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Editors

Sustainability in Energy and Buildings

Results of the Second International Conference on Sustainability in Energy and Buildings (SEB'10)

SMART INNOVATION, SYSTEMS AND TECHNOLOGIES 7

Springer

Robert J. Howlett, Lakhmi C. Jain, and Shaun H. Lee (Eds.)

Sustainability in Energy and Buildings

Smart Innovation, Systems and Technologies 7

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Foreword

KES International (KES) is a worldwide organization that provides a professional community and association for researchers, originally in the discipline of Knowledge Based and Intelligent Engineering Systems, but now extending into other related areas. Through this, KES provides its members with opportunities for publication and beneficial interaction.

The focus of KES is research and technology transfer in the area of Intelligent Systems, i.e. computer-based software systems that operate in a manner analogous to the human brain, in order to perform advanced tasks. Recently KES has started to extend its area of interest to encompass the contribution that intelligent systems can make to sustainability and renewable energy, and also the knowledge transfer, innovation and enterprise agenda.

Involving several thousand researchers, managers and engineers drawn from universities and companies world-wide, KES is in an excellent position to facilitate international research co-operation and generate synergy in the area of artificial intelligence applied to real-world 'Smart' systems and the underlying related theory.

The KES annual conference covers a broad spectrum of intelligent systems topics and attracts several hundred delegates from a range of countries round the world. KES also organizes symposia on specific technical topics, for example, Agent and Multi Agent Systems, Intelligent Decision Technologies, Intelligent Interactive Multimedia Systems and Services, Sustainability in Energy and Buildings and Innovations through Knowledge Transfer. KES is responsible for two peer-reviewed journals, the International Journal of Knowledge based and Intelligent Engineering Systems, and Intelligent Decision Technologies: an International Journal.

Published by Springer, 'Smart Innovative Systems and Technologies' is the KES flagship book series. The aim of the series is to make available a platform for the publication of books (in both hard copy and CRROM form) on all aspects of single and multi-disciplinary research involving smart innovative systems and technologies, in order to make the latest results available in a readily-accessible form.

The series covers systems that employ knowledge and intelligence in a broad sense. Its focus is systems having embedded knowledge and intelligence, which may be applied to the solution of world industrial, economic and environmental problems and the knowledge-transfer methodologies employed to make this happen effectively. The combination of intelligent systems tools and a broad range of applications introduces a need for a synergy of scientific and technological disciplines.

Examples of applicable areas to be covered by the series include intelligent decision support, smart robotics and mechatronics, knowledge engineering, intelligent multi-media, intelligent product design, intelligent medical systems, smart industrial products, smart alternative energy systems, and underpinning areas such as smart systems theory and practice, knowledge transfer, innovation and enterprise.

The series includes conference proceedings, edited collections, monographs, handbooks, reference books, and other relevant types of book in areas of science and technology where smart systems and technologies can offer innovative solutions.

High quality is an essential feature for all book proposals accepted for the series. It is expected that editors of all accepted volumes take responsibility for ensuring that contributions are subjected to an appropriate level of reviewing process and adhere to KES quality principles.

Professor Robert J. Howlett
Executive Chair, KES International
Visiting Professor, Enterprise: Bournemouth University
United Kingdom

Preface

Welcome to the proceedings of the Second International Conference on Sustainability in Energy and Buildings, SEB'10, held in the City of Brighton and Hove in the United Kingdom.

Organized by the KES International organization, SEB'10 formed a welcome opportunity for researchers in subjects related to sustainability, renewable energy technology, and applications in the built environment to mix with other scientists, industrialists and stakeholders in the field.

SEB 2010 attracted papers on a range of renewable energy and sustainability related topics and in addition the conference explored two innovative themes:-

- The application of intelligent sensing, control, optimization and modeling techniques to sustainability
  and
- The technology of sustainable buildings.

These techniques could ultimately be applied to the intelligent building

SEB 2010, the second conference in the SEB series, attracted over 100 submissions from around the world. These were subjected to a two-stage blind peer-review process. With the objective of producing a high quality conference, fewer than 30 of these were selected for presentation at the conference and publication in the proceedings.

The papers for presentation were grouped into five themes: Building Sustainability, Sustainable Power Generation, Sustainable Energy Policy and Strategy, Energy Monitoring and Management and Solar Energy Technology.

Two prominent research professors gave interesting and informative keynote talks. Professor Andrew Miller from the Centre for Sustainability of the Built Environment at the University of Brighton, UK, gave a talk entitled "Building Energy Efficiency: - Towards Energy Sustainability". Professor Roger Morgan from the School of Engineering at Liverpool John Moores University, UK, spoke on the "Displacement of Conventional Domestic Energy Demands by 'Green' Electricity".

