a'_{e3} C'_3}{h'_{e3}} - T'_3\right) + \frac{a'_3 S'_3}{\Sigma a'_{ii} S'_i} \Sigma I'_i f'_i S'_{vi} - \frac{h'_{i3} S'_3 k'_3}{h'_{i3} + k'_3} (T'_3 - T_a)$$

$$m'_4 c'_4 \frac{dT'_4}{dt} = h'_{e4} S'_4 \left(T_e + \frac{I'_4 a'_{e4} C'_4}{h'_{e4}} - T'_4\right) + \frac{a'_4 S'_4}{\Sigma a'_{ii} S'_i} \Sigma I'_i f'_i S'_{vi} - \frac{h'_{i4} S'_4 k'_4}{h'_{i4} + k'_4} (T'_4 - T_a)$$

chimney walls

$$m_a c_a \frac{dT_a}{dt} = \Sigma \frac{h'_{ii} S'_i k'_i}{h'_i + k'_i} (T'_i - T_a) - 2\dot{V} dc (T_a - T_{am})$$

air inside the chimney

Fig. 2. Mathematical model: system (5)

experimental results; in particular they confirmed the useful contribution given by the opening of the windows during summer evenings, in that this helps to lower the temperature of the walls. The optimum period of time for opening depends upon the thermal inertia of the building and ranges from 3 to 6 hours for low and high heat capacity, respectively.

With the help of the afore-mentioned mathematical model, it is possible to estimate the dynamic performance of a building, room by room, with varying external conditions. The method, however, does not enable us to study the result which may be obtained by structural and building modifications, in order to optimize the conditions of internal comfort. It was decided therefore, to modify the mathematical model in such a way as to include one or more of the following components: solar chimney, adjacent greenhouse, passive wall.

On this report, we are presenting the mathematical model, able to describe the thermal transient analysis of a building with a solar chimney.

Figure illustrate the chimney scheme. The energy balance equations are ordered in system (5) (fig. 2); they are written for the six walls that delimitate each room, for the air inside, for the four walls which form the chimney and the air inside the chimney.

In the equations (Ta) indicates the mean air temperature inside the pipe. In fact, it is to remember that the model considered has lumped parameters and so reference to each element is made by using the mean value of the variable concerned.

System (5) can still be written in the canonical form (1) and matrices (A), (B), (K) and (W) can be easily deduced from (5).

The algorithm used is still the one indicated in (2) and may contain modifications of the internal parameters, as it has already been described.

3. DESCRIPTION OF THE TERRITORIAL AND CLIMATOLOGICAL CONTEXT

Before carrying out this test, it is necessary to incorporate the considered building type in its territorial context. The land must therefore be seen in its morphological and climatological aspects.

The type is an extremely common one in a selected specific area of about 25,000 ha, which is situated on the eastern slopes of Mount Etna (maximum height about 3,300 meters) in Sicily,the southernmost region of Italy.

Being an island,though it is almost at the same latitude (36°) as North Africa (Tunisia, Algeria, Morocco), Sicily enjoys a more temperate climate, due to heat regulating effect of the sea and to the rich Mediterranean vegetation.

As to the specific area considered, the agricultural population settled in it is about 50,000; its altitude ranges from 700 metres to the sea level. The land shifts downwards to the east coast on the Ionian Sea, in an extremely uneven fashion, due to the volcanic origin of the area.

The presence of vast masses of seawater greatly moderates the climatic ranges. Nevertheless, in contrast with a sufficient amount of rainfall in autumn winter and spring, a long period of drought takes place, starting at the end of spring and ending at the beginning of autumn, thus lasting about 5 or 6 months.

The negative effects of this arid period, particularly in agriculture, are remedied by means of artificial irrigation obtained from the considerable resources of water underground, which are the result of winter rain as well as of the melting snow that, in the winter months (and sometimes well into the spring), covers the upper slopes of Etna with a picturesque white mantle.

There is a relevant amount of sunshine in the area: it enjoys an average insolation of 4.5 hours per day in winter, 6.5 hours in autumn, 7.3 in spring and 10.3 in summer, with an annual average of 7.2 hours/day.
As to the temperatures, they show a high daily fluctuation. In 1974, a year in which the climate was quite normal, systematic tests were carried out and the results were as follows (in degrees centigrade):

	June	July	August	Sept.
maximum temperatures average	28.5	30.8	32.3	26.2
minimum temperatures average	11.2	12.3	12.9	10.7
absolute maximum temperature	35.0	37.5	36.5	30.0
absolute mimimum temperature	7.0	8.0	9.0	8.0

As can be seen in all four months, there was an average difference between the minimum and maximum of 15.5 - 19.4° C.
With regard to humidity, the following figures have been surveyed:

	June	July	August	Sept.
average	60%	56%	54%	71%
maximum	98%	98%	93%	97%

During the day moisture increases at constant rate from the minimum recorded at 12 a.m. up to the maximum recorded at around 24 p.m. In other words, the most humid hours (to the limit of saturation) are the nocturnal ones, i.e. when the temperatures are at their lowest. This is linked to the night dew phenomenon, which alleviates the summer drought.
As for the wind, the area is characterized by the presence of winds coming both from the Ionian Sea and from inland Sicily. The effect of these winds differ, however, from season to season. In the summer the Ionian Sea breezes are cooler than the inland Sicily winds, because the latter are extremely warm, as they come from the Sahararegion of Africa, and are very humid, having crossed the Mediterranean Sea. In the winter the winds coming from North and West are very cold because, before arriving in the area under study, they come into contact with the snow on the summit of Etna.

4. DESCRIPTION OF THE BUILDING TYPE

It is stated that by "type" is meant the spacial and structural configuration corresponding to a particular way of living, determined by environmental, climatological, cultural, social and economic features; hence the constancy of ways and expressions of living and doing has led to similar patterns of buildings; each of them is called "building type". Every study of rural architecture must include a definition of the entire "farming countryside", which is understood to mean "the form that man, for the purposes of agricultural production, intentionally and systematically imposes on the natural countryside".
So in our case, rural building must be set within the context of the prevalent agricultural production (vinegrowing) during the period in which it was constructed, together with other kinds of transformations, like terracing and the formation of turrets.
In order to tackle the problems in the correct manner (also from the analytic-descriptive and historical-critical points of view) one must give

careful consideration to the cultural bonds which, over the years, were established between the Southern Italian civilization and the ones of other countries in Europe and in the Mediterranean Sea (Greeks, Romans, Arabs, Spaniards), that succeeded each other as the dominant civilization.
Thus, throughout Southern Italy, different types of rural buildings are found - scattered or in groups, simple or complex - which are called "masserie" (farm-houses).

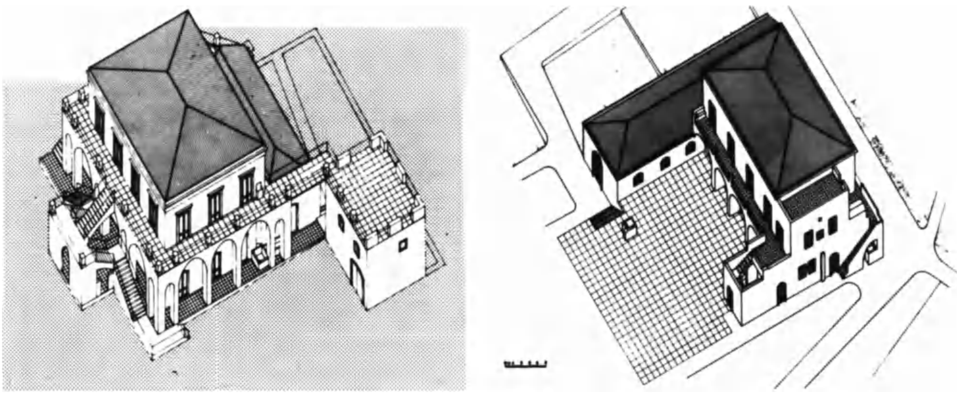

Fig. 3. Examples of farm-house ("masseria")

In Sicily, the scattered type of "masseria" (fig. 3) is most frequently situated along the coastal zones, favoured by the fragmentation of land holdings and the high yield of the crops, which before were vines and now are citrus fruits.
All this has enabled us to define the examined building patrimony as belonging to the dominion of the Southern European forms (late baroque) characterized by their quadrangular shape, with sloping roofs.
Within the boundaries of Southern European rural architecture, the area axamined is distinguished by the presence of three fundamental forms:

a) unitary dwellings (with the owner's house sited on or beside the spaces designated to production);
b) scattered dwellings (with the owner's house separated from the production area);
c) courtyard dwellings (with the owner's house and spaces devoted to production overlooking a single courtyard).

The first of these forms is clearly the most widespread in the district and an exhaustive explanation of this must be sought by carefully examining all the influences,varing in nature, which perform an important role in defining its architectonic structure.

The building was created by uniting into a single, compact architectural arrangement all the areas designed for different purposes, i.e. both necessary in, and complementary to production, in relation to the cultivation of the land (vinemill, cellar, store-houses, stables and farmer's house) and those designed for the owner to live in during the summer season (September-October is vintage time).
In extremely general terms, the building-type is laid out in two parts, one placed on top of the other.

The lower part contains the afore-mentioned spaces devoted to production, while the whole of the upper part is designed to accomodate the owner.
The two parts have no functions at all in common and, while the various spaces of the ground floor can be reached via internal road system of the land, an outside stair-case provides the link between the two floors and leads to a terrace-gallery which surrounds the owner's dwelling.
The diversity of the roles assigned to the two parts of the building is also emphasized by the differing architectural arrangements which were carried out for each of them. In fact, the geometry of the residential part is enriched with decoration, cornices, jambs and plaster strips made in cutting stone or, in the richest examples, in lava-stone (Etna basalt); whereas hardly any research has

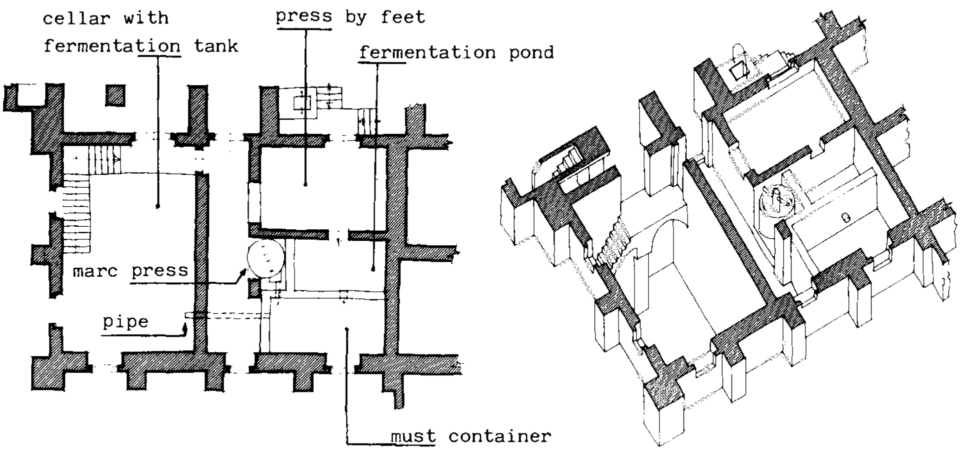

Fig. 4. Wine mill

been put into the composition of the underlying part.
Anyway the resulting architecture is a genuine expression of a culture which has deep roots in the social and economic structure of the region. All the building elements take peculiar relief in relation to the agricultural production. Thus, the sequence of spaces is closely connected with the performance of the activities. In this way, all the elements were born: the outdoor flights of steps to allow for the delivery (through windows so as not to give access to the pickers) of panniers full of grapes; premises for weighing the fruit, which determined the pay of the pickers or the equivalent in wine to be given by the local people who were not provided with vine-mills; the containers for the must collected; the pipes leading into the fermentation tank; the marc press; the cellar normally situated to the North and partially below ground, so as to maintain the correct temperature for the maturing of the wine in its casks (fig. 4).

5. CONSTRUCTION METHODS AND MATERIALS

The materials used in building construction come mainly from local production and are as follows.

(i) Lava-stone (Etna basalt) extracted from the quarries in blocks of 20x20x20 cm, subsequently shaped to suit the purpose with various metal points, whose size varied according to their use.

(ii) Calcareous stone (cutting stone), coming above all from the nearby provinces of Syracuse or Ragusa and used in a suitable shape, following traditional local techniques for shaping decorative or load-bearing elements.

(iii) Mortar made with sand and natural scree of volcanic origin.

(iv) Chestnut-wood taken from the woods on the slopes on Etna.

(v) Tiles and bricks produced in kilns using clay from the alluvial plain formed by the river Simeto to the South of Etna.

The construction methods are consistent with the technological evolution of the time in Southern Europe and with the necessary performaces.

The load-bearing masonry, made of lava and mortar, has a thickness multiple of the average stone size and is between 40 and 60 cm thick.

The roofing vaults on the first level were built as barrel vaults, cross vaults or pavillon vaults, according to the needs, so as to allow the large rooms to be covered and to give a certain freedom in the organization of the upper rooms.

As the roofing vaults on the second level did not have to withstand loads, they were constructed following a traditional local method which adopts a shaped, wooden framework, with the spaces filled with reeds (called "cannizzi") covered with decorative plaster and stucco, the latter of which is sometimes integrated with figurative paintings. The main roofing proper at the pop of the building was constructed using real chestnut-wood trusses, integrated with small warps also made of wood and completely covered by traditional local tiles (called "coppi e canali").

The colouring of the external plastering is a particulary important feature of the construction of the building. The colours most often found are dark natural and are obtained from the local earth of volcanic origin, with shades of grey (obtained with the "azolo") and of red (obtained with the "ghiara"). But bright colours are also found: pink or ochre, got by adding colouring soil.

6. APPLICATIONS OF THE CALCULATION PROGRAMME

As an application of the mathematical model described in 2., we consider it appropriate to study the modifications induced by adding a solar chimney to a building and, in particular, to compare the results of this addition on an already existing building. In this way, the simulation instrument can be used as a design indicator, so that suitable corrections may be made in a structure which is already in existence or has yet to be built.

For the typical building in the Etna region, as described above, we consider it best, for the summer cooling, to install a solar chimney to be built separately. The chimney, with appropriate canalizations in the attic and with transit valves, provides ventilation for all the rooms and, in particular, for those designed to accomodate the owner and situated on the first floor.

The dimension of the chimney must be such that it fulfils the needs of the entire building and must also have suitable ventilation pipe.

Nowadays we have progressed beyond this stage and, since we are also interested in winter problems, we are further perfecting the calculation procedures by considering the supplying of a passive wall and of a greenhouse.

Since the research is in progress, further details will be given during the PLEA 83 conference.

COMPUTER ANALYSIS OF BUILDING-VENTILATION AND HEATING PROBLEMS

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ABSTRACT

This paper presents a mathematical model, implemented in a general computer code, that can provide detailed information on the velocity and temperature fields prevailing in three-dimensional buildings of any geometrical complexity, for a given ventilation and heating arrangement. The model is based on the partial differential equations governing flow and heat transfer in large enclosures, containing heat sources. Turbulent flow is simulated and account is taken of buoyancy effects on both mean and fluctuating motions.

Two cases are considered, to demonstrate the capabilities of the present model, both referring to actual existing television studios. The program calculates the velocity and temperature fields throughout the three-dimensional configurations, and the results are presented in the form of velocity vectors and temperature contours.

The same procedure is applicable to any problem of heating, cooling, insulation and ventilation of buildings, predicting within practical resources the thermal and fluid-dynamics behaviour of the relevant systems.

KEYWORDS

Mathematical models; computer simulation; turbulent buoyant convection; building ventilation; three-dimensional configurations.

INTRODUCTION

The purpose of developing efficient ventilation and heating systems for buldings is to provide comfortable conditions for the people in them, both in terms of air temperature and velocity. Thus, a design that does not maintain a constant temperature of comfortable level is as inefficient as one that does but at the expense of creating unacceptably strong air currents. Furthermore, for audio studios for example, an additional design consideration is the noise level produced by the velocity gradients; high noise levels are transmitted to the microphones and lead to deterioration of the studio's acoustic quality. For the above reasons, it is important that detailed information becomes available on the velocity and temperature fields prevailing in a building of a given design, for a given ventilation and heating arrangement. The objective of this work is to demonstrate how a mathematical model, implemented in a general computer code, can provide this information in three-dimensional buildings of any geometrical complexity. A computational model of this kind, when fully validated, can provide the designer with powerful and economical means of evaluating alternative designs and energy sources.

MATHEMATICAL FORMULATION

The Differential Equations

The governing equations, describing the conservation of mass, momentum and energy can be written in the following general form:

Conservation of mass

$$\frac{\partial \rho}{\partial t} + \text{div}\ (\rho \vec{V}) = 0 \tag{1}$$

Conservation of fluid property, ϕ

$$\frac{\partial(\rho\phi)}{\partial t} + \text{div}\ (\rho\vec{V}\phi - \Gamma_\phi\ \text{grad}\ \phi) = S_\phi \tag{2}$$

where ϕ stands for the general conserved property, t for time, ρ for density, $\vec{V}$ for the velocity vector, Γ_ϕ for the exchange coefficient and S_ϕ for the source/sink of ϕ per unit volume. ϕ for the problems under consideration represents the three velocity components u, v, w in the three space coordinates x, y, z, the stagnation enthalpy $\tilde{h}$ (or temperature T), the kinetic energy of turbulence k, and the eddy dissipation rate, ε. Γ_ϕ and S_ϕ for these variables have been given elsewhere (Markatos and Cox, 1982) and are not repeated here. Buoyancy sources are included in the appropriate momentum equation. The generation terms of the k equation include both the shear production and the buoyancy production (Rodi, 1978; Markatos, Malin and Cox, 1982; Markatos and Cox, 1982). Further details may be found in the above references.

The Solution Method

The finite-domain technique is used which combines features of the methods of Patankar and Spalding (1972) and Spalding (1980), and a whole-field pressure-correction solver. The space dimensions (and time for transient cases) are discretised into finite intervals; and the variables are computed at only a finite number of locations, at the so-called "grid-points". These variables are connected with each other by algebraic equations (finite-domain equations) derived from their differential counterparts by integration over the control volumes or cells defined by the above intervals. This leads to equations of the form:

$$\sum_{\eta}(A_\eta^\phi + C)\phi_P = \sum_{\eta} A_\eta^\phi \phi_\eta + CV \tag{3}$$

where the summation η is over the cells adjacent to a defined point P. The coefficients A_η^ϕ, which account for convective and diffusive fluxes across the elemental cell, are formulated using upwind differencing. The source terms are written in the linear form $S_\phi = C(V - \phi)$ where C, V stand for a coefficient and a value of the variable ϕ. The pressure-correction equation is deduced from the finite-domain form of the continuity equation.

The "SIMPLEST" practice of Spalding (1980) is followed, in which the finite-domain coefficients of the momentum equations contain only diffusion contributions, the convection terms being added to the linearised source term. Upwind differencing for convection and harmonic averaging for diffusion are used. The w-momentum equation is solved by TDMA and the u and v by a Jacobi point-by-point procedure. The pressure-correction equation is solved over the whole-field (3D simultaneous solution). More details may be found in above references.

The solution procedure is incorporated into a general computer program for the solution of multi-dimensional, multi-phase problems, which has been described elsewhere (Spalding, 1981; Markatos, Rhodes and Tatchell, 1982; Markatos, 1983).

Irregular Geometries

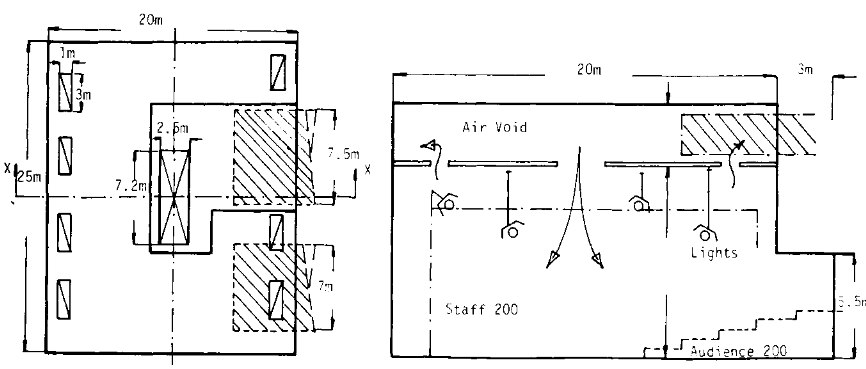
Irregular geometrical features encountered in buildings as well as objects inside them are modelled by use of "porosities" (Spalding, 1981; Markatos and Mukerjee, 1981; Markatos, 1983).

In this approach, each cell in the domain is characterised by a set of fractions, normally in the range from 0 to 1. These fractions determine the proportion of the cell volume which is available for the fluid, and the proportion of each cell-face area available for flow, by convection or diffusion, from the cell to its neighbour in a given direction.

APPLICATION OF THE MODEL

Test Cases Considered

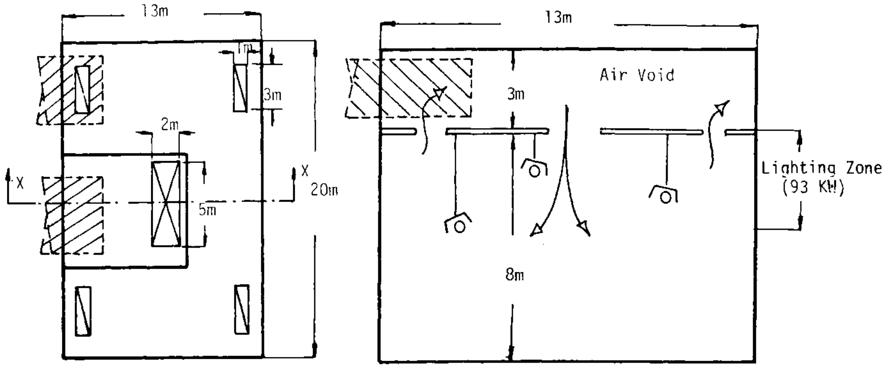
The simulation is concerned with the flow and heat transfer of ventilation air in large enclosures, containing heat sources. Two cases are considered both referring to television studios located in London, during performance. The two different configurations are illustrated in Figs. 1 and 2. In both cases ventilation air is



Plan View at Studio Ceiling　　　　Section XX Through Studio

Fig. 1. The Geometry Considered: Studio 1

brought into the studio through the ceiling, after passing through the supply silencers. This air jet penetrates into the studio, gets heated by the heat released by the lights and the actors/spectators, and rises towards the ceiling where it is extracted through the return silencers. The first configuration (Fig. 1), referred to in what follows as studio 1, includes seven extraction vents and a tiered seating area for spectators (Fig. 1); the remaining floor area being used as the stage for actors. The second configuration, Fig. 2, referred to as Studio 2, includes four extraction vents and no specially-designed seating area like Studio 1. Other pertinent input information is given in Table 1. The program calculates the velocity and temperature fields throught the 3D configurations described above. Three studies were performed; two using the input given in Table 1, and the third being for Studio 1, when the lights are switched off. Within each study several configurations for the inlets of the ventilation air were considered.



Plan View at Studio Ceiling   Section XX Through Studio

Fig. 2. The Geometry Considered: Studio 2

TABLE 1 Input Data Used in the Computations

Data	Studio 1	Studio 2
Air Volumes		
Supply (m^3/s)	18.0	9.0
Extract (m^3/s)	18.5	9.24
Air Temperature (^oC dry bulb)	12.0	12.0
Air Velocity		
Supply (m/s)	1.0	0.9
Extract (m/s)	0.9	0.75
Heat released by lights (total over lighting zone, KW)	150.0	93.0
Heat released by each sitting spectator (KW)	0.05	-
No. of spectators (max)	200	-
Heat released by each performing actor (KW)	0.1	0.1
No. of actors (max)	200	100

Boundary Conditions

Boundary conditions are specified as follows. At the ventillation air inlets a fixed mass flow rate is specified and also the values of velocity and temperature that this flow rate is bringing into the domain. At the extraction vents a fixed mass-extraction rate is the specified boundary condition for all vents. At the walls the no-slip condition is applied for the velocities, and wall-functions (Patankar and Spalding, 1972) are used to calculate the wall shear-stress. The walls are assumed adiabatic. Finally, the heat sources released by the performing actors, spectators, and the lights are added.

Physical Properties

The air viscosity is set to $\mu = 1.8 \times 10^{-5}$ kg/ms. The density is calculated as the following function of temperature, $\rho = 1/2.87 \times 10^{-3}$ T.

Grid-Dependence and Computer Storage

The reported results have been obtained using a non-uniform grid consisting of 13 cells in the x-direction, 16 in the y- and 13 in the z-direction. The solutions reported are believed to be not fully independent of the grid. The extent of this dependence has not been ascertained.

The program required 257 kilobytes of storage on a Perkin-Elmer 3220 mini-computer, of which 80 kilobytes was for incore storage of variables, with the remainder taken by the program object code.

Convergence and Computer Time

Good convergence was obtained after 400 sweeps of the domain, as judged by the magnitude of the absolute continuity error which was reduced to 0.3% of the incoming volume flow rate; the monitoring values of variables changing only at the fourth decimal place. Relaxation of the "false transient" type was used for the three velocity components, the value of the "false time step" being 0.1s for all of them. The converged, 400-sweep run with the 13 x 16 x 13 grid required 295 minutes CPU time on the Perkin-Elmer 3220 mini-computer. It should be mentioned that once a converged solution has been generated, it can be used as initial guess for other runs that will then require much less time. Thus the run of Studio 1 with the lights switched off required only 50 sweeps to reach the same level of convergence, when restarted from the solution for Studio 1 with lights on.

RESULTS AND DISCUSSION

Some of the results of the study are presented in Figures 4 to 14 in the form of velocity vectors and of isotherms. They have been obtained using GRAFFIC (Markatos and Pericleous, 1983). Figures 3 to 5 refer to the case of Studio 1 with the lights on. Figure 3 presents velocity vectors on the z-y plane passing through the middle of the studio.

Fig. 3 Velocity vectors on the z-y plane passing through the middle of Studio 1 (max. velocity = 1.45 m/s)

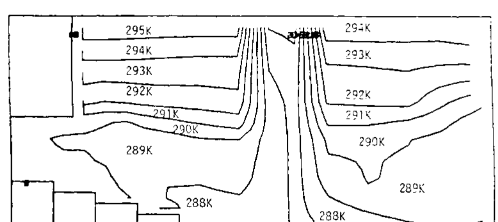


Fig. 4 Temperature contours on the middle z-y plane (Range 285 K to 295 K in 10 equal intervals)

It is seen that the cooling-air jet penetrates deeply in the Studio, reaches the floor and is then deflected outwards, towards the locations of the spectators and actors. Two vortices are observed: one on the stage where the actors are performing, and a weaker one at the top of the seating area for the spectators. Very low velocities prevail near the ceiling, away from the jet. Inspection of the field of the w-velocity component (the vertical component) reveals that along horizontal cross-sections w is of appreciable magnitude (up to 1.45 m/s) directly beneath the inlets and diminishes further away. The max w at the cross-section located 5.5 m below the ceiling is 1.38 m/s and diminishes to 0.6 m/s at the cross-section located 0.75 m above the floor. These velocities are considered high from the design point of view.

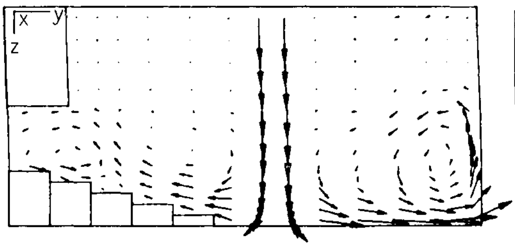


Fig. 5 Velocity vectors on the z-y plane passing through the middle of the Studio. Lights switched off (max. velocity = 1.20 m/s)

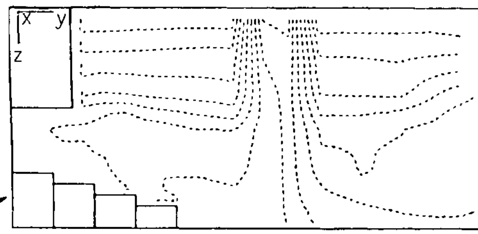


Fig. 6 Temperature contours on the middle z-y plane. Lights off (temperature range 285 K to 288 K in ten equal intervals)

Figure 4 presents temperature contours at the same z-y plane as above. Considerable asymmetry is observed between the spectators and actors' sides but comfortable levels are maintained on both (16 - 17^oC). The maximum temperature at the horizontal cross-section located 5.5 m below the ceiling is 16.7^oC as compared with the minimum value of 14^oC in the core of the cooling air jet. Near the floor, at the cross-section located 0.75 m above floor the maximum temperature is still 16.8^oC.

Figures 5 and 6 present the same information on velocity and temperature, respectively, for the case of Studio 1 with the lights switched off. Similar patterns are observed for both velocity vectors and temperature contours. However, the maximum velocity in the studio is now 1.20 m/s as compared with 1.45 m/s when the lights are on; and the maximum temperature has dropped to 15^oC as compared with 22^oC when the lights are on. Figure 7 presents velocity vectors for this case, from the top view, indicating the flow pattern at the horizontal mid-plane.

Figures 8 to 10 illustrate some of the results for Studio 2. Because of symmetry about the y-z plane, only half of the Studio is studied. Figure 9 presents velocity vectors on the x-z plane passing through the middle of the Studio, while Figs. 10 and 11 depict the temperature contours in the x-z and y-z mid-planes, respectively.

The results reveal that for this Studio the maximum w-velocity is about 1.20 m/s and appears around the middle of the height; and the maximum temperature near the ceiling, is 22^oC.

In an effort to obtain velocities of acceptable levels (about 0.3 m/s) in Studio 1, two further designs of the ventilation air inlets were considered. One consists of a single, but enlarged inlet, the second of nine small inlets, as shown in Fig. 11. Figure 12 presents velocity vectors and temperature contours for the large-inlet case, while Figs. 13, 14 and 15 present the same information for the nine-inlet case. For this case, the velocities have diminished to a maximum of 0.3 m/s and comfortable temperature levels are maintained near the floor. It appears clearly that this is the best choice concerning the ventilation arrangement for this Studio.

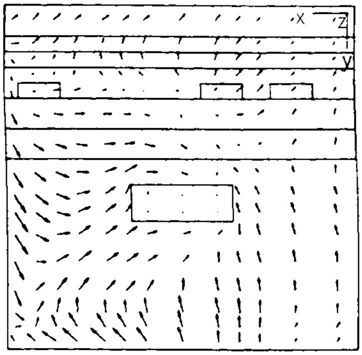


Fig. 7 Velocity vectors on the horizontal x-y plane through the middle of the studio (top view). Lights off.

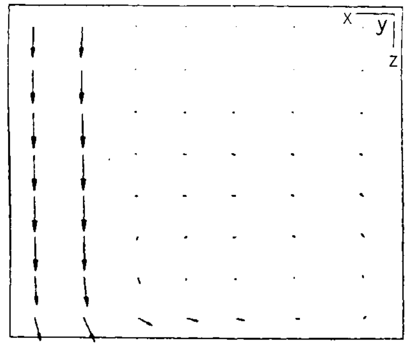


Fig. 8 Velocity vectors on x-z plane through the middle of studio 2

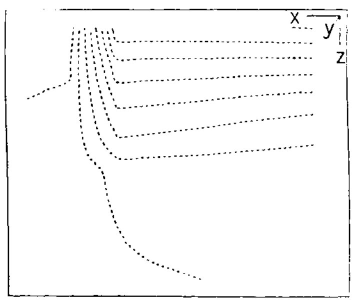


Fig. 9 Temperature contours on a x-z middle-plane (temperature range 287 K to 297 K)

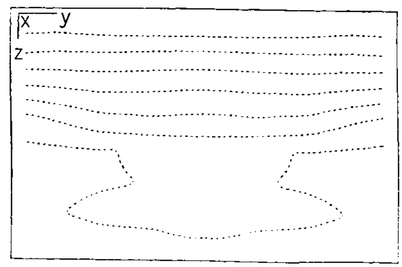


Fig. 10 Temperature contours on y-z middle plane (temperature range 288 K to 295 K)

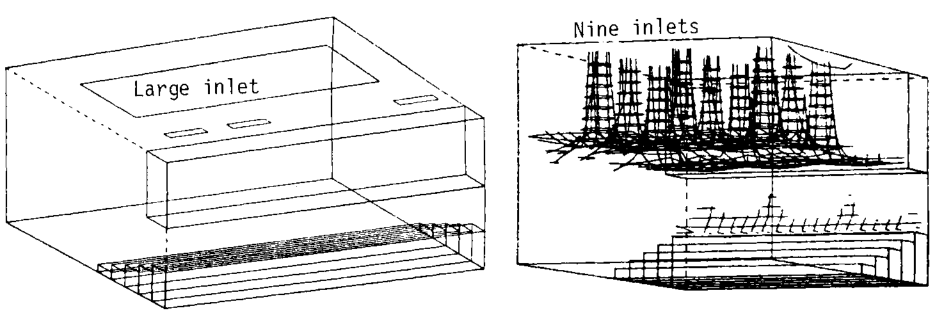
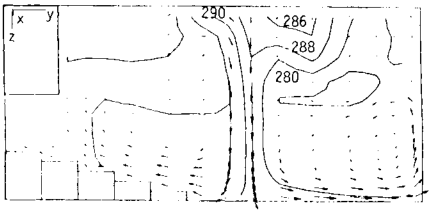
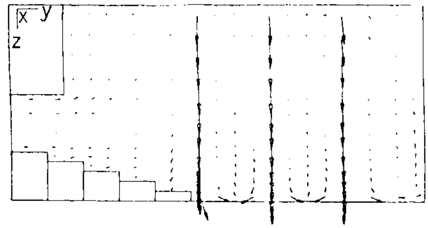


Fig. 11 Enlarged-inlet and nine-inlet configurations



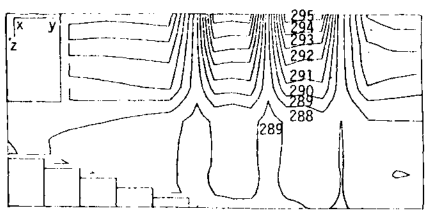
Large-inlet Configuration

Fig. 12 Velocity vectors and temperature contours on the middle z-y plane (max. velocity = 0.8 m/s, temperature range 280 K to 300 K in ten equal intervals)



Nine-inlet Configuration

Fig. 13 Velocity vectors on the middle z-y plane (max. velocity = 0.3 m/s)



Nine-inlet configuration

Fig. 14 Temperature contours on the middle z-y plane (temperature range 285 K to 295 K in ten equal intervals)

CONCLUSIONS

A computational method has been described, and used to predict flow and temperature distributions in 3D enclosures. The study demonstrated that numerical solutions for practical problems relating to buildings, such as, for example, heating and ventilation, can be obtained quickly and economically. Results have been presented and appear physically plausible. Since no grid-refinement studies were performed, no claim on the quantitative accuracy of the results can be made at present. However, the relative advantages and disadvantages of the various ventilation designs studied are clearly predicted, at least qualitatively. Further work is still required, particularly grid-refinement studies, and comparison of predictions with experimental measurements.

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COMPUTER MODEL OF AN HOT WATER STRATIFIED STORAGE WITH HEAT EXCHANGER

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ABSTRACT

Today, hot water production systems using water type solar collectors are operating in numerous countries of the world, particularly in the Mediterranean region. Use of a stratified storage tank for purpose of optimisation of thermal efficiency is overall indispensable, whatever is the nature of the apparatus (passive thermosiphon or active water collectors with plugged-in pump).

Although many publications relative to experimental studies of stratified storage exist, little has been published reporting efficicient simulation models of these stratified tanks, indispensable for a computer assisted calculation of the overall thermal performances of the entire water type collecting system.

Using monitoring of an hybrid water type system for purpose of validation, a computer model able to simulate thermal behaviour of a stratified storage has been developed. In contrast to other computer model, this program allows adding of an heat exchanger (solar circuit, ...) to the storage.

Precise description of the model will be given in this paper. Comparison of various experimental and simulated storage temperatures will be presented, as well as efficiency of the program to calculate thermal performances of the system will be presented.

1. INTRODUCTION

First pioneer works on thermal water storage simulation (ref 1-3) have been realised using very simple tools, like analog computer, simplified weather data bases, etc. They have thus been quite unable to describe in detail the dynamic behaviour of a water storage under pratical conditions of use.

A great amount of more recent simulation (ref 4 - 5) is still not better designed for accurate description of an hybrid or active system with an hot water storage, under "in-situ" conditions. Although thermal performance evaluation of the entire collecting system is possible, lack of accuracy in temperature dynamic behaviour description is characteristic of these different modern codes. Unrealistic assumptions made and relative to physical properties or to dynamical state of the store (constant storage top temperature imposed, solar thermal supply without heat exchanger, ...) explain this fact.

A computer model of a thermal storage has been developed and validated, using monitoring facilities of an hybrid water collector system (ref 6) . Among the particularity of the model, using a multilayer description of the water body (ref 1), solar heating supply by an heat exchanger can be simulated, with an accurate description of the thermal stratification mechanism.

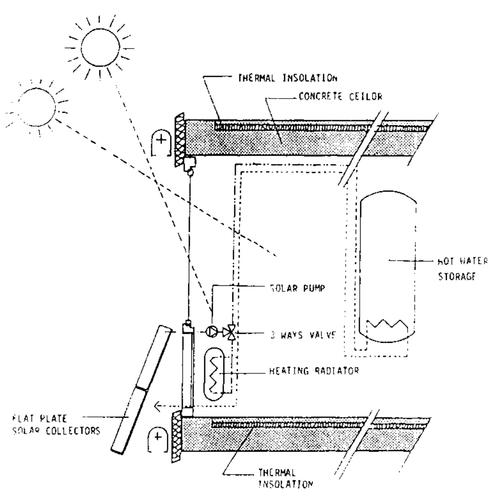
For purpose of validation, not only the various temperature dynamic variations have been compared to experimental datas, but also the energy balance of the system, which has been evaluated by means of simulation and compared to monitoring results.

In this paper, the mathematic model is presented, as well as accuracies of simulated temperatures and energy balance calculations are discussed.

2. SIMULATION MODEL

2.1 Simulated system description

The thermal storage simulated is an element of a water hybrid solar energy collecting system (see figure 1), implemented on the South facade of a calorifugated test cell. This test cell is one of the 9 thermally insulated rooms of the experimental solar energy laboratory LESO (ref 7) .



The hybrid water system, activated by a solar pump, is able to run under two operating modes : DHW production for a 5 to 6 person's family from April to September, and "solar heating" for 50 m^3 office during the heating season.

The stratified storage model has been developed for the simulation of the 360 liters DHW storage, as well as for both 300 liters heating radiators, necessary to the second operating mode.

The solar heating supply of the two different hot water storage tanks are characterised by the use of an heat exchanger. This has been realised for purpose of reducing the amount of anti-freeze fluid, necessary to the solar water circuit.

Fig. 1. Hybrid solar energy collecting system activated by a solar pump.

2.2 Water storage model description

The storage simulation is based on the well known multilayer model, presented by Sheridan and al (ref. 2) . According to his paper, the water tank is divided into three layers, characterised by an uniform temperature and exchanges of energy by means of mass transfer (see figure 2).

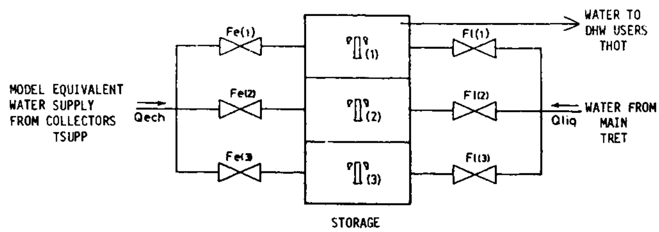


Fig. 2. Equivalent model of the storage and the heat exchanger.

Considering the simulation results, these rather crude assumptions neglecting thermal conduction between the layers, is satisfactory : convection bouyancies due to solar heating supply and dominating thermal conductive transfer explain this good agreement (ref. 4) . Water heated by the heat exchanger is assumed to migrate until it reaches a layer with an identical density. Same mechanism is assumed for cold water returning from the hydraulic main, which can greatly influence the top layer of the store, when DHW demand is important. Hot water for DHW use is assumed always to be drawn off from the higher layer, allowing to write :

$$T_{hot} = T(1)$$

where T_{hot} is DHW temperature and T(1) the water top layer temperature. T(2) and T(3) are the middle and low layer temperatures respectively.

In the literature, relative to this kind of work, solar heating supply is always supposed to flow directly into the tank, allowing to use a mathematic model assuming controlled valves on the water line coming from collectors (ref. 1-3) .

This can be applied to the cold water returning from the main, which physically flows through the storage. Behind Sheridan and al, we assume that the simulation factors Fl(1), Fl(2), Fl(3) controlling the opening of hypothetic valves are driven by returning water temperature Tret, so as :

Table 1

$Tret \geq T(1)$	Fl(1) = 1	Fl(2) = 0	Fl(3) = 0
$T(1) > Tret \geq T(2)$	Fl(1) = 0	Fl(2) = 1	Fl(3) = 0
$T(2) > Tret \geq T(3)$	Fl(1) = 0	Fl(2) = 0	Fl(3) = 1

Due to the presence of an heat exchanger on the hot water solar circuit, the same assumption cannot be directly applied to incoming heat from solar supplying line.

In opposite to other models (ref. 5) , which admits that heat gain from exchanger is only delivered to the lower layer of the storage, where the heat exchanger is generally placed, a more precise modelisation of the heat exchanges has been realised. This allows to account for thermal stratification due to solar heating supply by the heat exchanger.

2.3 Heat exchanger modelling

Heat exchanger equivalent model is based on energy conservation principle and is conceived for replacing heat exchanger by an equivalent direct flow configuration.

Evaluating primarily the mean logarithmic temperature (ref. 8) of the exchanger Texch, defined by :

$$\overline{Texch} = T(3) + (Texin - Texout) / Ln((Texin - T(3)) / (Texout - T(3)))$$

where :

Texin, Texout are the inlet and outlet exchanger temperatures, and assuming, in firstapproximation, stationnary state rules avalaible, one writes the temperature Tsupp of heated water surrounding the heat exchanger by :

$$Tsupp = \overline{Texch} - Uo / Ud . (Texin - Texout) / Ln((Texin - T(3)) / (Texout-T(3)))$$

where

Uo is the global thermal conductance of the exchanger from circulating solar hot fluid to lower cold water of the storage,

Ud is the thermal conductance from circulating solar hot fluid to heated water surroundingthe heat exchanger.

Using energy conservation principle, ones defines an equivalent direct circulating water flow from solar line into the store, supplying water at temperature Tsupp, by :

$$Qech = Qsol . (Texin - Texout) / (Tsupp - T(3))$$

where

Qsol is the real solar hot water flow rate through the exchanger (m^3/s)

Qech is the equivalent flow rate calculated, assuming direct injection of solar hot water into the store (m^3/s).

Same controlled valves can be assumed for the equivalent direct flow exchanges model, drived on this time by temperature Tsupp and simulation factors Fe(1), Fe(2), Fe(3) (see figure 2).

2.4 Energy balance equations

In regard to this model, energy balance of the layers can be done, accounting for the thermal capacity of the layers, and of the conductive losses through the insulated walls of the tank (see figure 3).

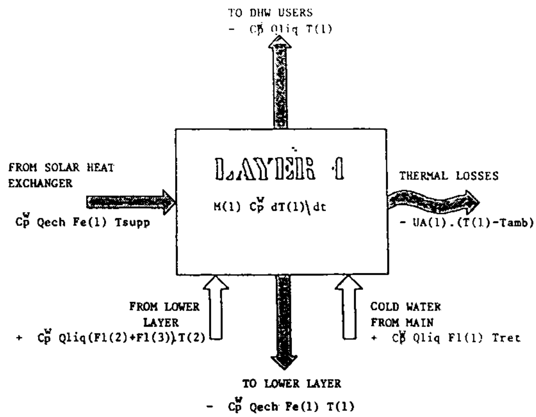


Figure 3 : Energy balance of storage top layer

Mathematical expressions are :

$$M(1)\,Cp^{W}\,\frac{dT(1)}{dt} = \rho\,Cp^{W}\,Qech\,Fe(1)\,.\,(Tsupp-T(1)) + \rho\,Cp^{W}\,Qliq\,Fl(1)\,Tret + \rho\,Cp^{W}\,Qliq\,(Fl(2)+Fl(3))\,T(2) - \rho\,Cp^{W}\,Qliq\,T(1) - UA(1)\,.\,(T(1)-Tamb)$$

$$M(2)\,Cp^{W}\,\frac{dT(2)}{dt} = \rho\,Cp^{W}\,Qech\,Fe(2)\,.\,(T(1)-T(2)) + \rho\,Cp^{W}\,Qech\,Fe(2)\,.\,(Tsupp-T(2)) + \rho\,Cp^{W}\,Qliq\,Fl(2)\,.\,(Tret-T(2)) + \rho\,Cp^{W}\,Qliq\,Fl(3)\,.\,(T(3)-T(2)) - UA(2)\,.\,(T(2)-Tamb)$$

$$M(3)\,Cp^{W}\,\frac{dT(3)}{dt} = \rho\,Cp^{W}\,Qech\,Fe(1)\,.\,(T(2)-T(3)) + \rho\,Cp^{W}\,Qech\,Fe(2)\,.\,(T(2)-T(3)) + \rho\,Cp^{W}\,Qech\,Fe(3)\,.\,(Tsupp-T(3)) + \rho\,Cp^{W}\,Qliq\,Fl(3).(Tret-T(3)) - UA(3)\,.\,(T(3)-Tamb)$$

where

M(1), M(2), M(3) are the equal masses of top, middle and low layers respectively (120 kg)

UA(1), UA(2) and UA(3) are the global conductances of the corresponding layers. Their values are 0.85, 0.75 and 3.14 W/K respectively.