The conference papers are now included in these proceedings, published post conference by Springer-Verlag in the new KES-Springer Smart Innovations, Systems and Technologies book series.

Thanks are due to the very many people who have given their time and goodwill freely to make the SEB'10 a success. We would like to thank the Deputy Mayor of Brighton and Hove, Councillor Garry Peltzer Dunn for opening the conference. We would like to thank the members of the International Programme

Committee who were essential in providing their reviews of the conference papers, ensuring appropriate quality. We thank the high-profile keynote speakers for providing interesting talks to inform delegates and provoke discussion. Important contributors to SEB'10 were made by the authors, presenters and delegates without whom the conference could not have taken place, so we offer them our thanks. The KES Secretariat staff worked hard to bring the conference to a high level of organization, and we thank them. Finally we thank the staff of the Holiday Inn, where the conference was held, and the people of Brighton and Hove for welcoming the event.

I hope that you will find the SEB'10 proceedings an interesting, informative and useful collection, of papers. I hope to see you at a future KES event.

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Bournemouth University, UK
Professor Lakhmi. C. Jain
University of South Australia, Australia
Mr Shaun H. Lee
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Keynote Lectures

Professor Andrew Miller
Centre for Sustainability of the Built Environment
University of Brighton, UK

Building Energy Efficiency: Towards Energy Sustainability

Abstract. Throughout the developed world the energy required for constructing, operating and maintaining our buildings represents a major proportion of the prime energy consumed and of greenhouse gases emitted to the atmosphere. Reduction in demand is therefore key to ensuring sustainability of energy supply, making existing buildings more efficient and constructing new buildings with optimum energy demands. It is also necessary to take a whole life cycle approach to the evaluation of energy consumption considering the embodied energy of the building materials and the demolition and recycling of the materials at the end of the useful life of the building.

This paper takes a whole life cycle approach to the analysis of energy efficiency in buildings. It considers the principles of design for energy efficient buildings and focus on the issues associated with improving efficiency in existing buildings and their adaptability for utilizing renewable energy.

Biography. Prof Andrew Miller is a member of the School of Environment and Technology at the University of Brighton and the Head of the Centre for Sustainability in the Built Environment.

Professor Roger Morgan
School of Engineering
Liverpool John Moores University, UK

Displacement of Conventional Domestic Energy Demands by 'Green' Electricity

Abstract. With an increasing proportion of electricity coming from renewable and from other low-carbon-dioxide sources, probably including nuclear in the future, it becomes attractive to look for a displacement of existing energy-consuming activities, both in the home and for activities associated with the home, away from fossil fuel burning appliances and towards electricity. However, this can be justified only if the increased electrical load is genuinely met from low-CO_2 sources. In practice, this probably means using as large a proportion as possible of the 'new' loads at night, using base-load generation. This would make the best possible use of generation capacity, especially if the proportion of nuclear and renewable generation is increased. It would also improve the utilisation of the transmission and distribution infrastructure, which, like the generation capacity, is not fully utilised at night.

A good example is private electric vehicles, which displace the use of petrol and diesel, which are still mostly fossil-fuel based despite the availability of bio-diesel and other bio-fuels. Private cars and bikes are typically kept at home in the evening, and need to be charged at home overnight. This has implications for the suburban electricity distribution network. Currently, most residential areas in the UK are cabled on the assumption of a 2kW (or even a 1kW) average demand. Any major increase in residential load, even at night, might involve reinforcement of the suburban distribution network, including both the substations and the underground cables.

Another good example is domestic space and water heating, which in much of the UK is dominated by natural gas. Replacing some or most of this demand by electricity would displace natural gas, which is not only fossil fuel based but also increasingly an import. This may mean a new lease of life for electric thermal storage heating. With the widespread use of hydronic (wet) heating systems in this country, any new thermal storage proposals need to be compatible with conventional pipes and radiators. This can be achieved not only with water storage, but also with a number of other thermal storage substances. But again, any increase in domestic load, even at night, might necessitate reinforcement of the suburban distribution network.

Are we prepared for the cost and disruption this would cause? Or can we use demand-side management to regulate the demand of new loads so as to make more effective use of the existing capacity?

This paper uses experimental evidence based on case studies, together with estimates based on existing information, to calculate the magnitude of extra electricity demand which might result from changing to electricity and away from the direct use of fossil fuel for domestic demands. An attempt will be made to include reductions in demand resulting from improved efficiencies and conservation

measures. The resulting figures will be used to estimate how much demand could be met without increasing generation capacity or reinforcing the transmission and distribution infrastructure, and what level of reinforcement might be needed if the whole of the demand is to be met by electricity.

Biography. Roger Morgan is an Emeritus Professor at Liverpool John Moores University, an honorary post which he has held since retiring from the Professorship of Electrical and Electronic Engineering in 2008. He has also held academic posts at the University of Brighton and the University of Ulster. His first job was with the Central Electricity Generating Board, where he was a research officer in nuclear power generation. After graduating from Cambridge University in 1964, his research career began with a PhD in materials science, but since the early 1970s has concentrated on energy efficiency and the effective use of natural energy sources. He is the author or co-author of over 150 papers and reports, and eight books. Since retiring, he has become a student again; he is enrolled in the External Degree through the medium of Welsh at Aberystwyth University. His other leisure interests include sea-going sailing, climbing mountains, and playing the mandolin in a folk-dancing band.

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Achieving Energy Efficiency in Office Building

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Abstract. This paper is to present a case of a newly built office building in the UK and to show how the energy efficiency technology in building might contribute to the energy conservation and therefore in full compliance with Part L building regulation. A large array of solutions are used which include the use of ventilation system with good high heat recovery system, limiting the heat loss and gain through the fabric by enhancing levels of insulation of building fabric to achieve lower u-values, limiting the heat loss and gain through the fabric of the building by improving air tightness to minimise any uncontrolled air leakage, provision of space heating and hot water systems which are energy efficient, improve daylight levels and reduce artificial lighting energy, provision of lighting control systems with appropriate lamps so that energy can be used efficiently improve control and monitoring of mechanical heating and ventilation systems. The office building in case study has shown the compliance with the building regulation and thus conserves the energy. Energy conservation and the compliance with building regulation are achieved through early incorporation into the building design.

Keywords: Energy Conservation, Sustainability, Building Services, Part L Building Regulation.

1 Background

Building energy use constitutes a significant proportion of total world energy consumption. In Europe for instance, 40-45% of the total energy use are consumed by the buildings [2.5.7. 8]. This striking figure of energy consumption should not astonish anyone as there is large number of mechanical and electrical equipments as part of M/E systems in building which is intended for heating, ventilation, air-conditioning and lighting. Due to the more intensive use of the M&E systems in building, the energy demand for building is continuously growing.

From the environmental point of view, it has been estimated that 4.5 out of 6 billion tonnes of industrialized countries carbon emission, half of it is due to buildings. Building more energy efficient structures may reduce carbon emissions by 60% or more, which translates to 1.35 billion tones of carbon, building more

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energy efficient structures will conserve conventional energy [1, 3, 9]. Because of the potential impact for significant savings in energy consumption and reduction of environmental burden, building energy conservation measures have received a fair amount of attention all over the world in the last few years [8]. The growing demand of building energy use has brought many concerns to the level that a stern measure has to be taken.

In the UK, the government has introduced a number of legislations to achieve energy conscious buildings, promote energy conservation and sustainability in the built environment. The Building Regulations Approved Document Part L, the Conservation of fuel and power has been in force since 6th April 2006. The intention is to reduce the substantial contribution of the built environment to energy consumption and carbon dioxide emissions.

2 Aims

The aim of this paper is to present a case of a newly built office building in England and to show how the technology in energy efficiency in building might contribute to the energy conservation and therefore in full compliance with Part L building regulation. This paper reviews how an office building can be designed to utilise energy efficiently and therefore conserve the energy.

3 Methodology

A case study which is showing the striking feature of energy efficiency is presented. The case is then analysed and evaluated against the compliance with Part L building regulation.

Various data sources for analysis used and are mainly coming from

- The project concept design document and reports
- The projects tender document documentation.
- Data from utility company, statistics in the UK
- Data from trusted sites/organizations, (e.g. CIBSE, BRE, BSRIA)

The building in case is taken directly from one of the author projects when he was working as a lead building services engineer. The grounds for the selection and analysing this case is based on the fact that there are quite a few good practices that could be adopt to improve the building energy performance and energy conservation.

4 Building Regulation Part L and Energy Conservation in Brief

Building regulations in the UK are regulation that seeks to ensure that the policies set out in the relevant legislation are carried out. Therefore, building regulations approval is required for building works in the UK. Building Regulations Part L in the UK imposes the requirement on building work which will ensure that a reasonable provision to be made for the conservation of fuel and power in buildings. It is part of the UK government strategy to reduce greenhouse gas emissions and to address global warming. It splits into four documents:

- L1A New dwellings
- L1B Existing Dwellings
- L2A New Buildings other than Dwellings
- L2B Existing Buildings other than dwellings

5 Brief Description of the Project in Case

As shown the figure 1 and 2 below, the building project in case is a newly built two stories open-plan office. Open plan offices are designed to allow more work spaces and place more occupants. It is also anticipated that the layout of the office needs to be made more adaptable to future change. When it is required the chance need to be quick and with minimum effort. But more importantly, open space offices are also part of the energy conservation strategy as only one centralized area is being heated, or cooled, and lighted. The design of the new office is based on the aspiration for high quality architectural design, visual transparency from inside to out, and a profile in keeping with the surrounding landscape.