Tamb is the ambient air temperature of the tank's room (^{o}C)

ρ and Cp^{W} are the water density and specific heat capacity respectively (kg and J/kg).

Resolution of the differential equations, as well as those describing the rest of the system, can be obtained by means of a Runge-Kutta resolution algorithm.

Using hour by hour meteorological datas and load values as inputs, the thermal dynamic behaviour of the store, coupled to the rest of the system, can be described.

3. SIMULATION RESULTS

Validation of model has been made using the first monitored period of the hybrid system, corresponding to dates 10 to 16th April 1982. Behaviour of insolation and DHW load during this period are illustrated on figure 4.

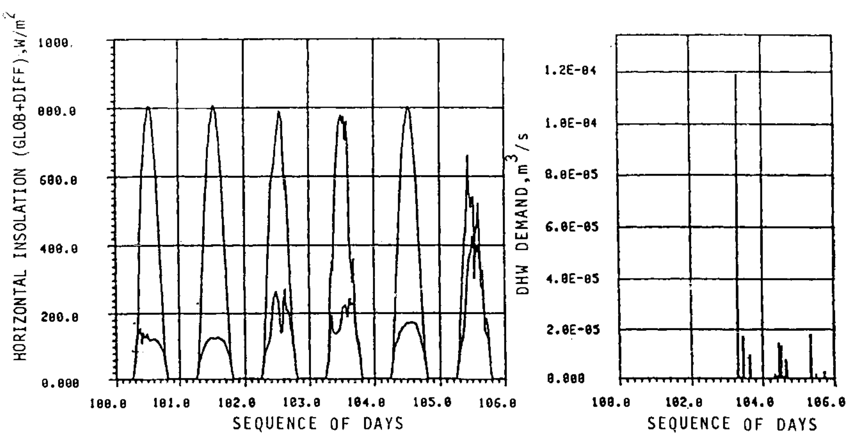


Fig. 4. Diffuse and global horizontal insolation (W/m^2) and DHW demand (m^3/s) during validation period (Days 100 to 106)

Figure 5 shows the excellent agreement between simulated values and experimental datas, obtained by means of resistive platine probes placed in the tank at level corresponding to the center of the model layers. On both figures, the typically small stratification value obtained between two higher layers appear. By the same way, strong influence of returning cold water on the lower layer is also described by the model as obvious on experimental results. Outof the extreme caseof strong DHW load, accuracy of the model is better than 1 ^{o}C.

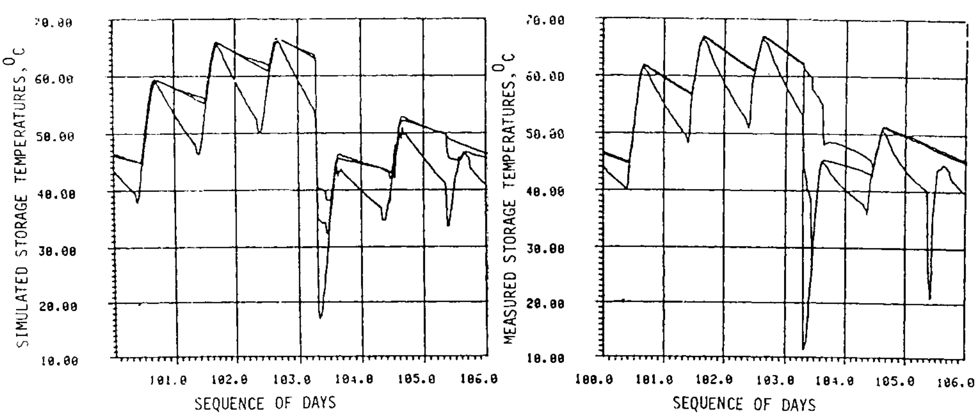


Fig. 5. Computed measured temperatures of the water storage

During the same validation period, the energy flow balance calculation made with both computed and measured hour by hour values have been effectuated.

Table 2 reports these results, allowing comparison of both energy flow balances. Accuracy of the simulation's values is presented in the right hand column.

Table 2 Energy flow balances evaluated by simulation and experimental monitoring (Period from 10 to 16th April 1982 - Days 100 to 106)

	Measured	Computed	Accuracy
Solar energy irradiation on collector	977.2 MJ	-	-
Energy delivered by collectors	353.4 MJ	326.8 MJ	7.5 %
Energy stored in the water tank	65.4 MJ	68.4 MJ	4.3 %
Energy delivered to DHW users	56.8 MJ	49.2 MJ	13.4 %

Due to its rather good accuracy, the use of such a model for purpose of dynamic simulation of a water storage and for thermal performances evaluation is possible. This has been done for the DHW production system presented, allowing rather good results, unless out of the extreme limit of non realistic DHW demands, correlated to strong buoyancies in the water tank and due to forced water circulation. Such a phenomena explain the model discordance of day 103 and decrease the accuray of thermal balance calculation (better than 10 % out of this case).

4. CONCLUSION

A computer simulation of an hot water storage coupled to a solar hybrid energy collecting system has been presented. Although based on a well known water multi-layer model, the algorithm presented is novel, why allowing utilisation of the model for purpose of dynamic simulation of such a water storage under real conditions of use. In particular, it allows to simulate a water store, using an heat exchanger on the solar supplying line of the storage, without loosing accuracy on storage temperature dynamic description.

Application of the model to any kind of water storage (DHW production, heating water radiators, ...) included in an active or hybride solar energy collecting system is possible. Results of these more extended simulations will be presented in an other paper.

AKNOWLEDGMENTS

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MODELING AND SIMULATION OF ACTIVE SOLAR HEATING SYSTEMS USING DAILY HOURS OF BRIGHT SUNSHINE

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ABSTRACT

A method based on daily hours of bright sunshine has been developed and used to evaluate the performance of active solar heating systems for different values of system parameters (collector area and efficiency curves; orientation and inclination; storage capacity; heating load). Comparisons of monthly and annual results with those obtained by other methods using measured values of global horizontal radiation show good results.

KEYWORDS

Modeling; active solar heating; hours of sunshine.

INTRODUCTION

The performance of active solar heating systems must be predicted for design purposes and economic evaluations: such predictions can be based on computer programs, such as TRNSYS (Klein and others, 1979) which simulate the dynamic response of the system and load under the continuously variable meteorological conditions; they can also be based on graphical methods, such as the f-chart (Beckman, Klein and Duffie, 1977) which result from compilations of many computer runs for "typical" systems. The main drawback of both these methods is due to the fact that they require as an input, the global radiation for the site under study. Such data are however scarce: thus, in Quebec for example, only six meteorological stations measure global solar radiation on a horizontal surface while the number of hours of bright sunshine is available for approximately 80 stations.

In this paper, an algorithm evaluating the performance of active solar heating systems from the daily hours of bright sunshine has been applied for several combinations of the parameters defining the system. The results of monthly and annual solar load fractions compare well with those obtained by the f-chart and ϕ-chart (Klein, 1978) methods which use measured values of global horizontal radiation.

METHODOLOGY

The algorithm -based on a model used by Chouard, Michel and Simon (1977) to develop performance nomograms for France- consists of the following steps.

1. Calculation at the site of interest for the day under consideration of:
- the sunset and sunrise time, T_{s2} and t_{s1}
- the theoretical hours of bright sunshine $N = t_{s2} - t_{s1}$
- the daily extraterrestrial radiation H_o incident on a horizontal surface
- the solar irradiation for clear sky conditions incident on a horizontal surface (I^*_{bh} is the beam and I^*_{dh} the diffuse component) for all instants t ($t_{s1}<t<t_{s2}$)
- the solar irradiation for clear sky conditions incident on the inclined collector surface (I^*_{bc} is the beam, I^*_{dc} the sky diffuse and I^*_{rc} the reflected component) for all instants t
- the incidence angle i of the beam radiation on the collector for all instants t according to standard relations (ASHRAE 1971, 1977; Duffie and Beckman, 1980).

2. Estimation of the beginning, t_1, and end, t_2 of solar energy collection which takes place only when cosi>0 and the collector efficiency is positive

$$\eta_{max} - m\ (T_s - T_a)\ /\ (I^*_{bc} + I^*_{dc} + I^*_{rc}) > 0 \tag{1}$$

Here η_{max}, m are the collector's characteristic values determined from the manufacturer's efficiency curve, T_s the average storage temperature for the day under consideration and T_a the corresponding mean daily ambient temperature. Since only the storage temperature at the beginning of the day T_s^-, is known, the value of $T_s = 0{,}5\ (T_s^- + T_s^+)$ must be estimated and confirmed at the end of the procedure.

3. Calculation of the daily totals of beam and diffuse radiation for clear sky conditions for a horizontal surface B^*_h, D^*_h and the inclined collector surface B^*_c, D^*_c by numerical integration of I^*_{bh}, I^*_{dh}, I^*_{bc}, I^*_{dc}, I^*_{rc} over the time interval N.

4. Calculation of the daily totals of global and diffuse horizontal radiation H_h, D_h under real (cloudy) sky conditions from the daily extra-terrestrial radiation H_o and the corresponding hours of bright sunshine n according to empirical relations such as those proposed by Iqbal (1979).

5. Calculation of the daily totals of the beam and diffuse radiation B_c, D_c on the collector under real (cloudy) conditions from the proportionality relations proposed by ASHRAE (1971).

6. Evaluation of the useful daily energy collected by the collector fluid which, by virtue of the expression for the instantaneous collector efficiency, can be approximated as follows

$$Q_u = \eta_{max}\ A_c\ (B_c + D_c)\ (t_2 - t_1)/N - m\ A_c\ (T_s - T_a)\ (t_2 - t_1) \tag{2}$$

A_c is the collector area. It should be noted that the term $(t_2 - t_1)$, which represents the numbers of hours of operation of the collecting system, depends on the average temperature T_s of the storage (see step 2).

7. The load requirements, if space and water are heated by the solar system, are

$$Q_e = 24\ GV\ (T_r - T_a) + k \tag{3}$$

where GV is the overall heat loss coefficient, T_r the required temperature in the house and k the average daily energy requirements for hot water.

8. The daily energy balance for the system is

$$M\,C_p\,(T_s^+ - T_s^-)\,/\,\Delta t = Q_u + Q_b - Q_e \qquad (4)$$

where M, C_p are respectively the mass and specific heat of the storage, Δt the time step (= 1 day) and Q_b the energy supplied by the auxiliary system. Equation 4 is used to evaluate the storage temperature at the end of the day, T_s^+, by one of the following methods:

a) if $Q_u > Q_e$, Q_b is set equal to zero and T_s^+ is calculated from equation 4.

b) if $Q_u < Q_e$ and T_s^- is greater than T_{so}, the minimum acceptable storage temperature, Q_b is set equal to zero and T_s^+ is calculated from equation 4; if $T_s^+ > T_{so}$, the storage can supply the load and the auxiliary energy source is indeed unnecessary; if however $T_s^+ < T_{so}$, the storage does not contain sufficient energy to supply the load. T_s^+ is then set equal to T_{so} and equation 4 is used to calculate the auxiliary energy Q_b.

c) If $Q_u < Q_e$ and $T_s < T_{so}$, both solar and storage energies are insufficient to supply the load: T_s^+ is then set equal to T_{so} and the auxiliary energy Q_b is calculated from equation 4.

The procedure starts with an initial guess for T_s^+ (usually equal to T_s^-) and performs the calculations in steps 2 through 8 until convergence is achieved. For the initial value on January 1st, T_s^- should be set equal to T_{so}.

APPLICATIONS

The computer program executing this procedure is quite simple. The algorithm however is more precise than the model by Chouard, Michel and Simon (1977) which uses a timestep of one month and does not take into account the internal energy of the storage although it calculates a different storage temperature for each month.
The program has been used to evaluate the performance of active solar heating systems at three Quebec cities: Montreal (lat: 45°30'; long: 73°37'), Normandin (lat: 48°51';long: 72°32') and Sept-Iles (lat: 50°13'; long: 66°16'). These are the only three sites of the 53rd parallel where solar radiation is measured in Quebec. Therefore they are the only three sites where solar applications are interesting and where the proposed algorithm can be compared with other existing performance evaluation methods.

The calculation of H_h in step 4 was performed using the long-term measured monthly averages of H_h, n and the corresponding calculated values of H_o, N at the three sites under consideration (Nguyen, 1983). The evaluation of D_h was performed according to the relation proposed by Iqbal (1979). Figures 1 and 2 show that the agreement between radiation values thus calculated and corresponding measured values is good.

The daily values of n, the number of bright sunshine hours, were calculated from a 3rd order Fourrier series expansion of the long-term measured monthly averages. The same approach was used for the evaluation of T_a, the mean daily ambient temperatures.

The computer program has been executed for approximately 200 systems defined by different combinations of A_c, η_{max}, m, collector orientation and inclination, T_{so},

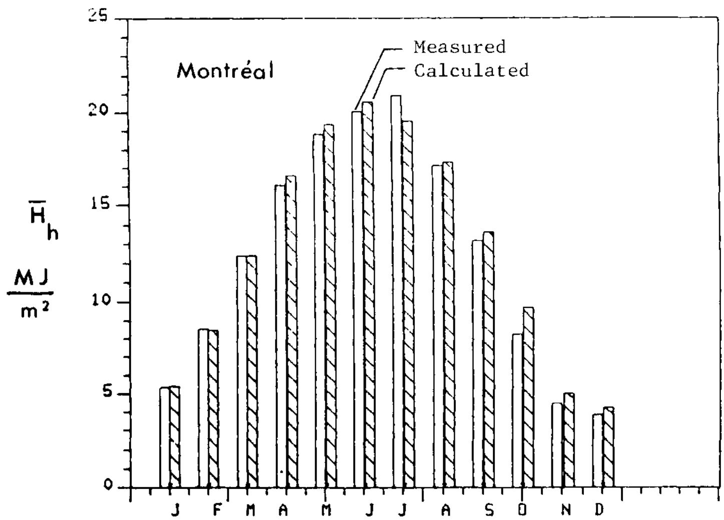

Fig. 1 Evaluation of monthly average global radiation predictions

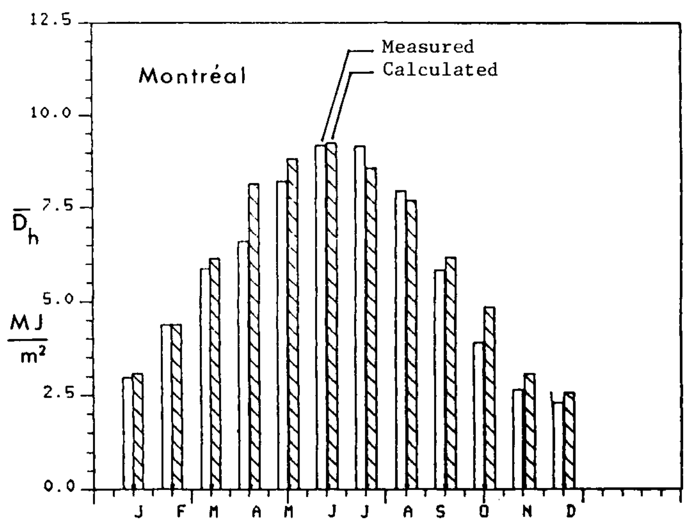

Fig. 2 Evaluation of monthly average diffuse radiation predictions

MC_p and GV. The simulation of the yearly performance of any particular system takes approximately 3 minutes of execution time if convergence of T_s^+ to within ±0.1°C is specified. The output includes the daily values of:

- the useful energy collected by the solar system Q_u
- the auxiliary energy Q_b
- the load requirements Q_e, and
- the storage temperatures T_s^+, T_s^-, T_s.

RESULTS AND DISCUSSION

The calculated results (Nguyen, 1983) show the influence of the different parameters on the solar load fraction. Thus, for example, Fig. 3 shows the monthly values of the solar load fraction for three different systems situated in Montreal and having: η_{max} = 0,75; m = -3,5 W/m^2°C; south-facing collectors inclined at 50°; MC_p = 9581 Wh/°C; T_{so} = 25°C; GV = 200 W/°C. These results demonstrate well known properties of solar systems such as storage saturation.

In order to test the precision of the proposed algorithm, the results it yields for the solar load fraction were compared with corresponding results obtained with the f-chart (Beckman, Klein and Duffie, 1977) and ϕ-chart (Klein, 1978) methods. For this purpose, the performance of a reference system having south-facing collectors inclined at 47,5 degrees and:

$$A_c = 10\ m^2; \quad \eta_{max} = 0,75; \quad m = -3,5\ W/m^2\ °C$$

$$MC_p = 958\ Wh/°C; \quad T_{so} = 25°C; \quad GV = 200\ W/°C$$

was evaluated at each of the three sites by each of the three methods with the appropriate inputs (n for the proposed algorithm, H_h for the f-chart and the ϕ-chart). Table 1 provides a comparison of the monthly and annual results. In general, the proposed algorithm gives consistently lower estimates, especially during the winter months.

The performance of several other systems was similarly calculated according to these three methods. Figures 4 and 5 show typical results for the annual solar fraction of systems having collectors inclined at 35°. They confirm the fact that the proposed algorithm predicts more conservative performances than the f-chart and ϕ-chart methods. It should be pointed out however that according to Fanney and Liu (1980) the f-chart overestimates annual results by about 10%.

CONCLUSION

The proposed algorithm provides a method for the evaluation of the performance of solar active heating systems from long-term monthly average values of the ambient temperature and the daily hours of bright sunshine. Its results for monthly solar fractions are probably underestimating the long-term average performance by as much as the f-chart overestimates it. The computer program implementing the proposed algorithm is quite simple and can be used as a design tool on a minicomputer.

ACKNOWLEDGEMENT

This study was carried out with the financial assistance of the Natural Sciences

Table 1. Solar load fraction (%) comparison for reference system

	Montreal			Normandin			Sept-Iles		
Month	Present method	f chart	ϕ chart	Present method	f chart	ϕ chart	Present method	f chart	ϕ chart
1	4,9	9,2	7,4	2,2	10,0	6,8	3,5	10,3	7,4
2	9,4	15,0	11,9	5,2	15,9	11,7	6,7	16,6	12,7
3	17,4	23,3	20,0	10,9	24,8	20,6	12,8	22,0	18,2
4	33,6	36,3	34,9	20,7	31,4	28,3	20,7	26,0	22,6
5	73,9	69,0	78,9	42,3	45,0	45,1	32,1	36,3	34,2
6	100,0	100,0	100,0	94,0	87,3	100,0	57,4	61,2	66,1
7	100,0	100,0	94,4	99,4	100,0	100,0	92,2	72,8	85,6
8	99,5	100,0	100,0	86,0	78,1	96,0	74,2	67,7	77,4
9	83,6	77,4	94,5	45,4	42,0	43,6	41,4	38,8	39,5
10	36,0	31,8	32,6	16,1	19,1	17,9	18,4	22,9	21,4
11	10,1	9,5	9,3	3,5	9,1	7,7	6,8	10,1	8,8
12	3,2	6,2	5,7	1,2	8,3	6,0	3,3	6,6	5,3
Annual	22,5	24,8	24,3	16,1	23,0	21,4	18,3	22,8	21,4

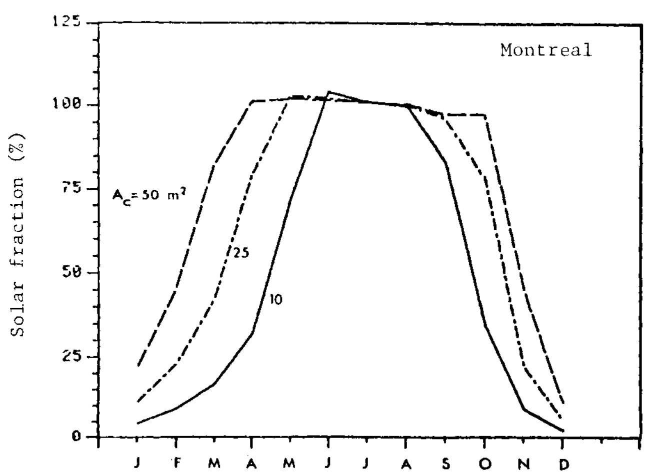

Fig. 3. Effect of collector surface on monthly performance

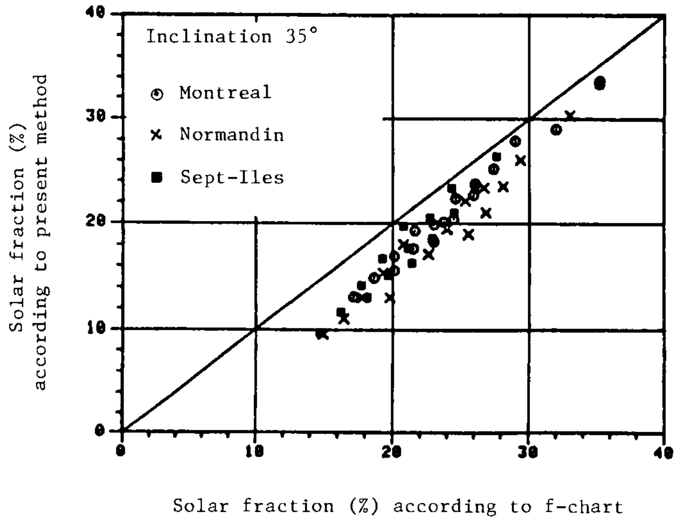

Fig. 4. Comparison of annual solar fractions

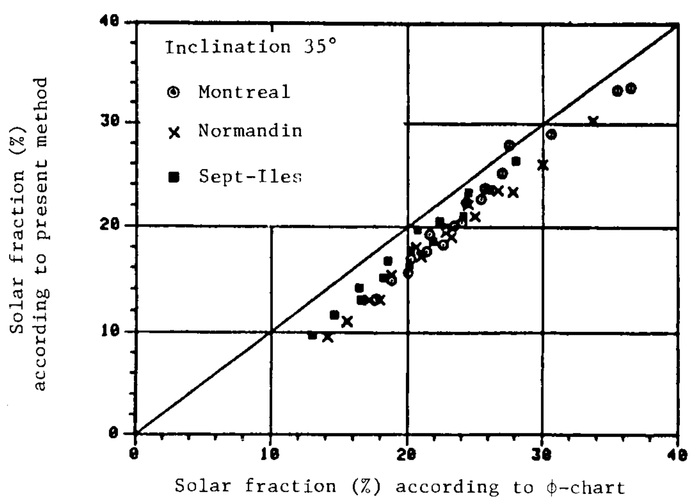

Fig. 5. Comparison of annual solar fraction

and Engineering Research Council of Canada.

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NUMERICAL MODELLING OF HELIO-GEOTHERMAL ENERGY UTILISATION FOR HOUSE HEATING

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ABSTRACT

Using a set of supply and storage wells, the low enthalpy geothermal energy and the solar energy stored into the aquifer can be recovered for house heating. In this work, a computer simulation technique is presented for studying the optimisation and the feasibility of the geothermal system, when the local groundwater circulation is known.

KEYWORDS

Geothermal energy; solar energy; heat pump; space heating; groundwater hydraulics; computer simulation.

INTRODUCTION

Low enthalpy geothermal resources are very important in Greece, as shown in the map of fig. 1. For example, in Northern Greece, near the river Strymon and the town of Serres, hot water at a temperature of 50-60°C appears at the surface of the ground. More information concerning the geothermal potential in Greece and the perspectives for applications of the available geothermal resources were given recently by Ganoulis, J. (1982). In fact, field measurements by the Institute of Geology and Mineral Exploration (IGME) indicate that most of the aquifers in Greece from 5 to 500 m in depth conserve a groundwater temperature greater than 12°C during the winter period. This energy can be recovered by means of a heat pump and utilised for space heating.

More than 30 per cent of the total energy consumption in Greece is used for space heating. Imported oil is the principal source for heat production in housing. Heating is necessary during six months of the year, because the winter is rather cold, especially in Northern Greece. Appropriate use and development of geothermal resources are very important for saving foreign currency from oil importation and will contribute to the independent social-economic development of the country.

Reliable hydrogeological and geothermal data are necessary to study the feasibility of a geothermal system. Furthermore pilot installations should prove the thermal

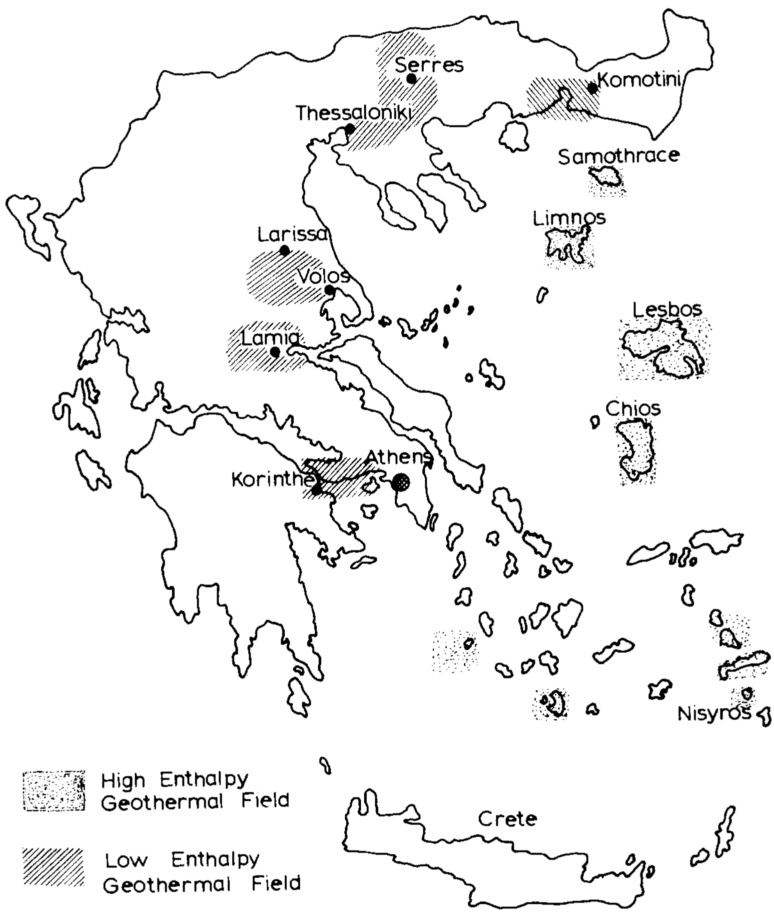


Fig. 1. Location of geothermal fields in Greece.

efficiency of the system for local climatic conditions. In any case, mathematical and numerical models are necessary for the prediction of different policies of the project.

In this work, a computer simulation model is presented allowing the computation of the hydrodynamic and thermodynamic properties of the geothermal system. The model can be used to optimize the operating conditions of the supply and storage wells and to evaluate the thermal efficiency of the system, for any specific conditions of groundwater circulation.

THE HELIO-GEOTHERMAL WELL SYSTEM

A single well can be used to extract the geothermal energy, when the energy demand for space heating is high. During the summer, water heated by solar energy can be reinjected in the same well (Doughty, C. and others, 1982).However, the doublet system i.e. a pair of supply and storage wells, is being recently widely applied, because it provides efficient solutions to several problems inherent to the single well system, such as protection of the groundwater reservoir and maintenance of groundwater pressure. (Ausseur, J.Y., A. Menjoz and J.P. Sauty, 1982).

The geothermal doublet implies, however, the disadvantage of forming a cold water body near the storage well, which, after some time, reaches the production well and lowers the thermal efficiency of the system. This inconvenience can be overcome by the helio-geothermal doublet, shown in fig. 2. During the summer, the water circulation is inversed and the cold water is heated using solar energy and reinjected

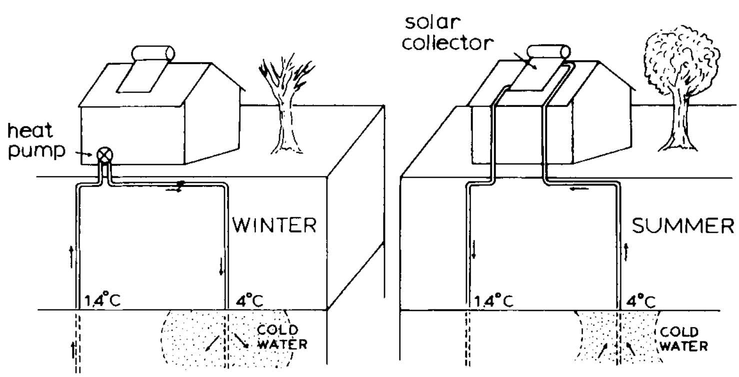


Fig. 2. The helio-geothermal doublet

into the aquifer. Thus two separate zones of cold and warm water are formed in the aquifer. In order to analyze the thermal efficiency of this device, expressed a ratio between recovered and injected energy, it is necessary to consider the hydrodynamic behavior of the system.

HYDRODYNAMIC CONSIDERATION

During the production cycle,the optimum operating conditions are obtained when recirculation between the supply and recharge well can be avoided. This is a hydrodynamic problem, as shown in fig. 3, where two different situations appear, with and without recirculation between the two wells, each case depending also on the specific direction of the uniform regional flow. The general optimization problem concerning the hydrodynamic circulation can be formulated as follows : given the production flow rate and the regional flow field define the number and the location of the geothermal wells in order to avoid recirculation of the flow between the supply and the storage wells.

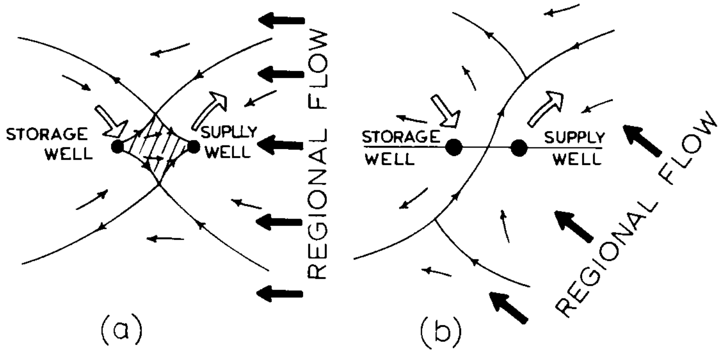
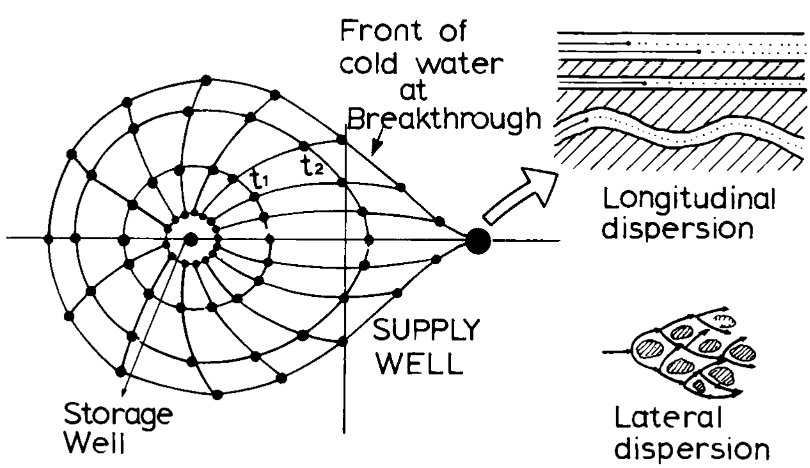


Fig. 3. Hydrodynamic operation of geothermal doublet in uniform regional flow : recirculation flow (a): separated flow (b)

THERMODYNAMIC BEHAVIOR OF THE SYSTEM

Heat is transported with the fluid particles from the storage to the supply well. This is the heat transfer by forced convection, shown in fig. 4.a, where the movement of a number of fluid particles is considered at different times. Heat conduction is a molecular mechanism of heat transport between the fluid and solid particles, but the microscopic structure of the soil produces the longitudinal and la-



Fif. 4. (a) Cold water propagation by forced convection from the storage to the supply well (b) longitudinal and lateral heat dispersion.

teral heat dispersion (fig. 4.b.), which is superimposed to the other mechanisms of heat transfer.

COMPUTER SIMULATION OF GEOTHERMAL PHENOMENA

Several computer codes have been developed in the Hydraulics Laboratory, Aristotle University of Thessaloniki, simulating efficiently the regional groundwater flow with pumping and injection wells (Latinopoulos, P., J. Ganoulis and D. Tolikas, 1982). The numerical algorithms are based on the boundary elements technique, which is very attractive in several aspects : no grid is necessary in the flow field, well singularities are simulated naturally, computation time and memory space are significantly reduced. Therefore most of the computing work has been done with a versatile and easily programmable micro-computer.

Knowing the hydrodynamics of the flow field, e.g. the distribution of the piezometric head, the streamlines and the velocity distribution, the thermal phenomena are next simulated by two different methods. The first is based on the numerical integration in two dimensions of a partial differential equation expressing the energy balance. This procedure leads to several numerical errors, unless higher order numerical schemes are used. The second method is based on the separation between forced convection and thermal dispersion. In a first step a number of a massless particles is introduced into the flow field to simulate the cold water propagation shown in fig. 4. The second step consists of the superposition of the thermal dispersion, using a finite defference scheme.

PRELIMINARY RESULTS AND DESCUSSION

An example of computation is presented in fig. 5 for a geothermal doublet having the following characteristics : production and injection flow rate $Q = 3\ell/s$, distance between the two wells $\ell = 30$ m, aquifer transmissivity $T = 4\times10^{-4} m^2/s$. The piezometric head distribution is automatically drawn by the line printer of the Apple-II microcomputer of the Hydraulics Laboratory, A.U.T. Each equally shadowed area corresponds to a piezometric head variation of 0.2 m. Velocity distribution is easily obtained from piezometric gradients and the computation of the temperatu-

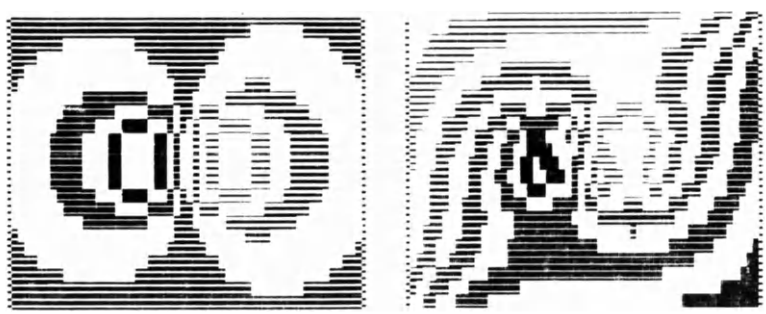


Fig. 5. Example of computation. Piezometric head distribution in geothermal doublet : (a) whithout regional flow, (b) with oblique uniform regional flow.

re variation allows the definition of the thermal efficiency of the system.

Computer simulation of low enthalpy geothermal fields is currently used to meet two distinct goals :
(a) Define the "optimum" geothermal well device in the hydrodynamic and thermodynamic sense. For example, apart from the pair of wells, one can also test the efficiency of a system comprising one injection and two or three supply wells.

(b) Provide a set of computer codes to study the feasibility of a geothermal system for any specific conditions of soil parameters, groundwater circulation, climate and operating cycles.

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THE COMMISSION OF THE EUROPEAN COMMUNITIES
PASSIVE SOLAR PROGRAMME

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SUMMARY

This paper outlines the work in the period 1980 to 1983 and being funded by Directorate General XII (for Research,Science and Development) of the Commission of the European Communities. The work includes a Call for Tenders for passive solar building components, a Performance Monitoring programme of several passive solar dwellings throughout Europe, a coordinated passive solar research programme, the First and Second European Passive Solar Competitions - 1980 and 1982, and an assessment study of the prospects for solar thermal energy in Europe.

INTRODUCTION

The Commission of the European Communities, Directorate General XII for Research, Science and Education, is conducting an energy research and development programme with the objective of reducing the Community's reliance on imported fossil fuels. This overall programme has a budget of 106M EUA* and covers the general areas of Energy Conservation, Hydrogen, Geothermal Energy and Systems Analysis, in addition to Solar Energy.

Within the Solar Energy programme, the following eight separate projects are being undertaken:

Project A	Solar Applications to Dwellings
Project B	Thermo-Mechanical Solar Power Plant
Project C	Photo-voltaic Power Generation
Project D	Photochemical, Photobiological processes
Project E	Energy from Biomass
Project F	Solar Radiation Data
Project G	Wind Energy
Project H	Solar Energy in Agriculture and Industry

The Passive Solar research programme falls within Project A as do the following other research programmes:

*1 EUA (European Unit of Account) = 45.24 BFR, 8.12 DKR, 2.30 DM, 68.55 DRA, 6.53 FF, 0.69 IRL, 1325.66 LIT, 2.55 HFL, 0.60 UKL.

- Performance Monitoring of Solar Houses in Europe
- Solar heat-storage systems
- Active solar heating systems for dwellings
- High performance vacuum collectors
- Test procedures for flat-plate collectors
- Solar cooling

They all share the 9.3M EUA* budget allocated to Project A for the current four year programme (1979-83). The passive solar programme is the youngest of them, having been started with a modest state-of-the-art report in 1979. This led to a meeting of some of the European experts identified, in which one of the most forcefully voiced suggestions was that of an architectural ideas competition. The CEC's "First European Passive Solar Competition - 1980" followed, with the aim of spreading passive solar design methods and principles to as many as possible within the European building design professions.

In response to the success of this first competition the Commission has set up various new activities, within the passive solar programme, which extended over the two remaining years of this four year programme. It has also extended the work of the Performance Monitoring Group to emphasise the reporting of the performances of passive solar dwellings in Europe. The passive solar research and development programme now includes the following:

Call for Tenders:
- Development of Passive Solar Components

Coordinated Activities:
- Performance Monitoring Group
- European Passive Solar Working Groups

Competition:
- Second European Passive Solar Competition - 1982

European Economic Assessment

With the exception of the Performance Monitoring Group and the European Economic Assessment, whose funds also cover other aspects of solar energy collection, the passive solar programme will have a total budget of 2.1M EUA for the two year period, of which the Call for Tenders is allocated 1.4M EUA, the Competition 200,000 EUA, and the Working Groups 500,000 EUA.

Project A is supervised by Dr W Palz and Mr T C Steemers in Directorate-General XII at the Commission. Dr Palz and Mr Steemers structured the Passive Solar Programme with the aid of both an appointed expert, Mr R M Lebens, and a Passive Solar Advisory Group. Each member of this Advisory Group was appointed by his country's representative to the ACPM (Advisory Committee for Programme Management).

The Passive Solar Advisory Group has now been amalgamated with the main Project A Advisory Group and the overall scientific expert is Mr Caes den Ouden of the Institute of Applied Physics, Delft. Together they have the task of monitoring the progress of the activities within the passive solar programme, selecting projects to support within the Call for Tenders, and they have nominated representatives in their countries to participate within the Passive Solar Working Groups.

A new call for tenders for passive solar demonstration projects is being prepared by Directorate General XVII. This will be for new housing projects. The announcement is expected to be made this year.

OUTLINE OF PASSIVE SOLAR PROGRAMME

Call for Tenders - Components

This is sponsored R&D work through direct contracts with industry, universities and other organizations within the European Communities. The call was published in the March 1981 issue of the Official Journal of the European Communities. The Commission contributes up to a maximum of 50% of the cost of each project. Close cooperation with the governments of the Community's member countries in awarding these contracts is achieved through the Project A Advisory Group and the ACPM, whose members are either government officials or their advisers. Thus the remaining 50% is carried by either the organization concerned or its government.

The call is specifically directed towards two types of passive solar components: architectural components and auxiliary heating systems. The contracts that have been awarded are for:-

A. Subsection: walls, facades, etc

- Hollow wall: architectural structural element alternative to trombe wall
  CTIP Solar SpA, Italy
- Research in and development of a passive solar energy facade in the "council housing" sector
  ERA Bouw b.v., The Netherlands
- High performance passive solar heating system with heat pipe energy transfer and latent heat storage modules
  Institute of Applied Physice TNO-TH, Delft, The Netherlands
- Transparent insulation for thermal storage walls
  Thermal Insulation Laboratory, Denmark
- A ventilated trombe wall unit
  Saint-Gobain Vitrage, France
- Study to design and manufacture an insulating translucent glass panel made with evacuated pyrex tubes
  Corning, France
- Research and development of a passive solar facade industrial component
  Rossignol S A, France

B. Subsection: Shutters, window systems, etc

- Temporary thermal insulation in the passive solar utilisation
  FES Fuhse Energie System GmbH, Western Germany
- Development of an independent shutter system for passive temperature control in buildings
  Fraunhofer Institut fur Solar Energiesysteme (ISE)
- Development of a thermal phase change store and a solar blind for use in conservatories and glazed roof spaces
  Fulmer Research Laboratories Ltd
- Development and testing of architectural components for passive solar energy use in transparent building facades
  Gesamthochschule Kassel, Fachbereich 12 - Architektur, Western Germany
- Development of a range of double windows including a solar control blind and internal shutters for use with passive solar houses
  Stephen George and Partners, Architects and Town Planners, UK
- Use in passive solar architecture of solar dousers with a seasonal effect
  Montepolimeri CSI, Italy

C. Subsection: Control devices, etc

- Development of an automatic temperature sensitive air control device for use with passive solar gain collectors
  Waterloo Grill Co Ltd, UK
- Self-acting power cylinders for controls in passive solar buildings
  Stephen George and Partners, Architects and Town Planners, UK
- Unit for local storage of solar gain
  Thermal Insulation Laboratory, Technical University of Denmark
- Design and development of a simple convective type solar air collector
  University of Thessaloniki, Greece
- Solar wall with tiles covered by a layer of spectral selective enamel.
  Laboratoires de Marcoussis, Centre de Recherches de la Compagnie Generale d'Electricite, France
- System for warming the new ventilation air using the solar energy in an individual house
  Societe Les Maisons Bruno-Petit, Direction Etudes et Projets, France

The development work on all the above projects is due to be completed by the middle of 1983.

Coordinated Activities

As the name suggests each of these activities has a single appointed contractor who is responsible for organizing and coordinating the work undertaken by several sub-contractors. The coordinating contractor is responsible for the progress of work carried out by the (usually) nine sub-contactors (one from each of the EC countries except Luxembourg), and for collating and publishing the results of this work.

Performance Monitoring Group (PMG)

This Group has drawn up reporting formats for the different solar systems being monitored. The task of collecting the data is carried out by subcontractors in each member country. The coordinator is responsible for collation and analysis of the data. One of the pre-requisites for a solar house to be included in the fifty or so houses being assessed by the Performance Monitoring Group is that it is already being monitored.

The cordinating contractor for the Performance Monitoring Group is: Energy Conscious Design, 44 Earlham Street, Covent Garden, London WC2, UK. The following individuals are members of the Group:-

Arnold Debosscher, Katholieke Universiteit Leuven, Celestijnenlaan 300 A, B3030 Heverlee, Belgium
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J Owen Lewis, Energy Research Group, Department of Architecture, University College, Richview, Clonskeagh, Dublin, Ireland
F Cecchi Paone, Fidimi Consulting Spa, 00144 Viale dell 'Arte 68, Rome, Italy
Dick Brethouwer and Caes Den Ouden, Institute of Applied Physics, TNO-TH, PO Box 155, 2600 AD Delft, The Netherlands

The results of the first phase of this Group's work have been published by Pergamon Press, in a book entitled "European Solar Houses, How They Have Worked", edited by W Palz and T C Steemers. Since the publication of this the group has entered into a second stage of collection and analysis. This has resulted in the production of data collection forms which include a set for Passive Solar projects. The final report is in three volumes: "Performance Monitoring of Solar Heating Systems in Dwellings." "Executive Summary and Recommendations"

"Solar Space Heating in Dwellings - An analysis of Design and Performance data from 33 systems."

"Solar Water Heating - an analysis of design and performance data from 28 systems."
All published by the Commission of the European Communities.

The PMG has also published a comprehensive book giving guidelines to the monitoring of solar houses. This book is available from Pergamon Press (3). To date the PMG is collecting data from 8 passive solar projects. The PMG has now entered a third phase in which it is evaluating optimum system designs for various locations in Europe.

European Passive Solar Working Groups

The Working Groups have recently been established to carry out research and to recommend work to be included in the next four year programme within the following subject areas:

- Simulation and Simple Design Models
- Design Guidelines
- Passive Solar Components
- Planning and Urban Design
- Retrofit and Rehabilitation
- Air Movement and Heat Distribution
- Thermal Comfort
- Test Facilities
- Educational Support

The proposed major tasks of the Working Groups are as follows:

- The selection and analysis of a passive solar computer model and the selection and testing of simplified models. This task has required a group of modelling experts and therefore it lead to the formation of a sub-group: the Modelling Sub-Group.
- The writing and publication of an extensive European Passive Solar Design Handbook. This will incorporate a large proportion of the results of the tasks outlined above and below.
- The collection and publication of a products catalogue for passive designers and for manufacturers of these products.
- The organization of a travelling passive solar workshop for mid-career education.
- The development of a comprehensive plan with detailed recommendations for the passive solar R&D programme over the next four year programme period.

The coordinating contractor for both the Working and Modelling groups is Ralph Lebens Associates.

The following individuals are members of the Working Group:

Belgium	P Caluwaerts, Belgian Building Research Institute
Denmark	Lars Olsen, Thermal Insulation Laboratory
France	M Bellanger, Societe d'Etudes Soreib
F.R. Germany	K Bertsch, Fraunhofer Institute fur Bauphysik
Greece	E Tsingas, University of Thessalonica
Ireland	J Owen Lewis, University College Dublin
Italy	Sergio Los, University of Venice

Netherlands	R G Kiel, Bouwcentrum
United Kingdom	Dean Hawkes, Cambridge University

The following individuals are members of the Modelling Sub-Group:

Belgium	A Dupagne (Chairman), University of Liege
Denmark	H Lund, Thermal Insulation Laboratory
France	M Raoust, Consultant, Paris
F.R. Germany	C Kupke, Fraunhofer Institut fur Bauphysik
Ireland	J Cash, Dublin Institute of Technology
Italy	F Rubini, Acta Corso Duca Degli, Turin
Netherlands	G Pernot, Technische Hogeschool Eindhoven
United Kingdom	J Littler, Polytechnic of Central London

Progress

The writing work on the handbook is now well advanced and production stage has already started. It should be published in late 1983.