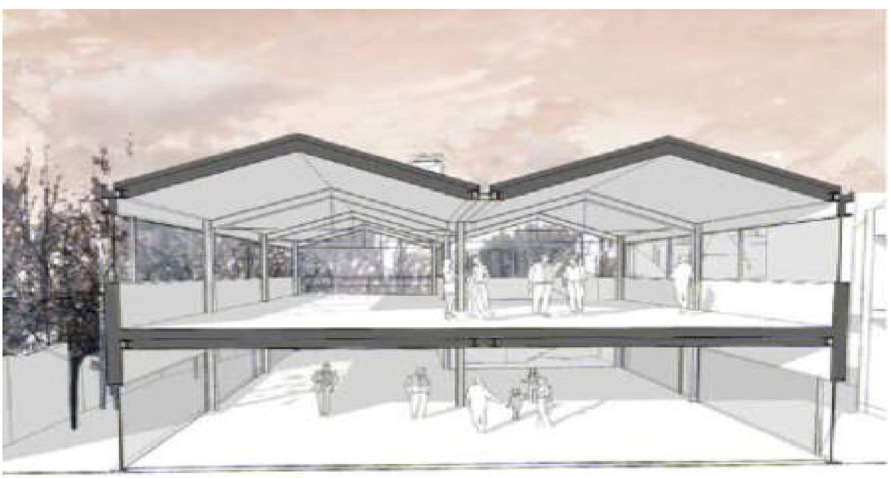

Fig. 1. The Building Project in Case area two stories office

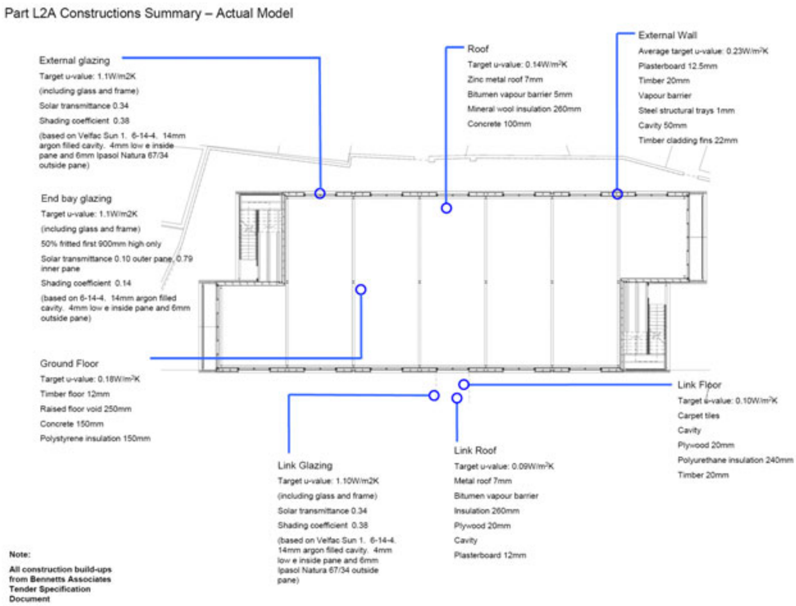

Fig. 2. Example Layout drawing of the building

The following table presents an internal design condition that is used in this office. It is from various guides and codes of practice for naturally ventilated offices.

Building type	Air Temperature	min. air supply rate (l/s/person)	Maintained Illuminance (Lux)	Daylight Factor	Noise Rating (NR)
Natural Ventilated office	23 – 27 °C	8	300- 500	2 - 5%	30 - 35

Internal design criteria are used as such in an endeavour to minimise energy consumption for the internal design criteria, but at the same times meet the CIBSE recommendations for a naturally ventilated building.

The energy profile of this office building is shown in the figure below.