The response from manufacturers has been very patchy. The common problem seems to be a lack of awareness of the potential market for passive solar applications.

Preparations for the workshop have gone hand in hand with the preparation of the design handbook, since much of the material will be the same. Contacts have been set up in each country. The first pilot workshop was held in London in April 1983.

The group has prepared a strategy paper for the passive solar R&D programme for the next four year period, which is being used by the Commission in their currrent planning of the programme.

First European Passive Solar Competition

Ralph Lebens Associates, was asked by the Commission to organize this competition, designated the 'First European Passive Solar Competition - 1980'. The competition was announced in early April of 1980, when the documents became available to the general public. The submission date for entries was 29 August 1980. The judging was in two stages: the first by technical assessors from all over Europe, and the second by a panel of international architects with experience in the field of passive solar design.

The prizes, totalling 30000 EUA, were awarded in November 1980, at a ceremony in the offices of the European Commission in Brussels.

The competition was open to architects and students of architecture resident in any of the EC countries, and entries were encouraged from multi-disciplinary groups. It was an 'Ideas Competition', for the application of passive solar design principles either to a new construction or to the rehabilitation of an existing building. Entries were invited in three separate categories:-

Category A: Multi-Storey Housing
Category B: Clustered Housing
Category C: Single Dwellings

There were 223 entries to the competition resulting in 11 prizes, 11 commendations and 3 special mentions. An exhibition of the winner's drawings and models has travelled throughout Europe. A book of the competition results, including the competition conditions has been published commercially (1). Total sales so far exceed 3,000.

Second European Passive Solar Competition - 1982

The aims of the second competition are to improve on the organization, distribution and response of the first competition, to attract more students (only 25% of the 225 entrants to the first competition were student entries).

The competition was launched in October 1981 and the final entry date was 27 August 1982.

Two categories were chosen by the judges:

Category A: High Density, Low Rise Housing
Category B: Retrofit and Rehabilitation of Dwellings

These categories were chosen because they were thought to represent the more pressing problems in housing in Europe. The single house category was omitted, this had been fully tackled in the first competition and it was not thought to be of such wide importance.

The Second European Passive Solar Competition has been funded by the Commission of the European Communities in Brussels, Directorate-General XII for Research, Science and Development. It was organised by Ralph Lebens Associates in London.

The following number of applications for the competition documents were received:

	Individuals	Schools of Architecture
Belgium	84	3
Denmark	75	-
France	366	1
Germany	376	4
Greece	27	-
Ireland	35	2
Italy	170	1
Netherlands	140	-
U K	119	9
Total	1395	20

The number of submissions for the competition were as follows:

	Category A	Category B	TOTAL
Belgium	8	8	16
Denmark	13	1	14
France	43	14	57
Germany	54	18	72
Greece	5	3	8
Ireland	5	1	6
Italy	28	3	31
Netherlands	18	4	22
U K	20	3	23
Total	194	55	249

It should be noted that 40 sets of documents were sent to each participating School of Architecture. The schools then selected their five best designs to be submitted. It was also possible for students to register individually.

The number of submissions from professional architects, architectural students and Schools of Architecture were as follows:

	A	B	TOTAL
Architects	133	42	175
Students	61	13	74

An international technical assessment team of 13 experts within this field conducted the first stage of the competition assessment in September 1982. This process took one week and was followed by a 3-day final assessment by five international architects with experience of passive solar design. Their awards were as follows:

CATEGORY A

1st Prize	UK £3000	- Christian Blachot and Bernard Cogne, Echirolles, France
2nd Prize	UK £2000	- Vincenzo Bacigalupi, Rome, Italy
3rd Prize	UK £1000	- Steve Tompkins, Bath, UK
4th Prize	UK £500	- Johannes Brucker, Stuttgart, W Germany

CATEGORY B

1st Prize	UK £3000	- Helena Jiskrova and Zdenek Zavrel, Rotterdam, The Netherlands
2nd Prize	UK £2000	- Michel Ripoll, Wasequehal, France
3rd Prize-shared	UK £500	- Ulla Falck, Dorthe Henriksen and Anne Marie Nielsen, Copenhagen, Denmark
3rd Prize-shared	UK £500	- Michael Muller, Dieter Berreth and Willi Kruppa, Ludwigsburg, W Germany

The winning entrants received their prizes on 13 December 1982 at a ceremony held at the Palais des Festivals in Cannes at the opening of the International Solar Architecture Conference. The best entries were displayed at the conference.

European Economic Assessment

The Commission has appointed Energy Conscious Design,(London), to carry out this assessment of solar thermal energy potential in Europe. The main conclusion of this assessment study is that the potential energy savings from thermal systems (including Active and Passive) is considerably greater than has been previously thought. This is when comparing the results of this study with official national government predictions. The European Economic Assessment is the subject of another paper by D Turrent (4).

Conclusion

The Commission is firmly committed to a large proportion of its energy R&D spending on solar. The diagrams attached show that while CEC spending is 10% of that of member countries for energy research, in the solar field CEC spending is 40%.

In the 1975-1979 programme CEC Solar research spending was 17.5M EUA (30% of the total), in the 1979-1983 programme solar research spending was 46M EUA (43% of the total). Passive solar research was only started by the CEC in this programme and so represents a small proportion to date, but it is seen as the solar technology with the most early chance of results and dissemination in the field and so its share of R&D funds is likely to be much greater in the Commission's forthcoming R&D programme which is now being prepared.

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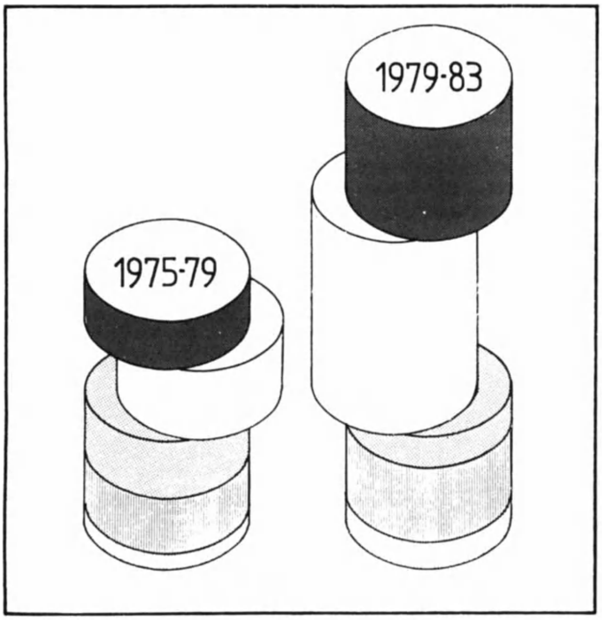
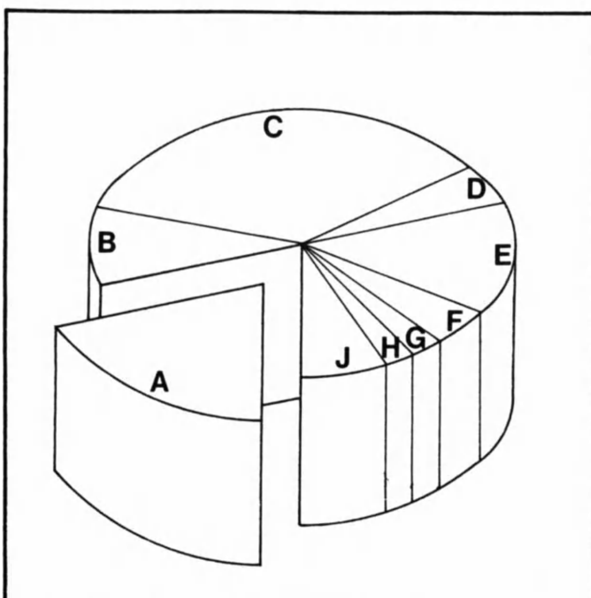


division of ENERGY programme budget

1975-79		1979-83
11·4	CONSERVATION	27·0
17·5	SOLAR	47·0
13·2	HYDROGEN	8·0
13·0	GEOTHERMAL	18·0
3·9	SYSTEMS	6·0
59·0	TOTAL MECU	106·0



division of SOLAR ENERGY programme budget 1979-83

PROJECT	MECU
A application to dwellings	9·3
B thermo-mechanical	4·7
C photovoltaics	15·9
D photochemical/biological	2·6
E biomass	7·4
F radiation data	2·0
G wind	1·0
H agriculture and industry	0·7
J other	3·4
TOTAL	47·0

CONSUMER ENERGY CONSERVATION POLICIES AND PROGRAMMES IN GREECE

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ABSTRACT

The paper reports the results of the first phase of a 1982 study conducted in Greece on Consumer Energy Conservation Policies and Programmes. The general objective of the study was to document and appraise policies and programmes, both implemented and proposed, with respect to their energy conservation potential and their impact on consumers and the environment.

KEYWORDS

Residential energy conservation; consumer protection; environmental protection; solar diffusion; policy evaluation.

INTRODUCTION

Research as summarised in this paper was carried out in 1982 as part of an ongoing multi-national study "Consumer Energy Conservation Policies (CECP)", coordinated through the International Institute for Environment and Society of the Science Center Berlin and supported by the Commission of the European Communities. The study includes at present also France, the Federal Republic of Germany, the Netherlands, the United Kingdom and the non EC-countries Australia, Sweden, and the U.S.A. Based on a common conceptual framework (see Joerges and others, 1981) the research teams in these countries have completed, in a first phase, studies of national energy policies, their interrelations with consumer and environmental policies, and a broad range of central and local, governmental and non-governmental conservation programmes directed at private households (for a comparative overview see Joerges and others, 1983). In a second phase of this cooperative research programme, studies of comprehensive community-level conservation programmes and their impacts on consumer energy conservation behaviours are now under way in the countries mentioned.

The first phase Greek study (for a complete report see Zografos and others, 1983) attention was given particularly to conservation strategies based on solar technologies. Greece, the only Mediterranean country participating in the multi-national study, could take a lead in the European context regarding transition to a renewable energy economy, and the follow-up studies proposed should contribute to the formation of a social science network supportive of such developments.

METHODOLOGY

The basic model of consumer energy processes applied in the study integrates behavioural conditions and outcomes at the level of consuming households, and policy conditions and interventions at the level of various agencies enacting conservation programmes. Table 1 indicates the major dimensions (capitalised) used for the description of policies and programmes. Table 2 gives a comprehensive categorisation of conservation approaches and energy use areas, applied both to the description of programme objectives and effects. (Note that examples contained in this table were chosen to represent a variety of potential conservation actions in different countries and that the use areas of space heating, hot water and household appliances were given main emphasis.) Table 3 shows the categorisation of policy instruments used for the description of programme strategies, i.e. nine types of communicative, financial and regulatory measures in support of intended technical, behavioural and institutional change.

The agencies which initiated consumer energy conservation programmes in Greece were divided into four categories: central, regional and local government agencies; utility companies; consumer and environmental protection organisations; and private fuel companies. While the study was policy-oriented in the sense that it aimed at the identification of past policy effects and future potentials, we do not conceive of consumers as passively reacting to policy interventions. On the contrary, consumers and their local communities are seen as goal-directed and responsible actors, served more or less efficiently by programmes issuing from the policy system in their legitimate interests concerning the quality of their lives and their environments.

RESULTS

Application of this model in the examination of existing energy conservation policies and programmes in Greece produced the following results.

Programmes are distinctive in that none are community-based or community-initiated. The national government and several private and public corporations have made piecemeal efforts to influence petroleum-based patterns of energy consumption in residential and commercial buildings, and in transportation. Regulations concerning conservation lack comprehensiveness. To be sure, new buildings are expected to meet stringent thermal insulation criteria but the existing stock of housing is not covered by these regulations. The price mechanism is the sole incentive available at present to induce property owners, building managers, and homeowners to upgrade building energy efficiency. Local and regional authorities have lacked in the past the resources to implement and enforce energy conservation requirements.

The new administration seeks to decentralise the decision-making process and to encourage the active participation of citizens. Programmes already in place are essentially information campaigns aimed at the improvement of the technical efficiency of energy use as well as a modification of behavioural patterns of energy consumption.

Insofar as ongoing programmes concretely express the policy-orientations of a nation's government, a broad and diffusely defined public constitutes the target population of programmes described. No regional, community or other local mechanism is in place to implement energy conservation programmes at present. What is more, no documentation of programme costs, appraisals of programme effectiveness, or, for that matter, informal evaluations on the part of the agency officials were forthcoming in our contacts with programme staff. The consumer-orientation of national energy policy in Greece has been relatively weak in the past. The absence of mechanisms integrating consumer policies (see Simitis, 1981) and energy policies

PLE-X*

TABLE 1: PROCESSES OF CONSUMER ENERGY CONSERVATION

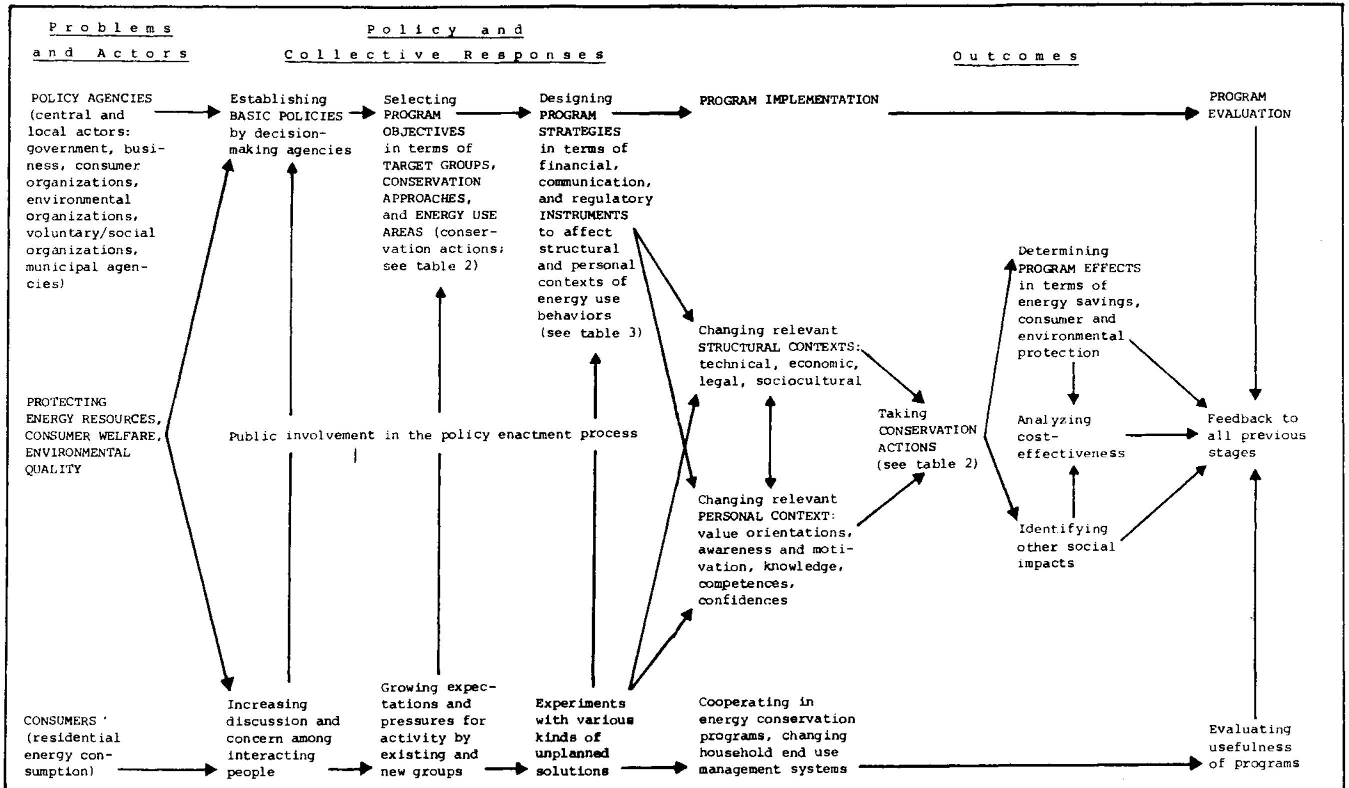


TABLE 2: TYPES OF CONSUMER ENERGY CONSERVATION ACTIONS (WITH ILLUSTRATIONS OF BOTH ONE-TIME AND REPEATED ACTIONS)

CONSERVATION APPROACHES	ENERGY USE AREAS			
	SPACE HEATING AND HOT WATER	HOUSEHOLD APPLIANCES	(TRANSPORTATION)	(CONSUMER PURCHASING)
EFFICIENCY IMPROVEMENT	Add insulation to the attic, walls, and floors. Have the heating system serviced regularly.	Insulate the hot water heater. Defrost the refrigerator/freezer regularly.	Buy a fuel-efficient car. Have the car tuned regularly.	Buy a small car. Repair broken appliances rather than buying new ones.
SOURCE SUBSTITUTION	Install a passive solar heating system. Use a wood stove for supplemental heating.	Install a solar hot water heater. Use a wood stove for cooking whenever it is lighted.	Buy a bicycle. Use gasahol as an automobile fuel.	Don't buy a clothes dryer, but dry with solar energy. Buy clothes made of cotton or wool rather than synthetic materials.
USE MODIFICATION	Install an automatic clock thermostat set at 20°C (day) and 13°C (night). Manually turn down the thermostat at night.	Lower the hot water heater temperature to 50°C. Turn off lights when not being used.	Organize a carpool for travelling to work. Ride public transportation to work.	Buy a microwave oven rather than a standard oven. Don't buy goods in plastic or aluminum containers.
LIFESTYLE ALTERATION	Live in multi-family rather than single-family housing. Close off one or more rooms during the winter.	Get rid of the TV set. Take showers rather than baths.	Move close to one's job location. Walk to work.	Live without a car. Share the use of household goods with neighbors.

TABLE 3: ENERGY CONSERVATION POLICY INSTRUMENTS

(TECHNICAL INSTRUMENTS)

COMMUNICATIVE INSTRUMENTS

1. INFORMATION: Informing people about the energy problem, their current energy use levels, how to reduce their energy consumption, and the effects of their conservation actions (feedback).
2. PERSUASION: Disseminating messages with strong psychological/emotional components, of either a positive or negative nature, to induce people to conserve energy or avoid wasting it.
3. PARTICIPATION: Exposing people to situations in which they will observe new activities, experience new expectations, and be influenced by others to organize collective conservation efforts.

FINANCIAL INSTRUMENTS

4. PRICING: Allowing energy prices to fluctuate in the marketplace according to supply and demand, on the assumption that energy use is relatively price elastic and will decline as prices rise.
5. TAXING: Imposing taxes on energy at some point from initial extraction to final end-use so as to raise energy costs above market levels or to discourage people from purchasing certain items.
6. INCENTIVES: Offering monetary or other benefits, such as grants, loans, tax credits, tax deductions, bonuses, or rebates to induce consumers to conserve energy or avoid wasting it.

REGULATORY INSTRUMENTS

7. STANDARDS: Setting, disseminating, and enforcing criteria for energy efficiency in the production and/or use of goods and services, including buildings, space conditioning, appliances and vehicles.
8. ALLOCATION: Controlling the distribution and/or consumption of energy through fuel allocation plans, restrictions on the use of energy-consuming equipment, or end-use quotas (rationing).
9. REORGANIZATION: On the community level, this involves using planning, zoning, and other legal techniques to alter building designs, land-use patterns, transportation systems, and overall patterns of life.

and programmes is parallelled by a pricing policy characterised by a pass-through of world market prices, inattention to income distribution measures, the total absence of programmes designed to offer assistance to disadvantaged target populations, e.g. the poor, the aged and physically handicapped, and inattention to the quality and efficiency of energy consuming appliances.

The programmes reviewed are noteworthy in another respect. Special advisers, offices and inter-organisational working groups for consumer/environmental aspects of energy policy and programming are conspicuously absent both with respect to a coordination of consumer policy and energy policy and to a coordination of environmental policy and energy policy. In general, national energy policy is strongly dominated by a supply-side orientation, while regional and local levels of government have in the past not had access to the arena of policy formulation. Similarly, while the need to attend to the environmental impacts of energy production and consumption is recognised, the overriding consideration in shaping Greece's energy policies has been, in the past, economic and industrial growth and development. The way the present administration manages trade-offs between industrial growth and environmental quality merits careful study.

CONCLUSIONS

Two themes currently inform Greek energy policy: utilisation of domestic and renewable energy sources, and diversification of energy sources and technologies including forms of imported energy and countries of origin. This policy emphasis is rooted in a determination to avoid economic and political dependency, to create jobs, and to limit the need for foreign currency. Energy conservation programmes targeted at the residential sector can summarily be characterised in the following terms:

- State-sponsored programmes as of 1981 were highly centralised, all initiated on the national level due to the dominant role of the national government in policy formulation. The current administration plans to offer economic and technical assistance to local governments for the purpose of fostering local and regional development programmes, including energy and environmental conservation.

- With the exception of the activities of the National Energy Council, all consumer oriented programmes in Greece focus on the provision of energy conservation information and moral exhortation. To date, none have been evaluated in terms of their effectiveness in achieving stated objectives.

- Legislative and regulatory initiatives have been directed at restraining energy consumption. However, efforts to ensure compliance have been weak and information systems required to facilitate implementation have not been established to date.

- Reductions in household energy consumption in Greece must be interpreted primarily as an effect of rising energy prices.

- Several non-governmental consumer and environmental protection organisations also have initiated energy conservation programmes. These seek to join energy conservation with environmental action and improvement in life quality. Consumer and environmental groups thus far have avoided conflict in articulating energy conservation strategies.

- While the general public has a relatively high awareness of the information campaigns sponsored by the National Energy Council (see Market

Research Center, 1980) there is a lack of systematic research specifying household effects of information campaigns in the domain of energy conservation behaviours.

Energy conservation measures taken by the previous administration were implemented without consultation of regional and local authorities, or citizens at large. Parenthetically, regulatory measures curtailing energy consumption in the commercial, industrial and transportation sectors also were unilateral in character and intended to augment the effects of price signals (see Chaikalis, 1982). The current administration, however, offers decentralisation of authority as an alternative to the process prevailing until 1982.

The implementation of new energy policies, particularly with regard to technologies based on renewable energy sources, warrants careful study, not only with respect to engineering and economic issues but particularly in view of organisational and behavioural aspects. As of now, the following can be stated with respect to solar penetration.

- Historical, climatic, institutional and economic factors facilitate the process of solar market penetration. Considerations of supply security and petroleum costs particularly encourage solar substitution. This is especially true with respect to the high costs of maintaining diesel systems on the islands. The dependence on residential electric hot water heating, furthermore, offers a substantial opportunity for near-term solar displacements of conventional fuels.

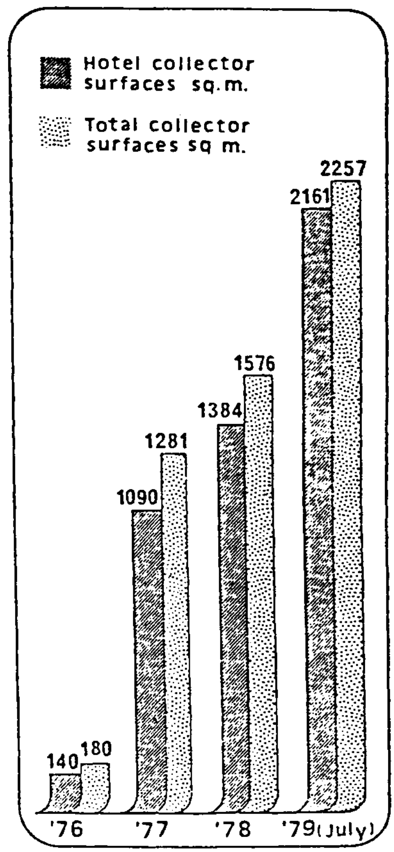
- Legislation stipulating targets for conservation as well as tax incentives for households and hotels have already encouraged social adoption (see Table 4). Also noteworthy is the historical experience with and the acceptance of wind systems, a factor considered conducive to the manufacture of appropriate technology. The public has begun to associate solar heaters with energy savings according to surveys conducted by the National Energy Council.

- Greece's entry into the EEC may contribute to spur the development of a solar industry both to offset the balance of trade deficits and to diversify the industrial base, in accordance with the strong position favouring the development of renewable energy sources articulated by the present administration.

- Solar advocates, however, must compete with other energy interest groups to secure public support, including proponents of off-shore oil development and of lignite and coal-fired plants. Furthermore, there is a high cost associated with central power systems based on solar energy (see Environmental Design Co., 1978). Given the competition for scarce resources, public and private investments in renewable energy has been relatively modest to date. The ability of the present government to mobilise more extensive resources for renewable energy poses a formidable challenge.

In overview, then, Greece currently lacks as yet a coherent, integrated set of consumer energy conservation programmes. With the exception of household and commercial solar, financial and regulatory incentives for conservation are virtually absent. Such programmes as do exist are devoid of systematic feedback in the form of evaluation studies. Their effects, both with respect to energy savings and to their impacts on consumer welfare and environmental quality, are therefore quite unknown.

TABLE 4



Source: Greek National Energy Council and Hellenic Industrial Development Bank, Major Solar Installations in Greece, n.d., Table VI.

RECOMMENDATIONS FOR FURTHER RESEARCH

Based on this first phase of research we have come to propose that further studies focus on the conditions facilitating the development of community-level conservation programmes. We suggest that this can be achieved by means of an empirical survey, in a selected city, of (1) "elite" (regional and local public policy makers in the fields of energy conservation, consumer and environmental protection) readiness to initiate programmes on behalf of community energy conservation, and (2) public support for programmes designed to achieve energy conservation goals.

On both levels, topics such as

- awareness and knowledge concerning such matters as information on solar tax credits, energy efficient equipment, requirements of electric heating systems, time-of-day pricing and the like;
- the readiness to initiate/participate/adopt energy conservation measures;
- form and impacts of educational campaigns on solar tax credits;
- perceived barriers and incentives

should be explored. At the same time, particular care should be taken to feed research results back into ongoing policy processes.

ACKNOWLEDGEMENT

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PASSIVE SOLAR RESIDENCES : PROTOTYPE EVALUATION AND IMPLICATIONS FOR CONSUMERS AND COMMUNITY PLANNERS

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ABSTRACT

Several examples of selected innovative residential designs and prototype construction are discussed. The designs use passive solar energy and feature considerable efficiency in material and energy consumption. Their evaluation by consumers, developers and others, as analysed by inter-disciplinary teams of researchers, are reviewed. For consumers and community planners, the relevance and usefulness of the diffusion-adoption theory and the role of communication in the processes of diffusion-adoption is suggested in achieving a wide acceptance of material and energy conscious innovative residential designs. These processes have been successfully used in commercial product marketing and in adoption of improved farming practices. It is suggested that changes in a family's energy consumption patterns may be influenced by numerous interrelated factors, including a perception of the need to change, the media by which the alternatives are communicated to the family, an evaluation of the available alternatives and or their economic feasibility, the complexity of the alternatives, the cost-benefit evaluation of alternatives, and other incentives to adopt a change or modification of its consumption pattern.

KEYWORDS

Passive solar residences; materials saving; value engineering; energy efficient solar design; diffusion-adoption theory; innovative residential design; community planner and innovative solar designs; livability and innovative designs.

INTRODUCTION

Primarily as a result of the high cost of oil since the early 1970s, alternative sources of energy have received attention from both the public and private sectors in countries all over the world. As residential heating and cooling had primarily been achieved, especially in the industrially advanced countries, with the use of fossil fuels, research efforts have been directed at investigating the practical application of solar energy for heating and cooling of residential buildings.

Many innovative designs have been developed by innumerable individuals and organizations. This paper maintains that the adoption of innovations is a complex process, which takes place in stages, and communication of the innovations plays an important role in the diffusion-adoption process. Unless the innovations are widely accepted and are affordable, the desired results may not be achieved fully. This paper examines the theory of diffusion-adoption and suggests its possible application in promoting the innovative solar residential designs. In this context, some selected designs are reviewed, along with a discussion of their evaluation by professionals and interested public and the efforts at dissemination of information about these designs. Further research in the application of the theory is needed to make the innovative designs more widely accepted. Sets of variables and possible indicators are suggested, which may be useful in directing the formulation of hypothesized relationships.

BACKGROUND OF SELECTED DESIGNS

Several innovative designs were developed by members of two Regional Housing Research Projects between 1973 and 1983. The Projects were funded primarily by the U.S. Department of Agriculture (USDA) through the Land grant universities (Agricultural Experiment Station), the Rural Housing Research Unit of USDA and by other Federal Agencies such as the Tennessee Valley Authority and the Appalachian Regional Commission. Scientists from twelve State universities in eleven Southern states of the USA (Alabama, Arkansas, Florida, Georgia, Maryland, North Carolina, South Carolina, Oklahoma, Tennessee, Texas, and Virginia), representing a variety of disciplines, participated in the Projects by forming interdisciplinary research teams in areas of common interest to accomplish the project objectives. Work is currently going on under the second Regional Project which runs from 1979 to 1984.

Research efforts by the authors of this paper were carried out under various objectives of the two Regional Projects. These efforts included the work by Newman and Hurst on providing innovative designs and assistance in the construction of prototype housing systems and subsystems aimed at achieving material and energy savings, the acceptability and economic feasibility of these designs, and Durrani's participation in developing procedures and questionnaires for an evaluation of these prototypes by consumers, builders, financiers, regulators and others. Other interdisciplinary teams have studied the societal and family constraints to the adoption of these innovations and alternatives, family decision making processes, and consumer acceptance of these designs. The delivery systems for producing, marketing and financing were also analyzed by interdisciplinary teams to maximize accessibility of quality housing. The Projects also aimed at developing effective methods of disseminating housing research information to consumers and key decision-makers in the area of housing.

Some selected work carried out by Newman and his colleagues at the Rural Housing Research Unit concerning the use of passive solar energy in residential designs, and the prototypes built in various localities are reviewed in this paper. The research and the prototype construction carried out by Hurst, including the two award winning designs entered in the National competitions sponsored by the US Department of HUD in 1980 and 1981, are also included in this review. The evaluations of various aspects of design, and the energy and material savings were analysed by interdisciplinary teams of scientists from the Regional Research Project. These evaluations are discussed here with the objective of relating them to the concepts of information dissemination to the consumers, producers and other decision makers involved in the adoption of innovative designs.

DIFFUSION-ADOPTION THEORY

We suggest that the diffusion-adoption theory developed by Rogers (1962) has a much greater relevance than is being realized to the adoption of innovative residential designs and technology aimed at achieving materials and energy efficiency.

According to Rogers:

> An innovation is an idea perceived as new by the individual. Diffusion is the process by which an innovation spreads. The diffusion process is the spread of a new idea from its source of invention or creation to its ultimate users or adopters... Adoption is a decision to continue full use of an innovation. The adoption process is the mental process through which an individual passes from first hearing about an innovation to final adoption.

In another study, Rogers and Agarwala-Rogers (1976) stress that in diffusion-oriented research the "future research must be designed so as to probe the time ordered linkages among independent and dependent variables. One shot studies can't tell us much about this." It would be imperative, therefore, to not only consider the linkages among the numerous variables but also to bear in mind that the process of adoption takes place in stages. There are other theoretical models in the substantive areas of communications, the structure and function of social system, organization structure and behavior, and community development that may be employed in promoting the adoption of the innovations. Earlier investigations (Ryan and Gross, 1943; Ryan, 1948; Wilkening, 1953, 1956; Hovland, Janis and Kelly, 1953; Beal and Rogers, 1957; March and Simon, 1959; Hassinger, 1959; Rogers and Svenning, 1969; Rogers and Shoemaker, 1971; Solo and Rogers (editors), 1972; Applbaum and Anatole, 1974; Bingham, 1976; and Rothman, Erlich, and Teresa, 1976 provide us with the examples of work relevant to these models and with examples of the diffusion-adoption processes.

Of particular interest to us are the studies concerning the introduction and adoption of innovative farm practices and the role of communications in this respect. Retrofitting the existing structures with solar heating systems in smaller towns, suburbs, and rural communities will probably be easier and economically more advantageous than in the densely populated, multifamily dwellings of urban areas. It has been claimed that the cost of incorporating a material and energy efficient design in new housing is less and it is more feasible there than in existing housing. The new housing, however, represents only a small share of the existing stock, and retrofitting would constitute a major portion in the process of adopting innovative technology in utilizing passive solar energy. Passive solar housing designs are, however, already being well publicized and they are easy to incorporate in the design of a new house. That is an advantage the new housing has over the existing housing.

The relevance of diffusion-adoption theory to the consumers and community planners may be illustrated by an example from the transportation field. In developing his model of travel mode switching behavior, Hartgen (1974) referred to the diffusion-adoption process and stated its "usefulness in understanding the process by which new products or new ideas (termed 'innovations') are adopted by the different individuals over time and thus diffuse (spatially and temporally) through various segments of population... As the number of persons adopting a new brand increases, its use is said to diffuse through the population, reaching some maximum level... The diffusion of a new brand of a product, then, reflects the sum of individual decisions about adopting it."

Hartgen (1974) further stated that the "product adoption is not an instantaneous event but a process," and it takes place through a series of stages. These stages, according to him, had been identified earlier by Wilkening (1953), Rogers (1962) and others, and may be described as being those of : 1) awareness, 2) interest, 3) pre-trial evaluation, 4) product try-out, 5) re-evaluation, and 6) adoption or rejection.

The rate of diffusion, according to Hartgen (1974), is determined by three general factors: a) the characteristics of the consumers, particularly their disposition to use the innovation; b) situational variables within which the consumer and the product co-exist (including the economic constraints); and c) the attributes of the product itself (including its relative social or economic advantage, its compatibility, complexity, and trialability). Certain attributes of the product such as the cost, complexity, compatibility, and triability would be especially important in the case of the solar systems/sub-systems as well as any other design related innovations. Their cost in terms of trialability, for example, would certainly be extremely high compared to a consumer product such as a new brand of tooth paste.

SELECTED DESIGNS AND DIFFUSION-ADOPTION PROCESSES

The RHRU's early efforts were directed mostly at the development of low-cost solar heating and cooling systems for low income rural family housing. The major concern was to make available a system that was affordable, easy to construct, install, operate and maintain, and that it was energy efficient. The prototypes designed and built for the purpose were, therefore, more concerned with the savings in materials and emphasized efficiency. They were almost custom instrumented and monitored for these purposes. These efforts saw the first solar attic, rock storage system houses designed, built, and tested in 1975 (Zornig, Godbey, and Bond, 1976; Zornig, Godbey, and Simmons, 1977). The houses were built at locations in Greenville and Clemson, South Carolina and included experiments with retrofitting. Considerable savings and greater efficiency in energy use were reported. Performance on these accounts were analyzed before and after occupancy.

The RHRU's next step was to combine the benefits of earth-insulation with solar heating. A prototype was built (Newman, 1979) at Clemson, S.C. and temperatures and energy consumption were monitored. The design included a panelized, "all weather", pressure-treated wood foundation which could be built locally or on site. Tests reported reduction in heat loss by upto 60%,and over 50% in the total energy bills. Another similar house was built in Versailles, Missouri with three additional heat sources (electricity, heat pump, and wood stove) to supplement the solar energy. The additional sources were monitored separately to test their performance in combination with solar heating. Certain problems relative to calibration with solar energy supply and control over wood stove output, and heat losses were reported (Simmons, Newman, and Harrison, undated, circa 1980). The authors also stated that "significant progress has been made toward overcoming the sociological and psychological deterrents to living below grade" in the designs developed by RHRU. The results of these experiments were reported upon by the research team members extensively during 1981 covering various aspects of design such as the wood foundation, light distirbution temperature comparisons, and data acquisition and reduction by micro-computer.

Further analyses of the many other earth sheltered, solar heated prototypes, and improvements in design and monitoring equipment were reported upon in 1982 (Newman, April 1982, June 1982; Godbey and Davis, 1982). These integrated solar systems were found to be effective and economical (costing about one-tenth of the more popular solar collectors); were usable in both new housing and as retrofit on existing houses; were safe, comfortable, dry and well lighted. The designs with a greenhouse also were found to be comfortable for both plants and the residents.

Several studies on the response from the consumers, builders, financiers, manufacturers and others have been conducted (since 1979) concerning a number of the prototypes developed and built with the assistance of RHRU or other scientists from the Regional Project. Stewart, McKown and Newman (1981) reported on the results of the surveys, conducted on three "open house" weekends, concerning a second generation earth sheltered house at Clemson, S.C. A number of important responses were received. The house was fairly close to their expectations; they were concerned about the energy problems, and seeing the solar water and space heating features they were convinced of the potential savings on this account. They were optimistic about their ability to obtain financing to build a similar house. Some who were not confident of obtaining such financing perhaps reflected their concerns about the "marketability, appraisal, and zoning issues", according to the authors. A substantial number of the visitors thought that a house of similar design would be acceptable in their own community. They were satisfied with such factors as sufficient natural light and privacy. Suggested design changes generally related to the size or plans of spaces (bed rooms, living rooms, entrance/exit, additional fireplace, etc.) which can be easily modified.

Consumer attitudes toward the solar green house combination and earth sheltered houses at Clemson were also studied by Bell (1979). Several other studies concerning the house plans and livability of these or similar house forms and alternatives have been proposed by students who are candidates for their Master's or Ph.D. degrees at universities participating in the Regional Research Project.

The two national award winning designs, the Hillside Fourplex and the Solar Pole-type, Tilt-Up Duplex, are the result of over two decades of research and development carried out by Hurst. The U.S. Dept. of HUD conducted energy efficient housing design contests in 1980 and 1981 under its program called, "Building Value into Housing". The program emphasized value in engineering and livability. Out of the approximately four hundred proposals received, twenty-nine were selected for design awards, most of which also won construction awards. Hurst's designs won both awards. They use passive solar energy and are material and energy efficient. Both designs eliminate considerable amounts of unnecessary lumber (up to 2/3rd framing in the Duplex and 1/2 in the Fourplex), and the energy supply of up to 40% or more is from the solar systems. These savings show up in reducing the total costs of construction and operation and thus make the houses more affordable.

The Fourplex has been built in Blacksburg, Virginia and is occupied. Visitors to the house, on two weekends in August 1982 were surveyed during an "open house" to seek their response to the Fourplex. The results are not available at the time of this writing. The Duplex is expected to be constructed in the near future. Being part of HUD's national housing demonstration program, a large number of builders, materials manufacturers, developers, financing institutions, and researchers are currently taking part in a number of research and performance evaluation activities on the Fourplex house.

All these designs have been presented and disseminated widely by a variety of communications media. These have included presentations at national, international, regional, and local conferences, regional workshops, writing in professional and popular publications (including those by the USDA's Experiment Stations, Cooperative Extension Services of the participating Land grant universities), newspapers, audio-visual presentations, holding "open houses" to demonstrate the functioning houses or their subsystems, and by providing technical assistance/consultation to builders using the prototype designs. As pointed out by Stewart, McKown and Newman (1981), concerning the earth sheltered prototype, building a greater number of houses with innovative designs would increase the exposure to these alternatives and help overcoming the "negative stereotypes held by those who have never experienced an earth sheltered house".

APPLICATION OF DIFFUSION-ADOPTION PROCESSES

Following **Hartgen's**(1974) analogy between the product adoption process in consumer behavior and an individual traveller's choice regarding the mode of his travel, it is submitted that a similar approach could be taken in analysing changes in the form and pattern of residential energy consumption and the processes a consumer would go through in the adoption of the innovative designs/technology.

Stated briefly, it is suggested that a family is part of a community. The family is also located within the geographic, social, and economic boundaries of a community, and lives in a dwelling whose characteristics are determined by the socio-economic status of the family. The energy consumption pattern of the family is influenced by the type of dwelling and the family's socio-economic status and demographic composition. Any modification or change in the energy consumption pattern of the family may be influenced by numerous interrelated factors, including factors such as the perception of the need to change, interest, communication of the alternatives, an evaluation of the alternatives available or feasible in terms of economic, social, psychological or other costs, the complexity of the alternatives and their cost-benefit evaluation, the availability of personal and or outside sources of financing, and adopting a satisfactory alternative which would result in meeting the need for modification in the consumption pattern of the family.

Bearing in mind the preceding brief statement, one may formulate a number of hypothesized relationships between numerous variables or sets of variables, viewed as independent, intervening, or dependent variables, and design studies to test these hypotheses. The variables suggested for this purpose, divided into two sets of assumedly interrelated variables, are as follows:

A. First Set of Major Variables

I. Independent variable : i) community typology (urban/rural) and size. II) Intervening variables (family characteristics) : i) socioeconomic status, ii) stage in the family life cycle, iii) ownership status, iv) housing aspirations and expectations. III) Dependent variables (physical/structural residential factors) : i) type of dwelling unit, ii) dwelling characteristics, iii) type of development (planned or unplanned), iv) family's energy consumption pattern (changes or modifications are sought in this variable).

B. Second Set of Major Variables

I. Independent variables : i) alternative energy sources, ii) conservation alternatives, iii) evaluation of alternatives -- complexity of alternatives, iv) evaluation of alternatives -- cost-benefit of alternatives. II) Intervening variables : i) communicative techniques -- individual-oriented, ii) communicative techniques -- community-and-organization-oriented, iii) financial support alternatives -- personal sources, iv) financial support alternatives -- outside sources (government/private organizations), v) acceptance (adoption)/rejection of alternative(s). III) Dependent variables : i) (change-in) energy consumption pattern, ii) observable impact on life style (changes).

Some of the indicators of the preceding variables may include the following examples.

A. I. Independent variable : i) community typology: selected size as rural or urban (e.g. less than 15,000 as rural; 15,000 to less than 50,000 as urban; and over 50,000 as metropolitan or major urban). II) Intervening variables (family characteristics) : i) socio-economic status: scores on education, income, and occupation, or occupation and education only, ii) family life cycle: stages in the family life cycle (based on combinations of age and or marital status of adults, and presence/ absence of children at home, their age and marital status.), iii) ownership status : owner, renter, others, iv) housing aspirations and expectations : indexes of aspiration, commitment to achieve goals and expectations, including elements relative to needs, current savings, possible additional financial sources, savings from home-grown food or other income supplement, income or occupation, and financial equivalent of "sweat equity" in meeting housing goals. III) Dependent variables : i) type of dwelling unit: single-family detached, multiple family structure, duplex, or other types, ii) dwelling characteristics: construction material; current condition or quality, iii) type of development: (location of residence) in unplanned community, (location in) planned community or subdivision (variations of planning concepts); existence of underground or above ground utilities and services, iv) energy consumption patterns: heating/cooling sources; insulation type, quantity and rating; house plan efficiency rating (e.g. in terms of BTU (British Thermal Unit) used per person, BTU consumed per sub-area unit of house, square feet per person to be heated/cooled; average energy units per person consumed over a fixed period of time; proportion of family budget allocated toward energy costs; ability to pay (constraints).

B. I. Independent variables : i) alternative energy sources: solar, geothermal, wind, others, ii) conservation alternatives: increasing structural efficiency through insulation, repair, rehabilitation, etc.; improving design of existing heating/cooling systems for greater efficiency; new systems, designs, techniques; general conservation measures; new energy-efficient homes in or outside the conservation oriented subdivisions, iii) and iv) evaluation of alternatives: complexity and number of special devices needed, their manufacturing and off-the-shelf availability (convenience factor); delivery system; need and availability of specialized labor to implement the alternative to be adopted. II) Intervening variables : i) and ii) communication effectiveness through analysis of changes in the knowledge, attitude, and overt behavior of individuals, organizations and communities; various communication models and techniques; organizational structures and behavior; complexity of information and level of competency of intended receiver of the information, iii) and iv) financial support alternatives: sources and variety of financial support; variable costs; other methods of providing financial assistance as incentives to adoption of an alternative energy form, v) acceptance or rejection of alternative(s): quantitative indicators of actual adoption of various alternatives. III) Dependent variables : i) consumption pattern: quantitative indicators of variations in consumption, ii) impact on life style: indicators of impact on budget and life style.

CONCLUSIONS

Housing presents a complex interplay of producers, financiers, regulatory officials, and consumers. Housing is one of the most expensive investments a family makes in its life time. It is often associated with strong, though intangible at times, socio-psychological considerations. Most structures also have a long life span. Any design improvements or technological innovations in a housing system or subsystem, requiring substantial additional expense on part of the home owner, are likely to receive a careful cost benefit analysis by the consumer and the financing institution. A house is also location bound and, therefore, its physical characteristics are influenced by its locational attributes. Acceptance and marketability of a house within these locational constraints are important factors for the home owner. The adoption of innovative designs, technological improvements, the availability of technology related to these designs,and use of solar energy as an alternative source, are influenced by the media as part of the diffusion process. Greater awareness of the alternative forms of housing and sources of energy, and a demonstration of the efficiency in the consumption of materials and energy help in promoting the adoption of innovations. The interrelationships among various factors which may help in developing further research designs in the diffusion-adoption processes are suggested. The results of these studies could help community planners and promoters of solar technology and innovative residential designs in providing a better understanding and application of the diffusion-adoption processes.

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PASSIVE COOLING TECHNIQUES FOR THE ARCHITECT IN BARODA, INDIA

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ABSTRACT

This paper describes the design implications of passive cooling techniques for Baroda, India, whose climate is characterized by alternating hot dry and hot humid seasons. Comfort requirements and site specific climatic conditions are used to identify the areas in which passive cooling is required. Various Passive Cooling techniques are examined in light of their basic scientific principles and their applicability is evaluated. The paper also deals with the management aspect of communication and information transfer of passive cooling techniques to the architect in Baroda.