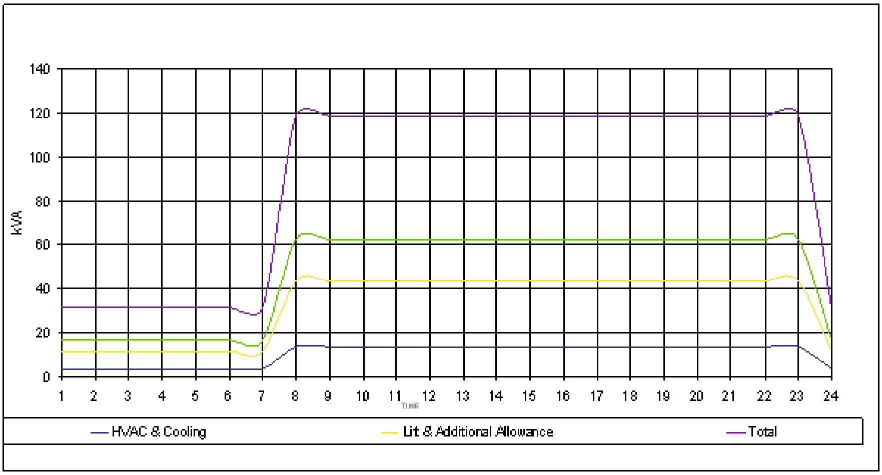

Fig. 3. Offices Electric Load Profile

6 Analysis and Results

6.1 Energy Meters and Sub-metering

Energy meter might be useful instruments for energy conservation awareness as it will provide the building operators and occupier's sufficient information for monitoring the energy consumption. It provides building operators the clear figure of how much energy is being used, and how energy consumption differs across zones in the building, the action to reduce the usage and employ more energy efficient practices will more likely to happen. Information gathered from meters might also be used for energy certification and benchmarking. Part L building regulation requires that reasonable provision would be to enable at least 90% of the estimated annual energy consumption of each fuel to be accounted for.

Regarding the energy meter and sub-meter, provision of meters is installed in the incoming services which include individual meters to directly measure total electricity, gas, oil and LPG consumed within the building. Additional sub-metering is provided for final electrical distribution boards, motor control centres providing power to fans and pumps, boiler installations.

Installing meter and sub-meter in this project might provide potential benefit to energy conservation. However, this potential could only be turned into real benefit in case the awareness of the potential energy saving is turned into actions.

6.2 Electrical System

Various methods in electrical services can be used to conserve energy such as: Demand Side Management, PF (Power Factor) Management. The demand side management is implemented through the use of energy efficient equipments such as energy efficient luminaries.

The power factor (PF) is used to improve the power factor of electrical installation to achieve a power factor of at least 0.95. This is ensured through the installation of Intelligent Power Factor Controller.

6.3 Ventilation Strategy

With the advent of the concepts of efficient energy use focus has shifted towards buildings becoming more air tight and having lower levels of ventilation. This is due to the fact that as buildings become better insulated and conduction heat loss is reduced the proportion of heating and air conditioning load due to ventilation has increased and may offer the largest scope for reducing energy demand. It has also been shown that increased levels of ventilation improve performance of occupants.

This office building is equipped with both natural and mechanical ventilation as shown on the above figure. Natural cross ventilation during periods of suitable ambient conditions is provided via opening windows and trickle vents. When the ambient conditions are not suitable to enhance the thermal comfort levels of the internal occupied zones, a mechanical ventilation system comprising of two supplies and extract of dedicated air handling units located adjacent the external stair cores will discharge supply air to the office via a pressurised floor void and displacement grilles. The air handling units provide a constant 19^{o}C air supply. The air handling unit (AHU) is also provided with heat recovery to reclaim energy for the exhausted air.

The WC areas are mechanically ventilated via extract ductwork system with branches serving each toilet cubicle. Each toilet core is provided with a twin fan extract unit which will be located at high level. The system will operate when the toilet is occupied this being sensed by PIR detectors complete with variable run-on timer facility.