KEYWORDS

Human comfort; passive cooling techniques; passive cooling information transfer; hot-humid climate design.

INTRODUCTION

Urbanization, a result of rapid industrialization in India, has been accompanied by blind replacement of traditional housing with new western models. Today, the high energy costs and power cuts in industrial areas make it imperative for the architect in Baroda to understand Passive Cooling and re-examine the current trend of energy intensive, concrete and glass houses. Traditional housing, though climate sensitive, is not directly usable as it is rural based, with low initial cost, but high maintenance and restricted to local materials. But there is a wealth of information in traditional design and the architect should study it to understand the underlying passive cooling principles and use these techniques within the existing social framework and incorporate the materials and technology of today.

The aim of "Passive" design is to develop a house in which the inhabitant is "comfortable" without additional energy intensive heating or cooling devices. The first step in this design process is to understand what environmental conditions are required for the inhabitant to be comfortable (Human Comfort). The next step is to study the existing site environment (Climatic and Site Constraints) and identify the conflicts of external conditions with human comfort needs. The third step is to examine how Passive Cooling Techniques can resolve these conflicts.

HUMAN COMFORT

Comfort is both tough to quantify and a very individual matter, as subjective as it is objective. Comfort for an individual is affected by various factors, including the physical environment (dry-bulb temperature, relative humidity, mean radiant temperature, air movement, etc.), acoustic environment, physical factors (level of activity, clothing, age, body shape, diet, skin colour, etc.) and psychological factors (decor, colour and personal expectation).

In the context of Baroda, thermal comfort is the most critical. An overview of the thermal process in the human body explains how radiant heat, air temperature, air movement and humidity affect thermal comfort. All human processes convert food to energy with heat as a by-product. But since the human body temperature must remain relatively constant at 98.6°F, in a warm environment this excess heat must be dissipated. Heat can be lost by conduction, convection, radiation, or evaporation. Conduction is possible if the body is in contact with an object cooler than itself. Convection is possible when the air temperature is cooler than the body surface temperature. Radiation occurs when the average temperature of the surroundings is lower than the body surface temperature. But with high ambient temperatures in Baroda, little heat can be lost through any of the above ways, so the only mode of heat loss is evaporation. Evaporation is the process of absorption of moisture by the air accompanied by a drop in temperature. The rate of evaporation is affected by amount of air movement and relative humidity. For air with low relative humidity, the evaporation process is as follows: The air in contact with the skin absorbs humidity from the skin, becomes heavier, and this heavier air tends to descend and is replaced by dry air at the skin surface. This cyclic process is quite rapid and provides enough evaporation for comfort. However, if the relative

Figure 1 Bioclimatic Chart - Olgay

humidity is high, the air is only able to absorb small quantities of moisture from the skin and this small increase in moisture is not enough to make the air descend. This air forms an envelope, about 2 cm. thick over the skin, and this prevents further evaporation. To allow further evaporation this envelope must be removed by movement of the surrounding air and replaced by fresh air. The only way to remove excess body heat in hot, humid conditions is by high air movement. It is to be noted that the emphasis is more on the "quantity" of air movement. The reason for this is that even in a hot, humid room without significant air change, evaporation can take place if air movement occurs.

Based on numerous studies, "Psychometric charts" have been developed to correlate air temperature, relative humidity, air movement and radiant heat. However, most of these are based on western "ideals" of comfort and in absolute terms are not applicable to Baroda, where acclimatization and long term adaptation (generations of existence in similar climate) have led to people being comfortable at higher temperature and humidity levels. These charts also often overemphasize the adverse effect of high humidity and underemphasize the significance of moderate air movement. But some charts, like Olgay's as shown in Figure 1, try to account for these extreme climates. Olgay's chart helps identify the trend of correlations between the climate variables, and emphasizes that at sites like Baroda, with high dry-bulb temperature and high relative humidity, the only mode of achieving comfort is through air movement.

CLIMATIC AND SITE CONSTRAINTS

Baroda: Latitude 23°N Longitude 73°E
Height above MSL 34m
Climate: Composite - described below:

	Max. Temp (°C)	Min. Temp (°C)	Avg. Range (°C)	R.H. (%)	Wind Dir.	Calm (%)
Summer	41	27	12	47	SW-NW	23
Monsoon	34	27	6	81	SW-W	12
Winter	30	12	10	52	N-NE	54

The hot, dry summer months usually have a strong, cool wind from the southwest (especially strong in the evenings) and people in Baroda tend to sleep out in the open at night to exploit this wind. As is obvious from this chart above, the monsoon period is the toughest to design for, but fortunately the winds are strongest at this time and there are few calm days. Due to the high humidity and temperature, cooling is only possible through air movement.

Site: Individual site constraints are discussed later in the paper under "Site and Shape Criteria". In general, Baroda is highly industrialized, causing higher ambient temperatures during the day and also potential pollution problems. Industrialization has also meant energy shortages (electricity power cuts) and restricted water during summer. Increased housing shortages has caused a spurt of highrise complexes, and as there are minimal zoning laws, any adjacent vacant site could be so developed leading to a complete change in microclimate.

PASSIVE COOLING TECHNIQUES

In view of the Human Comfort Criteria and Site and Climatic Constraints, the major problem is cooling during the hot, humid period. The solution to this is: 1) Minimize the heat build-up inside the house, and 2) Maximize air movement. This section will try to explain the basic principles of conventional passive cooling techniques and evaluate their efficacy in light of the two criteria mentioned above.

Ventilation is the most effective cooling technique for hot, humid climates. An accompanying paper in this conference by the same authors deals at length with the role of ventilation in hot, humid climates (Ref. 1).

Landscaping, Daylighting, and Sunshading are all important aspects of passive cooling. These are explained and evaluated in an accompanying paper (Ref. 1) in this conference.

Insulation is a technique useful for climates with large diurnal ranges. The house is well insulated so that the heat doesn't enter it in the day nor the cold at night. For this technique to work effectively, the average temperature (over day and night) must be comfortable. Also, good insulation requires little or no openings to minimize heat exchange. But the average temperature in Baroda is not comfortable and large openings are required for ventilation, so insulation in general is not appropriate for Baroda. However, roof insulation (as in a double roof) is good as it helps minimize heat buildup in the house during the day. This is discussed in the section on "Roofs and Stilts" in Ref. 1.

Thermal mass, like insulation, is a technique useful for climates with large diurnal ranges. An example of this is thick adobe walls which absorb heat during the day (in the process protecting the house) and radiate the heat inward at night. This is effective in desert climates where the heat of the day can be used in the cold nights, but for the small diural range in the monsoon period in Baroda, this technique is ineffective.

Site and Shape Criteria. Climatic data is available for Baroda in general, but the actual wind and solar insolation will depend on the specific site and its surroundings. When designing for ventilation, the wind and shading characteristics of the actual site should be used. To minimize heat gain, the building surface area should be small, i.e., a low surface to volume ratio, resulting in a dense building. But for ventilation, the building should be shallow and porous to allow wind to pass through, and as ventilation is more important, this governs. A thin building running east-west is optimal as it has small walls on the sides which receive maximum insolation (east and west), it is shallow in the general wind direction and during critical monsoon months has inclined winds (leading to maximum air movement (Ref. 1)).

Room Orientation and Location should be based on the function, activity level, and time of utilization of the room. Commonly used areas should be the best ventilated while functionally less important rooms like the garage, baths, and store room can have poorer ventilation and may be placed on the west side (as the west gets maximum heat). Areas used in the evening and night like the living room and bedroom should be on the south side, as this side receives least heat during the day (hence being coolest in the evening), and also has maximum ventilation (since the wind is from the south and is usually strong in the evening). To miminize heat gain in the house, major heat sources like the kitchen should be isolated (insulation wise) from the house. This can be done by cavity walls. The kitchen should have windows designed for constant ventilation and vents for heat from the stoves. A small shaded verandah (or balcony) adjacent to the kitchen also helps as it provides a cool exterior space to perform household related chores like cutting vegetables.

Ceiling Fans are not a "passive" technique, but they are a dependable, economical and effective cooling strategy for hot humid climates. As explained earlier, physiological cooling occurs due to air movement and hence electric ceiling fans which cause large amounts of local air movement within a room are very effective at cooling. Currently in Baroda, architects tend to use one large (40") ceiling fan per major room. For maximum efficiency, a 40" fan requires at least 30" of air space above it, but with today's low ceilings this is not possible and so these large fans should be replaced by more numerous smaller ceiling fans. Portable table fans can be used for additional local cooling. Ceiling fans are especially effective in summer as they cause cooling through local air movement without introducing hot air from outside. They also provide an inexpensive backup cooling system for calm days.

Courtyards are an essential component of traditional housing in the hot humid areas of Latin America, Asia and the Mediterranian. Courtyards (sometimes superposed with vegetation) provide a cool zone for the house throughout the day. The principle behind them is as follows: At night the cool atmospheric air descends into the courtyard replacing the warm air present there. In the daytime, the sun heats up the top layers of air, but the lower layers of air are unaffected and these provide "coolth" all day long. The process of heating up the top layers can be minimized by keeping the courtyard small in the east-west direction.

Earth Cooling and underground housing is the latest fad in the western world. This technique is based on the fact that the earth is cooler below ground level, and so a house located there will be cool and comfortable. But there are many arguments against using this strategy in Baroda. Due to the high relative humidity in Baroda, condensation would occur on the walls and floor. Excavation costs are high and due to lack of good waterproofing, there would be seepage during the monsoons. As explained earlier, ventilation is essential in Baroda, but earth cooling greatly restricts ventilation. Also, current social values in Baroda would not accept the concept of "windowless" mud houses. A more plausible application of Earth cooling on a smaller scale is berming. Partial berming of west walls would decrease heat buildup in the evening, and use of vegetation (grass or creepers) on these berms would aid heat dissipation. Berms are quite economical, as exterior walls are masonry and so can support the lateral load of berms. However, berms may cause seepage in the monsoons and hamper ventilation.

Water Cooling through evaporation is an excellent cooling media in hot, arid conditions, but is inappropriate in humid climates. In contrast, water as thermal mass (in the form of roof ponds) is growing in popularity as a passive cooling technique in the USA. The underlying principle is that the water is covered with insulation during the day (and so provides "coolth" to the roof all day) and at night it is uncovered to lose heat through radiation to the night sky. But in Baroda, the night sky is often cloudy and this adversely affects heat loss from the roof ponds. Roof ponds for evaporative cooling are useful in summer months, but for effective cooling the water should be less than 2 inches, so that the point of evaporation is close to the point of maximum heating (the roof). Other problems with roof pond are the increased dead load on the roof, breeding of mosquitoes, leakage and lack of water during the summer months. Also, roofs are used extensively for drying clothes, curing food and for sleeping on in summer. However, localized water cooling in summer is very effective. This is done by using damp, porous straw mats ("Khus-thati") over windows. These mats are dampened every few hours and the moist mats filter and cool the hot dusty summer winds as they enter the house. Also available are electric "water coolers" which are economical, consume little energy and are very effective for windless summer days.

No single passive cooling technique is sufficient, but after understanding these techniques, evaluating their effectiveness, cost-benefit ratio and practicality, it is possible to develop a hybrid Passive Cooling design for a comfortable and low energy intensive house in Baroda.

COMMUNICATION AND INFORMATION TRANSFER

The energy crisis has led to widespread awareness of passive cooling techniques in the West, but knowledge of these techniques is less prevalent in India. It would be ideal to educate everyone about passive cooling, but for practical purposes, it is important to first reach the architect as he is in overall charge of design and construction. To reach the architect, one should use both direct means as well as existing institutions. For Baroda in particular, the architect can be contacted in person through the IAA (Indian Architects Association) or through municipal records (as all practicing architects have to be registered and licensed by the municipality). Baroda also has two architecture schools with a tremendous resource of faculty and libraries. In addition, Baroda is a leader in energy related industries such as solar heaters and cookers, wind energy conversion systems, insulation, etc.

An optimum way to get all these agencies to interact would be to organize a passive cooling conference. It should be jointly sponsored by the IAA, the architecture schools and funded by the industries. The architects can be individually invited by obtaining addresses from the municipality (or the IAA). To get constructive participation at the conference, it would be useful to preinform the architect about passive cooling. This could be done by sending each architect a short paper explaining basic passive cooling techniques and their efficacy for Baroda. The conference could be highlighted by inviting a few guest speakers such as well known architects from Bombay and Delhi, energy and low cost housing consultants, and editors of architectural journals.

The actual conference itself should be divided into two sessions. The first would be lectures by the architectural school faculty on applicable passive cooling like ventilation, sunshading, etc. It would include discussion on the usefulness and practicality of these techniques. The second session would be a series of group discussions chaired by the guest speakers and would emphasize on what can be done with passive cooling.

After the conference, the architects will need sources of information to further study these techniques. The resources for this are the two architecture school libraries, the research units in industry and the Architectural Association. However, to access this information, an extensive cross reference index needs to be developed. This could be done by the faculty at the architecture schools through student projects.

The next step is an industry sponsored design competition for a passively cooled house. This would both give the local architects an impetus to develop passive designs as well as generate publicity about passive cooling. Most industries in Baroda have some housing for their employees, and the industry sponsoring the design competition can actually construct the winning entry and this would help evaluate the cost effectiveness of passive design. A similar competition could also be sponsored for students.

The publicity generated by the conference and the competition will also focus the attention of faculty in the architecture schools on passive cooling and could lead to formal courses for students in this field.

CONCLUSION

The authors had circulated a previous version of this paper to leading industrialists in Baroda. Based on this paper, Jyoti Consultants, a firm involved in development and manufacture of energy related products (such as solar cookers, solar heaters, wind energy conversion systems and energy plantations) sponsored a conference at Baroda in December, 1981. Prior to the conference, Jyoti Consultants sent the invited architects three papers (including a 40 page paper by the authors on Passive Cooling for Baroda). The conference was well attended and resulted in some exciting plans (far beyond the authors' expectations). The architects spontaneously formed teams to look into various aspects of passive cooling including developing programs for students, literature surveys and reviews, publicity and developing a simple pamphlet explaining passive cooling for the homeowner. One team was set up to examine ten "comfortable" and ten "uncomfortable" existing houses and see how they support passive cooling theories. In retrospect, Passive Cooling techniques have reached the architect in Baroda today, and hopefully should lead to a new generation of low energy-intensive, comfortable houses in Baroda.

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PASSIVE SOLAR DESIGN PRINCIPLES IN MASS HOUSING IN AUSTRALIA

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ABSTRACT

The Australian continent encompasses a wide range of climatic regions. Early houses showed a degree of climate sensitivity, but more recent ones place greater reliance on mechanical systems for heating and cooling, with inevitable consequences for energy use.

The principles of correct orientation, glazing, shading, insulation and thermal mass are well understood by many Australian researchers and architects. The Government is helping to promote these principles through pilot projects and information services. There are no technical barriers to adopting them in mass housing if they can be promoted effectively to the housing industry and its customers.

KEYWORDS

Passive solar house design; low energy house design; mass housing; project housing; Australia.

INTRODUCTION

The continent of Australia encompasses several climatic regions, from tropical to cool temperate as shown in Fig. 1. Most of the population lives in urban areas, with over 63% of it concentrated in the metropolitan areas of the six state capitals and Canberra, the Federal capital. Some indication of the age, size and climate of these cities is given in Table 1.

The six state capitals were all capitals of independent colonies until Federation into the Commonwealth of Australia in 1901. Each developed its own building style which grew out of local climate, materials and topography, and the building fashions imported by its settlers. There were no local precedents for the early builders to draw on. The indigenous aboriginal population lived nomadically and built only temporary shelters of bark, or used caves when available. The early housing forms of the settlers were those of Georgian England adapted as the needs and meagre resources of the colonies allowed.

Table 1 Australian Capital Cities

	Year Settled	Population at June 1981 ('000)[1]	Annual degree - days to base 15^oC [2]
Sydney	1788	3281	215
Melbourne	1835	2804	693
Brisbane	1824	1087	41
Adelaide	1836	953	437
Perth	1829	918	198
Hobart	1803	171	1167
Canberra	1911	246	1421
Total Metropolitan Population		9 460	
Total Population, Australia		14 927	

1. Australian Bureau of Statistics, Australian Demographic Statistics Quarterly, September, 1982
2. Walsh, P.J. and Spencer, J.W. Heating Degree Days for Australian Localities, CSIRO Australia, 1980

These styles were soon found to be uncomfortably hot in the long Australian summers, except in Tasmania with its relatively cool climate. Summer comfort became the dominant design requirement, and houses developed verandahs, shaded windows, and massive walls. They had to be heated to remain comfortable in winter, to the extent that open fireplaces allowed. Another adaptation was the elevated northern bungalow of timber frame construction. Some of the typical colonial and modern housing styles are illustrated in Fig. 2.

Climatic adaptation has decreased rather than developed in the twentieth century. The integration of the state economies has led to a degree of national standardisation in housing tastes and forms. Great variations in local climate have been countered by increasingly costly and energy-intensive heating and cooling systems. Yet relatively simple design measures could increase comfort and reduce energy requirements all year round in most of Australia.

DOMESTIC ENERGY USE

Some 8.6% of primary energy used in Australia in 1980-81 was in the residential sector. This sector used about 12% of delivered energy, with extensive use of electricity and other derived fuels. By comparison, nearly 38% of delivered energy was used in industry, and 38% in transportation (Department of National Development and Energy, 1982). The average energy use per household varies with climate and other characteristics, from 36 GJ in the year 1980-81 in Queensland to 96 GJ in Tasmania.

Energy is used in the residential sector mainly for space heating and cooling, water heating, lighting and other electrical appliances. The proportion of energy used for each purpose is difficult to determine, but most estimates assign about one third to space heating and cooling, one third to water heating and the rest to other uses. The energy used for each purpose and the mix of fuels varies from state to state. For example, the average household

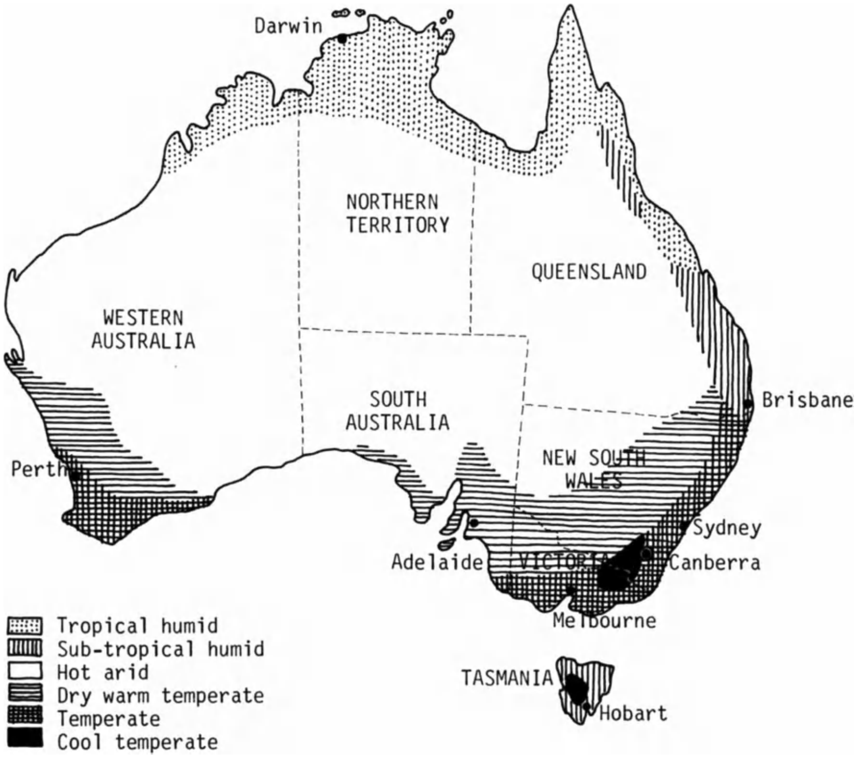

Fig. 1. A broad classification of Australian climates

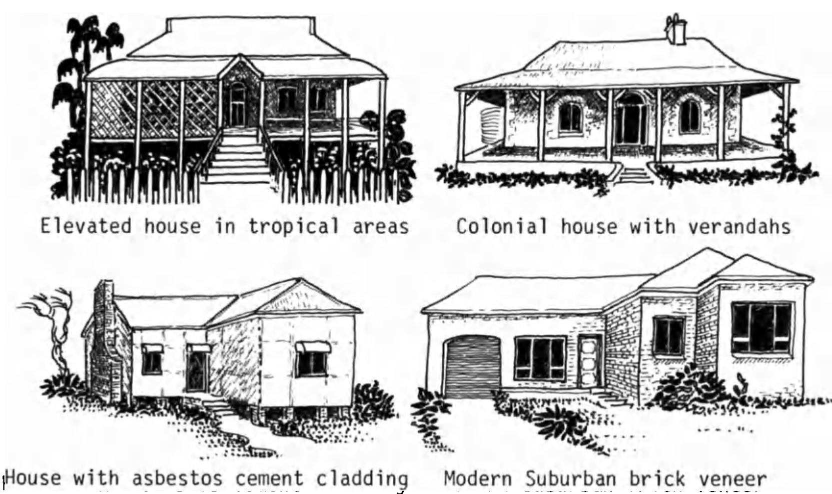

Fig. 2. Typical Australian housing types

in Victoria uses 80% more delivered energy than the average in New South Wales. Most of the difference can be attributed to greater demand for heating, and to the greater penetration and lower conversion efficiency of gas, as opposed to electrical appliances.

PASSIVE SOLAR DESIGN PRINCIPLES

The passive solar design principles most applicable to Australia are those which reduce winter heating requirements without leading to summer discomfort. The amount of energy that can be saved appears relatively modest at the national level, since domestic space heating is estimated to account for about 4% of national delivered energy, or some 90 PJ annually. Heating is proportionally more important in the southern winters however, where there is a generally high level of winter insolation.

Planning and Orientation

The direction of the sun's transit in Australia is, of course, to the north. The northerly aspect provides the greatest potential for controlled admission or exclusion of solar energy. A rectangular floor plan elongated along the east-west axis will maximise northerly aspect and also minimise the area of the west wall, which is particularly vulnerable to solar gain in summer.

The potential for ideal aspect and layout is largely determined by the site geometry. New suburban housing subdivisions are laid out either by large private developers who also build their standard house models, or by government land commissions who then sell blocks to developers or direct to individual housebuilders. There is an almost universal preference for main living areas to face the street, so site orientation is crucial. The issues of correct orientation and of overshadowing of adjacent houses have not received general attention until recently.

Glazing

The shading of windows in summer is a critical requirement in most parts of Australia. This can be most readily reconciled with the requirements of useful winter heat gain with windows on the north side, protected by an overhang matched to the latitude. Pergolas with deciduous planting, and moveable external blinds, are also widely used for seasonal shading control.

The optimum proportion of glazing varies with location. Excessive window areas lead to summer heat gain problems, even if the glass is shaded, since summer air temperatures of 35°C or more are frequent in most population centres. Heat loss in winter is also a problem unless the windows are properly managed with curtains or external shutters.

Thermal Mass

Massive walls have traditionally been used as a thermal moderator during the brief hot and cold spells in the temperate parts of the country. They have been less successful in the hot arid areas, where they tend to be uncomfortably warm for sleeping at night. The Commonwealth Experimental Building Station has recommended a composite construction in those areas since 1952 (Drysdale, 1952). Sleeping areas in lightweight construction would cool rapidly at night, while living areas of heavyweight construction would stay cool for most of the day. This form of construction has not, however, been widely adopted, especially since airconditioning has become readily available.

The disadvantage of thermal mass in cooler areas was evident in the winter, given the inefficiency of the popular methods of heating last century. Even now, although the full range of fuels and heating equipment is widely available, whole-house and continuous heating are not common, and intermittent heating regimes are not assisted by massive wall linings. For these reasons, and through increasing preference for framed and brick-veneer construction, the internal wall lining materials of detached dwellings are tending more to the thermally light. A survey of outer wall materials conducted in 1980 by the Australian Bureau of Statistics (ABS) suggested that nearly 70% of detached dwellings in Australia had internal wall linings of low thermal mass (ABS 1980).

In many cases, timber floors contribute to the thermal lightness of the envelope. The benefits of heavyweight construction for controlled winter heat storage are now beginning to be appreciated. A study by the CSIRO using the ZSTEP computer program has concluded that thermal mass assists year-round thermal comfort in the temperate areas, without artificial heating or cooling. With intermittent space conditioning, thermal mass in the floor reduces artificial heating and cooling requirements in all areas (Walsh, Gurr and Ballantyne 1982).

Insulation

The value of ceiling insulation is readily apparent to anyone who spends an Australian summer under a galvanised steel roof. Dried seaweed, sawdust and wheat threshings were all used as insulation as early as the 1850's. Locally manufactured rock-wool and imported aluminium foil became available after 1918 and, after 1945, insulation with rock-wool became the standard practice for flat and low roofs. These roof shapes have remained in a minority, however, and the popular Australian roof remains pitched and poorly insulated.

Less than 42% of existing single household dwellings in Australia were known to have ceiling insulation in 1980. At the same time only about 11% were known to have wall insulation (ABS 1980). The rate of insulation in new housing is higher, but still by no means universal.

Possible Energy Savings

There is obvious scope for the promotion of better thermal standards and passive solar design principles in mass housing in Australia. Szokolay (1982) identifies three distinct categories of possible improvement to the typical house, with the following estimated savings.

No-Cost Improvements. These include basic passive solar design principles such as orientation, fenestration, shading, insulation and positioning of thermal mass, as well as reasonably air-tight construction. The estimate of possible space heating energy saved is 30-40%.

Extra Energy Conservation Measures. Those include added insulation, double glazing, night insulation of windows, weatherstripping and perhaps ventilation heat recovery and earth berming. The estimated saving is 10-30%.

Passive Solar Techniques. These include components such as clerestorey windows, trombe or water walls, greenhouses or sunspaces, adjustable shading devices and variable insulation systems. The estimated savings is 24-37%.

The first category of improvements is the most attractive, since it promises the greatest savings at virtually no cost. Whatever the demonstrable advantages, however, they can only be successfully promoted with due regard for the structure of the Australian mass housing market.

THE HOUSING MARKET

The dominant housing form in Australia is the single-family, single-storey detached dwelling on a tenth of a hectare of land. Detached houses represent about 74% of the dwellings built in the last 3 years (ABS 1982b), even though the popularity of flats and terrace houses has risen considerably in the last decade. Despite the depressed state of the industry, the number of dwellings completed in each of the last 3 years to mid-1982 is about 135,000 or nearly 3% of the national dwelling stock.

Australians place a high value on home ownership, and indeed have the highest owner-occupancy rate in the world. There is a constant demand for an expensive and resource consuming product, usually at the urban fringe, as metropolitan populations grow and new households are formed.

Although Australians like owning houses they do not, as a rule, build for themselves. Currently, about 30% of dwellings are built by owner-occupiers (ABS 1982a), mainly subcontracting out certain trades and doing the less-skilled work themselves. Of the remaining 70%, it is estimated that not more than 5% would be built to the design and under the supervision of an architect. Therefore, some two-thirds of the dwellings are built by project builders, either as a standard design for a client or in anticipation of later sale.

The housing market is a conservative one. The variation in the product offered by various builders is usually superficial. Stylistic innovations which often appear first in architect-designed houses, filter through to the mass housing market up to a decade later, and often in a poorly digested way (Boyd 1968). Builders cannot afford to deviate from what they perceive as market taste, or they may be left with an unsaleable product, especially if any innovation involves extra costs. This conservatism, together with low energy costs, has meant that the basic thermal characteristics of most project housing are relatively poor. There is obvious scope for promotion of passive solar and low energy principles.

PROMOTION OF DESIGN PRINCIPLES

Broad support for energy conservation has emerged in Australian society in recent years. This has come about through a combination of rising energy prices and government-led publicity, particularly focussing on transportation fuels. The energy awareness of industry, commerce and householders has improved. The next step is investment in more energy-efficient plant. This is already occurring to some extent with automobiles, industrial equipment, commercial buildings and occasionally in private houses. The following groups are promoting low-energy design on a wider scale.

House Designers

Most of the recent Australian examples of passive solar houses have been designed by architects or informed owner-builders. Many of these have been publicised in books (Szokolay and Sale 1979) and through architectural awards. The New South Wales chapter of the Royal Australian Institute of Architects award for "merchant housing" in 1982 went to a project home designed around passive solar principles.

Industry Associations

The Housing Industry Association, to which many of the project builders belong, is also beginning to promote energy-efficiency in the products of its members. The South Australian branch, for example, is instituting a new category in its "House of the Year" Awards for 1983: the Energy Efficient House Award, sponsored by the South Australian Energy Council.

A major three-year project to promote passive solar design principles directly to builders has recently begun in several states. It is funded jointly by a consortium of Federal and some State Governments and the manufacturers of certain building products. The project aims to establish optimum energy-efficient house types for selected climatic zones with the help of the CSIRO, and to advise builders on how to adapt and promote their own designs accordingly.

Government

The Federal and State Departments of Energy promote passive and low energy design by funding research and demonstration projects, by sponsoring building design awards and by producing information for prospective house buyers and builders. The process is complicated because several departments and levels of government are invoalved in administering building and planning regulations. In some areas, notably Canberra, the planning and public housing authorities have themselves promoted low energy designs (National Capital Development Commission, 1977).

The Australian Housing Research Council has commissioned a study on design guidelines for energy efficient housing estates (Solarch 1982). Such an estate of approximately 400 houses, all sited for optimum orientation, is to be built in Sydney by the Housing Commission of New South Wales, which together with the Energy Authority of New South Wales, has already sponsored experimental passive-solar versions of its own houses.

The issue of guaranteed solar access for roof collectors and perhaps for entire houses is beginning to receive attention from several State Governments. The general policy in energy matters is for encouragement rather than legislation, however; while mandatory insulation standards do not apply in Australia, although some State Governments have at times considered them, the Federal Government offers tax incentives for home insulation.

Project Builders

Despite encouragement, research and some examples of government-built houses and subdivisions, the rate of penetration of passive solar design principles into the vast private project building industry can only be described as glacial. The houses built by the handful of builders offering solar or low-energy designs probably constitutes less than 2% of annual volume. These few houses are concentrated at the expensive end of the market, in the grey area which merges into one-off houses.

The advertising of the project market indicates the builders' perception of current market tastes. Project builders do not avoid automobile-style comparison shopping. In fact they welcome it as a chance to emphasise the aspects of their designs which they believe will sell. Of the sixty-nine builders advertising in a recent guide, only five chose to mention the words "solar" or "energy" (Project Home Buyers Guide 1983). The design of two of these was distinguished only by a solar hot water system, which several builders are now offering as an option, in any case. It is disturbing that some builders still offer even roof insulation as an option rather than as part of the basic package. The chief selling points are still value for money, spaciousness, finishes and stylistic attributes.

Despite the low level of overt interest, there is some feeling in the industry that passive solar housing could successfully be marketed as a psychological and symbolic product if the right formula were found (Burford 1982). The external expressions of passive solar design may well prove to be the best vehicle for promoting it in a mass housing market which has traditionally been more concerned with fashion than with design for climate. Ironically, design for climate could itself become a fashion. This may be reinforced by the established tendency for architectural innovations to filter through, eventually, to the project home market.

CONCLUSION

There is considerable scope for improving the thermal comfort and energy efficiency of mass housing in Australia, by the wider adoption of passive solar design principles. Information on these principles is readily available, and further research and demonstration projects are proceeding. The key to general adoption of these principles seems to be in the construction practices and marketing of the project building industry and in the expectations of its customers.

ACKNOWLEDGEMENTS

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DEMONSTRATION OF ENERGY EFFICIENT HOUSES AS INTEGRATED SYSTEMS

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ABSTRACT

This paper first deals with the concept of Energy Efficient Houses as Integrated Systems. Quantitative Analysis is used to show that evenly distributed insulation is more effective than excessive insulation applied to only one element of a house and that ventilation rates are a critical factor in determining the magnitude of energy loss. For a new approach to be adopted on a large scale, it is suggested that a means to implement Planned Change is required. Various models to bring about this change are discussed with an indication of the final recipe used for a Demonstration Project.

KEYWORDS

Energy Efficiency; Low Energy; Integrated Design; Thermal Comfort; Demonstration; Planned Change; CLER Model.

INTEGRATED DESIGN OF ENERGY EFFICIENT HOUSES

This first part of the paper argues the case for, and demonstrates the advantages of, the Integrated Approach to Energy Efficient Design. The basic concept is explored by way of worked examples, attention being given to insulation & ventilation levels, solar gain, thermal comfort and the control of condensation.

The Concept

Energy Conservation by applying insulation to the fabric of the building is now a fairly common practice. However, the net effect of applying more than one measure on the thermal dynamics of the building, due to interaction of the elements, is not adequately understood by the designers (Makkar, 1979). Nor is the contribution of radiant temperature toward thermal comfort or the relationship between the thermostatic setting of temperature and draughts and other factors (Fanger, 1970).

As the following analysis will show, the reduction in energy demands of a house goes hand in hand with the improvement of thermal comfort. In other words, any insulation measure to reduce energy consumption will inevitably result in an improvement in thermal comfort; (with the exception of the trivial case where underheating is chosen as the way to reduce consumption).

Quantitative analysis of energy loss, carried out to include the various insulation measures, ventilation rates, incidental gains (due to inhabitants and energy uses in houses such as TV, lighting and cooking), solar gains and balancing of radiant and ambient temperatures illustrates the need and the procedure for the integrated approach.

No Insulation

An end of terrace house on a site in London is chosen as an example. Taking into account the site, the clients brief etc. the resultant design as envisaged by the architect is the starting point for this analysis. The integrated approach as developed in this paper does not require any architectural compromises, instead, it deals with the possibilities for energy reduction and thermal comfort for a given basic design.

This design is shown in Diagram 1 and includes 100mm insulation in the loft but no other insulation measures; orientation is East-West. The energy consumption to maintain 20^{o}C ambient temperature is 14,004 kWh. (Note: Adjusted Degree Day method of energy loss calculation is used throughout this paper. It includes 22kWh/day as incidental gains due to 4 persons (Siviour, 1976). It also includes useful heat provided by solar gain according the orientation and size of glazed areas). This case is common practice in London and establishes the base point. Table 1 gives the areas and 'U' values of each of the elements of the building. The ventilation rate of 2 ac/h assumes that no special measures are taken to reduce ventilation. This figure is the average of air change rates for similar houses for varying wind conditions around London.

Element	Area m^2	'U' Value $W/m^{2o}C$
Roof	48.77	0.35
Ground Floor	48.77	0.62
Glazing - East	5.15	3.6
Glazing - West	7.92	3.6
Glazing - North	0.9	3.6
Walls	73.31	1.0
Ventilation Volume 218m^3	2 air changes/hour	
Total Energy Consumption: 14,004kWh		

Table 1

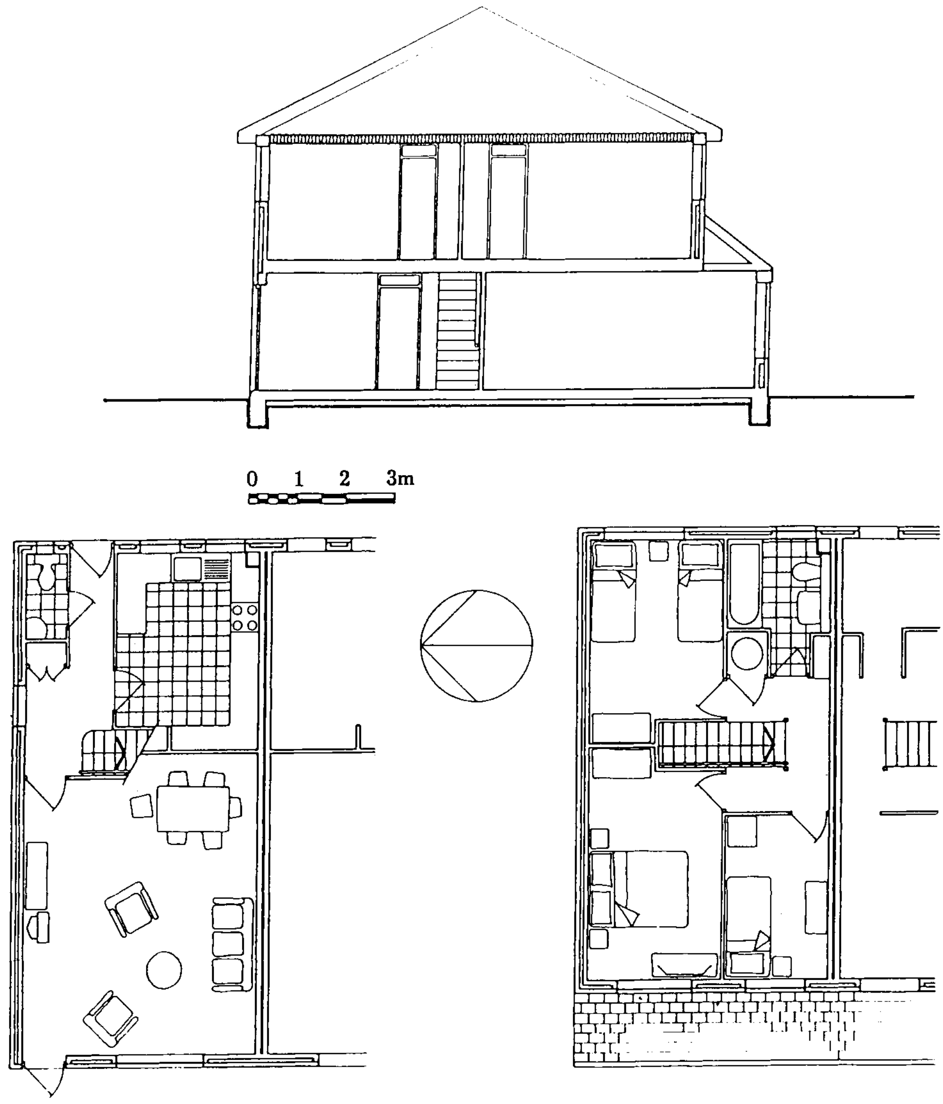


Diagram 1: Basic House Plan

High Insulation of Roof -v- Moderate Insulation Throughout.

Two alternative modes of insulation are applied to this house:

(1) Insulation in the loft is increased to 400mm without dealing with any other element.

(2) Insulation is provided moderately to various elements thus 140mm in the loft, 50mm in the walls and 50mm under the floor. Ventilation rate remains 2ac/h for both options.

Table 2 gives the resultant energy consumptions for these two options:

Element	Option 1 Insulation & 'U' Value (Thick insulation to one element)		Option 2 Insulation & 'U' Value (Moderate Insulation to all elements)	
Roof	400mm	0.1	140mm	0.26
Ground Floor	NIL	0.62	50mm	0.31
Glazing - East (with curtains)	NIL	3.6	NIL	3.6
Glazing - West (with curtains)	NIL	3.6	NIL	3.6
Glazing - North (with curtains)	NIL	3.6	NIL	3.6
Walls	NIL	1.0	50mm	0.31
Ventilation	2ac/h		2ac/h	
Energy Consumption	*13,393 kWh/pa*		*9,642 kWh/pa*	
Energy Reduction from base of 14,004 kWh	*611 kWh/pa* *4%*		*4,362 kWh/pa* *31%*	

Table 2

It can be seen that when the very thick insulation to one element is redistributed evenly to all the elements (of the fabric) this results in considerably greater savings.

Effect of Reduction in Ventilation Rates

If measures are then taken to reduce the ventilation rate from 2 ac/h to 1 ac/h, which can be achieved by draught-stripping and providing draught lobbies (as shown in Diagram 2), the energy consumption for this option (3) reduces to 5,121 kWh/pa = 63% reduction from the base consumption.

An interesting point to note here is that the reduction of 4,521 kWh in energy requirement due to halving of ventilation rate suggests that it is one of the most effective measures for energy conservation.

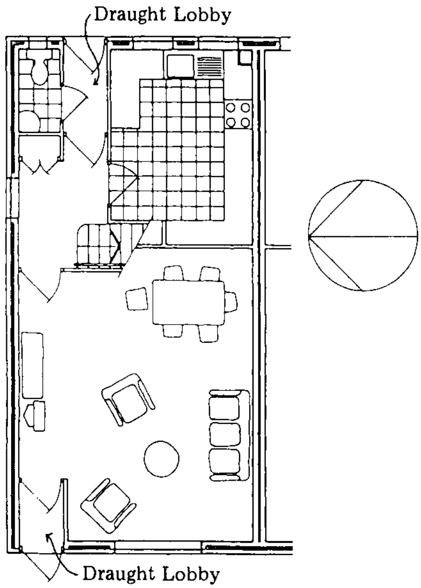


Diagram 2

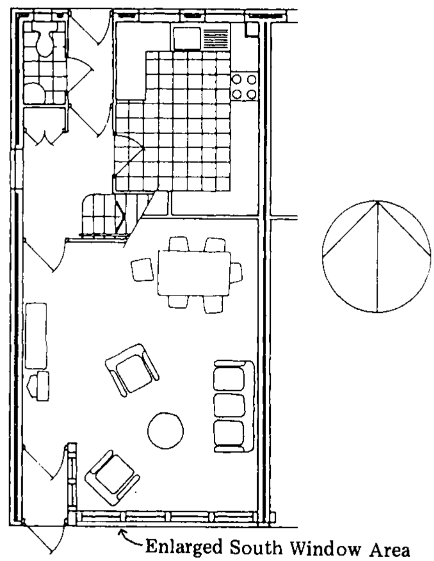


Diagram 3

Solar Gains

Having taken these measures it is now possible to consider the effect of orientation on energy consumption. So far it was assumed that the orientation was E-W, with the living room facing West. If now the house is orientated North-South, with the living room facing South, the calculated energy consumption is reduced marginally by 66 kWh to 5,055 kWh per annum. This means that orientation, by itself, for this type of house, is comparatively insignificant. If the window area is enlarged to the total width of the living room (Diagram 3) and curtained at night the calculated energy consumption is *increased* to 5,281 kWh/pa.

At this stage it is important to note that it is not being suggested that solar gains -v- energy loss through glazing *always* result in increased energy consumption, merely that a simple approach does not always achieve the desired results. For example in situations where openings on the South side are increased with an equivalent decrease in glazed area on the North side this *will* lead to a net saving of energy (Turrent & colleagues, 1980). This case is not discussed quantitatively here.

A glazed wall is now added, internally, to the living room and it is assumed that a means exists to distribute the solar gains to the rest of the house. (Diagram 4).

The Atrium thus created is unheated by the heating system. The calculated energy loss now is 3,954 kWh/pa. a further reduction of 1,167 kWh/pa from the previous option when part of the South wall was simply glazed. In the house in the example, redistribution of solar gains was achieved by drawing the air from the atrium into the house by a warm air heating system.

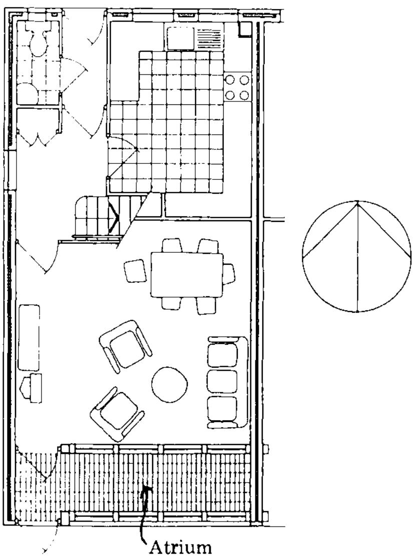
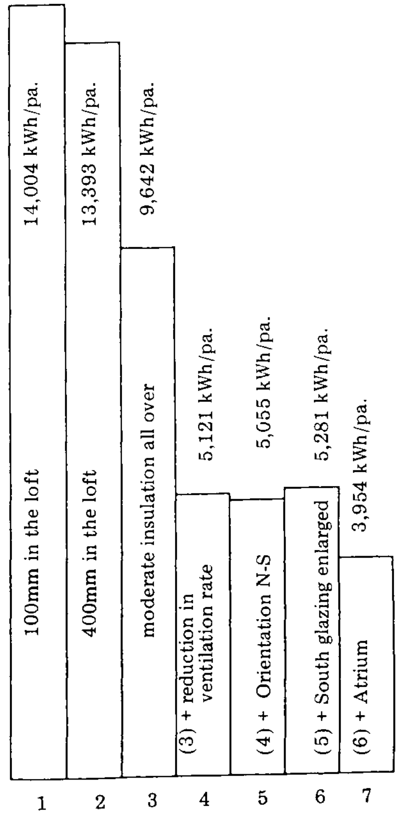


Diagram 4



Graph 1

1st Integration

Graph 1 gives a summary of energy reduction as a result of integrating more and more energy saving measures.

It may be noted that deliberate attempts at increasing solar gains resulted in comparatively little saving in energy. It is however worth noting that 1,167 kWh/pa solar gain is still equal to 23% of 5,121 kWh - being the residual energy requirement of the house after the initial energy conservation measures have been applied (represented by column 4 in Graph 1).

Ambient -v- Radiant Temperatures

The perception of thermal comfort depends upon the ambient temperature, the mean radiant temperature inside the house and air movement, assuming fixed clothing and activity levels according to the habits of the people and the humidity level in the house.

Assuming low levels of air movement, the (simple) relationship between perceived temperature - called resultant temperature, t(res), the ambient temperature, t(ai), and the radiant temperature, t(r) (CIBS, 1978) is given by

$$t(res) = \frac{t(ai) + t(r)}{2}$$

Thus it can be seen that the mean radiant temperature makes about the same contribution to the resultant (perceived) temperature as the ambient temperature. The importance of the radiant temperature can therefore be assessed.

Balancing the ambient and radiant temperatures to achieve the resultant temperature of 20°C while 0°C exists outside, the following relationship for the options considered previously is obtained:

	Radiant Temperature °C	Ambient Temperature °C
100mm in the loft	18.3	21.7
400mm in the loft	18.9	21.1
moderate insulation all over	19.3	20.7
enlarged south glazing	19.2	20.8
south facing atrium	19.3	20.7

Table 3

2nd Integration

The 2nd stage of integration deals with improving the surface (radiant) temperatures in order to reduce the ambient (hence paid) temperature. In the cases considered the radiant temperature has been found to improve consistently with increased distribution of insulation. If the mean radiant temperatures were found to be too low, then special measures would have been required to improve them. As the radiant temperatures have turned out high, this exercise is unnecessary. But the principle remains sound. A small mathmatical exercise will show that it is not possible to reach a radiant temperature of 20°C so long as the resultant temperature remains at 20°C. (With external temperature at 0°C).

Assuming the final ambient temperatures as given in Table 3, calculations were carried out for net energy losses. Results for energy losses taking radiant temperature into account and without taking these into account are given in Table 4 for all the specifications discussed earlier.

Specification	Orientation	Annual Energy Consumption kWh	
		Radiant temperature NOT taken into account	Radiant temperature TAKEN into account
(1) 100 mm in the loft	E-W	14,004	14,394
(2) 400 mm in the loft	E-W	13,393	13,783
(3) 140 mm in the loft 50 mm in the floor 50 mm in the walls	E-W	9,642	10,140
(4) As (3) + ventilation rate halved	E-W	5,121	5,439
(5) As (4) Orientation N-S	N-S	5,055	5,374
(6) As (5) South glazing enlarged	N-S	5,281	5,695
(7) As (6) Atrium created	N-S	3,954	4,273

Table 4

The Integrated Approach was developed and successfully used for a number of developments. Currently there is a project at 31, Lawrie Park Road, London S.E.26. where a Demonstration Suite has been set up. This project is funded by UK. Dept. of Energy and the E.E.C. However, the concept of demonstration, to achieve replication, required special research effort. The rest of the paper deals with the Concept of Demonstration as a Strategy for Planned Change.

DEMONSTRATION OF THE INTEGRATED APPROACH TO ENERGY EFFICIENT BUILDING

Introduction

The development of the concept of Demonstration resulted from the juxtaposition of two main factors:

Firstly, a growing awareness in the minds of the authors that for the widespread adoption of energy saving techniques in buildings, it is not sufficient simply to provide rational proof of the existence and efficacy of the measures and

Secondly, the introduction (by both the UK Department of Energy and the EEC Directorate - General for Energy) of "Demonstration" programmes afforded the opportunity/funding to explore the problem in depth and propose, implement and evaluate a method of overcoming it.

The Problem

The designs of the *majority* of buildings currently under construction, or undergoing major refurbishment, pay scant regard to energy conservation. (At least this is the case in the UK). There are now certain requirements regarding thermal standards incorporated in the Building Regulations and these are, of course, complied with (except they are not always adhered to in London - which has a different type of Building control with no specific thermal requirements). However, the Building Regulations standard is fairly low - lagging a long way behind what can be achieved at a reasonable/acceptable cost - in time, effort and money - particularly through use of the Integrated Approach. The materials and techniques are available and cost-effective but are not being utilised, except by a small minority of individuals and groups.

In order for energy conservation to be more widely implemented in buildings it is obviously necessary for a change to take place - a change in the behaviour of those responsible for commissioning, designing and constructing the buildings and their services. There are two ways in which change occurs - one is a gradual process whereby new ideas/knowledge/technology are slowly absorbed into society, the other is by "Planned Change". The first, 'natural' process *is* occuring - society in general is becoming more aware of the need and value of energy conservation but this is an extremely (some would say 'painfully'?) slow process and our aim is to speed it up. We therefore turn to the concept of *Planned Change.*

Planned Change

Planned Change is defined as,

"a method which self-conciously and experimentally employs social knowledge to help solve the problems of men and societies'" (Bennis and colleagues, 1976)

and

"where a change agent deliberately intervenes in a situation and manipulates social processes to obtain a preferred subsequent situation". (Bhola, 1982).

There are three groups of strategies for planned change:

Empirical - rational
Normative - re-educative
Power - coercive.

The first group is rather simplistic, whereas use of the third group is not generally socially acceptable. The 'normative-re-educative' group is a much broader category - embracing the numerous interactions between individuals, groups, institutions, societies and the natural environment and including overt behaviour, value and belief systems, cultural norms, roles and relationships and perceptual and cognitive orientations. One particular theory/model for planned change which falls within this group - Bhola's "Configurational Theory for Innovation Diffusion and Planned Change: The CLER model" (1982) - will be used later in this paper to explicate the principles of Demonstration.

First it is necessary to look at which individuals or groups should be the 'target' of the planned change or the potential "change adopters". Ideally, it would be desirable to influence all parts of society at one time so that the change would be wrought throughout society and thus operate more effectively. However, it is generally impractical, as in this case, for the change agent (the authors) to intervene in all groups and at all levels. Therefore, attention must be focused on the individuals/groups/institutions which are: (a) most influential in terms of solving the given problem and (b) most accessible (or can be made so) to the change-agent.

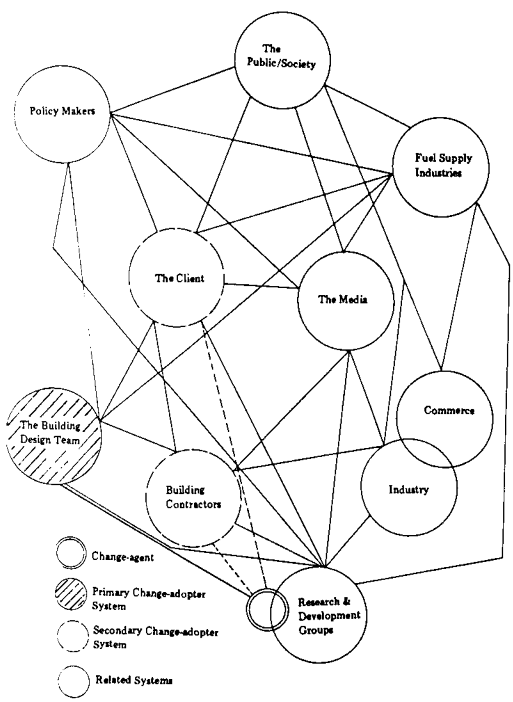


Fig. 2.1 Interrelationships between Involved Groups

In the area of energy conservation in buildings there are 5 broad categories within society who may have an influence on its implementation:

(i) Policy/decision makers.
(ii) Society as a whole including the building users and clients.
(iii) The media.
(iv) Industry including the fuel industries.
(v) Designers and constructors of buildings, their services and their environment.

Some of the interrelationships between these groups are indicated in Fig. 2.1.

Of these, the last group - the professionals involved with the building process - was seen to be the one which could most *directly* affect the energy-efficiency of the buildings and, was also the group in which the change agent could most directly intervene. The behaviour of the other groups with regard to this subject - and indeed, other aspects of societal life - will affect the likehood of the desired change taking place. For instance, should the government and the fuel industries drastically increase or reduce fuel prices, this would affect others' perception of the need and value of energy (fuel) conservation. Therefore, the change agent, whilst concentrating on bringing about change within the building professions, will also attempt to influence these other groups in the same direction, to whatever extent is possible, so as to strengthen the effect of the change strategy.

Demonstration and the CLER Model for Planned Change

Demonstration has been defined as,

"a means whereby, in a non-formal situation, an awareness of the practicality of the subject may be imparted and uncertainties reduced by presenting appropriate information in a suitable format - taking into account the needs, attitudes, previous experience and perception of those to whom it is directed so that they consequently change their existing practices and adopt the desired practices". (Ince, 1981).

In this specific case the desired change is that building practitioners (architects, surveyors, services engineers, quantity surveyors and builders) should incorporate energy conservation measures in their buildings so as to reduce the fuel consumption whilst maintaining or improving comfort conditions.

This definition is closely comparable to the work of Havelock and Benne (1966) who identified two phases in imparting knowledge - preparation of the message and transmission of the message. They saw message preparation as consisting of four steps - assembly of all the relevant facts/data/information; recording the information so it is understandable and acceptable to the receiver; screening (reviewing/evaluating) and 'packaging'. They considered the most effective vehicle for the transmission of knowledge as being, "opportunity to experience it firsthand or through observing a demonstration". It is, of course, widely accepted that first-hand experience is the most effective strategy for learning/changing, but in the case of energy conservation in buildings there are two barriers to utilising this - firstly, some impetus is required to encourage people to provide themselves with the experience - it cannot easily be given to them, secondly, the time-scale of building (anything from 9 months to 5 years or more) mitigates against the immediacy of experience. The aim then, is to provide a Demonstration which as closely as possible imitates direct experience.

Bhola's CLER model (1982) is a useful tool for identifying the various elements of the situation within which the change agent must operate and consequentially indicating the strategies and tactics which can be utilised to bring about the desired change.

The model is represented as: Change = f (C, L, E, R) where

C stands for the network of *c*onfigurational relationships, which include the change-agent and the (potential) change-adopter;

L stands for *l*inkages within and between change-agent and change-adopter systems;

E stands for the *e*nvironment surrounding the change-agent and change-adopter systems;

R stands for the *r*esources available to the change-agent for promoting change and to the change-adopter for adopting/incorporating the change being offered.

The network of configurational relationships (C) is the network of relationships between any two social configurations of individuals - the change-agent may belong to any configuration and so may the change-adopter. In this specific case, the change agent is a small group and the potential change-adopters are groups of professionals (architects, surveyors, etc.) some of whom are also linked together in various institutional configurations as indicated in the network in Fig. 2.2 below:

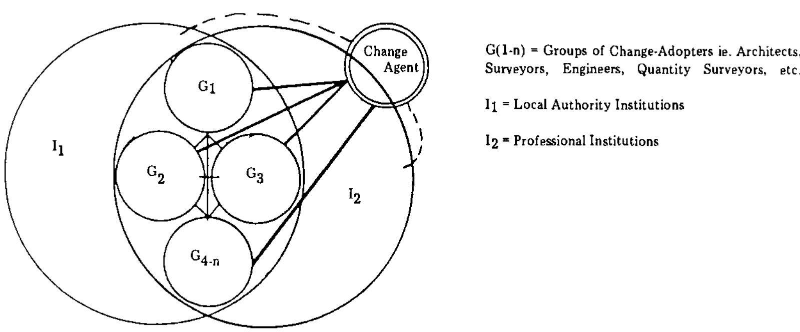


Fig 2.2. Groups of Change Adopters

Linkage (L) is the potential for communication - in either personal or impersonal mode - between the change-agent and the change-adopter and also within the change-adopter systems. In the case of the specific demonstration under consideration there are some existing linkages between the change-agent and some of the change-adopters - these linkages need to be re-inforced and others need to be created - these will have been formed once the change-adopters have been persuaded to visit the Demonstration - at that point the potential for communication will have been created. Encouragement to visit the demonstration will be via notices in relevant professional journals, invitation by mail and word of mouth. There are some linkages - specifically between potential change-adopters and others within the change-adopter system who are strongly opposed to the desired change, which it would be *desirable* to sever. It is unlikely, however, that the change agent will be in a position to achieve this severance and must therefore allow for the counteractive effect of these individuals/groups.

Environment (E) comprises the physical, socio-cultural and intellectual conditions and forces which impinge on the change-adopters and may have a supportive, neutral or inhibiting effect. Some of the environmental factors influencing the demonstration of energy conservation at the present time are:

Supportive	Neutral	Inhibiting
Increasing awareness of need for conservation	High levels of unemployment (will encourage some to embrace additional skills; others will be too 'careful' of their job to be adventurous)	*Apparent* surplus of fossil fuels
Fuel pricing policies		Few incentives - e.g. tax or rates reduction.
Conservation is gradually emerging from being a subject only for 'cranks' to being 'respectable'		Relatively low level of Government support.
		Modest requirements of Building Regulations.

The Resources (R) available for the demonstration of energy conservation (looked at under Bhola's groupings) are:

Conceptual: The professions concerned already have, to a great extent, the necessary cognitive and technical skills to embrace the concepts and techniques of energy conservation, providing that they can be brought to a state of readiness/willingness to do so. Skills will be enhanced through the exhibits and through literature to take away. Attention will also be drawn to sources of assistance, consultancy services for specific projects and the availability of a computer program for analysing heat losses and the comparative effectiveness of measures in specific cases. Data from the continuous monitoring of the energy-efficient buildings, round which the project is centred, will be displayed, together with costs of the measures and the techniques of implementation - including a film of the actual building in progress. Visitors to the Demonstration during the first 6-9 months will also be able to visit the new houses in course of construction. One example of the new houses will subsequently be open to visitors - the demonstration suite itself serving as the example of the energy-efficient rehabilitation. There is also a facility to hold seminars within the Demonstration Suite.

Influence: influence resource is really a use of power - directly or indirectly - and is related to work on attitude change which has indicated that a change is more likely to take place if the proposal comes from a 'respected' source. In relation to the demonstration project the change agents are developing lines of indirect influence by:

(a) convincing local politicians, heads of design departments/practices and others in similar 'elite' positions, of the need/benefits of energy conservation. (This has to be achieved outside the demonstration project itself, but by similar means). These individuals/groups may then influence those over whom they have any kind or degree of power to adopt the change, or at least to visit the Demonstration (with a pre-disposition towards adoption).

(b) through use of the media to create a pre-disposition towards the change - there will be an 'official opening' of the Demonstration Suite by a public figure - to stimulate media interest (among other reasons) and reports about the project will be circulated to relevant technical/professional journals and to the National Press.

All four elements of the CLER model act co-operatively and must be considered as a combined force although it may, in some circumstances, be possible, or preferable, for the change-agent to manipulate only a selection of the four variables. Where it is *desirable but not possible* to manipulate all four variables, the desired change may not be achieved, or only partially achieved. In this Demonstration project it is possible that the desired level of change *may* not be achieved for various reasons, e.g. personnel not being granted time off work to visit the Demonstration or, not being given additional time, or manpower, to design energy efficient buildings or, perhaps, the 'rewards' for adopting the change are not 'visible' or high enough compared to perceived cost.

Demonstration of the Integrated Approach to Energy Efficient Design: A Strategy for Planned Change in a Specific Situation.

'Demonstration' in this instance is used to describe a particular strategy/mode of presenting knowledge with the intention of bringing about a behavioural change. The desired change is that building professionals will take steps to ensure that their buildings are 'energy-efficient' i.e. use the minimum amount of fuel whilst preserving (or improving) the quality of life of the building users. There are various strategies which could, theoretically, be employed to bring about this change - such as, for example, making more stringent regulations, creating social/moral pressure or doubling the salaries of those who comply! Such strategies, even if seen as desirable, could not be implemented by the particular change-agent in this particular case. The use of Demonstration as the change strategy was indicated both by its characteristics (of being a close substitute for direct experience) and by a particular set of (externally supplied) conditions.

The 'external' conditions which acted in favour of the Demonstration strategy were that the change agent was able to obtain funding for a 'Demonstration project' (from the UK Dept. of Energy and the

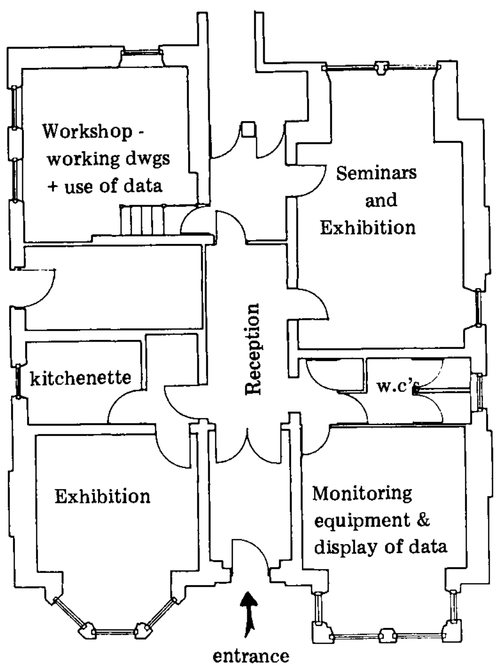


Fig. 2.3 Layout of Demonstration Suite

EEC) and a local authority (London Borough of Lewisham) was prepared to provide the sites for the new building and the rehabilitation of old houses to energy efficient standards. The authority was also prepared to allow the use of part of one old house for the Demonstration for a period of at least 2 years. The Demonstration project is located in a "Demonstration Suite" comprising four large rooms (and ancillary services) being the ground floor of one of the old houses which has been rehabilitated to energy-efficient standards. (see Fig. 2.3).

Certain restraints were imposed as a result of the location (e.g. from outside the Suite should appear as an integral part of the house) and by the funding bodies. Within this framework it has been possible to devise a Demonstration made up of a number of elements which together make up this strategy for Planned Change.

The Demonstration will include the following elements, all of which will be oriented to take into account the needs, attitudes, previous experience and perception of the potential change-adopters (building professionals):

1. A permanent exhibition presenting:

   (a) The principles of the Integrated Approach to Energy Efficient Building;
   (b) The techniques, materials and equipment used in the new and rehabilitated houses to achieve energy conservation;
   (c) Some of the advantages and disadvantages of various techniques;
   (d) Indications of relative costs and savings of different measures;
   (e) Examples of other energy-efficient buildings;
   (f) Indications of how various measures could be applied in different situations.

2. A film recording the actual implementation of the energy conservation measures during the building process.

3. A full monitoring system - recording internal and external temperatures and fuel consumption - to indicate the effectiveness of the designs in achieving comfort in the dwellings *and* saving fuel. The monitoring system will provide daily summaries of this information so that visitors can relate the previous day's figures with their own recollection of that day's climatic conditions. There will also be a computer-generated graphic display where the thermal behaviour of any of the 33 monitored dwellings over any given day can be viewed in a condensed mode - to give a 'feel' for how the buildings respond to climatic conditions over a period of time.

4. A variety of literature for visitors to take away - including reproduction of the information contained in the exhibition; design details ('hints and tips'); lists of relevant trade associations, manufacturers/suppliers of energy saving equipment/materials; bibliography of publications and an indication of individuals and groups with experience in this field who could be approached for design assistance.

5. Facilities for small (up to 25 persons) seminars are available within the Demonstration Suite, with members of the change-agent system available, if desired, to participate in seminars, or to accompany visitors to the suite and discuss the subject with them - this interpersonal activity is not intended to be 'forced' on the visitors, but can be a very effective change tactic when it is found acceptable by the change-adopter.

Outline of Evaluation Methods to be Employed

Evaluation of the Demonstration will be carried out firstly during the first 6 months or so of the operation of the project with a view to modifying the elements according to the evaluation results. Further evaluation will be carried out following these modifications. At both these stages it will be possible only to evaluate the *immediate* effects of exposure to the Demonstration and may not indicate whether any change will endure for a length of time. Therefore, some of the visitors will be contacted some 6-12 months after their visit - to discover whether the change has endured.

A questionnaire has been devised which all visitors will be asked to complete. It is in two parts - one to be completed before exposure to the Demonstration and the second part immediately after exposure. It is also intended to interview some visitors *during* their exposure to the Demonstration and to *observe* others - these techniques being used to evaluate which elements of the Demonstration have most impact or are confusing or insufficient.

The evaluation of the longer term effects of this change strategy will probably need to be carried out by a postal questionnaire, though it may be possible, and would be desirable, to interview some of the change-adopters after a period of time has elapsed.

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CONTINUING EDUCATION FOR ARCHITECTS AND ENGINEERS ON THE SUBJECT OF ENERGY CONSERVATION AND RENEWABLE ENERGY USE

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ABSTRACT

The problem of unemployment among young Architects is pronounced. Continuing education is used to provide the unemployed with crucial new knowledge in the field of Renewable Energy Architecture. The experience of a seminar, and its conclusions are described.

KEYWORDS

Continuing education; unemployment; renewable energy architecture; environmental conditions in Crete.

INTRODUCTION

Recently, the problem of unemployment among Architects has grown to alarming proportions. Although the local picture is believed to be better than the national, a recent report notes (Danalakis, 1983) that within the Department (Nomos) of Iraklion there are 160 Architects out of whom only 23% are fully employed, while 55% of them are unemployed, and 22% have part-time employment. Unemployment seems to be the rule especially for the young graduates.

To ease the unemployment situation, an attempt has been made, through continuing education, to provide some of those unemployed with crucial additional knowledge in the highly productive field of energy conservation-and-use of renewable energy resources.

Between November 15 and December 17, 1982, a five-week five-hour/day seminar-workshop was conducted for 30 Architects, and Engineers (unemployed, and up to 30 years of age) in Iraklion, Crete. The subject was: "Energy conservation in manufacturing industry and buildings". The seminar was organized within the local chapter of the Technical Chamber of Greece (TEE-TAK) with the collaboration of the Greek Productivity Center (ELKEPA), and the Greek Employment Agency (OAED), and with the financial assistance of the European Community Fund.

Similar seminars were organized during the second half of 1982 in Athens, Salonika, Patras, Kavalla, and Volos.

SEMINAR TOPICS WITH EMPHASIS ON LOCAL ENVIRONMENTAL CONDITIONS, AND TRADITIONAL CONSTRUCTIONS

The environmental conditions in Crete are conducive to the utilization of renewable resources of energy (Papazoglou, 1981). From measurements of the solar radiation and wind speed available by the Public Power Corporation (1982), we note the following conditions for 1980:

Chania: season	Aver. Ambient Temp. degrees C	Hours of Daily Solar Rad. hours/day	Daily Solar Radiation cal/sq-cm,day
Winter	11.4	3.4	188.2
Spring	15.7	7.2	462
Summer	25.5	11.6	620.3
Autumn	20.1	7	340.5

Pahia Ammos: Average wind speed for May, 1980: approx. 6 m/s, and

Ano Moulia: Average wind speed for December, 1980: approx. 10 m/s.

Notable traditional structures for the utilization of the aeolic potential are the windmills in Crete. There are two distinctive types of windmills prevalent in east Crete: the mono-kairos windmills (Calvert, 1975), and the sail mills of Lasithi (Calvert, 1978). Another traditional renewable energy related construction is the fireplace (tzaki) in most typical village houses.

One part of the seminar dealt with the potential energy savings in the local manufacturing industry, and therefore, was addressed mainly to the Engineers in the group. The topics most relating to the Architects in the group were:

1. Renewable energy resources: solar; wind; biomass; wave energy.

2. Visits and study of the local industry for the manufacture of solar collectors for water heating.

3. Visits and study of the different types of traditional windmills in Lasithi.

4. Passive solar buildings.

5. Thermal insulation for buildings.

6. Electrical energy savings in buildings. Selection of proper lighting fixtures, and power devices.

7. Economics of energy use. Engineering economy studies for sound investments in energy saving installations, and renewable energy utilization.

8. Existing laws, and incentives for investments in energy conservation projects, and renewable energy resources use.

9. The use of solid fuels (including wood).

10. The application of microprocessors for optimum energy management.

PANEL DISCUSSION WITH CONCLUSIONS

At the end of the seminar a panel discussion was held to assess what had been accomplished, and to draw pertinent conclusions. The main points were:

1. New buildings should meet optimum standards of energy-use efficiency, and should harness local renewable energy resources. Therefore, the Architects should design buildings for aesthetic appearance, and for minimum energy consumption.

2. Planning associated with ambient/renewable energy use, must be locally based; since it is highly dependent on local environmental conditions, local needs, and local social factors.

3. Testing of the hardware for the construction of solar buildings (e.g. solar collectors for water heating) is necessary to ensure quality, and to meet acceptable standards. The establishment of a laboratory to aid the local solar-hardware manufacturers is important.

4. Future seminars/workshops are needed for Architects, Engineers, and at the same time for businessmen, and entrepreneurs in the local building business, and industry, on the subject of energy conservation, and renewable energy use.

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A PASSIVE SOLAR DESIGN EXERCISE

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ABSTRACT

A short course in passive solar concepts, based around an intensive design exercise is described. Its value as an educational medium, and as a means of generating new ideas is discussed in the context of the designs produced, and the subsequent analyses of their thermal performances. Recommendations are made for improving the effectiveness of future exercises.

KEYWORDS

Education, design exercise, passive solar housing, sunspace, retrofit, computer simulation.

INTRODUCTION

At the Energy Studies Programme of the Architectural Association Graduate School (AAGS) the bulk of our teaching programme consists of diploma and research degree courses. These are addressed to architects and graduates in other design disciplines wishing to specialise in passive building design as a post-graduate diploma or degree option.

Many designers, however, although increasingly interested in the subject can ill afford the time or the expense of full-time study. Meanwhile, the rate of development in the state of the art has made self-education a difficult task. Lately short courses and workshops have been on offer, starting in America and now in some European countries, to introduce professionals to the principles and practice of passive design.

In Britain, although short courses on energy topics have been organised for several years under the auspices of the Royal Institute of British Architects and the Chartered Institute of Building Services, few of these have focused on passive solar design and the subject is not being formally taught in schools of architecture.

This paper describes the results of such a short course organised in the form of a design workshop at the AAGS in London last June and makes recommendations for the planning of future exercises of a similar nature. The event was sponsored by the Energy Technology Support Unit (ETSU) of the U.K. Department of Energy. It was seen as a pilot exercise to explore the possibility of involving schools of architecture in the series of design studies, co-ordinated by A5 Architects, which ETSU has commissioned as part of its current Passive Research Programme.

Hence, besides educational aspects our objective in the exercise was also to assess its output and potential for producing new design ideas. This task is now completed and the results are presented in a detailed report together with the contents of the course, the documentation distributed during the design exercise and the drawings produced by the participants. (Yannas and McCartney, 1983)

THE DESIGN EXERCISE

Programme

The event was held over four days on two consecutive weeks. The first two days were structured as a design workshop and were introduced by a short lecture course. Tutorial advice, specially prepared documentation, selected literature and computer facilities were available throughout. Participants were offered the option to continue developing their schemes in their own time and to make arrangements for evaluating and refining the designs with the aid of thermal simulation on a subsequent day. The final day consisted of the presentation of the design schemes to an invited panel of experts.

Design Brief

The design brief called for the provision of glazed enclosures (sunspaces or conservatories) to reduce heating requirements and as an amenity for typical two-storey London terrace houses. Two houses on each side of a street were to be renovated for a Housing Association with the work eventually extending along the terrace. Participants were free to design for either or both sides of the street.

The brief gave some information on the structural condition of the buildings (uninsulated solid brick construction) to draw attention to particular constraints or possibilities. A full set of 1:50 scale drawings were supplied together with two axonometric views and a 1:500 site plan. Graphical documentation was also supplied showing the levels of insolation received on different building surfaces, the shading effect of external obstructions and the thermal transmittances of building elements.

Participation

Participants included two third year architectural students, four postgraduates and three practicing architects. Only the latter had design experience with British housing, but most of the participants had done some reading or had attended lectures on passive solar heating previously.

Thermal Analysis

Manual methods for estimating the contribution from passive solar systems (Balcomb and colleagues 1980; CEC, 1982; Claux and colleagues 1982) can be cumbersome and

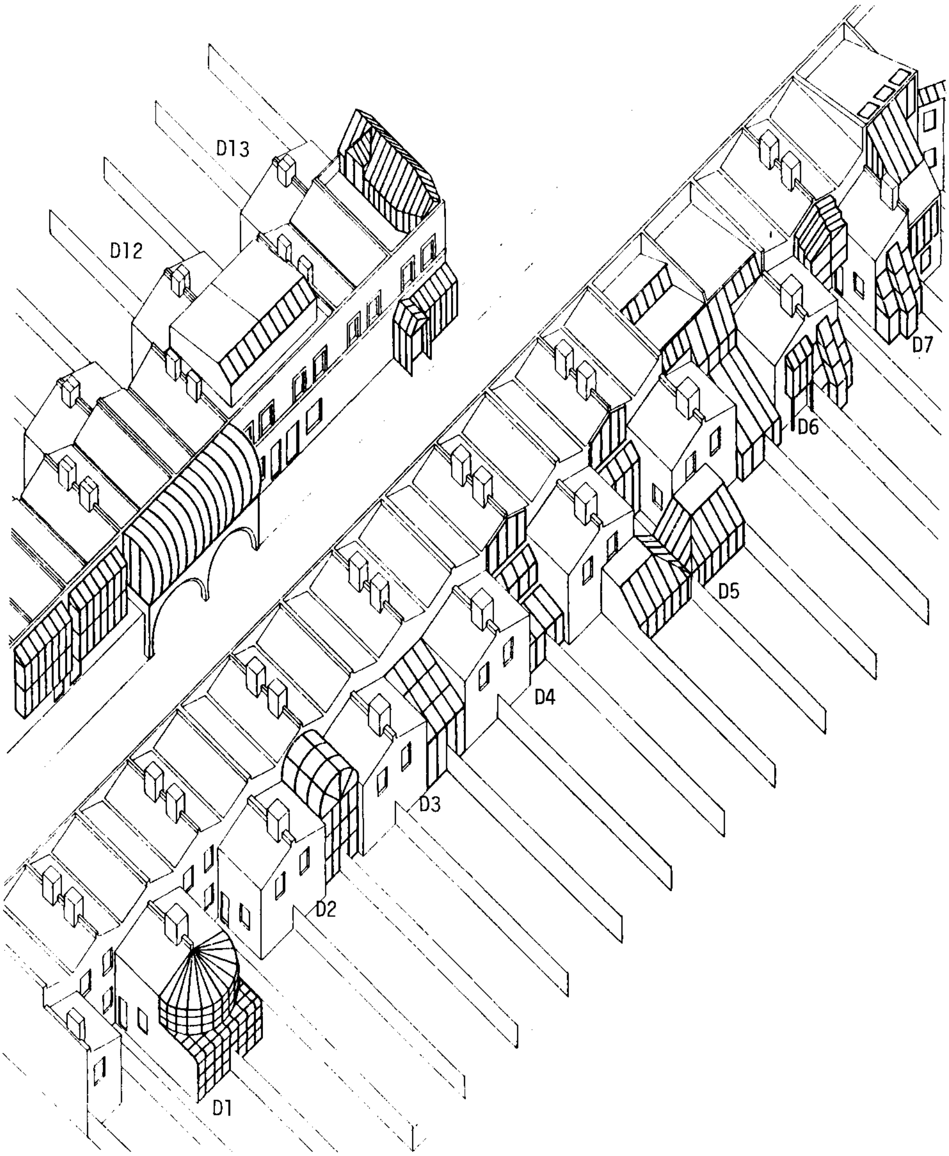


Fig. 1. Collage illustrating the variety of conservatory retrofits produced during the design exercise.

distracting in the context of a short design exercise. Rules of thumb reported in textbooks and conference proceedings have been mostly of American origin and their application in other contexts can be misleading. In Britain, there are as yet no established calculation procedures or design handbooks; much of the research work required to produce these is still in progress.

Participants at the exercise were, therefore, not required to undertake thermal calculations during design but relied instead on the handouts and on tutorials for general guidance. For further support during design development and for final evaluation of designs, two micro-computer programs were selected for application with the APPLE II. In this paper we refer to the use of one of these; the SCRIBE system, developed by Cedric Green (Green, 1982). SCRIBE incorporates modules for daily and seasonal simulation using user-defined thermal network models of up to ten nodes, as well as graphics modules with the capability to draw "solar projections",- parallel projections of buildings as viewed from the sun's position.

THE DESIGN SCHEMES

Thirteen schemes were produced during the exercise, featuring twenty two individual conservatories. A collage of all of the designs is shown in Fig. 1.

None of the schemes was developed beyond the stage of sketch design. Given the time required for modelling and simulation, detailed quantitative assessment of each scheme was impractical as well as unnecessary. The procedure of evaluation that was adopted consisted first, of assessment of each scheme against empirical criteria and of tabulations and comparisons of key parameters (the location and size of the solar aperture, the area of building envelop enclosed by the conservatory etc). This analysis identified a number of specific problems in individual schemes as well as commonly shared features and errors.

Second, from the results, two conservatory models were selected (Fig.2) and thermal simulations were carried out separately on six variants of each to assess the performance and fuel savings achieved by the conservatories as a function of location, aperture, number of glazings, thermal capacity, mode of heat transfer and the level of thermal insulation in the house.

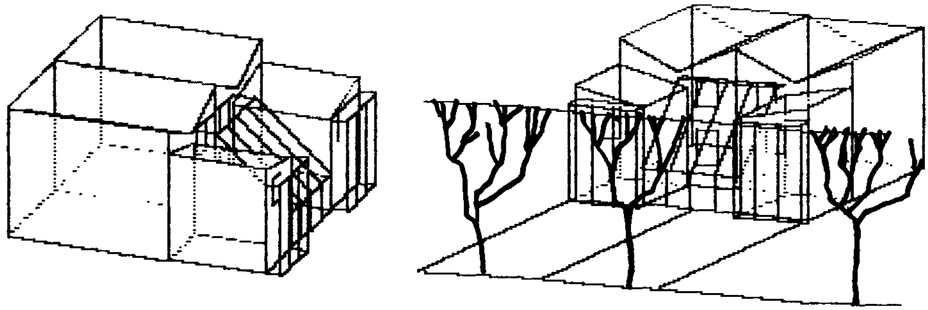
Third, 'solar projections' of the buildings and conservatories were obtained using the SCRIBE programs. These were produced for different months at two hourly intervals of mid-month days and used for visual assessment of shading of the conservatory apertures by other building elements or trees (Fig. 2)

Evaluation of the Designs

a) In all the schemes the conservatory became an important, sometimes even dominant architectural feature. With some of the designs the result was a distortion of the character and structure of the original house. In others, the integration of the conservatory was achieved without fundamental changes to the existing structure.

b) Overshadowing seems to have been recognised as a serious problem and its avoidance became an important factor in siting the conservatories as witnessed by the number of roof-top conservatories. None of the latter, however, was considered economically feasible in the context of this design brief.

c) Some conservatory designs incorporated glazing which will not give net benefits



(a) (b)

Fig.2. Two views of a pair of houses showing the courtyard and the extension conservatories assumed for the simulations. The drawings were produced by the SOLPRO module of SCRIBE and illustrate shading of the conservatories by other building elements and by trees for a) 1700 hours on June 15th and b) 1200 hours on December 15th.

from solar gains due to poor orientation.

d) Five of the schemes contained more than one conservatory as a strategy for simplifying the problem of heat distribution.

e) In some schemes the conservatory was incorporated into the living area and could lead to large temperature fluctuations and an increase in heating requirements.

f) Few of the schemes made provisions to prevent summer overheating. Thermal simulation showed temperatures above 40°C inside the conservatory in some designs during summer days.

g) Taken together the designs illustrate a rich variety of options available for possible solar retrofit projects. Some of the designs may be of interest also in the context of terrace houses of a different type. The roof-top designs in particular would be more appropriate for the more common types of pitched roof construction in London.

None of the participants considered pulling down the extension and redesigning the entire rear area of the house.

h) Several of the designs incorporate features which would be worth developing further. This is particularly true of D2 (Fig.1).

This design, however, along with others of the courtyard conservatories assumes that the conservatory is to be shared between two adjoining houses.

THERMAL SIMULATION

The results of the simulations, expressed in terms of annual back-up heating requirements, are given in Fig. 3.

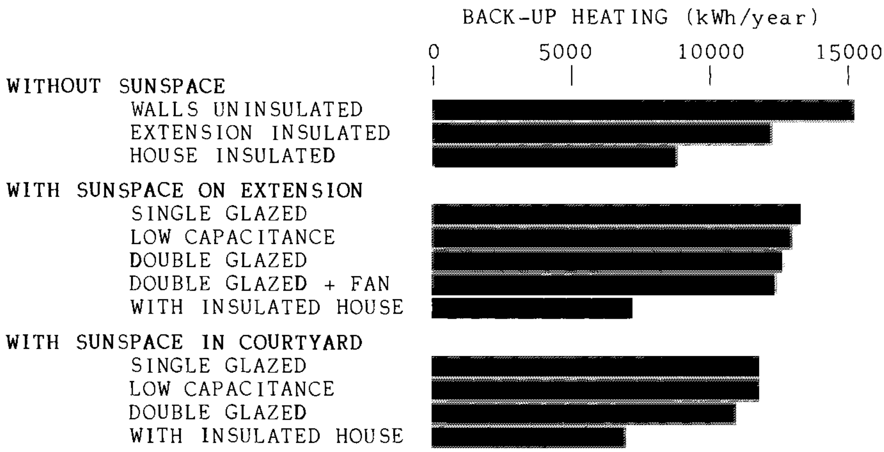


Fig. 3. Comparison of simulated annual auxiliary heating (in useful heat) for the cases modelled.

The courtyard conservatory was shown to achieve higher savings than the extension model, - 300 KWH per square metre of solar aperture compared to 127 KWH. This is because the courtyard conservatory, which encloses a larger surface area of the house, performs more effectively as a thermal buffer.

The savings achieved by the conservatories were comparable to insulating the external walls of the extension block, but substantially lower than insulating all the house walls[1]. With whole house insulation the savings attributable to the conservatories dropped to 145 KWH per square meter of solar aperture for the court yard design and to 91 KWH for the extension. However, it would be very rare for a Housing Association or Local Authority to insulate a whole house.

The addition of double glazing or of a fan did not seem to be worthwhile in general, although they might play an important role in particular cases. Also, the savings did not appear to be sensitive to changes in the thermal capacity of the sunspace.

Obstruction to Solar Access

a) There is overshadowing of the courtyard by the extension block and conservatory attached to it, especially during morning hours in mid-winter. Shading would increase the more the conservatory is set back into the courtyard. The problem

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1. U-values of uninsulated walls 2.1. W/m^2K, with insulation 0.66 W/m^2K; roof U-value 0.35 in all cases.

is overcome in designs which enclose the whole courtyard, such as D2, and is also avoided by roof-top designs.

b) On the north side of the street there is shading of the front facade up to first floor during part of the heating season.

c) The row of trees along the southern border of the site also represents an obstruction to conservatories below first floor level, especially those located on the extension.

d) With the conservatories fully shaded from direct radiation annual savings were reduced by about 40 per cent.

e) None of the obstructions cast any significant shadows during summer months and provisions must be made for summer shading to avoid overheating.

Discussion

Passive solar retrofitting is still a marginal economic exercise in the U.K. Establishing a convincing economic case will require attention to the unique characteristics of specific projects and design ingenuity in integrating energy-saving features with other architectural requirements. With their limited experience and within the span of a few hours over the two days of the workshop, participants were faced with a challenging design problem and had to make decisions on a number of difficult questions. Few had time to take advantage of thermal simulation and earlier difficulties with running the programs prevented us from offering a predesign assessment of possible design strategies.

Since some decisions had to be made without sufficient knowledge of their implications, many participants seem to have preferred to concentrate on form and less on feasibility. However, most of the schemes show that a great deal of thought was given to designing the conservatory and its integration with the existing building. In discussion after the event all the participants felt that they had learnt a lot from the exercise and would gladly repeat the experience. Despite the rather heavy constraints that it posed, the design brief was found very appropriate and none of the participants rejected it in favour of the alternative of a new house design with few constraints. In assessing the exercise as a whole we found that it did come up with some innovative ideas - on the siting, form or uses of the conservatory -, illustrating possibilities for imaginative retrofits, as well as the practical limits to housing rehabilitation. Detailed development of these ideas is, however, an exacting task that is probably outside the scope of such short courses.

In the time allotted, thermal simulations were undertaken on only a few of the design schemes. A number of simplifying assumptions had to be made in modelling the complex geometries of the conservatories. Except for directing attention to summer overheating, the results of these simulations came too late to affect design proposals. The simulations carried out after the exercise did not alter our empirical assessment of individual schemes in any fundamental sense. They did, however, provide a numerical basis for establishing the relative importance of the characteristics we had considered. This type of information, based on modelling of a few typical conservatory cases, would be a very useful input from the outset of such exercises helping to direct participants.

ORGANIZING THE DESIGN EXERCISE

The design exercise required extensive preparation, as well as considerable time for assessing individual designs and for modelling and simulation. To some extent the length of preparation and of staff involvement seemed to be inversely related to the length of the event. Given, however, the results and documentation of this pilot exercise subsequent events could be run, on the same or similar design brief, more effectively and with little additional preparation. It would seem sensible to plan such workshops for multiple repetition to avoid the need for high participation fees.

Modelling and simulation can easily become the most time consuming activities for the staff running the workshop. The programs used in this workshop required several days for familiarisation and were rather slow in operation. Programs based on simplified calculation procedures can be faster and perhaps more appropriate for assessing options at sketch design level. We are at present studying an updated version of SUNPAS (Solarsoft Inc., 1983), a program specifically written for passive solar design analysis and based on the Solar/Load Ratio correlation technique (Balcomb and others, 1983). The program appears to be suitably fast and easy to use. An earlier version of SUNPAS was rejected because of its poor treatment of conservatory designs. There are still problems in that the SLR method has not been validated for European conditions and that SUNPAS does not operate in metric units. The suitability of European programs based on other simplified methods, such as the Methode 5000 (Claux and others, 1982), needs to be investigated.

The SCRIBE simulation programs, on the other hand, have been validated experimentally in Britain (Green and Riley, 1982) and the system as a whole offers a rare combination of drawing and calculation capabilities which make it a very powerful tool and an attractive option for small architectural practices. In workshops that might combine passive solar design with hands-on experience of microcomputers, SCRIBE could carry participants through to final design stage (with plans, sections, axonometrics, details) and detailed calculations with only occasional use of pen and paper.

For this pilot exercise, the length of time spent in designing was to a large extent determined by the participants themselves. Due to other commitments, very few of them were able to devote more than ten hours altogether to design. In commenting on the exercise, they all wished they could have put more time into developing their designs. The length of the course, therefore, is largely a function of participants' needs and time limitations. A very short course may still be the only viable option for some practicing architects. Working in teams, including an expert, could allow design to proceed faster and into greater detail.

For practicing architects who can take half or one day a week off from their offices for one or two academic terms, courses can be planned to allow more time for designing and thermal evaluation and to ensure better retention on the part of participants. This format is now being discussed for new courses planned at the AAGS for the next academic year. For full time students, the longer courses are both more appropriate and easier to prepare, especially if integrated with other parts of architectural training.

CONCLUSION

The combination of a lecture course and design project into a workshop provides a good framework for introducing architects to the principles of passive solar design. Where the supporting material is not readily available in the form of design handbooks and analytical tools, organising the workshop requires extensive preparation. The length of preparation does not decrease and may even increase for shorter courses. To be economical such courses should be planned to be repeated several times using the same design project and supporting material.

Unless participants had had previous experience in passive design the quality of their designs depends directly upon the support provided by the course and time spent designing. Housing retrofit is a relevant topic likely to be popular as a design project. The difficult design problems it can pose should not be underestimated.

Pilot design exercises such as the one described here can be instrumental in identifying such problems and in providing material that can help assess design options faster and more accurately in subsequent workshops. Working in teams under an expert could be an additional way for identifying appropriate solutions and can be expected to produce more detailed designs in a shorter period of time than working individually. Where feasible, courses extending over a longer period can be more effective.

The availability of fast, easy to use and flexible computer programs is crucial if thermal (and economic) analysis is to be part of the design process rather than a form of final evaluation. A system such as SCRIBE, which combines drawing capabilities with thermal analysis, offers the possibility to organise the course as a workshop in computer-aided design, but is less effective as a medium for quick thermal analysis at sketch design level.

ACKNOWLEDGMENT

The design exercise was partly funded by the Energy Technology Support Unit (ETSU) of the UK Department of Energy and organised in collaboration with A5 Architects. Fig. 1 was drawn by Alejandro Aguirre Pina from drawings produced during the design exercise.

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ARCHITECTURAL MEANS FOR ENERGY CONSERVATION IN RECENT DUTCH HOUSING PROJECTS

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ABSTRACT

A systematic description of some developments in the field of energy-conscious design in recent Dutch housing-projects is presented.
A method of description has been developed, based on a theoretical model of architectural space. The descriptionmethod may be useful in other design-situations.
In the last decade concepts for Dutch energy-efficient houses can be distinguished.

KEYWORDS

Energy-conscious architectural design; energy concept; housing; domain theory; The Netherlands; design policy; design methods.

INTRODUCTION

The description of developments in the field of energy-conscious design could easily lead to an endless enumeration. To prevent this a method to describe plans in a systematic way has been developed. The conceptual model of the "domain-theory" is the theoretical base for this description-method.

A MAP OF ARCHITECTURAL SPACE

The domain-theory (Bax, Trum, 1982) offers a map of architectural space. Besides architectural design is considered to be a policy-making process.
In the map a spatial world and a human world have been distinguished.
The term order is coined for those particular parts of both the human and the spatial world that are comprehended, controlled and changed by man.
In the human world several orders may be distinguished, for example a social order and an economic order. The spatial world is considered to comprise only a spatial order.
The spatial order is divided in levels or scale regions. The spatial order contains spatial elements. They may be characterised in terms of functions.

There are three categories of functions of spatial elements: utility, durability and feasibility. These categories will be called domains.
In the field of energy-conscious architectural design the functions related to durability, that is maintaining accomplished spatial conditions and combatting unwanted changes, have a special meaning. In the durability-domain three kinds of constructional elements can be found:

- Support elements, which ensure the preservation of form.
- Separating elements which have an insulation function, in order to preserve environmental conditions they prevent transport of noise, light, moisture, heat, etc..
- Installations which preserve environmental conditions by means of transport of matter and energy.

ARCHITECTURAL DESIGN AS A POLICY MAKING PROCESS

The architectural design is considered to be a process in which policy is established. Policy in this respect is the allocation of values in the various areas of the architectural design field. An architectural element is a means to reach certain preconceived purposes. Energy-efficiency is one of the sub-goals to be reached in the design of an architectural artifact.
In each domain or even in a part of a domain an aspect-design can be made. In the durability-domain it is possible to distinguish a constructional design and, as a part of the constructional-design, an energy-design.