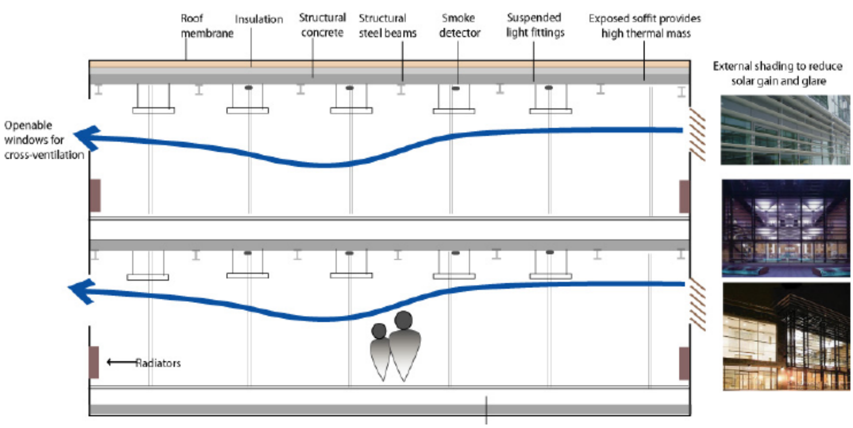

Fig. 4A. Natural Ventilation Environmental Strategy

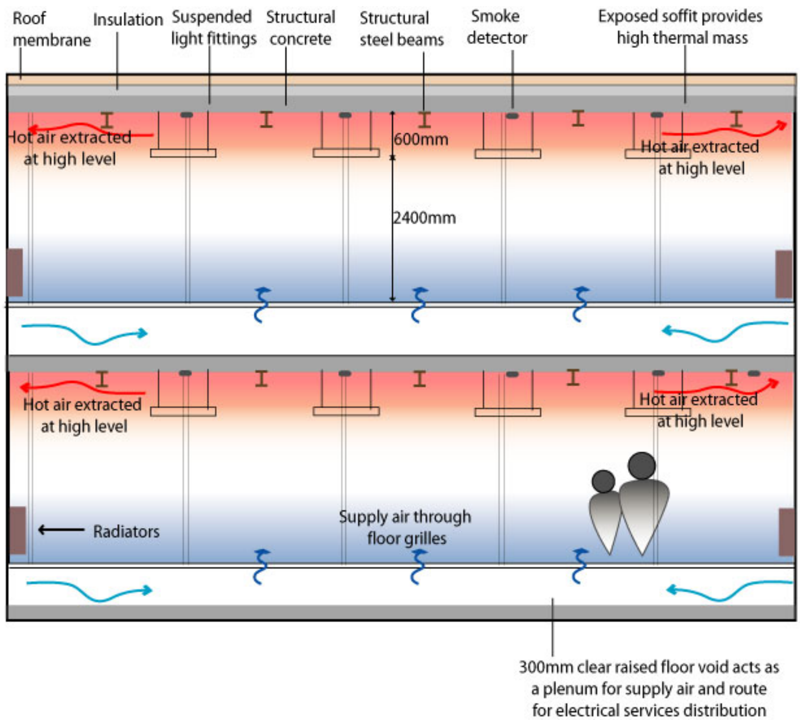

Fig. 4B. Mechanical Ventilation Energy Conservation Strategy

Tempered supply air is introduced to the office spaces via the floor void which will serve as a supply air plenum integrated with the flooring system. Air will then be discharged into the office area through floor mounted swirl diffusers. This air will then mixed with air within the office space to maintain the required conditions. Floor grilles are made available and distributed across the two office floors. The system will be fully flexible with the ability to relocate the floor tiles as required whilst maintaining the integrity of the floor plenum.

Return air is drawn back into the system through return air ductwork at high level of each office floor via return air grilles.

6.4 Lighting and Daylighting

The lighting in this office project which incorporates the daylighting is considered early in the design stage; because it is at this stage the major decisions affecting the daylighting is made and any significant changes to the daylighting in the later stage are very much more difficult and costly. Many buildings have good natural light and ventilation, but may suffer related problems of glare, excess solar gain, heat loss and draughts. This building has been designed as such that optimise between getting a good natural light but at the same time reducing glare, excess solar gain effect.

6.4.1 Daylighting

Daylight makes an important contribution to the light levels and atmosphere of an interior and may provide sufficient illumination for substantial periods in some offices, avoiding the need to use the electric lighting. The daylighting aspects of a building are determined primarily by the form of the building and its windows, factors fixed at the design stage.

Through the careful designed of building envelopes, the daylighting shows that this building has relatively good daylight factor. This indicates that the electrical lighting load within the thermal model can be reduced assuming that artificial lighting will not be switched on constantly. The lighting load has therefore dropped to $10W/m^2$ in the office areas.

To complement the daylighting, the building energy conservation features are also enhanced by the use of energy efficient artificial lighting installation. The energy efficiency of an artificial lighting installation depends on:

- The efficiency of the various components of the system: lamps, ballasts, luminaires,
- The way in which they are used, often strongly influenced by the control system and the daylight availability

The 26 mm diameter fluorescent tube is used instead of 38 mm tube. These slimmer lamps produce approximately the same light output as the larger diameter lamps of the same length and colour temperature, but consume about 8% less energy. Apart from the lamp, reflectors and control gear has been carefully selected to make the artificial lighting to become more efficient. In some areas the reduced overhead lighting is applied as appropriate, as it is anticipated that the task lighting will be used at some workspaces.

The general lighting comprises of high frequency low energy fluorescent lamps to improve energy efficiency and keep maintenance costs to a minimum. Offices lighting is provided with pendant luminaries utilising direct/indirect light distribution. In general lighting which complies with CIBSE LG7 is used, in open plan office. Metal halide and low voltage halogen luminaries are used for decorative effect and accent lighting in the reception areas.