PATTERNS

Within every problem there can be found smaller problems or sub-situations, and for each of them solutions might also be found. Problemsolving usually consists of resolving lots of small situations leading towards a collective end or goal. Patterns are typical solutions to individual parts of the problem. Patterns can be developed or found wherever previous experience or a collection of bits and pieces exists.
The means-end approach enables to relate the individual patterns in a means-end hierarchy.
For example: The sub-goal is energy-efficiency. It can be reached by:
A. Minimizing winter-heatloss.
B. Maximizing the benefits of solar heatgain in winter.
Sub-subgoal A. can be reached by means of:
<u>A.</u> Minimizing heatloss due to infiltration and ventilation.
<u>B.</u> Minimizing heatloss due to transmission.
Sub-subsubgoal <u>A.</u> can be reached by means of:
A' Earth berms.
B' Airrecirculation systems.
C' Evergreen trees.
D' Draught screens.
And so on.

CONCEPTS

Not all possible patterns are applied in an energy-design. In a design a useful and effective combination of patterns is desirable. Fundamental different combinations of patterns are called concepts.
It is possible to distinguish concepts in every domain or subdomain, in every aspect-design. The term "concept" enables to relate the various areas of the architectural design field.

METHOD OF DESCRIPTION

In the description of each concept the following items are discussed:

1. Energyconcept: Which patterns have been used to reach the energy aims.
   The patterns are clustered in two ways:
   a. To their effect on the heatbalance:
   - Decreases winter heatloss due to transmission (A)
   - Decreases winter heatloss due to ventilation and infiltration (B)
   - Increases winter solar-heatgain (C)
   - Provides an efficient auxilliary heating system (D)
   - Maximizes the benifits of internal heat sources (E).

   b. To the architectural levels on which they occur:
   - Urban lay-out (I)
   - Building (II)
   - Detail (III).
2. Relations to other concepts:
   a. Utility (X)
   Which kind of use is assumed.
   b. Feasibility and durability (Y)
   Which special technologies have been applied.
   c. Human world: (Z)
   - Economic order.
   - Social order.
   - Ideological order.
   - Political order.

RECENT DUTCH ENERGYCONCEPTS

In the last decade various concepts for Dutch energy-low houses can be distinguished.

1. *Standard*
   Energyconcept:
   According to the current Dutch standard.
   Insulation of walls and roof 4 - 5 cm (A/II).
   Double glazing groundfloor windows (A/II).
   2600 m3 natural gas/year.
   Relations:
   Other concepts as usual, no special technologies (Y), no special use (X).

2. *Improved insulation*
   Energyconcept:
   Insulation of walls and roof 6 - 8 cm (A/II).
   Insulation groundfloor 4 - 5 cm (A/II).
   Double glazing (A/II).
   Caulked construction joints and gaps (B/III).
   Weatherstrips on doors and windows (B/III).
   1700 m3 natural gas/year.
   Relations:
   See standard.
3. *Active*
   Energyconcept:
   See improved insulation, + solar collectorsystem (C/II).
   1000 m3 natural gas/year.
   Relations:
   Special installation necessary. Other concepts as usual. High investments, not economic. Mid-seventies solutions. Trust in technologies.

4. *Radical Passive*

Energyconcept:
Good insulation of walls, floor and roof 10 cm (A/II).
Special glazing (A/II).
Insulating shutters (A/II).
Solar friendly urban lay-out (C/I).
Passive solar systems like greenhouses, large windows on south (C/II).
Thermal zoning (A/C/II).
Mechanically controlled ventilation (B/II).
Air locks (B/II).
High efficient heating system (D/II).
High thermal mass (E/C/II).
600 a 700 m3 natural gas/year, only a small contribution of solar energy (15 - 20 % of total heat load), in spite of special solar energy systems.
Relations:
Special use is assumed, energy responsive life-style, often an ecological ideology, recently also in "high-tech", expensive passive solar systems are not economic, late seventies solution.

5. *Super Insulation*

Energyconcept:
Very good insulation of walls and roof (20cm) (A/II).
Good insulation of groundfloor (12cm) (A/II).
Special glazing (A/II).
Insulating shutters (A/II).
Small north windows (A/II).
Passive solar windows on south (A/II).
Thermal zoning (A/C/II).
B,D, E see radical passive.
300 a 400 m3 natural gas/year.
Relations:
Special use is assumed, energy responsive life-style, special technologies are necessary, economic under special conditions, early eighties solution.

6. *No Nonsense*

Energyconcept:
See radical passive but without passive solar systems and shutters.
800 a 1000 m3 natural gas/year.
Relations:
No special use is assumed, early eighties solution, inspired by economic crisis and no-nonsense policy, combined with cheap building technologies and simple urban lay-outs, presented by the large building-companies and housing co-operations

7. *Radical Formalism*

Energyconcept:
See improved insulation, radical passive or super insulation.
Special architectural forms, like balls and pyramids.
Relations:
Presented by architects, pseudo-architecture.

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BTPI - A BUILDING THERMAL PERFORMANCE INDEX

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ABSTRACT

The adoption of a method for evaluation of the thermal quality of buildings might be an incentive for building energy management.

In this paper, an empirical method is proposed which qualifies the thermal performance of buildings through the entire year. The thermal quality parameter (BTPI) is intended to be an instrument for the implementation of new energy regulations for buildings, especially for those that are located in areas with mild climate and no heating or air conditioning systems.

KEYWORDS

Building thermal performance; energy policy; building energy management.

INTRODUCTION

The thermal quality of buildings is an increasingly important parameter when comparing the performance of different designs: it allows the characterization of the thermal performance of a building; it represents an instrument for balancing economics and comfort; and it may help in the implementation of policies for building energy management.

Therefore, it is important to adopt a method to evaluate the thermal quality of buildings and more important yet, a method that is simple and easy enough to be implemented in a generalized manner bearing in mind the multiplicity and diversity of education levels of the people that take part in building design and licencing procedures.

The thermal performance of a building should be the result of a compromise between the quality of the structure of the building required to satisfy thermal objectives and the respective economic consequences in terms of initial investment in the building envelope and operating costs of the energy systems. In these buildings, comfort is a precondition, but one can also think about those buildings, where the comfort level is very poor.

According to the traditionally used parameters of thermal qualification, a building is designed to optimize either heating or cooling economics, respectively where heating or cooling loads predominate.

The more conventional parameters for heating purposes are the coefficients U [W/m^2K] and G [W/m^3K], the former taking into account the thermal resistance of the only envelope and the latter including also the air infiltration losses. Both are insulation-related parameters and include neither the consequences of solar protection in summer nor those of solar gains in winter.

The consideration of all main aspects of building thermal performance may demand the adoption of a "parameters list" related to the quality of the thermal response of buildings to the external climatic conditions, as it is proposed by C.S.T.B.* (1976, 1977). The parameters that are usually listed are, in winter: 1. Volumetric heat loss coefficient (transmission + infiltration) - G coefficient; 2. Overall heat transfer coefficient (opaque elements) - U coefficient; 3. Window transmission; 4. Window infiltration; and, in summer: 1. Ventilation requirements; 2. Shading; 3. Thermal inertia; 4. Roof condition (insulation + solar protection).

The CSTB method establishes reference values or reference intervals for the above listed parameters which correspond to acceptable or good thermal performance of the building under given climatic conditions. When any two parameters influence each other the reference values are obtained from double entry tables which lead to the definition of zones of quality regarding the mixed effect of those two parameters.

The CSTB method, in spite of considering winter and summer performance separately, seems apropriate and accurate, at least if all reference values are based on field measurements and audits. Nevertheless, it appears to be too much complicated to be of practical use by all kinds of technical people involved in the building industry.

More recently the B-coefficient (Anquez, 1979, 1981) which takes into consideration the solar heat gains in winter was introduced in France. B expresses the heating needs after the consideration of solar and internal heat gains.

On the other hand, the interest of characterizing the thermal quality of a building by a single figure has been growing. In 1982, Bondi, has proposed a coefficient P_t as an extension of the parameter U. P_t takes into accoun the envelope's thermal capacity and the maximum and minimum inside temperatures, calculated by mathematical models. Compared with the CSTB method, the P_t method still doesn't consider solar heat gains but includes thermal inertia as a winter parameter.

The National Building Research Institute (NBRI), in South Africa, has developed an empirical procedure which is referred to as the CR-method and is based on an experimentally verified correlation $(\alpha_i/\alpha_o)\ (1/R_s) = 48{,}9\ [(\sum C R_s)\ \exp(-0{,}903)]$ established with the ratio of the difference between the mean values of the indoor maximum and minimum dry bulb temperature (α_i) and the difference between the mean value of outdoor maximum and minimum temperatures (α_o) and the product of the active heat storage capacity of the structure as a whole (C), and the weighted or equivalent resistance to heat flow (R_s) of the exposed building envelope (Wentzel and van Straaten, 1982).

Directly or indirectly this method takes into consideration all main factors determining the thermal response of a building: the heat storage capacity; the level of

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insulation of the envelope; the solar heat gains, both direct and indirect; the ventilation rate; the heat gain from internal sources; and finally, the condition of the roof.

In spite of being a method of real interest the CR-method still seems very complicated to be broadly used for licensing of mass housing. Furthermore, while the application of this method does not leave any doubts when a certain type of climatic conditions is clearly predominant, the situation is not as clear when both heating and cooling loads have comparable orders of magnitude.

The thermal characterization (or qualification) can be useful even in those cases where neither heating nor refrigeration are considered. In these cases, the problem consists of verifying whether it is possible and useful to talk of the thermal performance referred to the thermal response of a building during the entire year in a given location.

The generalisation to the entire year seems particularly useful and applicable to the case of buildings in areas of mild climate where the thermal inertia, the sun control and envelope's thermal resistance work at the same side both in winter and in summer. Conversely infiltration is favorable in summer and unfavorable in winter.

That is why we tried to obtain an empirical building thermal performance index, that, rather than having a definite physical meaning, gives a quantitative comparison between the actual building thermal quality and the reference values recommended for given climatic conditions of a particular location.

This method will obviously need further work, including assessment through "in situ" measurements, simulations and audits. Anyway it represents the starting point of a program to define an instrument for energy regulation of new buildings, in particular, residential buildings.

METHODOLOGY

The methodology is illustrated on the flow chart (Fig. 1) and consists of:

1. Portuguese climatic zones are typified for summer and winter and the relative importance of the seasonal loads is selected establishing scenarios of climatic predominance between winter and summer conditions for a given zone. The predominance factors (p_w, p_s) are thus defined.
2. A selection of thermal quality parameters for winter and summer conditions is made, mainly on the basis of CSTB and NBIR lists. According to climatic zones each of those parameters will receive a value designated by reference value (RV);
3. The quality of a given building is characterized by the actual values (AV);
4. The comparison between actual and reference values leads to a set of evaluation values (EV);
5. The evaluation values are weighted by the predominance factors and combined to obtain the "building thermal performance index", BTPI, using the expression

$$BTPI = \frac{p_w \sum_{i=1}^{n/2} E_{wi} + p_s \sum_{i=1}^{n/2} E_{si}}{n}$$

where n is the number of selected parameters with an equal number of parameters (n/2) for each season.

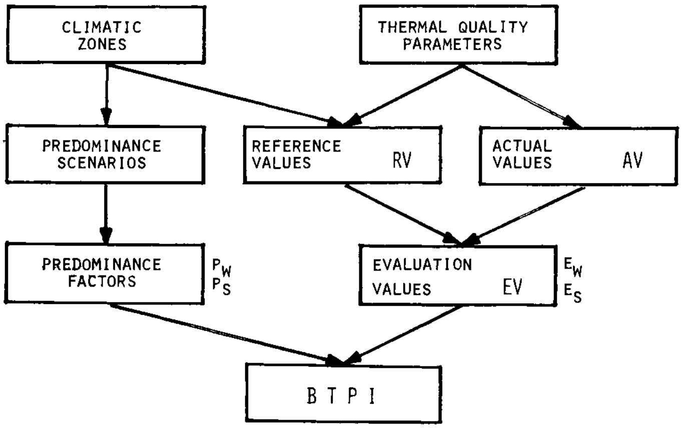


Fig. 1. Flow chart for BTPI calculation

Obviously, the values attributed to (p_W, p_S) and (E_W, E_S) are empirical. According to the criteria adopted the BTPI will vary between 0 and 2, the optimum corresponding to 1. Ideally, values of BTPI less than unity correspond to a building with insufficientthermal quality for that particular location. On the other hand, BTPI values greater than unity correspond to buildings with an economically uninteresting thermal quality. BTPI > 1 is not a statement about heating expenses but rather it means that for the particular location, the building is overinsulated, or has a superheavy structure which cannot be economically justifiable, i.e, equivalent comfort conditions can be obtained with a smaller initial investment.

Without a more accurate verification of the meaning of the reference values and predominance factors a range of BTPI = 1 $\pm$ 10% is considered to be acceptable.

EXAMPLE

Tables 1 and 2 list the parameters that were used in this example. Compared with a previous stage of development (Abrantes and Fernandes, 1982) two new parameters were considered: "solar gains" in winter and "wall absorptivity" in summer.

Fig. 2 shows what kind of evolution results to the BTPI after introducing a specific modification such as the reduction of glazing area; better insulation; the orientation of the glazing area predominantly to south. It is also possible to compare the evolution of the coefficients B and G according to modifications introduced. Only relative values are shown for coefficient B.

For a typical example of a portuguese dwelling the method leads (fig. 3) to the conclusion that the thermal quality of the building is clearly below the acceptable value (BTPI = 1) all over the country.

As described here, Fig. 3 compares results obtained with 8 parameters with the previously referenced 6 parameters. As we could expect the introduction of a fourth pair of parameters smooths the variation of BTPI.

TABLE 1 - REFERENCE VALUES FOR THE WINTER THERMAL QUALITY PARAMETERS

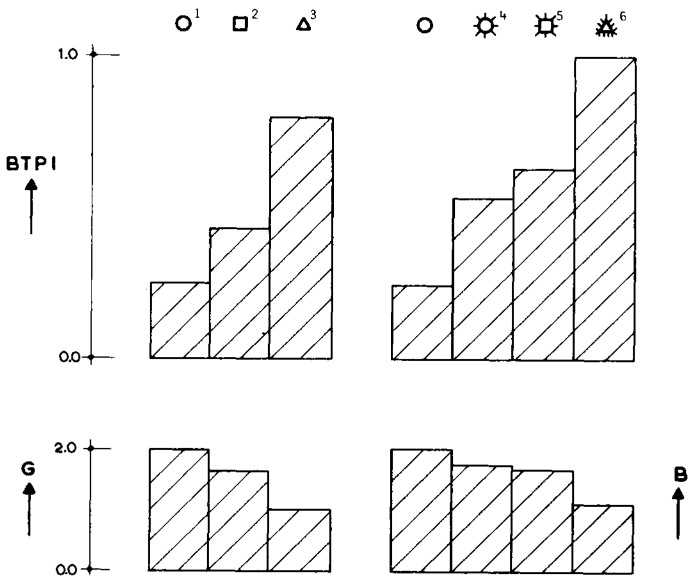
	CLIMATIC ZONES[1]	HIII	HIV	HV
1. Overall Heat Transfer Coefficient [$w/m^2.k$]				
Walls (> 100 Kg/m^2)		1.00	1.15	1.35
Walls (< 100 Kg/m^2)		0.85	0.85	0.85
Roof		0.50	0.70	1.00
2. Window Transmission[2] [$w/m^2.k$]				
Ag/Af < 1/5		4.20	5.80	5.80
Ag/Af > 1/5		3.10	4.20	5.80
3. Window Infiltration[3] [$m^3/h.m$]				
A'g/Af < 1/6		6-12	6-12	-
A'g/Af > 1/6		2-6	2-6	6-12
4. Solar Gains[4] [%]				
Inertia	High	14	12	10
	Medium	12	10	8
	Low	10	8	6

[1]Climatic zones according to $UEAt_C$; [2]Ratio between glazed area and floor area; [3]Ratio between operable window area and floor area. The flow rates were adapted from a $UEAt_C$ classification (1976) and are referred to $\Delta P = 100Pa$ and a window placed less than 6 m above ground level; [4]The reference values listed are ratios between south-facing glazed area and floor area.

TABLE 2 - REFERENCE VALUES FOR THE SUMMER THERMAL QUALITY PARAMETERS

			CLIMATIC ZONES[1]	EII	EIII	EIV
1. Ventilation Requirements[2]						
Inertia	High			S/D	S(ns)/D	D
	Medium			S(vp)/D	D	D
	Low			D	D(ns)	*[4]
2. Shading Coefficient[3] [%]						
Inertia	Ag/Af[1]		Orientation			
High/Medium		< 1/5		45	25	15
		> 1/5		25	15	10
Low		< 1/5	ES(W)	25(15)	15(10)	*[4]
		> 1/5	ES(W)	15(10)	10	*[4]
3. Wall Absorptivity						
Density	< 100 Kg/m^2			-	0.3-0.5	0.2-0.3
	> 100 Kg/m^2			-	-	0.3-0.5
4. Roof Conditions [$w/m^2.k$]						
Inertia	Absorptivity		Density			
High/Medium	$\alpha < 0.3$		-	-	-	0.70
	$0.3 < \alpha < 0.7$		> 200 Kg/m^2	1.15	0.95	*[4]
	$0.3 < \alpha < 0.7$		> 200 Kg/m^2	0.95	0.70	*[4]
	$\alpha < 0.7$		-	0.70	*[4]	*[4]
Low	$\alpha < 0.3$		-		0.70	0.70
	$0.3 < \alpha < 0.7$		-	0.70	*[4]	*[4]

[1]See table 1; [2]S-envelope openings in only one wall; D-idem in at least two walls; (ns)-opening must face north or south, (vp)-small openings only; [4]Percentage of the radiation incident on a glazing which enters the space; [4]Those combinations are not recommended.



[1]typical example
[2]smaller openings
[3]plus better insulation
[456]with solar gains

Fig. 2. Evolution of BTPI with envelope modifications

CONCLUSIONS

The BTPI method leads to results that are within the expectation regarding calculations and previous experiences.

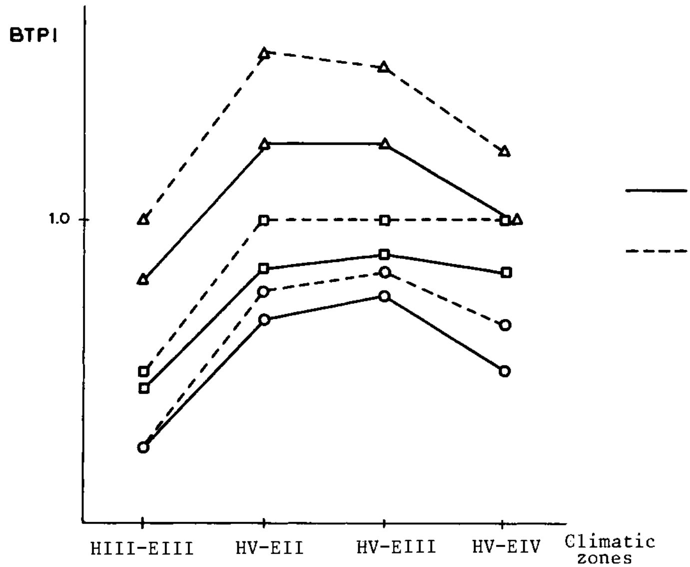
The BTPI is a method that may have application restricted to countries with mild climate, specifically, mediterranian climate.

The BTPI answers several questions posed before: it gives a single figure; it covers the entire year; it considers the sun control, the inertia, the ventilation requirements and the infiltration.

The major limitations associated with the BTPI - method are the difficulties related with:

- the generalisation to the entire year
- the right choices of the number, nature and degree of interdependence of parameters and the subjectivity of establishing climatic scenarios and predominance factors.

Further studies and experiments will allow to check and, eventually, to perfect the method.



— 8 parameters
--- 6 parameters
more symbols on fig. 2

Fig. 3. BTPI values for different climatic conditions

ACKNOWLEDGEMENT

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ANALYZING ENERGY PATTERNS IN SOLAR GREENHOUSE-RESIDENCES

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ABSTRACT

Electric consumption was monitored in a solar greenhouse-residence for the years 1979-1982. The kilowatt-hour use was compared in the solar prototype and the typical, all-electric dwelling using the Schedule RA of the local utility company. The energy use profiles for the solar prototype are consistently lower than its all-electric counterpart. Total house energy costs also follow a similar pattern. Comparison of the solar prototype to the all-electric dwelling demonstrate the potential economic savings of solar greenhouse-residences.

KEY WORDS

Solar greenhouse-residence; electric rate schedule; long-term savings; internal rate of return; payback period.

INTRODUCTION

A solar greenhouse-residence was monitored for the years 1978-1982. Architectural performance, solar energy utilization, horticultural performance and thermal comfort requirements have been subjects of investigation in many solar prototypes. This paper will compare the electrical consumption and total effective cost patterns for a solar greenhouse-residence prototype to the average, all-electric home located in the Piedmont Region of North and South Carolina. Using the historic energy use and cost data from the prototype and utility company, projections of long-term economic savings will be determined. The analysis will identify energy use profiles as a function of seasonal demands and the electric rate structure. The extent of energy conservation in the prototype will be analyzed and will determine, in part, if the additional capital investment in the solar greenhouse-residence is financially viable.

DESCRIPTION OF PROTOTYPE

A solar greenhouse-residence was built and occupied in November 1978 and is located four miles west of Clemson, South Carolina, USA. Design criteria for the building have been discussed in previous reports (Zornig, Davis and Bond, 1976). The building is classified as a "hybrid" solar distribution system. The design consists of a greenhouse (27.9m^2) and house (128.8m^2) with their thermal environments integrated during the winter months. The passive solar features provide 62% of the total house and greenhouse heating requirements. During the summer months, the greenhouse and house environments are independently vented. The horticultural design features of the prototype have been reported in earlier reports. The market value of the vegetables produced in the solar greenhouse averages $260 a year (Ezell and colleagues, 1979). The house air distribution system is composed of an independently controlled solar collector and house heating/cooling system. During the heat collection mode, excess heat from the greenhouse is moved to the house or rock storage. A differential thermostat activates a damper and collector blower. Auxiliary heating and cooling is provided by an electric source heat pump. The heat pump air handler also distributes solar heat to the house and is controlled by a combination two-state (2°C increment) heating and cooling thermostat. The heating thermostat was set at 20°C, and the cooling system thermostat was set at 25°C.

Comfort levels in the prototype have been determined not to be static, but dynamic in that "skin-load" exposure to seasonally (and daily) changes in the weather are reflected internally. Studies have indicated the prototype thermal comfort levels fluctuate within acceptable limits (Davis and Godbey, 1982). There are times of the year when auxiliary heating or cooling is required. These normally occur during January and February for auxiliary heating, July and August for auxiliary cooling. However, the auxiliary energy input (i.e. use of electric heat pump) is substantially reduced from that of conventional housing.

DESCRIPTION OF ELECTRIC RATE SCHEDULE

The electric service to the prototype is provided by the Blue Ridge Electric Cooperative, which purchases its energy supply from Duke Power Company. Since the Blue Ridge Electric Cooperative could not provide monthly summaries of their all-electric houses, it was decided the minor differences in the utility company's rate structure would not substantially effect the analysis. The rate schedule used in this discussion is the all-electric Schedule RA rate as determined by Duke Power Company. This rate schedule applies only to residences, condominiums, mobile homes, or individually metered apartments in which the energy required for all watering, cooking and environmental space conditioning is supplied electricity (Duke Power Company, 1983). The residence is to be insulated so that heat losses (as calculated by the utility company's heating manual or the current edition of the ASHRAE Guide) shall not exceed 0.158 watts (0.539 BtuH) per sq. ft. of net heated area per degree F temperature differential. The utility company furnishes a 60 Hertz Service through one meter, at one delivery point, usually single-phase, 120/240 volts. The rate structure used during the period covered by the analysis is listed in Table 1.

The rate structure, which is considered "inverted", sets the cost of the first 1000 kWh of use per month at a lower rate than the cost of all use over 1000 kWh. All rate increases are presented to and approved by the South Carolina Public Service Commission prior to implementation.

TABLE 1 South Carolina Retail Rate Schedule RA - 1979 to Present (1)

Effective Date from	Effective Date through	Basic Facilities Charge $/Bill	Energy Charge, ¢/kWh 0-1000 kWh	1000 kWh	Rate Schedule Revision No. (2)
1-01-79	1-31-79	4.30	3.2104	3.5104	21* (-.0413 ¢/kWh)
2-01-79	2-28-79	4.30	3.3234	3.6234	21* (+.0717 ¢/kWh)
3-01-79	3-31-79	4.30	3.1533	3.4533	21* (-.0984 ¢/kWh)
4-01-79	4-30-79	4.30	2.9666	3.2666	21* (-.2851 ¢/kWh)
5-01-79	5-31-79	4.30	2.8713	3.1713	21* (-.3804 ¢/kWh)
6-01-79	9-30-79	4.30	3.2517	3.5517	21
10-01-79	5-31-80	4.30	3.3878	3.2766	25
6-01-80	1-27-81	4.30	3.2622	3.6010	25/26
1-28-81	5-31-81	4.45	3.3900	3.7500	27
6-01-81	10-17-81	4.45	3.6662	4.0262	28
10-18-81	11-30-81	4.85	3.9713	4.3637	29
12-01-81	5-31-82	4.30	4.2254	4.6054	31
6-01-82	9-14-82	4.30	4.3007	4.6807	32
9-15-82	11-30-82	5.05	4.5553	5.0153	35* (+.0502 ¢/kWh)
12-01-82	5-31-82	5.05	4.5051	4.9651	35

(1) Source: Duke Power Company, Charlotte, NC
(2) Fuel charge using rate schedule revision no. 21 as base
* Adjusted to approved fuel cost level

Electrical power meters were installed in the prototype to measure power consumption used by the total house, the heat pump compressor unit, heat pump air handler and the solar collection blower. Only the total house electrical demand, i.e. solar electric consumption, heating and cooling, domestic hot water and lighting is discussed in this paper. Table 2 shows the average monthly kilowatt hour

TABLE 2 Average Monthly Kilowatt Hour Comparison

Year	Month	Utility Co. Schedule RA (1) Actual	Adjusted to Normal (2)	SGR Actual	Year	Month	Utility Co. Schedule RA (1) Actual	Adjusted to Normal (2)	SGR Actual
1979	J	2,618	2,639	1,629	1981	J	2,660	2,409	1,335
	F	2,904	2,486	1,340		F	2,539	2,380	1,110
	M	2,415	2,212	946		M	1,839	1,993	969
	A	1,407	1,614	700		A	1,438	1,446	766
	M	979	1,114	654		M	919	1,031	717
	J	964	1,014	757		J	1,080	980	661
	J	1,027	1,234	844		J	1,359	1,157	656
	A	1,269	1,299	1,108		A	1,366	1,331	852
	S	1,180	1,197	828		S	1,118	1,226	763
	O	950	986	725		O	994	976	698
	N	1,254	1,242	1,160		N	1,205	1,181	972
	D	1,796	2,005	1,464		D	1,890	1,770	2,048 (3)
Total		18,790	19,043	12,155			18,407	17,880	11,547

Year	Month	Utility Co. Schedule RA (1) Actual	Adjusted to Normal (2)	SGR Actual	Year	Month	Utility Co. Schedule RA (1) Actual	Adjusted to Normal (2)	SGR Actual
1980	J	2,275	2,431	1,542	1982	J	2,597	2,320	1,362
	F	2,482	2,347	1,211		F	2,431	2,297	892
	M	2,279	2,023	926		M	1,831	2,003	794
	A	1,459	1,439	701		A	1,439	1,414	710
	M	981	1,041	646		M	1,043	1,010	656
	J	998	1,018	819		J	1,024	999	976
	J	1,246	1,247	1,187		J	1,193	1,215	1,294
	A	1,474	1,303	1,051		A	1,294	1,350	871
	S	1,334	1,189	892		S	1,120	1,139	762
	O	1,116	925	667		O	969	999	832
	N	1,283	1,177	1,025		N	1,177	1,162	859
	D	1,940	1,861	1,272		D	1,522	1,748	1,006
Total		18,867	18,001	11,939			17,640	17,710	11,014

(1) Source: Duke Power Company
(2) Adjusting the actual kWh/customer for differences from normal use to the length of the billing period and degree hours in the month of billing
(3) Billing period of 40 days, usual billing occurs monthly

consumption of both the solar prototype as compared to the average, all-electric home in the region. These figures represent monthly billings. For the economic analysis, the "adjusted to normal" figures were used. These figures are calculated by adjusting the actual kilowatt hours per customer for the differences from normal due to the length of the billing period and the degree hours in the month of billing (Duke Power Company, 1983).

RESULTS

Electricity use and costs for the prototype passive solar greenhouse structure and the average, all-electric home are compared. In addition to comparing the actual electrical consumption and costs over a 4-year period for these two structures, the 4-year electricity use patterns will be averaged into an "average year use." This "average year use" data will be used to analyze the economic savings of the passive solar greenhouse structure over a 25-year period, assuming the 4-year use electric pattern is relatively stable. Long-term savings (difference in total system cost over a 25-year period), internal rate of return (interest rate that specifies the level of savings that results from project expenditures) and payback period (time required to amortize the initial capital outlay from annual energy cost savings) are estimated under specified electricity rate levels. The levels of actual electricity use over a 4-year period in the solar prototype and typical, all-electric house are shown in Fig. 1. This graph displays a consistent pattern of lower electricity use in the solar house that has only one exception over 48 months of data. The average monthly difference in use was 565 kWh with a range of -79 kWh (i.e. 79 kWh more being used by the solar house) to a maximum monthly maximum monthly difference (or savings) of 1405 kWh. It can be seen in Fig. 1 that

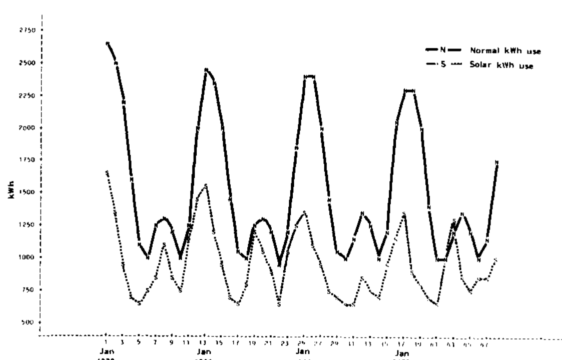

Figure 1. Plot Of Solar Prototype And Normal, All Electric Residential Usage By Month (January 1979 - December 1982)

largest savings came in the winter months. The average reduction in electricity consumption from the all-electric to passive solar residence of 565 kWh/month represents 37% less electricity usage in the solar residence.

During the 4-year data collection period between January 1979 and December 1982, electricity rates increased by about 40%. One effect of this increase may be noted in the peak utilization levels shown in Fig. 1. For both prototype houses, peak monthly consumption (observed in January of each year) had declined. For the solar residence, use fell from 1629 to 1335 kWh per month. For the all-electric house, peak usage fell from 2639 to 2320 kWh per month. The rate of decrease has fallen, however, for the last year of comparison. This reduction in peak use, while rates are increasing, illustrates the limited price elasticity of electrical demand.

For ease of analysis, 4-year electricity use data were summarized into an annual or average use year. Figure 2 illustrates this pattern of electricity consumption. This annual average clearly indicates the points noted above: lower electricity usage for the solar system, similar overall patterns and greatest savings in the months when heating is necessary.

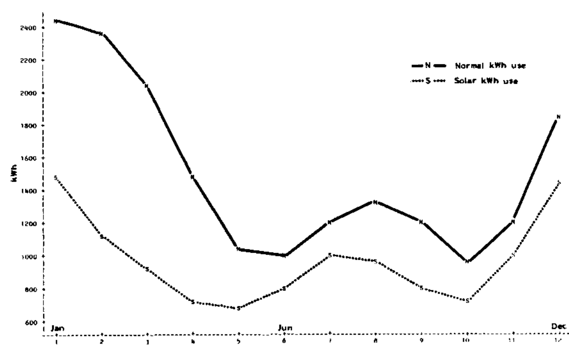

Figure 2. Average Monthly Use From Four Years of Data For One Year

Actual cost for electricity between 1979 and 1982 in the two prototype houses is shown in Fig. 3. The general pattern observed is the higher level of monthly electricity cost associated with the all-electric systems. These differences are particularly striking in the winter months. While the average monthly cost difference over the 4-year period between the two systems is $22, peak month winter cost savings of the solar system range between $42 and $64. Again, only in one month, July 1982, was the cost (and consumption) greater for the solar residence. The cost differential for this month was one dollar. Due to the rather consistent increases in electricity rates, the reduction in (peak) usage over time has not led to a decrease in cost for either system. The overall difference in monthly

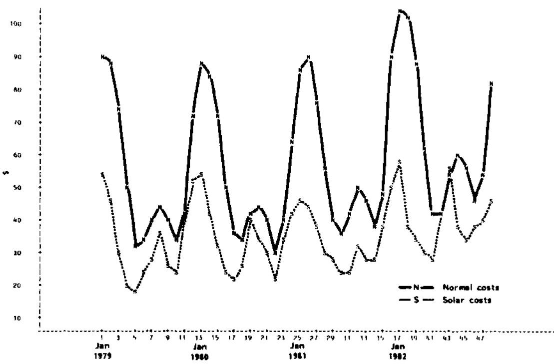

Figure 3. Solar Costs vs. Normal All-Electric Residential Costs By Month (January 1979 - December 1982)

cost between the solar and all-electric systems has not increased or decreased greatly. However, it appears that the variability of cost savings has been increasing over the 4-year period. This is probably due to the greater number of recent rate increases as shown in Table 1.

Estimating the economic savings of the passive solar, greenhouse system over the all-electric heating system is a major focus of this paper. The basic economic equation considers the levels of initial investment, maintenance costs and electricity costs for each system. The difference in total system costs over an assumed 25-year life of each system is the cost savings of the solar system. This is illustrated in the following equation:

All-Electrical System Costs - Solar Systems Costs = Solar System Savings

or

$$K_e + OMR_e + C_e = K_s + OMR_s + S + C_s \quad (1)$$

where: K = capital cost or the initial cost of each system

OMR = maintenance costs

C = electricity costs

S = savings of the solar system

and subscripts are as follows: e = all-electric system

s = solar system

Because the maintenance costs for the two systems are assumed to be equal, equation (1) reduced to the following:

$$K_e^{(p)} + C_e^{(a)} + = K_s^{(p)} + C_s^{(a)} + S^{(a)} \quad (2)$$

The superscript (p) denotes a present value or current cost, while (a) denotes a cost value expressed in annualized terms.

Based on local equipment and installation costs, the initial cost (at 1978 prices) of the solar system is $5,000, and the comparable cost of an all-electric system is $3,200. Electricity costs are estimated over the 25-year period using the "average use year" calculated from the 4-year data and applied the current (April 1983) RA rate structure of the utility company. Over the past four years, the utility company rates have increased by about 10 percent annually. To provide a realistic range of cost estimates, three rate structures are used to estimate life cycle costs. Current rates over the entire 25-year period provide a lower limit on rates. A second rate structure assumes a 5 percent annual increase, which is a conservative inflation level for electricity costs. The highest level of assumed rate increases is continuation of the 1979-1982 trend of 10 percent annual rate increases. For the purpose of analysis, monthly values of electricity costs are aggregated to annual figures.

Standard techniques of engineering economy were applied to equation (2) and annual savings of the passive solar system over the all-electric system were computed. The estimation of savings indicates the net difference between a higher initial expenditure of $1800 for a system that yields constantly lower electricity costs of $316/year under the current rate levels. The results of these analyses are summarized in Table 3. At 9 percent interest rate (which is the initial mortgage rate of the solar house), annual savings, including amortization of the added capital cost, range from $133 at constant electricity rates to $381 for 10 percent annual increases in rates. From the table, one can see that as interest rates (or opportunity costs) of capital increase, the annual savings of the solar system decrease.

A second way of estimating the economic attractiveness of the added initial investment required for the passive solar greenhouse system is to compute the internal rate of return. With a 5 percent annual increase in rates, the $1800 initial investment pays a return of 22% in terms of reduced energy costs over the 25-year period. The rates of 17 to 24% for other levels of electricity rate increases are clearly attractive levels of return for such a low risk investment.

A third means of viewing the economic viability of the solar option is the payback period, or time required to amortize the initial capital outlay from annual energy cost savings. At the 9 percent interest rate, the payback period ranges from 6-1/4 to 8-13 years, depending on the level of utility rate increases. As noted in Table 3, even at a very high interest rate of 15 percent, the solar system still has a reasonable payback period.

TABLE 3 Economic Comparisons of Passive Solar Greenhouse-Residence and Schedule RA-All Electric Residential System (1)

Economic Measures	Electricity Rate		
	Constant Rate (2) (1983 Level)	5% Annual Increase over 1983 level	10% Annual Increase over 1983 level
1. Annual Savings of Solar System at Specified Interest Rates:			
9%	$135	$257	$381
10%	$118	$236	$354
12%	$ 87	$194	$301
15%	$ 38	$131	$224
2. Interest Rage of Return for Added Investment in Solar System:	17%	22%	24%
3. Payback Period for Added Solar System Investment at Specified Interest Rates:			
9%	8-1/3 years	7 years	6-1/4 years
10%	8-5/6 years	7-1/3 years	6-1/2 years
12%	10-1/5 years	8 years	7 years
15%	13-5/6 years	9-1/2 years	8 years

(1) Based on 4-year 1978-1982 prototype electricity consumption, 25-year life, and $1,800 added expense for solar system

(2) Electricity monthly rate as of May 1983: Base rate of $5.05, 4.505¢/kWh for 0-1000 kWh and 4.9651¢/kWh for over 1000 kWh

DISCUSSION

In the data presented during the 4-year period, 47 out of the 48 months show the solar prototype consuming less kWh per month than the typical, all-electric dwelling covered by the utility's company service. The winter collection period, typically November through March of the following year, shows the greatest difference both in energy consumption and in total house energy costs. The period between June and August of the same year, however, indicates a lower difference in energy use and costs. These results may be attributed to a number of design factors. The solar prototype is primarily designed as both a solar collector and a food growing area to extend the growing system. Since the greenhouse encloses that portion of the house to outside heat loss, the net effect of the solar addition is the modification of the outside conduction and convection losses from the building fabric. This agrees with previous findings of house thermal comfort and heat loss (Davis and Godbey, 1982). Natural cooling strategies mainly rely on nocturnal cooling of the storage mass under the floor in addition to natural ventilation. The effectiveness of these techniques for cooling are directly influenced by the ambient temperatures and humidities. These strategies appear to have a reduced effect on cooling than the strategies incorporated for heating.

The comparison for electric consumption over four years shows a decline in kWh use in both the solar and non-solar dwelling types. The former indicates a consistently lower monthly energy consumption profile. While electric use in the solar prototype is decreasing, the cost of kilowatt use per hour is increasing. This is attributed primarily to the cost increases associated with the electric rates and basic utility service.

The analysis demonstrates the potential savings of the solar prototype. This case study makes reasonable assumptions of future electric rate levels and interest rates. The study, however, does not prove conclusively that passive solar design will yield significant economic savings. A random sample of comparable houses with each type of heating and cooling system is required to permit conclusions that can be broadly applied. Future consideration must also be given to an examination of energy use and costs of other heating systems (i.e. oil, natural gas), different architectural configurations and other rate schedules.

The estimation of future electricity rates is a highly speculative matter. Rate levels are dependent on a number of variables such as sources of energy, peak demand, population growth, company infrastructure, user preference, conservation policy and utility commission behavior. The extent to which these and other factors will effect future rate increases cannot be predicted. As a result of this uncertainty, a range of rate increases was used in the economic analysis. It is assumed utility rates will not decrease from present levels within the next 25 years regardless of technical breakthroughs. Inflation alone will prevent any reduction in rates. Using the 48 months of data as a guide leads us to assume a 10 percent annual increase in utility rates. It is also assumed this value as an upper limit on rate increase, as some degree of technological progress, and user conservation will inhibit inflationary pressure.

CONCLUSIONS

In recent years, solar greenhouse-residences have become popular solar house types. The utilization of solar energy and the growing of food are some of the more obvious non-economic benefits of these structures. When compared to conventional, all-electric housing, the benefits derived from these solar dwellings can include reduced electrical consumption and reduced electrical costs. The greatest reductions in kWh use occur during the heating season with January as the month showing the greatest savings. Cooling strategies remain difficult to deal with effectively in warm-humid climates. During the 4-year period, electricity rates increased 40 percent. The average reduction in electricity use in the solar prototype is 37% less than the typical all-electric house. While energy use is declining in both the prototype and all-electric houses, the cost of energy is increasing. Economic savings of the passive solar house over the all-electric house type indicate a reasonable payback period in favor of the former.

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INDOOR CLIMATE PROBLEMS IN POLISH APARTMENT BLOCKS

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ABSTRACT

411 flats in typical Polish apartment blocks were investigated. Air temperature, mean radiant temperature and air humidity were measured indoors. Thermal insulation of clothing worn by the occupants in their flats was estimated. The occupants were also asked to evaluate their thermal comfort sensation and to rank in order of preference various features of their flats. The results have shown that the flats provided a satisfactory degree of thermal comfort and that the air temperature was the most important single factor influencing the comfort sensation. The thermal insulation of clothing varied very little during the seasons.

KEYWORDS

Thermal comfort; apartment blocks; air temperature; clothing insulation; energy savings.

INTRODUCTION

Indoor climate conditions and their evaluation are dependent on various aspects of a technical, financial and even cultural, nature. These conditions should satisfy varying preferences of individual occupants whose thermal comfort assessments are also affected by their state of health. Although thermal comfort sensations can most accurately be investigated in climatic chambers, information obtained in the laboratory does not refer directly to the complex environment of inhabited apartment blocks or other types of housing. The reason for this discrepancy lies mostly in the fact that other factors such as standard of finishing, appliances, noise and even presence of neighbours all influence the final judgment of thermal comfort. The laboratory determination of thermal comfort is well documented (Fanger, 1973; Cena and Clark, 1981) but there is still need to relate these to the actual conditions experienced in inhabited dwellings.

RESULTS AND DISCUSSION

411 flats in apartment blocks of typical construction in the cities of Wroclaw and Walbrzych, Poland, were investigated over a period of two years. The mean indoor air (T_a) and radiant (T_r) temperatures, relative humidity (RH) and clothing insulation (I) are presented in Table 1. The means are given for a whole year period and separately for heating and summer seasons. The clothing insulation is specified in the empirical unit of clo, 1 clo corresponding to a thermal resistance of 0.155 m^2 K W^{-1}.

TABLE 1 - Micrometeorological Data

Period	T_a, °C		RH %		T_r, °C		I, clo	
	Mean	σ^2	Mean	σ^2	Mean	σ^2	Mean	σ^2
Whole year	21.8	1.8	59.7	18.5	22.6	1.8	0.57	0.2
Heating Season	21.8	1.9	60.5	19.9	22.6	1.9	0.59	0.2
Summer Season	21.6	1.5	50.5	13.2	22.5	1.8	0.50	0.2

Tables 2, 3, 4, and 5 present the distribution of the averages of air temperature, radiant wall temperature, relative humidity and clothing insulation for different sensations of thermal comfort. The ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) seven point scale of warmth was used. The central category (rating of 4) is conventionally regarded as the comfort level ("comfortable" or "neutral"). The categories 3, 4 and 5 denote the wider range from "slightly warm" to "slightly cool"; this range is regarded as acceptable. The ranges 1 to 2 and 6 to 7 refer to "cool-cold" and "warm-hot" conditions, respectively.

TABLE 2 - Mean Air Temperatures, °C

Period	Mean	For comfort sensation in the category of			
		4	3-5	1-2	6-7
Whole year	21.8	21.7	21.8	21.0	23.1
Heating Season	21.8	21.7	21.8	20.9	23.5
Summer Season	21.6	21.7	21.6	21.2	22.1

TABLE 3 - Mean Relative Humidity, %

Period	Mean	For comfort sensation in the category of			
		4	3-5	1-2	6-7
Whole year	59.7	59.7	59.0	67.1	51.9
Heating Season	60.5	60.5	59.5	69.0	52.1
Summer Season	57.5	58.4	57.8	61.1	51.1

TABLE 4 - Mean Radiant Temperature, ^{o}C

Period	Mean	For comfort sensation in the category of			
		4	3-5	1-2	6-7
Whole year	22.6	22.5	22.5	21.7	24.1
Heating Season	22.6	22.7	22.7	21.6	24.3
Summer Season	22.5	22.4	22.4	22.0	23.7

TABLE 5 - Mean clothing insulation, clo

Period	Mean	For comfort sensation in the category of			
		4	3-5	1-2	6-7
Whole year	0.57	0.55	0.56	0.63	0.53
Heating Season	0.59	0.57	0.57	0.64	0.59
Summer Season	0.50	0.50	0.51	0.54	0.40

The values in Tables 1-5 show comparatively little variation both between the seasons and among the thermal comfort categories. The clothing insulation of inhabitants had nearly the same value for the whole year and the heating season and was statistically different only for the summer period. In all cases the averages for the narrow (category 4) and wide (categories 3-5) thermal comfort ranges were identical. This indicated a low degree of thermal liability in the flats. The inhabitants obviously dressed lightly (0.5 to 0.6 clo) regardless of the season. The thermoneutral conditions (category 4) for a particular value of clothing insulation were selected as such by 45% of respondents. The other 50% voted them as from 3 to 5. Only 5% referred to the same conditions as outside of the comfort range (categories 2 to 6). A change of $3^{o}C$ in the air and radiant temperatures lowered or raised the comfort sensation by one category in about half of respondents.