To balance between achieving a good daylighting factor but at the same time preventing excessive over heating in summer, the control system ensure that automatic controlled blinds and window coverings on all solar exposed windows during appropriate times of the day is in operation. The control system also ensures to operate the blinds and windows when rooms are not in use to block excessive direct sunlight.

6.4.2 Lighting Control System

Four methods of lighting control are used:

- Time-based control,
- Daylight-linked control,
- Occupancy-linked control, and
- localised switching

Occupancy sensing has been shown to be an effective means of reducing lighting energy use in offices [3, 6, 12]. Time scheduling can also save significant energy in similar way in large spaces [16]. Time scheduling saved from 0.7 to 6.6 percent or an average of about 5 percent. Occupant sensors in similar areas saved from 9.0 to 14.6 percent, with an average of about 10 percent [4, 10, 11].

Further improvements in energy efficiency are achieved by using automatic sensing of daylight levels and sensing the linking to occupancy to reduce the illuminance level and the number of hours for which electric lighting is used and from switching off electric lighting when a space is unoccupied. Therefore, the lighting control strategy for a particular space in this building depends on the daylight availability and the type and pattern of occupation.

Localised switching is used where only part of a large space requires the electric lighting to be switched on, either because the other parts are unoccupied or because daylight there is adequate. In addition Localised switching will increase user satisfaction by allowing occupants to have more control over their working environment through the use of localised switches.

Studies in open plan offices have shown wide variations in user preference for lighting with some occupants switching their lighting on under almost all conditions and others doing so only on rare occasions. This produces noticeable energy savings compared with the common situation where the lighting in the entire space is controlled with a single switch.

For spaces with negligible daylighting, a combination of time switching and localised switching cover most situations, although care is necessary to ensure that the lighting is not automatically switched off to leave dangerous blackout conditions. For installations with sparse and intermittent occupancy, localised switching will eliminate the need for the whole space to be lit when only a small part is in use; occupancy detectors are particularly suitable for such spaces

7 Heating System

Low temperature hot water for heating is used and it is generated by 2 No 83kW low NOx atmospheric wall hung gas fired room sealed boilers located within the office building cupboard. Balanced flues are terminating through the office external wall. Air for combustion and plant room ventilation is provided via louvers located in the external wall.

System make-up and pressure is maintained by pressurisation unit. The unit is provided with high and low pressure switches and expansion vessel to inhibit the boiler operation in the event of an alarm. Primary heating pump set is used to maintain the minimum flow through the boilers and overcome the primary circuit resistance. Separate pumped distribution circuits will be provided to facilitate a constant temperature circuit serving the heater batteries of the air handling plant and a compensated circuit to serve the radiators.

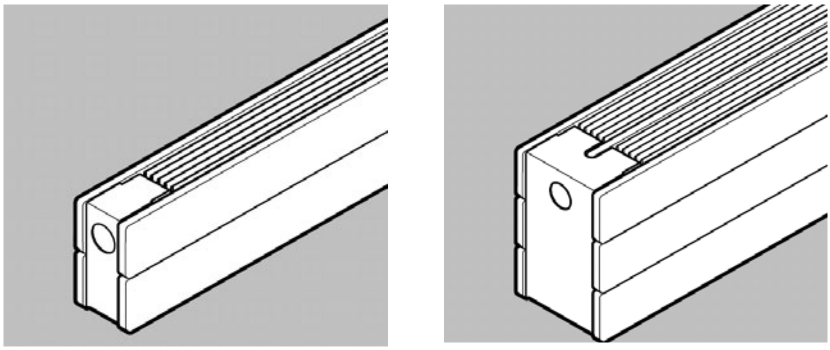

Fig. 6. Panel Radiator for general Heating

Steel panel radiators as sown on the above figure are used for general heating. Each radiator is provided by a thermostatic valve on the flow connection and a lockshield valve on the return.

8 Insulation and Building Fabric

The building fabric and envelopes is to reduce demands upon energy consuming M&E system. As part of an integrated energy efficient design to achieve energy conservation, exposed (and semi-exposed) elements are insulated to produce an insulated building envelope. Filling cavity walls with insulation is used as the first instance wherever possible as it is one of the most cost-effective options. Roof and floor slab insulation (including slab edge insulation) are particularly important as well. In the pitched roofs, at least 200 mm of insulation is used, laid in two layers, one between the joists and the second across the joists to prevent thermal bridging. A gap at the eaves allows ventilation and prevents condensation. Battens is used to raise access walkways above the insulation.