The mean values of thermal comfort sensation are given in Table 6. They are nearly identical, which suggests that the respondents adapted equally well to their indoor environment, regardless of season. This could be expected from the other measurements and supports a similar conclusion drawn by Humphreys (1981) who examined the relationship between the comfort temperature and the mean indoor temperature for various climates and found that these two temperatures are closely related. In other words, people tend to accept the thermal environments to which they are accustomed.

TABLE 6 - Thermal Comfort Sensation

Period	Mean	σ^2
Whole year	3.92	1.17
Heating Season	3.91	1.22
Summer Season	3.92	1.04

A rating of 4.0 corresponds to "comfortable-neutral" on the seven point warmth scale

The relationship between the thermal comfort assessment (Y) on the ASHRAE scale and the other variables is given by the equations:

$$Y = 0.257\ T_a - 1.67$$

$$Y = -0.053\ (RH) + 4.15$$

$$Y = 0.232\ T_r - 1.326$$

$$Y = 0.369\ I + 4.12$$

and by $Y = 0.1203\ T_a - 0.0061\ (RH) + 0.0776\ T_r - 0.00002\ I - 0.081$. Table 7 presents correlation coefficients for all five variables.

TABLE 7 - Correlation Coefficients

	Ta	RH	Tr	I	Y
Ta	1.0	0.39	0.69	-0.01	0.32
RH	-0.39	1.0	-0.24	0.05	-0.21
Tr	0.66	-0.21	1.0	-0.1	0.29
I	-0.01	0.05	-0.1	1.0	-0.14
Y	0.32	-0.21	0.29	-0.14	1.0

T_a - air temperature, RH - relative humidity,
T_r - radiant temperature, I - clothing insulation,
Y - thermal sensation

The above results show that the thermal comfort sensation was dependent most strongly on the indoor air and radiant temperature and to a much lesser degree on the relative humidity and clothing insulation. The latter cannot be generalized as people obviously adapt their clothing habits to the conditions in which they live and the clothing insulation can also be regarded as a function of thermal comfort conditions. The subjective thermal comfort sensations reported in this paper have been verified by comparison with the values of Predicted Mean Vote calculated according to Fanger (1973) and Subjective Temperature defined by McInytre (1976). These indices are derived from physical measurements and also from physiological data and the agreement found was satisfactory (within 10%).

TABLE 8 - Assessment of Flats

Feature	Number of Points Awarded
Lay-out design	3660
One family occupancy	3637
Standard of heating and ventilation	3412
Low noise level	3284
WC Separate from bathroom	3145
Size of rooms	3107
Standard of lighting	2718
Space	2590
Balcony	2551
Standard of decorating	2490
Standard of appliances	2454
Number of rooms	2246
Built-in furniture	2115
Large hall	2085

The occupants were also asked to rank in order of preference the various features of their flats. The selection of features included in the questionnaire was arbitrary and referred to some aspects not experienced by occupants. For example, none of the flats was shared by members of more than one family. Similarily, not all of the flats had their own balconies. Most preferred (Table 8) was a good lay-out of flats, closely followed by one family occupancy, effective heating and ventilation, low noise level and acceptable size of rooms. Another factor ranked highly was an extra WC, separate from the main bathroom. The differences between all these categories were not statistically different. Most surprising was the relatively low importance of the number of rooms although this result might have been influenced by the fact that larger families would usually occupy larger flats.

CONCLUSIONS

In summary, the typical apartment blocks in Poland provide a satisfactory degree of thermal comfort for their occupants; their assessments do not differ from other European or North American occupants. The indoor air temperature was the most important factor determining the thermal comfort sensation. The relatively high mean values of indoor air temperature and relatively low values of clothing insulation, particularly in the heating season, indicate possible strategies for energy savings.

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WINDFARMING: LARGE-SCALE GENERATION OF ELECTRICITY

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ABSTRACT

Windfarming--the use of many wind energy conversion systems (WECS) collectively to generate electricity on a large-scale has been recently developed in the United States, especially in California. As a new form of renewable energy, it appears to offer considerable promise for further development in those regions of the world where there are suitable wind resources--i.e., where there are annual average wind speeds in excess of 14 mph.

KEYWORDS

Windfarm; wind energy conversion systems (WECS); wind turbine generator; electricity generation; grid interconnection.

INTRODUCTION

The purpose of this paper is to describe the main events that led to the development and installation of the first commercial and public wind farms and to consider further application of this new form of renewable energy throughout the world.

The modern concept of windfarming was first advanced in the United States in the 1970s by Marcellus Jacobs and by William Heronemus. Jacobs proposed installing a thousand 10 kw wind turbine generators connected to the grid to supplement electricity produced by the existing power stations. The generators were to be placed one mile apart along a line from Minneapolis to Great Falls, Montana. The Heronemus plan envisaged thousands of 5 mw wind stations offshore on floating platforms or fixed towers sited across the prevailing winds in the Gulf of Maine.[1]

It took a number of events over a ten-year period to turn these visions into reality. The first was the 1973 OPEC oil embargo which caused a dramatic increase

[1] The New Wind Power, Jon Naar, Penguin Books, New York, 1982, pp. 226-27.

in the cost of oil and most forms of energy including electricity. This stimulated the search for alternative sources of energy. To encourage the development of renewable energy the United States in 1978 enacted the Public Utility Regulatory Policies Act (PURPA) which required utilities to buy solar- and wind-generated electricity from privately owned sources with facilities under 80 mw at "fair rates" and to supply power to them "without discrimination."[2] The act enabled the owner of a grid-connected wind turbine to sell power to the utility or to anyone else. The arrangement also benefited the utility by offering it a new source of energy that could ease the pressure on peak load demand and help offset the utility's need to invest in new plant construction.

At about the same time the United States Federal Energy Act and other legislation provided substantial incentives for installing wind energy equipment. These included tax credits of up to 55% which, combined with existing business depreciation allowances and tax shelter provisions, opened the way for the formation of third-party groups attracted by the prospect of profitably selling electricity produced by windfarming.

The wind-farm format itself was made possible through a series of technological innovations--solid-state synchronous inverters and induction generators through which the new WECS could be connected to the utility grid; microprocessor "brains" controlling the operation of hundreds of wind turbines from a central director; improved aerodynamic efficiency derived in part from aerospace and helicopter experience--as well as from the increasing availability of wind turbines from manufacturers in North America and Europe.

THE FIRST COMMERCIAL WIND FARMS

The first wind farm was a pilot project at Crotched Mountain, New Hampshire, where in 1980 a private company, U.S. Windpower (USW), installed twenty 30 kw wind turbines of its own design. Although most of the machines broke down in harsh winter winds, the project served as a testing ground for an eventual 80 mw USW wind farm that is being installed in the Altamont Pass, California, some 40 miles east of San Francisco, where the annual average wind speed is 17 mph. By February 1983 there were more than four hundred 50 kw USW turbines of an improved design on line. Each unit generates about 75,000 kwh of electricity a year (enough for ten average American homes) which is sold to Pacific Gas and Electricity at 6 cents per kwh.[3] Other wind farms are under development at Altamont including Jess Ranch with over three hundred 55 kw Fayette wind turbines on line by March 1983 and Farrell/O'Keefe Properties operating Fayette and Vesta turbines as part of a 16.8 mw project.

In the Tehachapi mountain region 100 miles north of Los Angeles there is another concentration of wind farms, the largest of which are Zond Systems and Oak Creek Energy Systems, each with more than two hundred wind turbines of various types selling electricity to Southern California Edison. Oak Creek also leases land to other windfarm developers and accepts their power for sale to the utility. Commercial windfarms are also being installed in Hawaii (on the islands of Hawaii and Oahu), Montana, Vermont, and Massachusetts. The majority of wind turbines installed to date are in the 50-100 kw range, although a number of larger systems including 500 kw machines are now coming on line. The reasons for using smaller systems are partly financial, partly availability; also many windfarm developers believe that smaller systems are easier to repair and maintain and thus cause

[2]The New Wind Power, pp. 161-62.
[3]New York Times, February 14, 1983.

less "down time" than the very large turbines.

LARGE-SCALE SYSTEMS

In the United States the use of megawatt-scale WECS in windfarms has been confined to two Government-funded research projects, one at Goodnoe Hills along the Columbia River in southern Washington state, the other at Medicine Bow, Wyoming. The former is financed by the U.S. Department of Energy and operated by another Federal Agency, the Bonneville Power Administration. It consists of a cluster of three Boeing MOD-2s--2.5 mw, twin-bladed, horizontal axis wind turbines--and is designed to demonstrate the technologic and economic feasibility of very large wind turbines, especially as complementary to hydroelectric power generation and storage. The Wyoming project, funded by the Department of the Interior, incorporates a Boeing MOD-2 and an even larger system, the prototype 4 mw Hamilton Standard WTS-4 as well as several smaller units. Ultimately the DOI hopes to install 150 mw of wind turbines in the region.[4]

The Goodnoe Hills machines have experienced serious mechanical problems. Shortly after its official dedication in 1981 the first unit failed to feather and over-sped, burning out its generator and damaging the drive train. This necessitated repairs of $2 million. In November 1982, after more than a thousand operating hours had been accumulated on each machine, circumferential cracks were discovered on the low-speed shafts of the second and third units, causing the shutdown of all three turbines and of the MOD-2 at Medicine Bow until the shafts can be redesigned and replaced.[5]

Operation of the WTS-4 has been much more successful and it has generated just under 500 mwh of electricity since it went on line in September 1982. A similar Hamilton Standard machine, the WTS-3, has produced slightly more than that amount in approximately the same period of synchronized operation.[6]

INTERNATIONAL WINDFARM DEVELOPMENT

Outside of the United States the first two countries to initiate windfarm projects are Greece and Italy. In 1982 an array of five 100-kw, horizontal axis, twin-bladed Aeroman turbines were installed on the island of Kythnos, 50 miles south of Athens. This windfarm is operated by Demosia Epicherese (Greek Public Power Company) as a joint Greek-West German research project. The Kythnos Aeromans are located across a bluff 800 yards from the shore and are expected to produce 250,000 kwh a year in the 14+ mph annual average wind speed at the site, supplying 25% of the island's electricity needs presently supplied by diesel oil.

At Alta Nurra on the north coast of Sardinia the Italian National Electricity Agency (ENEL) is installing a windfarm of ten 500 kw FIAT wind turbines that are expected to go on line in early 1984. According to ENEL, other Italian islands including Sicily are being considered for wind energy development. Sardinia alone could yield 100 mw of wind-generated capacity and it is believed that some 400 mw of wind energy supplying about a billion kwh of electricity a year could be installed in Italy by 1995.

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[4]EPRI Journal, December 1981.
[5]Wind Energy Report, January 14, 1983.
[6]Statement to U.S. House Committee on Energy Development, March 15, 1983, by Arthur Jackson, Hamilton Standard.

THE CALIFORNIA EXPERIENCE

The operational record of the first California windfarms has been generally very good. USW reports a better than 90% performance of its systems with electricity production particularly abundant during the periods of strong wind (mid-March to mid-September) when the wind velocity averages more than 20 mph. Both USW and the neighboring Jess Ranch suffered no damage during a very heavy storm in December 1982 that blew down utility transmission towers and blacked out half the customers of Pacific Gas & Electricity in the Altamont area.[7]

At Tehachapi, Zond and Oak Creek have a diversified range of wind turbines including Zond's own 40-kw Storm Masters, 25-kw Carters, 50-kw Blue Maxes and a number of European machines--65-kw and 100-kw Vestas from Denmark and 100-kw Windmatics from the Netherlands. "At first we had our share of mechanical breakdowns, but we are doing much better now," said Robert Gates, Zond's marketing manager, adding that his company had found the European machines "more reliable."[8] On the other hand Steve Cummings, president of the Oak Creek wind farm, reported that in his experience the Texas-made Carter system was one of the most proven in the industry: "It runs extremely well, giving us 99% of our machines running at a time."[9]

Having completed the major part of its windfarm installation, Zond is focusing its engineering on the design of more sophisticated control circuitry that will be less subject to false or out-of-synchronization connections due to line noise and surges. Their engineers are evaluating photo-transistors for isolation from grid noise and have built a tachometer control circuit which monitors the wind turbine shaft speed to a small fraction of a cycle for finer control. Another feature of the Zond Farm, which employs 25 people full-time and another hundred when construction is under way, is a computerized system of recording the sequence of controller functions so that in the event of malfunction the memory will help reconstruct the sequence of events that led to the failure.[10]

At present most windfarms step up the 480 volt AC electricity generated by their WECS to 12000 volts before selling it to the utility. Zond, however, believes that it can save money by building its own substation in order to step up the power to 66000 volts. "We can build it for 3/5s of what it would cost SCE and get it done in six months as opposed to eighteen," said Gates.[11]

There are more than 2000 wind turbines already on line or planned for the end of 1983 in California wind farms with a total capacity of more than 125 mw.[12]

ENVIRONMENTAL IMPACT

All of the wind farms developed to date are located in regions distant from major population centers and thus there have been very few cases of interference by the wind turbines with television or radio communications. Nor have there been complaints of noise from turbine rotors or generators which does not travel more than half a mile. Impact on local wildlife and cattle has also been negligible. "Our main problem is that cows like to rub their backs on the windmill towers!" said Gates. At Oak Creek it was found that birds liked to nest in the back of the

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[7]American Wind Energy Association Windletter, December 1982.
[8]Wind Industry News Digest, September 1982.
[9]Solar Energy Intelligence Report, August 30, 1982.
[10]Wind Industry News Digest, September 1982, pp. 1-2.
[11]Personal communication to Alex Naar.
[12]Renewable Energy News, February 1983, pp. 20-21.

nacelle on the Carter machine. The solution was to cover the opening with a small net.[13]

In the California wind farms, turbines are sited at varying distances from each other--usually between 1.5 and 3 rotor diameters side-by-side and between 5 and 9 diameters front to back. Most of the windfarms have been considerate of the land on which they are built. To cover over the scars of construction, to stabilize the terrain and keep dust to a minimum, both Zond and Oak Creek have reseeded their land with native grasses.

In the United States wind farms have been well received by local communities because they represent a new and growing industry with tangible benefits in the form of jobs, capital investment, housing, and overall prosperity. Most windfarm developers have been careful to comply with local zoning ordinances and to take part in public hearings designed to overcome institutional or environmental barriers.

CONCLUSIONS

1. Windfarming as a source of large-scale electricity generation is demonstrably feasible technologically and economically.

2. This non-polluting form of energy has the additional benefits of helping reduce the need of utilities to increase their plant capacity and of reducing the demand for imported oil or nuclear power.

3. It is too early to judge the relative merits in wind farms of megawatt-scale wind turbines compared with the smaller systems predominantly being used.

4. Windfarming appears to offer considerable potential for many regions of the world where there are: i) wind regimes of at least 14 mph on annual average basis; and ii) sufficient funding from private or public sources to finance the purchase, installation, maintenance, and operation of large numbers of WECS.

5. The most likely sites for windfarming are mountain passes, open plains, offshore locations, and small islands such as Kythnos and Sardinia where pilot projects are already under way.

6. A growing body of information on windfarming is now available to private and public developers and agencies interested in expanding the use of this renewable and relatively inexpensive source of energy.

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[13]Personal communication to Alex Naar.

CENTRALISED BUILDINGS CONTROL SYSTEMS FOR ENERGY MANAGEMENT

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ABSTRACT

Public and private buildings are constructed in such a way that they include a great variety of technical utility and service systems. The nature of these systems varies in the sense that they are responsible for operations ranging from air-conditioning to lighting.

Because of the increasing cost of energy and labour, centralised control systems have been introduced, to control the above building functions.

A central building control system operates by using signals from sensors distributed in the energy consuming areas. The state of hardware of the sensors, determines the reactions of the central controller either as time-dependant functions or as overriding operations. Optimum operation of the building system can reduce energy consumption by as much as thirty percent.

Functions include automatic time-scheduling of all lighting loads, manual override for individual loads, air-conditioning and heating scheduling.

This paper will review some of these central energy systems, from the energy manager's point of view and attempt to give some useful ideas to architects and engineers of how to save energy in buildings, by using microprocessor technology.

KEYWORDS

Centralised energy management; technical specifications; acceptance; future trends.

INTRODUCTION

Rising energy costs in recent years, combined with the dramatic reduction of costs in computer hardware, have created a new field in energy management in general and in buildings in particular. Centralised computer control systems for optimum energy utilisation in buildings, is a major breakthrough helping the struggle for lower energy costs and better energy management.

As domestic and commercial buildings are continually equipped with more comprehensive utility systems, the need for optimum control of these systems is becoming more apparent, as the existing electromechanical control systems of the past are becoming more and more inadequate. Moreover the complexity of the new building utilities, which serve the perpetual thirst for more comfort , makes operation, maintenance and monitoring increasingly difficult.

Comparison of the cost of these utilities, to the total cost of the building, shows that they account for more than 50% of the total investment. As a result, and to achieve high availability and utilisation factors, continuous monitoring is required, which minimises the dangers of unexpected breakdowns and low efficiency. These increasingly complex functions cannot be undertaken by the operating staff alone. That is where the need for centralised control systems arises.

SYSTEMS DESCRIPTION

The whole system comprises of a central microcomputer, an interface, a storage medium (disc, cassette etc.), the power supply, the visual display unit (V.D.U.) and the printer and the local controllers.

The microcomputer is where all the inputs are analysed and according to the software provided by the company to suit the needs of the customer, commands are outputted, to compensate for any unwanted changes sensored by the local controllers.

The interface translates the signals coming from the controllers (plant items), to computer language and is software controlled.

Whereever there is a need for data recording, a storage medium is used. Such operation is very useful for future reference and statistics as it shows the optimisation provided by the system.

The power supply unit provides the internal voltage required by the system. This can include a battery back-up system in case of power failure.

The V.D.U. enables the minute-to-minute checking of all components of the plant. The printer provides a hard-copy of all operations.

The controllers are measuring devices which obtain information optically, acoustically and with registration units either automatically or by keyboard commands. There can be direct and/or analog input control, from the controllers, which interface with the central computer.

SYSTEMS ON THE MARKET

There are various systems on the market, ranging from small systems for domestic applications, to large systems with thousands of input/output channels. Most of them are in a modular form, which allows flexibility of operations and also makes expansion easy in order to cover for future loads.

Some of the companies producing microcomputer energy management systems are:

MEMS (micro energy management system)
GEC (measurements)
AEG - Telefunken
IEM (Invicta Energy Management Ltd.)
MEM (electronics)
Johnson Control Systems
Transmitton

AECON (Automated Energy Conservation Ltd.)
Holec Energy
Simplex - GE Ltd.
Systemation Ltd.
Energy Management and Control Systems Ltd.

Most of the competing systems are very similar, and differences exist mainly in data space and processing power. Such micro-systems can cost from £1,000 to £100,000 depending on the size of the building, the utilities provided and plant size, complexity of software, peripherals and so on. There are also systems which incorporate more than one microcomputer for the control of the same building. The use of distributed computers, for energy management, provides some advantages over the centralised systems but the fact that local computers have to communicate among themselves anyway, might present problems.

By using such computerised systems, recent experience has shown that energy savings of up to 30% can be achieved, in addition to lower maintenance expenses (including a smaller payroll). A system installed at British Aerospace at Brough, England by Transmitton, has saved the company about 7% of the total heavy oil fuel bill and it is expected to have a payback period of one year. The computer continually monitors and records the temperatures via 21 sensors and 5 outstations, and optimises the use of heat and hence the use of oil. Before the start of the shift, heating is switched on, at the latest time possible, to reach the required temperature. When the temperature is reached, the heating fan is switched off. When all the areas supplied by the same pipeline are switched off, then the computer instructs the boilerman to close the main valve of the pipeline. At the end of the shift, the computer switches off the system at the earliest possible time.

Another system installed at the Vauxhall cross offices, England, by Delta (Electronics Division), provides considerable energy control, and in association with low-energy consumption lamps and individual controls for air-conditioning and heating, produces running and maintenance costs of around 60 pence per square foot per year, for the 48,000 square foot building.

The computer system used, controls maximum demand, by load shedding, i.e. switching off staircase heaters, cutting lighting to half level and so on until the overall demand is reduced to below the overload level. There are manually operated switches for overtime, which operate for one hour at a time.

THE FUTURE

All energy conservation schemes, to achieve their purpose, have to be clearly accepted at the top and enjoy employee participation. Computerised energy systems have an added problem. The fact that computers are supposed to be looked upon as a threat to jobs of energy-managers and engineers. Fortunately computerised energy management systems are but one of the tools available to the energy engineers. This is because the current computer technology cannot provide the decision making of the energy engineer, who is to choose among systems and select the one most suited to his needs, and it certainly does not provide the ability to persuade top management and employees of the need of energy conservation.

Computerised systems can be operated without specialised skills. Software is provided by the consulting house or even by the computer company in the form of standard packages, which can be altered to suit individual needs. Expansion of a given system is usually easy as systems come in modular form. Payback periods range from six months to three years. Recent statistics show that the building controls market is predicted to increase by 76% by the year 1988, and to reach

$662,000,000.[1] The largest market sector for building control systems will continue to be office building with an estimated 26% share in 1988, up from 24% in 1981. A 16% share for medical buildings will remain constant. Systems in special purpose buildings will increase their share from 15 to 17%. The largest advance of all will come in educational buildings, with an increase from 16% to 19%. Retrofittings will become a booming market, as controls of the Fifties and and Sixties are ageing, and produce high energy costs.

The future is projected to be very promising for centralised computer energy management systems, and it has to be, as the era of cheap energy is gone for good.

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[1] Building Control Systems Markets in Europe

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BUILDING ENERGY EFFICIENCY AND THE FIRE PROBLEM

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ABSTRACT

Several energy conservation measures have been documented as contributing to fire ignition. These range from long-term heat entrainment resulting in smouldering ignition to the effects of prismatically focused solar energy on the internal components of solar collectors. This paper examines key ignition problems in energy efficient features and methods of controlling their impact. Secondly, it discusses general fire problems in buildings and ways in which energy management measures might be expected to influence the outcome of a building fire. Open planning, "envelope" configurations, air-tightness, thermal massing and other considerations are identified. Finally, the paper examines the role of energy features in terms of occupant survival of a fire. Toxicity of fire by-products, effects of incomplete combustion resulting from super-insulated areas and influences on egress features are considered.

KEYWORDS

Toxicity; safety; construction; energy; fire.

INTRODUCTION

Concern for energy efficiency in the built environment is hardly a uniquely contemporary phenomenon. Throughout the history of international development, cyclical attention has been directed, toward and away from measures to improve energy efficiency and to otherwise control resource consumption. The Roman Empire used legal sanctions to radically reduce dependency on scarce wood supplies but relaxed constraints when new supplies were found. Similarly, the Southeastern United States made quite widespread use of solar domestic water heating around the time of the Second World War but its use was soon abandoned as more convenient natural resource-based sources of energy became available. In general, it would appear that the duration of such cycles of resource conservation has been determined by a simple cost/benefit analysis; when the "cost" of pursuing a line of energy control seems to exceed real or expected benefits, the effort is curtailed.

In the present context, energy efficiency is seen as an increasingly urgent local and national priority. Technological advances in the area are anxiously awaited, and their introduction into widespread use is accelerated wherever possible.

A strong positive public image is undoubtedly important for major technological progress in energy management. However, the potential threat of enthusiastic public support is that the clearly identifiable benefits of energy-related innovation can obscure some equally significant costs. Ultimately, without a balanced assessment of both its positive and negative impact, implementation of resource efficient technology can occur more quickly than attempts to control its adverse consequences. This paper, then, will examine the impact of energy conservation measures on another critical building factor, occupant safety from fire.

A STATISTICAL OVERVIEW

National fire incident reports serve as a useful starting point for examining the relationship between fire safety and energy conservation. At the present time two major fire data collection systems are in operation in the United States, The National Fire Protection Association's National Fire Experience Survey, and the Federal Emergency Management Agency's National Fire Incident Reporting System, referred to as NFIRS.

The most recent data, up to and including the year 1981, shows, first of all, that fire's impact has historically been most critical in residential occupancies. One and two family dwellings, apartments, mobile homes, hotels and other types of residential occupancies accounted for 80-90% of all fire fatalities. For 1981 residential occupancies were responsible for 80.1% of all fire fatalities, 46% of the total dollar loss and 65% of all injuries. One and two family dwellings alone accounted for 54.5% of all fire fatalities in 1981 (Jones, 1982).

These alarming statistics, relative to other types of settings, are explained by several factors. The time spent in dwellings is quite high especially the highly vulnerable time spent sleeping. Additionally, factors which contribute to fire development and evolution such as building and housekeeping practices are most difficult to regulate in residential occupancies.

The significance of these factors to the present discussion is that the residential setting has tended to be the site for a great deal of energy experimentation. Any failure in the system with respect to the fire problem is therefore magnified by the inherent vulnerability of occupants in this setting.

The resurgence of interest in solid fueled heating, an almost uniquely residential phenomenon, is a case in point. During 1981, heating equipment was identified as the source of ignition in 31% of all residential fires, for a total of 174,883 incidents. This occurred at a time when all other major fire causes, other than incendiary/suspicious types, were in a significant decline. Further examination, however, reveals that the role of non-solid fuel heating as a fire cause has remained rather constant and that the dramatic increase observed is almost totally due to the increased impact of coal and wood fired heating equipment. Over the past two years, there has been widespread experimentation with solid fuel as an alternative source of heating, a result of which has been its greater than 100% increase contribution to fire ignition.

ENERGY CONSERVATION AND FIRE IGNITION

Smoldering Ignition

The recency of the surge in energy conservation innovation and its still relatively limited application restricts further detailed statistical treatment. From the data available, however, it is possible to identify several common ignition scenarios related to energy conservation features. These are summarized in Fig. 1.

As mentioned above, the most common scenarios involve solid fueled energy conversion equipment, that is a wood or coal stove, igniting a structural component or an item of room contents. Here, the "critical relationship" tends to be a lack of adequate spatial clearance between the equipment and the material ignited or uncontrolled spread of the equipment's solid fuel, either as burning materials or glowing embers (Jones, 1982).

Though not as common at this point in time, an analogous scenario is beginning to appear with respect to other types of energy conversion equipment. With increasing frequency, modified gas and liquid-fired furnaces/heaters and solar collectors of varying types are being reported as sources of ignition of structural components and room contents. Again, a critical factor appears to be the proximity of the heat producing or confining source to combustible materials.

Two additional factors are particularly significant to fluid-filled solar collection panels; the extent to which the collector's lens system prismatically concentrates heat on internal components, and the low temperature pyrolysis characteristics of adjacent materials. (Low temperature pyrolysis, the chemical decomposition of materials at temperatures well below that required for immediate ignition) To date, several incidents have been reported of materials used in the construction of solar energy collector panels undergoing structural breakdown as a result of internal heat build-up. In some cases, gradual charring and heat entrainment have led to smoldering ignition of panel components and adjacent materials. Such conditions have been known to develop over periods of time as short as a few months (Harvey, 1980; Wood, 1980). Unfortunately, too little is presently known about critical values of duration and intensity of heat exposure leading to low temperature ignition. Further investigation and monitoring of existing installations is needed to minimize fire hazards under these circumstances.

Electrical Ignition

Electrical equipment malfunction forms the basis for another range of scenarios with a high probability of occurrence. From 1971 to 1981, electrical equipment arcing and overloading accounted for 13.1% of all multiple-death fires (Jones, 1981). Though not tied solely to energy conservation activity, fans, pumps, motors and other electrical components are used often enough with all methods of energy conversion to constitute a significant threat. For this source of ignition, appropriate sizing and maintenance play significant preventive functions. Isolation of potentially problematic features within fire resistive enclosures represents a more active safeguard, however.

Contributions of Insulation

A final significant ignition scenario related to energy conservation measures is rather different than those previously mentioned. This involves the contribution of insulating materials, in two ways. In the past, many insulating materials have, themselves, been volatile fuels. When placed in contact or close proximity to a closed heat source, smoldering ignition occurred. In the presence of a plentiful air supply, a rapidly developed building fire often resulted.

Widespread availability of fire retardant insulating materials has done a great deal to neutralize the problem of insulation-fueled fires. However, ignitions resulting from improper design and installation continue to be a significant problem. Insulating materials are often placed in tight proximity to heat sources, preventing adequate heat dissipation, and ultimately leading to the ignition of adjacent structural components.

Safeguards Discouraging Ignition

In summary, most problems related to energy saving measures as ignition sources can be controlled by applying one of the following general concepts. First, and most critically, spacing requirements between heat generating and concentrating equipment and adjacent materials must be established and maintained.

Secondly, the configuration of assemblies must be such that adequate air movement is provided for areas of possible heat build-up and confinement. This is particularly true with respect to placement of insulating materials and the design of enclosures for solar collectors. Finally, electrical components should be so designed as to minimize the possibility of significant heat production.

ENERGY CONSERVATION AND FIRE EVOLUTION

Spatial Influences on Fire Spread

In the absence of more detailed statistical data, the ignition scenarios described above represent a threat of unknown magnitude. There is no present reason to believe that energy conservative building designs will be involved in fire situations to any greater or lesser extent than their more conventional counterparts. On the other hand, it is important to consider the behavior of structures if they should, for whatever reason, be the site of a fire. In this regard, energy efficient designs tend to embody a unique combination of characteristics.

One major characteristic of significance is the spatial configuration of units. Conventional construction has tended to develop around the creation of separate and discrete compartments which can be isolated from one another through the use of walls and doors. Though this practice evolved for quite different reasons, it functions to divide interior space into separate fire areas. A fire's movement from one area to another can, to some extent, be retarded by the presence of these barriers.

Compartmentation works well in spaces heated by centralized systems. However, where sources of heat gain are very localized, as in passive solar designs, the need to move warm air into remote areas generally dictates a more spatially open plan. As a result, when a fire does develop in one portion of a structure, there is little inherent resistance to its movement throughout the building (Lerup, and Associates, 1977). In some applications, problems of spatial openness are compounded by room geometry. For example, low ceiling heights are advantageous in terms of concentrating heat at low levels where it will be most appreciated by building occupants. Under fire conditions, however, heat which might otherwise be dissipated into the larger air volume impinges directly on overhead structural materials and is deflected horizontally for a distance of five to seven times its expected vertical movement.

Perhaps the most critical configuration in terms of fire spread is the "envelope" concept. To date, the author is aware of no specific incident involving an envelope structure. However the interconnecting void spaces which surround the habitable portion of such structures, and their small cross-sectional proportions can be reasonably expected to contribute to rapid fire evolution and full building involvement should a fire develop.

Safeguards Against Fire Spread

Solutions to the fire spread problem are difficult for structures requiring a visual openness between spaces for reasons of aesthetic appeal or thermal efficiency. Extensive use of noncombustible materials is an important contribution to fire protection, but it must be recognized that movable household contents by themselves generally provide sufficient fuel to support fire development. Another option is the use of heat and/or smoke activated high volume fire and smoke venting in different building sections. While the introduction of active air change will intensify fire involvement in one area of a structure, its drawing of fire and products of combustion out of other areas provides a major contribution to overall loss control and life safety.

Where spatial connection between areas is necessary only for air movement, ducts, fans and transfer grilles can be equipped with heat activated smoke dampers. These allow high volume air change under normal conditions, but automatic compartmentation when required for fire isolation and control.

One final alternative means for fire control is low-cost, low pressure sprinkler systems for household use. These systems are in the early stages of application and refinement. The success of this fire control method in large scale, open industrial applications promises satisfactory results in open plan energy conservative designs as well.

Considerations of Air-Tightness

Insulation and air-tightness represents a second important factor affecting fire development in energy efficient structures. The rate of fire evolution in buildings is almost totally dependant on the quantity of air available to support the combustion chain reaction. As structures become increasingly air-tight the probability of a rapidly building, open-burning fire diminishes. If windows, doors, vents and other avenues of oxygen infiltration survive the early intense phases of fire build-up, the chances are good that the fire will be smothered. Lacking adequate intensity to preheat and ignite additional fuel, it may even self-extinguish.

However, along with the apparent virtues of tight spaces and their influence on combustion control are two significant liabilities. The first of these, the threat of an oxygen deficient atmosphere to occupant survivability, will be discussed in the next section. A second concern deals again with the rate of combustion. If an initially hot fire is gradually reduced to a smoldering one, combustion becomes incomplete. Super-heated, unburned gases are produced and the fire reaches its critical state; if air is limited or excluded the fire will go out. If, however, air is suddenly admitted, as in the sudden failure of a window, the fresh air would complete the combustion "triangle" of air, fuel and heat and rapid combustion of the fire gases would take place. "Flashover," a near-instantaneous flame spread over a large area would occur if several openings occured simultaneously in an unconfined space. However, should oxygen be admitted to a hot confined fire from below an explosion of devastating potential could result in destruction of a large portion of the structure.

It should be noted, however, that the probability of a successful self-extinguishment is sufficiently remote and the potential risk sufficiently high that super-insulation in itself, cannot be considered a favorable fire protection feature.

Again, major compensatory measures might include zoned smoke/heat venting and/or integrated sprinkler system protection.

Inherent Limitations on Fire Spread

Some forms of energy efficient construction have improved inherent fire performance, in at least one important respect. Thermal storage, as used in various forms in passive solar installations, has a retarding influence on fire development. The rate of flame spread is directly related to the energy available to pre-heat and decompose adjacent fuels. The greater the thermal mass present, the more heat drawn away from the combustion process and the slower the rate of fire growth. Additionally, materials suitable for use in thermal storage tend also to be of limited combustibility. Therefore, thermally absorptive spaces are likely to have relatively light fuel loads.

LIFE SAFETY FROM FIRE AND ENERGY CONSERVATION

Respiratory Hazards

Thus far the discussion has focused only on the relationship between energy-efficient structures and fire behavior. Perhaps the most significant relationship, however, is the combined, unilateral impact of fires in such structures on the people contained within them. Due to the number of permutations possible, a great deal of generalization is necessary. Several points do, however, have widespread applicability.

With respect to occupant safety, insulation practices again play a significant role. A basic concern with any material which limits air change in a structure is the extent to which it will adversely affect the quality of the occupants atmosphere.

Potential off-gasing of toxic products, even at normal room temperatures, has been a topic of recent research interest. At fire temperatures, virtually any structure's contents will produce lethal mixtures of combustion by-products. Heavily insulated and air-tight spaces influence this process in two ways. First, due to a low rate of air change, toxic gases are confined within the structure where occupants are most likely to be exposed to them. The heavy particulate matter of the smoke also tends to obscure vision and inhibit movement out of the threatened area. Secondly, the smoldering combustion which results from a progressively diminished oxygen supply leads to less complete combustion and higher concentrations of toxic by-products.

Insulation materials themselves are frequent sources of toxic gas production during combustion. Ureaformaldyhyde, polyurethane and many treated cellulose insulations constitute unusually serious respiratory hazards during fire situations.

Finally, automatic smoke and heat venting equipment becomes a feature of necessity when dealing with otherwise air-tight, difficult to vacate spaces. Though ventilation of fire charged buildings can ultimately lead to greater fire severity and structural damage, the benefits of reduced heat intensity at floor level, reduced toxic gas levels, and improved visibility which can result from a well engineered ventilation system seem to represent a favorable trade-off.

Emergency Egress

A second life safety concern is the general reduction in alternatives for emergency exiting from many energy efficient structures. Viewing windows as potential sources of heat loss, some designers have drastically reduced window areas in bedrooms and other occupied areas, or have included window configurations unsuitable for escape or rescue. This is a particularly common problem in some earth sheltered structures where all openings and exits may be concentrated along a single wall, and often at some distance from the vulnerable sleeping areas.

Compensatory measures should be provided when departure is made from the standard practice of providing multiple and remote means of building exit. By code, many non-residential occupancies are required to provide sprinkler protection where long exit travel distances are necessary. A similar model may be appropriate for energy-based plan variations.

For earth sheltered designs where conventional grade level exits are not possible, pull-down access ladders up to the level of the sheltering grade may provide a practical option. Since this would require movement through levels of greatest heat intensity. Protective enclosures would be essential, however.

SUMMARY

In conclusion, it is fair to state that in many significant respects energy-efficient building designs presently being produced behave significantly differently under fire conditions than their more conventionally built counterparts. Certain energy conserving features, especially when in combination with one another, represent formidable life safety hazards under fire conditions. To minimize the possibility of these features contributing to ignition, generous space should be maintained between all combustible materials and heat producing or radiating sources. Heat absorbing components should be designed so as to provide for cooling air flow between them and the supporting structures. Decomposition of internal materials in solar collectors and similar heat gain devices should also be considered with respect to possible heat build-up and ignition problems over time.

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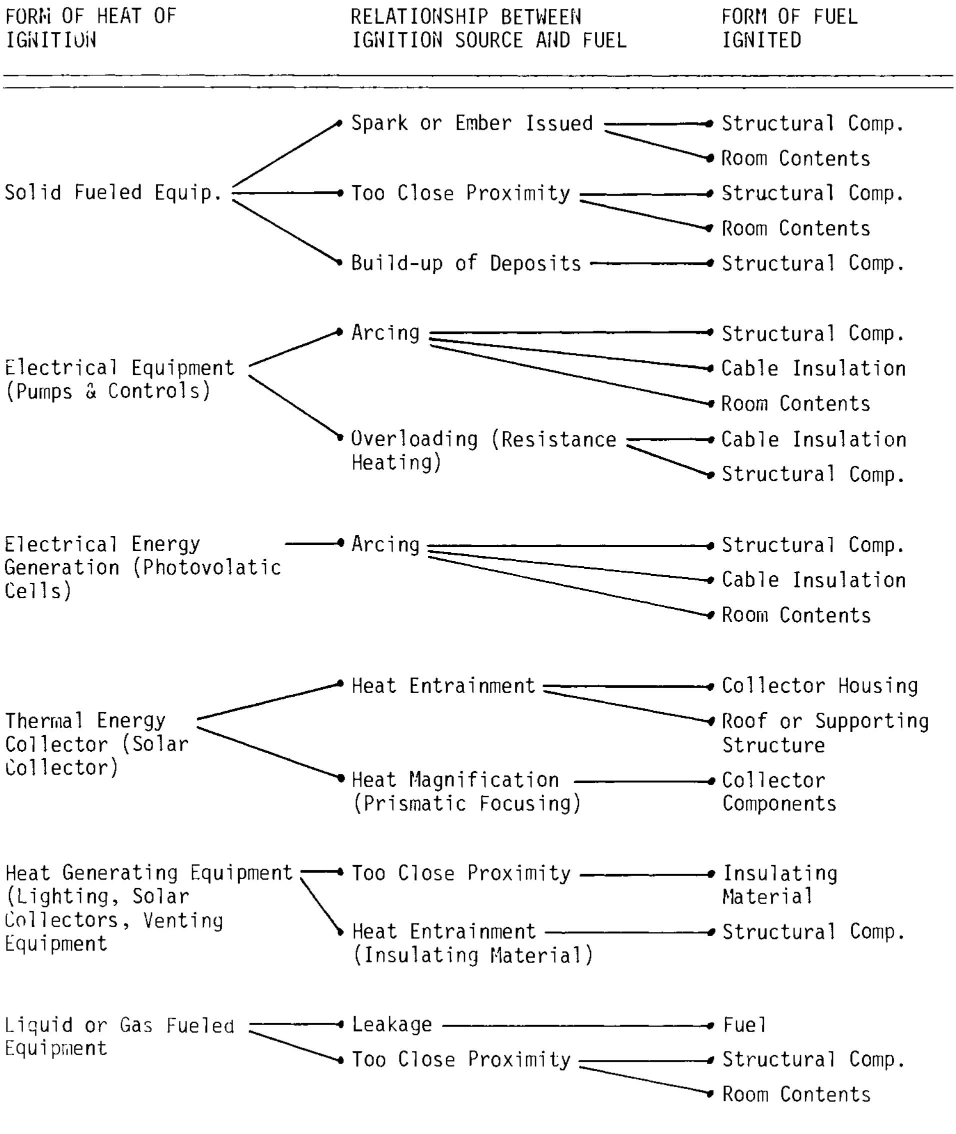

Fig. 1 Potential Energy Conservation - Based Ignition Scenarios (adapted from J. C. Jones, 1982).

SYSBLD2: A Computer-based Designing System for Multi-family Housing

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ABSTRACT

This paper reports on the development of a computer program which generates designs for multi-family housing from a database of apartment plans and their components. These plans are associated with a precast concrete modular housing system, although the program has been designed to be generic. The program development is part of an overall re-evaluation and update of an industrialized housing system to include passive energy technology. Design criteria are linked to the driving program by objective functions which, in turn, are linked to the energy and economic database through file procedures. The programn is written in PASCAL. Data input is interactive using a keyboard or digitizer; output is graphic.

KEYWORDS

Housing. Industrialized Housing. Markov Chains. Generating Systems. Designing System. Transition Matrix. Passive Solar Technology. Energy. Building Economics. Stochastic Processes.

INTRODUCTION

Housing falls into a class of architectural problem with very specific, topological and socio-economic constraints. There are also clear constraints on energy use, materials and design. Regardless of whether there are specific locational constraints, there are very particular "rules" regarding the design, analysis and implementation of housing. The use of rules lend to housing the potentiality for a systematic approach and the development of a designing system.

The underlying concept of a designing or generating system is that with a given set of rules which represent as many constraints as plausible a unique building can be generated by the computer. The problem of housing design, while not entirely rational and reaching closure, is the class of problem most able to be segmented and considered as a series of algorithms. Output from the program can be of many forms ranging from simple alphanurmeric strings representing the plans to perspective drawings or plans generated internally and displayed on the CRT or routed to the plotter. The limitation upon visual sophistication is the time available for programming the problem and the availability of input/output devices.

The computer program, SYSBLD2, has been developed to generate solutions to a limited set of problems in housing design. The design of the housing has been initially viewed as a "formal system". (Hofstader, 198Ø)

The program has been coupled to a precast concrete housing system which has been developed to have a minimal number of parts which can be assembled into a large number of different buildings. In the building system, there are two classes of modules: wet and dry; wet modules being defined as those modules requiring plumbing; dry modules are all others. The designer establishes a database of apartments with these modules and a few additional special parts for greenhouses, balconies, roof monitors or stairs.

The overall study of which this program development is a part explores the simplicity of the concrete module as a design element, the complexity of its analysis, and the potential for accurate analysis of passive and low energy alternatives, long term economic benefits, and affordability. The development of the program and its required database has provided structure to other requirements of the research.

The hierachy of parts or components in the ensemble are defined in Table 1 and illustrated in Fig. 1.

Symbol	Name	Definition
M	module	12 ft. x 12 ft. base unit
S	segment	modules in one "row" and floor of an apartment
A	apartment	collection of modules; a collection of segments
B	building	a collection of apartments and a circulation system
xl	attributes	characteristics of a system element

Table 1

These symbols may be used to represent the module, segment, and apartment in the following manner:

M(xl,x2,...,xn)

represents the module, M, and its attributes

S(xl,[Ml,M2,...,Mxn],x2,...,xn)

represents the segment, S, and its attributes and modules

A(xl,[Sl,...,(Ml,M2,...,Mxn)],S2(M3,M4,...,Myn),x2,...,xn)

represents the Apartment, A, is segments, modules and their attributes, plus additional attributes of the apartment

Attributes are specific characteristics of a system element which distinguish the element from all others. An element of the system, on any level: apartments, segments, modules, or panels: has a set of characteristics which define it, or exclude it from a set of items.

The attributes (x1,x2,...,xn) can cross-represent the system at various levels and may be summed by types, depending upon the data they represent, as will be shown in a later example. Output from various programs and sub-programs can be attributed to the modules and/or aggregates of modules. For example, the heatloss, Q, of a segment of modules is the sum of the heatloss for each module. In general,

B = (sum of) A1,A2,...,An
S = (sum of) M1,M2,...,Mn

and therefore the attributes of the building, B, can be obtained as a summation of the attributes of A, S, or M from the database, depending upon the data type.

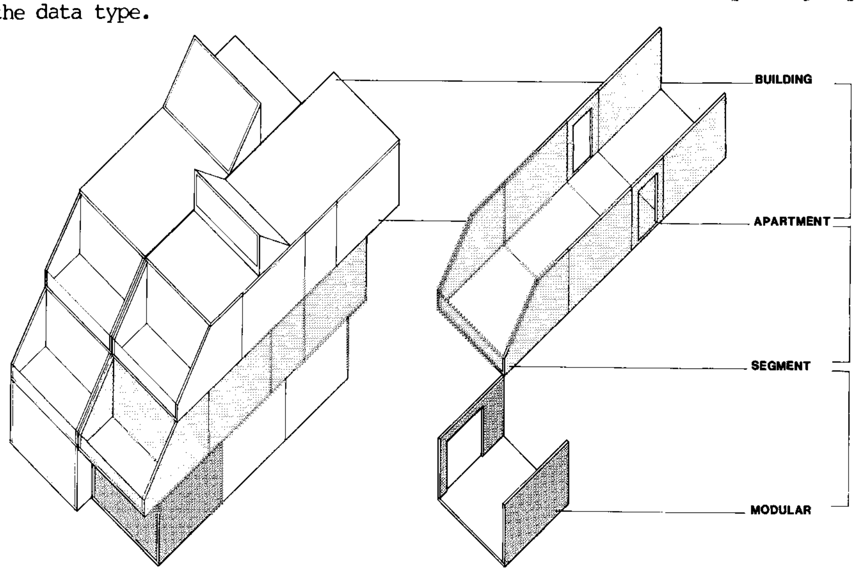

Fig. 1 The hierachy of components

SYSTEM COMPONENTS

The four major components of the designing system are:

1. The physical arrangements of the site.
2. The physical arrangement of the building.
3. The thermal analysis of the building.
4. The economic analysis of the building.

These four components are not independent, and have linked sub-components details within them. Furthermore, they are both recursive and solveable through successive approximations. While many solutions can be arrived at through generating techniques, it is more plausible to establish clear and objective constraints at the outset of the analysis and design process or there are few practical solutions.

One way of diagramming the computer program is as follows:

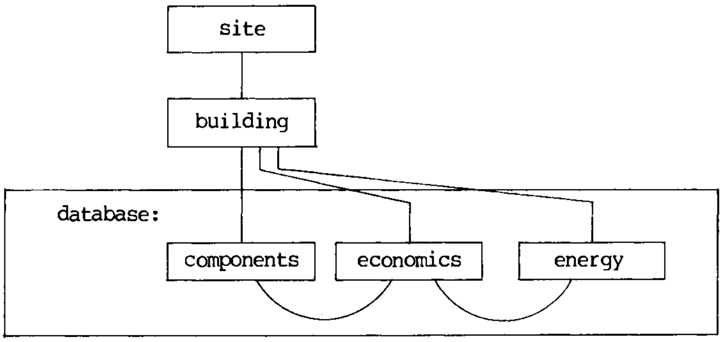

Fig. 2. Sysbld2

Information about the modules is stored in the database. The database takes two forms: 1) A collection of Apartments developed "by hand" from an assemblage of modular components. (The program looks at ways to array or arrange this modular ensemble.) 2) Data, raw or calculated, which represents the attributes or properties of the modules, segments or components of these potential ensembles.

While the conceptual starting point for the "design system" can either be at the level of the module, M, or at the next level of aggregation, the Segment, S, SYSBLD2 looks at Apartments and Segments as the lowest aggregate of the unit.

Nonetheless, some elements of the database - segments, for example - need to have pointers to the level of the module, M, and the panel, P. Whatever the starting level, the data associated with A is calculated as the sum of the modules, M, or the segments, S, and the attributes associated with them.

Some of these data may be pre-established in workable combinations through a list with pointers for A's attributes, so that when A is called, when working on the level, it automatically aggregates the associated data. The re-use of the data is designed to reduce storage requirements, calculations, decisions, and errors.

THE SITE

Before the building can be considered, the site must be examined. The site analysis defines the "solution space" in which the program puts the building. Each site has associated with it certain properties and boundary conditions which define external constraints to the building. These properties include size and shape, contours, zoning envelopes, land costs, subsurface conditions; boundary conditions can be streets main or secondary, adjacent site uses and configurations, views.

EXIT REQUIREMENTS AND THE CIRCULATION SYSTEM

Before the building can be generated another major constraint to the problem must be considered: the location of a circulation system. Stairs, elevators and corridors which generally associated with the building as a whole and not with the apartments.

The access to apartments has, as its limiting constraint, the means of egress from the apartments. (BOCA Code, 1978) There are three specific breakpoints in the exit requirements in multi-family housing: 1) two family units, 2) multi-family below three stories and 3) multi-family above three stories. In medium to hi-rise housing, another breakpoint is whether the size of the property is large enough to require corridors between the stairs. The circulation pattern therefore is the framework from which to hang the apartments.

The algorithm for the multistory case proves quite interesting. The building code requires two means of egress from each apartment, provided, in the case of buildings below certain height limits, by a stair and a fire escape, and in the case of hi-rise buildings, by two stairs either in a core or connected by a corridor not to exceed 100 ft., in the unsprinkled cases. Rounding off to even modules makes the distance between stairs 8M, where M = 12 ft. 10 in. The program therefore suggests stair locations at intervals of 8M. The designer can choose stair locations from the set displayed or "see what the machine does" with potential corridor locations. The potential for an improved fit will be an expanded database of apartments.

THE BUILDING

After analysis of site constraints the problem is to develop, at a high level of detail, a particular building, which accomodates the site. The problem is to generate a building from apartments, A1,A2,A3,...,An to meet a predetermined objective function. The building will be limited by a set of predetermined internal and external constraints.

The general problem in housing and urban design is not to design one building but to design a large number of buildings and to create an overall environment which has some variety to it. In other words, a basic assumption has been made that the way to solve the "housing problem" is not only to build a large number of housing units (or buildings), but also to make them different, provide they meet certain specific criteria. It has been further assumed that the way to make them different is to avoid repeating typical arrangements.

The design of a building, where each apartment is placed sequentially, can be considered a stochastic process. The designer is working in a probability space where the placement of an apartment, An, is the outcome of some action, c, and the total result is a sequence of possible outcomes. It should be evident that by assigning probabilities as to the outcomes (based on real constraints) that the sequence of outcomes will differ on each pass through the sequence. Therefore, the designer need only focus on the sequences and the probabilities and not on the whole.

The measure of a sequence space is completely determined by:

a) the starting probabilities or distribution
b) the transition probabilities

The conditional probabilities, the transition from one state, S, to another, Sn, can be viewed as if placed in a tree diagram. The probability of reaching down any particular pathway in the tree is the product of the probabilities of going down any particular branch. The underlying mathematical abstraction has the property of a Markov chain.

After possible circulation systems have been established, apartments can be located in relationship to it. The decision to allocate any one apartment next to another must take into account 1) the prior decisions which have been made locating either constraints or other apartments and 2) the remaining range of decisions that can be made with logical possibilities.

In other words, a series of decisions has to be made that determine which apartment goes next to or above each other apartment. In the theorectical case, a matrix of probablity that one apartment, Al, follows another apartment, An, can be constructed. The general form of transition matrix will be as follows:

prior decision	present decision			
a1	p11	p12	p13	,...,pn
a2	p21	p22	p23	,...,p2n
a3	p31	p32	p33	,...,p3n
an	pn1	pn2	pn4	,...,pnn

where $p1 + p2 + p3 + \ldots + pn = 1$

The transition matrix, TMx, can either be a constant matrix, offering the same probability at each instance of entry or it can have trends, modifying itself after each decision. Another way of developing the transition matrix is to cluster the prior decisions in order to reduce the independence of the decisions. A "string" of values can be considered the "prior" decision.

The transition matrix must take into account any number of factors with which the designer or planner is concerned. For example, suppose that a building with 400 apartments is most feasible for a particular site. The market indicates that the apartment distribution should be 20 per cent efficiency apartments, 32 per cent 1-bedroom apartments, 36 per cent 2-bedroom apartments and 12 per cent 3-bedroom apartments. Suppose, further, that a certain percentage of efficiency apartments and 1-bedroom apartments are for the elderly and that elderly people seem to like living on the third, fourth and fifth floors of the building, children, on the other hand, should live closest to the playground, single women nearest the south side of the building and bachelors on the north side. Apartment distribution is therefore a series of conflicting trends which can be resolved by the stochastic arrangement of the apartments. The modifying transition matrix created to solve this problem would take the changing probabilities into account.

THE ROLE OF THE DESIGNER

SYSBLD2, in its present format, is not intended to replace the designer. The program modifies the decision-making process by altering the time and place of design decisions. Rather than either designing a typical floor, or trying to design the building as a whole, the designer can concentrate on the relationship between one apartment and another and leave the design of the building as a whole to the program. Design decisions are shifted to the micro-level, where detailed analysis of spatial, economic or energy considerations can be made.

The successful operation of SYSBLD2 depends upon the number of elements in the database, and the ability of the designer to solve the "packing problem". Depending upon the size of the database, SYSBLD2 can generate a large number of whole buildings which will satisfy the series of constraints set up by the designer at the outset. There is a possibility that the constraints to the problem can be set too tightly to solve the problem. The program chooses a starting place, chooses an apartment after looking ahead to see how much space remains and continues to choose apartments, considering its context, until it is complete.

The program, having studied the context and the database and chosen an apartment, will save the other possibilities for that location until it finds a valid set of apartments for that entire floor. By saving the apartments, the program does not have to go back to reconsider its decisions and avoids the possibility of duplicating an unworkable arrangement by returning to a poor branch of the tree. While random selection does not preclude search down the same branch of the tree it is probably more efficacious to save good results. Except in some of the simplest of cases, this procedure can result in a considerable saving in time. The program can generate potential solutions until one of two things occurs:

1) All apartments are placed.
2) All the possibilities are exhausted.

If the last alternative occurs the program prints a summary of the information it has generated with the message:

Floor XX Has No Acceptable Arrangement of Apartments.
Suggest reviewing problem constraints.

There will be no attempt to complete any of the remaining floors with apartments. At this juncture, the designer can modify some of the input criteria.

The potential arrangement of apartments on one floor, or the positioning of vertical elements, such as core modules, effect the results on the floor above it, as in the case of a duplex apartment. In this way the selection of one apartment can be influenced by the previous selections of all surrounding apartments. Two story apartments are placed as a unit with a flag set for an obstruction on the next floor.

At some time in the future, after experience in hand modifying the constraints, the program can be expanded to include constraint modification. Indices can be developed which indicate the degree to which arrangement are not acceptable.

SUMMARY

SYSBLD2 is a computer program which generates and tests potential site plans and buildings from a database of apartments, their components and their associated attributes. The program creates, internally, a solution space by examining the site, establishing exit constraints and sequentially placing apartments using stochastic methods. The program has a database which establishes the linking or non-linking of apartments both to each other, to their wet cores, to the circulation system and to their attributes. The steps in the design process include the generation of segments from sets of modules, the generation of apartments from sets of segments, and the generation of buildings, floor by floor, from sets of apartments. The decisions at each point are constrained by sets of objective functions or generated randomly using Markovian transition matrices. On the larger scale, SYSBLD2 generates site plans from aggregations of buildings.

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ENERGY CONTROL IN BUILDING DESIGN
AN APPLICATIVE GRAPHIC METHOD

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ABSTRACT

The problems one has to face when planning bioclimatic buildings are basically due to the lack of such tools as can efficiently outline the design's energetic behaviour when the first planning takes place, thus enabling control to be repeatedly carried out on the whole of initial design choices. Graphic tools have been conceived capable of meeting the above requirements to cope with such drawbacks. By means of these tools the seasonal energetic demand can be met in a given climatic area for the building in question to be heated. That result can be ensured by knowing a limited number of data (building type and orientation, ratio of dispersion surface to volume, average trasmittance of the envelope, kind of glazing, framework heaviness). The way the chart has been devised points out how the above mentioned data affect the energy demand of the planned building. The design in question can be therefore effectively and quickly amended, according to the required energy results, by cyclic process inside the areas the chart is made up of.

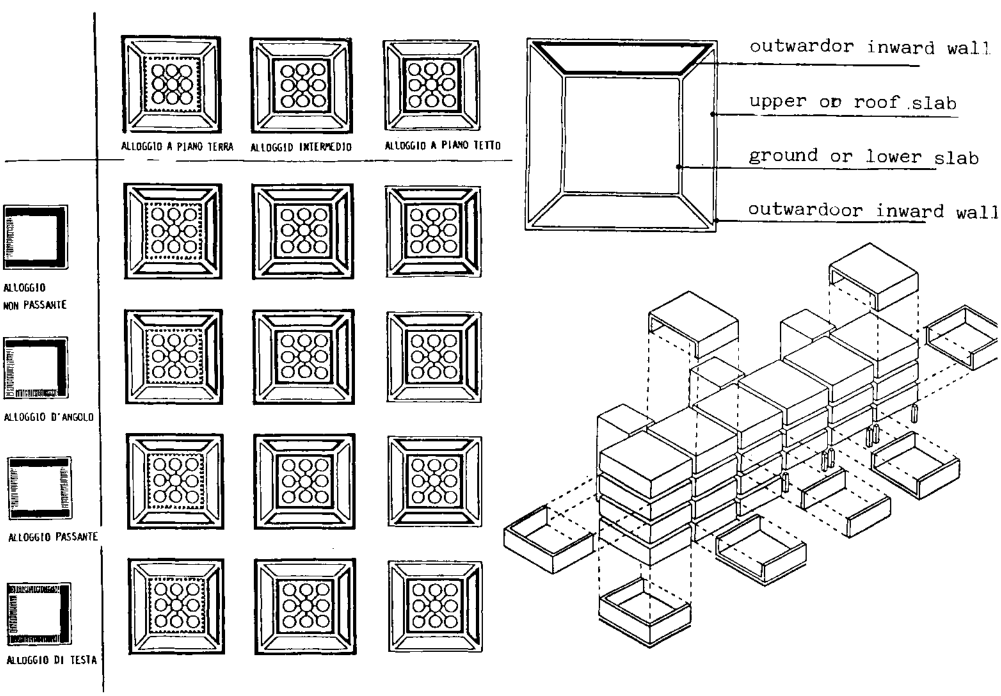
1. THE BIOCLIMATIC DESIGN

When bioclimatic design was introduced, a shift on controls on climate and energy behaviour of the building took place, starting from end stages, when the building had been completely laid out and the system had to be adjusted to it up to intermediate stages when volume, shell and windows may still be changed and amended. Recent studies show that these decisions should be taken still earlier. As a matter of fact, the best cost benefit ratio concerns early choices: these determine the building's whole volume, its siting, general arrangement which are already dealt with, in most cases, at the town-planning level. We are by now examining detailed plans which select, orientation, volumes, building types, etc, who are not yet so well defined, as to be checked. The building's general features being however decided so as to provide major savings, whatever ensues in therefore already influenced. Should early choices prove incorrect, energy improvements would be baffled. The ratio of investments to energy savings may be illustrated by an asymptoptic curve. Whilst in early choices great benefit is obtained at little costs, later changes, which amend earlier faults by means of sophisticated instruments, require great expenditures to get small benefit. To carry out as early controls as possible, is therefore our de-

sign problem.
Three issues arise:
- there should be comparatively simple controls, as the design stage is still unsettled and many suggestions can still be put forward; on that account control times should be shortened and the plan should not be too defined;
- architects or civil engineers are often entrusted with these controls and, being not familiar enough with the rather complicated calculation instruments of energy budgets, cannot carry out their task if it proves too complex;
- the tools should be kept at high scientific level; if energy controls are to be carried out at early stages, control level should not be lowered. On the other hand the energy choices are unlikely made at early stages if these problems are not being solved.

2. CUBIC MODULES AND BUILDING TYPES

We have then considered what the architect's work is like in the early stages of the design process, and have tried to set up a system which could fit in with the techniques of the corresponding stage. Space modules have been created, sometimes called "macromodules", by means of which the performance system design can be defined. It was decided that the macromodule is a module having a 3 m long side. Many building types are usually found in this country's dwelling buildings, which are obtained bv variously arranging these modules together.



The size of the cube is given by dwelling buildings' storey height and deepness; that may be achieved by arranging the modules in different sizings: 6, 9, 12, 15,or 18 m; this module is of little importance as far as the size of the framework is concerned, as it does not depend on partition walls; it has even less impact on the width of the building owing to the large amount of modules it is made up of. These modules have a varying number of autoside-facing sides, according to their setting in the whole building. If we consider which arrangements are possible, we get 24 different types of modules which, if differently arranged make up building types all featuring an orthogonal space structure. Each module therefore features a given number of outside-facing, thus dispersing, sides, but it also shows south-facing sun energy collecting sides. Provided it is alloted a specific technology, each module can be characterized by its own energy budget. Each of the 24 modules has undergone simulated energy testing. The following parameters have been changed by turns:
- orientation;
- transmittance, technologies of the envelope of the building;
- glazed surface as regard orientation;
- main features of climatic area.

Relationships and repetitions have emerged from data processing, which suggested we should be able to arrange the above data into nomographs; these would make the outcome more immediately apparent and design choices directly amendable. Nomographs have been set up for each climatic area. They chacacterize the following different building types:
- south- and north-facing row houses and apartment blocks;
- east- and west-facing row houses and apartment blocks;
- tower houses.

A monograph has also been worked out for the different climatic areas. Overheating effects may be thereby controlled. The designer can so avoid mistakes due to incorrect information on climatic conditions. He can also choose the suitable monograph according to the building type of his project. A feed-back loop can now be set up between the designer and the monograph. This makes possible a step by step evolution of the design by selecting all solutions and amendments which can improve the energy performances of the building. the nomograph translates design decisions into seasonal consumption terms by simulation; so the energy results of those decisions may be immediately appraised. The energy demand only stands out when planning is completely carried out if the usual tools are used. These can not be succesfully used at the early stages of design process where the efficiency of the designer's choices ought to be quantified in energy terms. The present graphic system has been arranged ti find a solution to that issue and to make the task easier for the designer. The methods evaluate to a fair degree of accuracy how great the energy seasonal demand of any building is, whose components' performances are known. Another issue we have dealt with is how to collect the environmental data of the building site. Meteorological data are always difficult to analyse; the use of charts offers the designer a solution; in fact he does not need long and tiring research arranging all data into the climatic environment.

3. CALCULATION METHODS

To work out the energy demand of a building, we are today using some calculation methods based on computer programs and detailed simulation of the environment thermal behaviour under actual weather conditions. Nevertheless these methods are difficult to come by; their use is not widespread, expensive and complex as it is now. Since they however make the survey easier of a wide range of building types and, at the same time, they exactly evaluate the different items which are to be entered in the thermal budget of a building, they have been employed to set up simplified easy--to-use calculation method of the energy demand for both heating and cooling. This method has been later employed to set up the graphic method.

3.1 Simplified Calculation Method

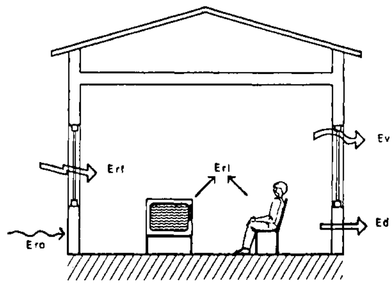


Fig. 1

If we take into account the average values of the climatic data referred to the period in question, the energy demand is worked out by means of a thermal budget. This takes different components in (Fig. 1) and may be expressed by:

$$E = E_u - \eta E_i$$

where:

E = energy demand for the period in question;

E_u = outgoing energy in the period in question;

E_i = incoming energy in the period in question;

η = efficienty of free energy.

The flow of outgoing energy can be worked out as follows:

$$E_u = E_d + E_v$$

where:

E_d = outgoing energy by transmission due to the temperature gap between the inside and the outside;

E_v = outgoing energy caused by ventilation.

The incoming energy may be expressed by:

$$E_i = E_{rf} + E_{ra} + E_{ri} + E_{ro}$$

where:

E_{rf} = incoming energy caused by sun rays striking on glazing;

E_{ra} = energy caused by sun energy storing in the framework;

E_{ri} = energy caused by inside sources (lights, people etc).

Efficienty of free energy, η , is variable from 0 to 1; changing weather conditions should be accounted for possible environmental overheating, in winter also. In that case the inside temperature rises above the fixed level and losses to the outside increase. Allowing for heat losses increase, the amount of available energy should be reduced, provided we set the indoor temperature uniform and equal to the fixed one. η value will depend on the following data for its special meaning:
- ratio of energy losses to free energy;
- mass of the envelope;
- specific transmittance of the envelope.

3.2 Necessary Data for Simplified Methods To Be Used

a) Data of the building:
   - geometry and orientation;
   - thermophysical features of the outer envelope, slabs and partitions: total transmittance, mass per surface unit.

b) Working conditions of the period in question:
   - inside temperature;
   - ventilation rate;
   - inside sources of heat.

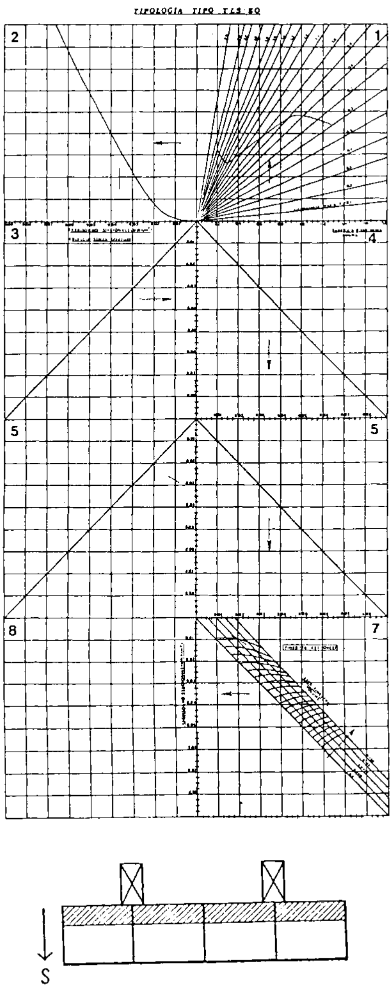
c) Climatic data of the period and site in question:
   - average outside temperature;
   - total radiation for different orientations;
   - average wind speed for the period in question.

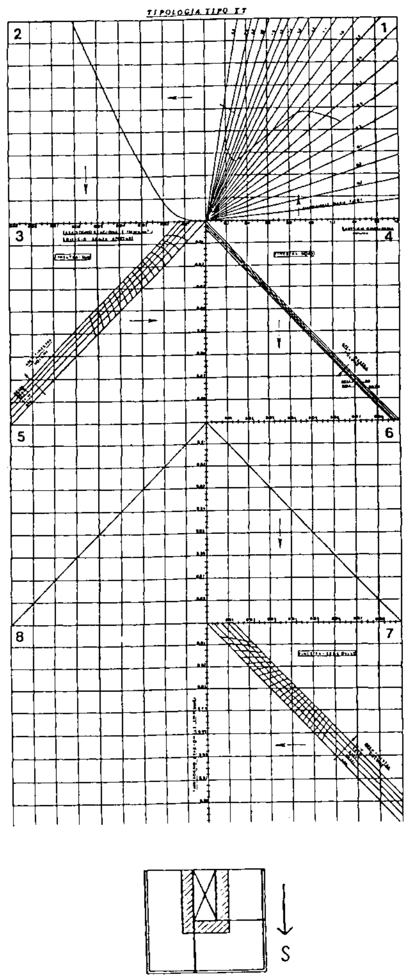
4. PROPOSED CHARTS

Once the above mentioned calculation method has been applied to a basic set of modules, seasonal energy demand may be worked out provided the climatic features of the building's site are known. For each basic module different design and technological hypotheses have been made to stress such data as mainly affecting the energy behaviour of the building. For instance, the rates of opaque and transparent surfaces of the envelope have by turns been changed; the same applies to such thermophysical features of the envelope as transmittance and framework weight. Putting the outcomes together according to each building type's requirements, the energy demand has emerged for a great amount of types. After the results have been examined, those data stood out which mostly affect the energy behaviour of a building. They are:
- preference orientation;
- shape factor (ratio of the dispersion surface to the envelope volume);
- specific average transmittance of the envelope;
- size, orientation and kind of glazing surfaces;
- coefficient of shading;
- specific mass of the envelope.

On these grounds, charts have been arranged for each climatic area. They separately show how those data act on energy demand. These charts are respectively available for:
- building types developing alongside the north-south axis (row houses and apartment blocks);
- building types developing alongside the east-west axis (row houses and apartment blocks);
- building types with no preferred orientation (detached houses, tower blocks).

In conformity with what has been shown in the first point (preference orientation), the other data are, on the contrary, charted in the diagram, each diagram being made up of many areas, each of which represents single working data and points out the way the same data are tied up with the energy demand. (Fig. 2a,b).





5. APPLICATIVE EXAMPLE

Charts are now available for the four climatic areas the Veneto region has been divided into. Once the site and the kind of the building to be planned is known, it is clear which chart should be used. Each chart is divided into 8 sectors, each sector representing single working data. In sector 1 straight lines represent different values of the average transmittance of the envelope, expressed by:

$$K_M = \frac{\sum_1^n K_i S_i}{\sum_1^n S_i}$$

where:

n = number of dispersion surfaces;

K = coefficient of total transmission of each surface (W/m2 K);

S = area of each surface (m2).

The variable which may be defined as the ratio of the envelope's total dispersion surface (S) to the contained volume (V) is transferred on to the abscissa. Sector 2 curve shows the energy demand of a building by considering the ordinate relevant to the point of intersection of the available data, i.e. S/V and K_m, regardless of sun rays penetrating through the glasses. With regard to an envelope with a specific mass M, amounting to less than 500 kg/m2, as defined by the ratio of the envelope's total mass to the floor's total area, obtained by adding each storey's surfaces, continuous straight lines are shown in Sector 3 which represent available south-facing glazing area; dotted-line curves have also been traced which, starting from the straight line at 45°, provide how much the energy demand changes (shown on the ordinate scale) as the glazing area varies (shown by the straight lines). The same applies to Sector 4 in which north-facing windows are dealt with. Sector 5 and Sector 6 show the same quantities as Sector 3 and Sector 4, but they refer to envelopes having a specific mass M over 500 kg/m2. Sector 7 stresses the influence of the east/west-facing windows, no matter what the mass of the envelope is. These last have been considered together in the same sector because the relevant solar radiation have the same value. Sector 8 shows the whole demand of the building; besides, straight lines are shown at 45°, which make it possible to compare the results obtained from the building types in question and the results of a plan as good as Act n. 373 on transmittance values provides for. The different use of the chart depends on:
- either a comprehensive checking of an already laid-out plan;
- or a study for a plan.

5.1 Energy Comprehensive Checking of Already Laid-out Projects

Provided that thermophysical and geometrical features of the building types in question are known, all data have been defined which are necessary for the charts to be used. When we get to know the S/V and the K_m (Fig. 3) average transmittance ratios, we can spot a point called 'a' in Sector 1. If the relevant ordinate is transferred on to Sector 2 curve, we can find a point called 'b', which in turn locates a 'c' point on the abscissa. This last represents the energy demand of the building on the same scale, regardless of sun rays coming through the glazing surfaces, as we have already said. The energy supplied by sun rays striking on glazing surfaces is accounted for by employment of the following Sectors. If the value of M is below 500 kg/m2 and there are south-facing windows, then we move upright from 'c' point to meet the straight line corresponding to the actual size of windows in 'd' point. If there are also north-facing windows, we should horizontally move from 'd' point to Sector 4 to meet the straight line corresponding to the actual size of windows in 'e' point. If there are no east- and west-facing windows, we vertically move to 'f' point of Sector 7 which corresponds to no window. In Sector 8 we can see the whole heating demand of the building type in question on the ordinate. We can check whether the plan is well-founded by comparision with the outcomes of a plan as good as Act n. 373 provides for. Figure 3 illustrates how the chart should be used, which deals with the preferred-north-south-axis orientation type with specific mass M $\leq$ 500 kg/m2 and north- and south-facing windows only.

5.2 An Analysis of Energy Performance in Design Process

If we want to examine how the different design choices affect the heating demand of buildings, we must act this way. Once a hypothetical plan of the envelope has been drafted and the kind of building materials chosen, the values are singled out of S/V and K_m average transmittance of the envelope, which at this stage we consider as completely blind. At this early stage, using Sectors 1 and 2 of Figure 4 (see Section 3.1), this building's demand may be found out. Let's now pretend we want to open some south-facing windows; if the value of M is below 500 kg/m2, then we should employ the curves traced in Sector 3. On this Sector's ordinate we can read the values of the energy demand allowing for the impact of the windows. 'c' point is clearly shown in Sector 2; if we trace an upright line from that point to the straight line at 45° shown in Sector 3, 'd' point on the same line is found, whose ordinate indicates the value of the heating demand of the still blind building. Starting now from 'd' point and moving alongside the dotted-line curve, we meet different sizes of glazing area (continuous straight line); (should not the said curve be traced on the chart, it may be drawn up by interpolating the values of the adiacent ones). We now get some points whose ordinate indicates the heating demand of a building with as many glazing surfaces as are indicated by the value of the window's area. The different consequences of the openings therefore vary according to the insulation extent of the framework itself; the way can also be immediately by which realized the energy demand can be reduced to a minimum. Once the features of south-facing type have been outlined, we are going to see what happens when the windows are being orientated the other ways. Let's suppose we wanted to open a north-facing window. Sector 3 shows 'e' point which represents south-facing building types only. If we transfer that point's ordinate on to the straight line at 45° of Sector 4, it indicates point 'f'. If we now start from this point and move alongside the dotted-line curves, shown in Sector 4, to meet the continuous straight lines relevant to the possible north-facing windows, new points are spotted whose abscissa represents the value of the energy demand in the new circumstances. If the other sides have no windows, from the new point called 'g' (corresponding to a given north-facing glazing area) we vertically move to meet the straight line at 45° in Sector 7 (no windows are taken into account) and get point 'h'. Point 'i', as indicated in Sector 8, shows the energy demand. We can besides move alongside the straight lines at 45° to meet the scale of the abscissae and make a comparison with the results obtained from a building framework as good as Act n. 373 provides for. The different glazing areas have increased the value of the average transmittance of the building against the original value of a completely blind building. It is now necessary to check whether the plan fits in with the volume's total dispersion U coefficient limits set by Act n. 373. For that purpose the chart may be used the other way round: the new average transmittance can in fact be worked out and compared with the top value fixed by law, the latter being in turn spotted on the chart.

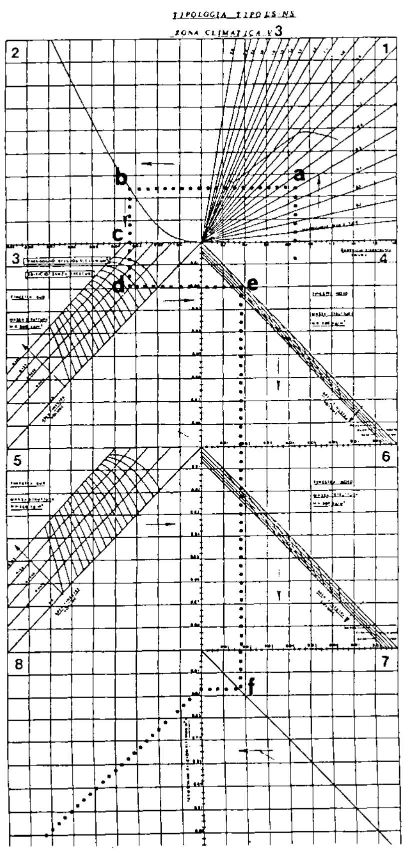


Fig. 3
Energy Comprehensive Checking of
Already Laid-out Projects

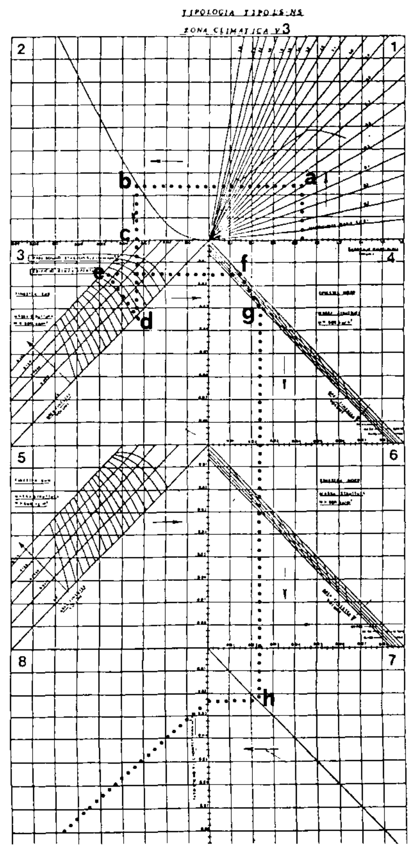


Fig. 4
Analysis of Energy Performance
in Design Process

6. FUTURE DEVELOPMENTS

Owing to the way they have been arranged, the above mentioned charts can easily fit in with other working hypothesis, concerning the following data:

- an examination of the shading brought about by different obstacles whatever they are (overhangs, balconies, other buildings ect);
- an appraisal of energy supply from different passive systems (Trombe walls, sun spaces, air collectors) based upon the climatic features of the site and on the type of adopted solution;
- an economic survey of suitable decisions to bring the costs/benefit data to an optimum.

7. CONCLUSION

The graphic tools we have been proposing, though easy to use as they are, can provide any designer with what is necessary to correctly design a building from the energy point of view. Whatever the climatic environment, this kind of tools can be arranged for any area outside Veneto. That makes their use universally applicable. A range of three different charts is now available for each different climatic area of Veneto, whereby the following type-list can be drawn up:

i) mainly South- and North-orientated buildings types (two/three-storey raw houses, apartment blocks);

ii) mainly East- and West-orientated buildings types (raw houses and apartment blocks);

iii) isolated block building type (detached houses, tower houses).

The charts have been arranged for all climatic areas of Veneto, as environmental conditions typical of each climatic area make up the very framework of the different areas of the chart. If these are properly used, the task is made easier for the designer who is hence ridded of the toiling and uneasy task of reaserching the climatic data. These, obtained as they often are, from different sources, cannot be easily understood and look contradictory and heterogeneous.

PASSIVE SOLAR SYSTEMS VERSUS ARCHITECTURE

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ABSTRACT

This paper proposes to stress the importance of design pursued in order to obtain efficient energy savings.
The relevance given to the system explains the interest for a conception centred more on the project rather than on the product.
The bioclimatic (or energetic) quality, that has become a normal architectural one, refers to the crucial problems of the scientific research and of the site transformation, as they appear in the context of architectural culture.
The design is then analyzed and structured in the operations that characterize its process, stressing, between these operations, the value of the architectonic ones.

SCIENTIFIC METHOD AND SITE'S TRANSFORMATION

Bioclimatic architecture shouldn't be presented as one of the many mouvements or one of the many fashions which animate the discussion in the architecture cultural context.
To give a real contribute to the improvement of environmental quality in building production those who are engaged in bioclimatic planning should give up the avant-garde tone and realize the normality of these researches.
Good architecture has always been a bioclimatic architecture, but today, after the energy crisis, no building quality can be found apart an energy control of the planning.
Non-bioclimatic architecture is therefore an architecture without quality.
At this point, one should recognize the unilaterality of the various mouvements which, being unable to face architecture's complexity propose schematic solutions, stressing only one of the project's many dimensions. Thus we have buildings determined only by technological and productive factors, or only by formal factors. It wouldn't be correct if we should now have buildings determined only by energetic factors. The variable energy isn't certainly the only variable, neither the most important one between those which influence the solution of the project problem. The new movement must accept the actual problem such as it appears, and must organize the complexity avoiding to elude it with easy simpleness.

But in this way, the architecture of complexity (which includes also the bioclimatic dimension) faces two main problems of the ärchitectural culture.
The first problem regards the scientific method applied to the design - though - phisics and geometry, building science, thermodynamic certainly are fixed reference points that no real designercan neglect, the history of Modern Mouvement proceeds through a continuous effort in order to extend the rationality of the design. The development of the architectural design as a scientific discipline begins with L.B. Alberti, who wanted to transform it from a mechanical to a liberal art, and continues with Lodoli who intended to apply Galileo's science to the architectural design development. It then continues with Simon who, with the sciences of the Artificial, faces in modern terms the problem of a scientific design
The architecture's object should be more the transformation of a site of an environment from one condition to another, rather than the merely fitting of a building in the environment itself, is the second problem to be faced.
This happens as well with the functional architecture planned starting from the inside of the building, as with the urban architecture (which starts with TEAM X research) planned starting from the outside of the building, from the public space system.
Bioclimatic architecture provides a very significant contribution to these two fundamental problems.
Urban analysis becomes important when the site's transformation from one condition to another regards, as it mostly does, an urban site. The climatic resources analysis acknowledges to the site a new dimension common either to urban or rural sites, which also allows to make the management more economic.
An effort has often been made to try to identify the emergent architecture's characteristics as on answer to the energy crisis - this architecture has been in turn called passive, bioclimatic, solar. We have already dealt with the difficulties met when this architecture is considered as one of the many mouvements present in the current architectural culture.
It is interesting to understand how the bioclimatic architecture find its place in the current position's setting.
If we report the various mouvements to the two problems already debated upon, regarding the scientific method and the site's transformation; and if we strongly assemble the great variety of positions, three mouvements may be identified enabling us to analyze this architecture's specific role.
A first group includes the regional and vernacular architecture based on an empiric approach to the design's problems, that claims architecture's autonomy, being partly art and partly .science, as regards the traditional disciplines.
This position considers architecture's evolution without breaks as regards the part.
The current design process is then supposed to have developed itself through craft's transmission, and it is only in this tradition's context that quality in architecture may be achieved.
This group also includes advocacy planning mouvements and all those who are inclined to deny a specific architecture theory.
The second position pursues the object of developing an architectural theory based on a marxist-scientific approach.
"Neorealismo" and "Tendenza" characterize this mouvement that refers to researches carried out by architects of the Left, in the period between the two world wars.
A specific method of analysis and planning intended to check the validity of hi-

storical materialism in research and in practice is carried out in the architectural composition, and in urban planning.

There are many critical reconstructions coherent of this mouvement's continuity, which can be traced back to the enlightement architecture following an historical development reflecting the society's development.

The third group includes a great variety of positions which may be characterised by the critical rationalism's positions and by social-democratic reformism.

The experiences aiming to integrate the architectural design through a systems approach, in the context of a scientific and technological process, belong to this group.

Many researches on the rationalization of the building and on the system design's methods belong to this group.

In bioclimatic architecture there are two positions which may be considered consistent with the first and the third of these three groups.

A great part of the planning experiences developed in various european countries and in post-revolutionary Russia, determined by considerations as regards sun orientation and by the climatic situation as a whole belong to the second group.

To the first group belong the projects and the interventions in radical contraposition to modern society and in agreement with pre-industrial technologies, current in the local traditional building, anonymous or popular, following the post-industrial development trend.

A catalogue of the works on solar or bioclimatic architecture, as regards this group, can easily be made.

The third position instead, includes all the researches for the development of scientific techniques of bioclimatic planning integrating the climatization problems (heating and cooling) with those of acoustics and of natural and artificial lighting.

To this group belongs the idea of the building as a cibernetic system, regulating through a dynamic envelope the energy flow between inside and outside, and the planning of innovating technologies aiming at an always greater rationalization of the production processes.

These positions state therefore different forms of integration in the architecture of solar energy uptake. This way of laying out the problem may seems too theoric and not very practical, but I think that there is nothing more practical than a good theory.

DESIGN TOOLS

Design tools for bioclimatic architecture has been developed in recent years in order to solve some problems arosen as a result of energy crisis.

In specifying the role of these tools within design process, the same difficulties are met with as when introducing other scientific tools, quite apart from the distinctive features of energy issues.

The first step in the development of design tools aimed at obtaining energy efficient buildings has been the application to design process of computer programs that mechanical engineers had already developed for heating and cooling systems. However, architects were unprepared to use such tools, which had been therefore simplified and translated into graphic tools (diagrams and nomographs).

The need of using energy control tools in the first stages of the design process encouraged this simplification: But the problem cannot be solved in such a way, because design tools ought interact with each other in order to organize the design process' complexity.

In the development of design tools that are useful in the first stages of the design process, the basic question is not the simplification, also graphic, of existing procedures, but instead the development of design languages wich can generate efficient solutions for bioclimatic buildings.

According to recent studies in design methods, we could consider the design process as a complex set of different operations which should be subdivided into three categories:

1. Models to simulate the future performance of design hypotheses;
2. Models to assess the efficiency (cost/benefit analysis) of the simulated solutions;
3. Models to generate through design languages the solutions to be simulated and assessed.

Most of existing design tools fall within the first two categories.

They are analytical tools and sophisticated or simplified computer programs.

The future research work to be done in order to make the design process more balanced, and to provide architects with appropriated tools to be used in the schematic design, should develop the models of the third kind.

Architecture could contribute to this work, not only as the final result of the design process but, as in the case of shape grammars, as a way of developing architectural information, without the need of translating it into other languages, that are less efficient within the design process.

More attention should therefore be given to the design process (considered as the software of the production or construction process), in order to improve the efficiency of the tools and techniques for an architecture of the complexity.

The different role of simulation and evaluation models (model 1 and 2) compared with that of language models in architecture can now be considered.

The first two models are part of the engineer's culture; the third one pertains to the architect's culture.

When a change in the environment or in the users requires a innovative design, the proposed solution appears as an index.

The device solving a technical problem is experienced as an index which can be decoded only by people knowing its context.

The repeated use of such an index involves a coding process which gradually transforms it into a signal.

At present, the task of design is to transform the indexes of bioclimatic building into architectural signals, to move from an organ-function relationship to an expression-content relationship.

This transformation is the specific task of architecture.

The coding process, the shift from index to signal, transforms what was an object of knowing into a language, which is at the same time an object and a cognitive tool.

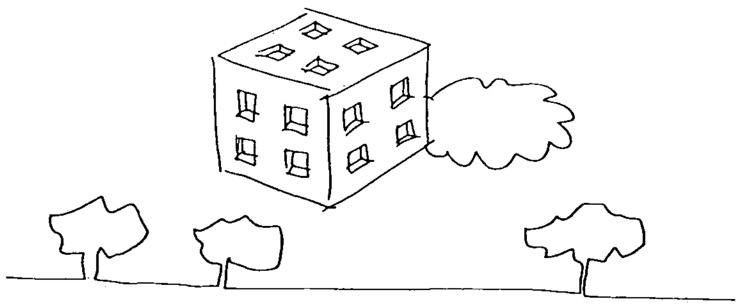
THE ARCHITECTURE OF DESIGN

We have given evidence of the importance of design, as a service, for energy saving.

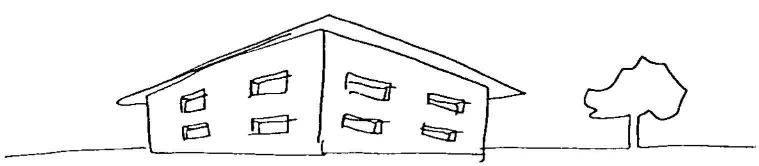
Between the design tools we have considered architecture the most important one.

We shall now show how architecture works to pre-structure the design and to give

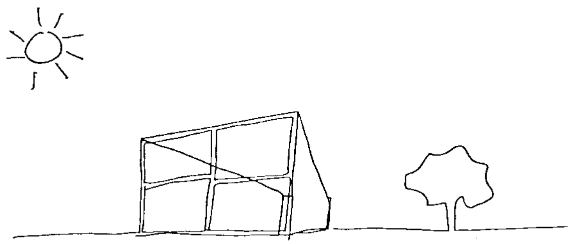
it all the necessary language support.
Let us take in consideration the evolution of a building type through a planning which, starting from architecture, goes through a series of energy controls, and ends again as architecture.
Compactness is an object that should be systematically pursued to formulate an energy conserving building.
In that sense, the cube is the optimal form, after having of course given up the idea of a sphere.
But the cube is the most compact form only if all the walls have the same transmittance and this would be possible only if it could float in the sky.



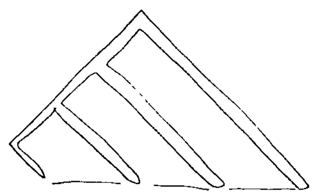
When the gravitational field keeps the cube pressed against the ground and rain and snow fall on it the transmittance of the floor and roof is less than that of the walls.
The optimal form now is no longer the cube, but a square plan parallelepiped whose height is inferior to the plan side.



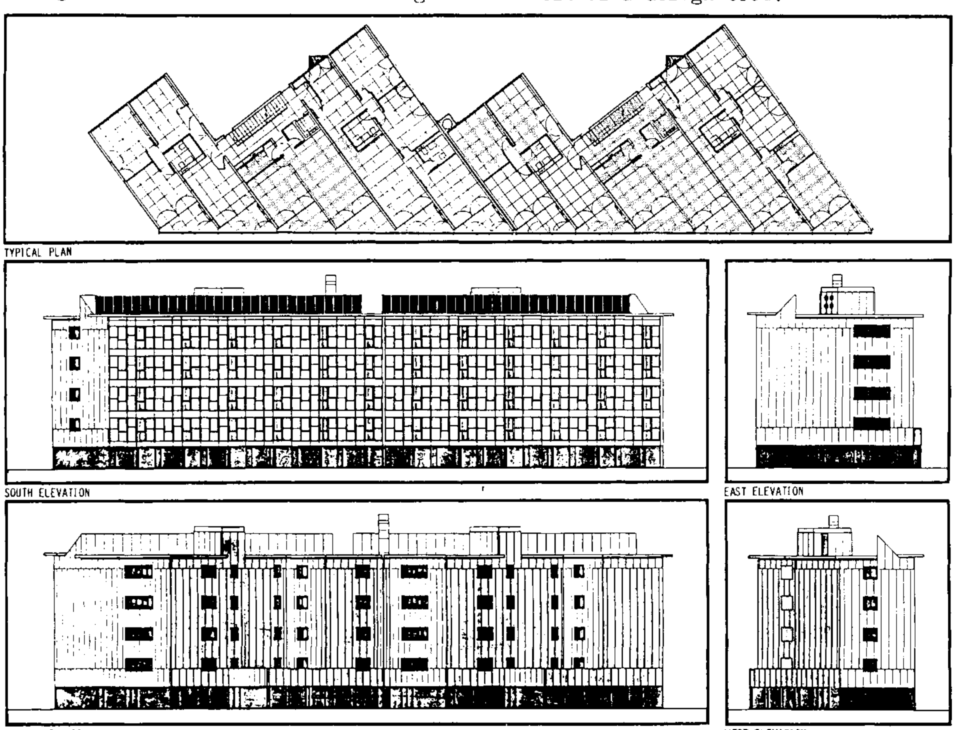
The anisotropy due to gravity, differentiating the walls, alters the form corresponding to the optimal compactness.
But we now find another anisotropy which still more alters the walls owing to solar radiation.
Owing to the sun, the south-facing wall becomes less dispersing, as it gains what it looses.
This wall therefore becomes bigger than the one facing north, which looses energy without gaining anything.
The shape obtained is that of a trapezium or of a triangle, the sides being determined by their transmittance.



A last point regards the South façade.
There is a anisotropy between morning and afternoon due to the thermal mass. Owing to this thermal mass the temperature changes causing an irregular climate during the various hours of the day.
The building's geometry helps us again to solve the problem. The trapezium or the triangle should - infact - be asimmetric so as to correct this last anisotropy.



Many triangular building types may be found in bioclimatic architecture. That coding of this form could become of great interest as a design tool.



AUTHOR INDEX

H

I

J

K

L

M

N

P

R

S

SUBJECT INDEX

T

U

V

W

Z