Improvements in glazing technologies over recent years provide enormous opportunities in this building project. Quite significant the reduction of U values can now be readily achieved compared with few years ago. This makes it possible to get a good daylighting factor but at the same reduce the overheating in summer. Building fabric has been chosen to meet the requirement of revised U values, air leakage and heat gain requirements.

Attention is also paid to avoiding thermal bridging. Heat loss from thermal bridging occurs where one element of a building is more poorly insulated, and thus colder, than the other parts. Thermal bridges are also associated with condensation. This it has been anticipated that this will occur around windows, doors, and at the junctions between external walls, floors and roofs.

The thermal bridging is avoided by maintaining continuity of insulation. Where this is not possible, overlap the insulating layers techniques is used to prevent a direct thermal bridge this is enhanced by the use a material with good insulating properties to bridge the gap between the layers.

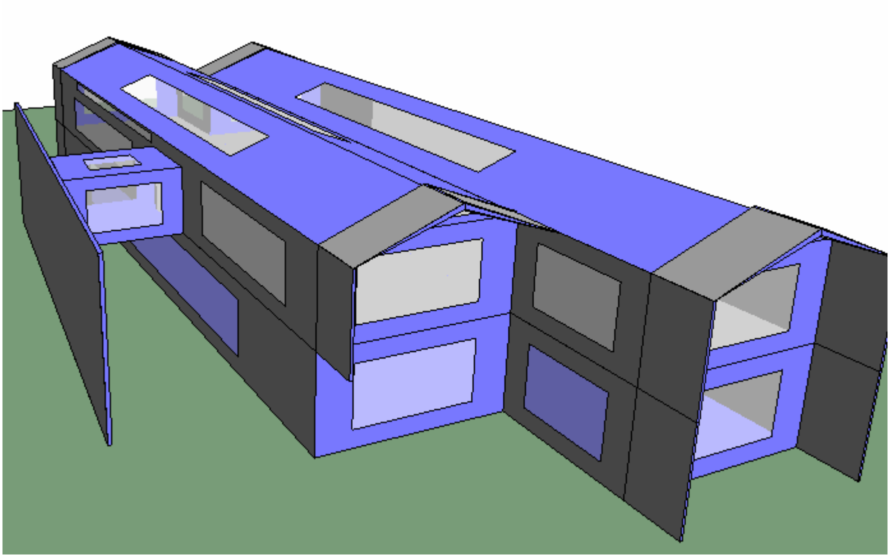

Fig. 7. Building envelopes with glazing, 20% Roof Areas as Roof Light and 40% of Façade Areas

Background air leakage is minimised and controllable ventilation is provided by means of purpose-designed openings. It has been identified that the main air leakage paths are:

- Joints around components, e.g. windows
- gaps between one building element and another
- Holes where services pass through the construction.

In this leakage parts, care has been taken to ensure that these areas are well sealed. Minimum U values for various elements of the building fabric have been used.

External shading is used to prevent solar radiation from entering into the buildings and reduces the cooling load, results to better control of overheating and indoor temperatures. Space cooling load may be reduced by 30%due to proper shading. The office provides an element of shading to the North West of the Site. The south east corner is affected by overshadowing primarily during the early morning in all seasons.

9 Discussion and Conclusions

The introduction of the legislation has made necessary for the buildings in the UK to have a better energy design and performance and the requirement to use more efficient M&E systems in building. Approved document Part L2A is intended for new non-domestic buildings.

The office building in case study has shown the compliance with the building regulation and thus conserves the energy. Energy conservation in office building and the compliance with building regulation are achieved through early incorporation into the building design. A large array of solutions exists to achieve energy conservation in building. Design has to consider flexibility along with the ideal design solutions, and must allow for the building to be satisfactorily commissioned and maintained. These criteria are incorporated into the design of building in case study, which are:

- Ventilation system with good high heat recovery system.
- Limiting the heat loss and gain through the fabric by enhancing levels of insulation of building fabric to achieve lower u-values.
- Limiting the heat loss and gain through the fabric of the building by improving air tightness to minimise any uncontrolled air leakage.
- Providing space heating and hot water systems which are energy efficient.
- Improve daylight levels and reduce artificial lighting energy. Artificial lighting energy is achieved thorough provision of lighting control systems with appropriate lamps so that energy can be used efficiently.
- Improve control and monitoring of mechanical heating and ventilation systems

Results from previous studies suggest that the key feature of an energy efficient building as a meaningful way to contribute to energy conservation is expected [2,9]. Full consideration should be given to operating costs, instead of the all too common short-sighted approach of only considering capital investment. But nevertheless the reasonable saving could be regained from the use of less energy during the operational life of the building.

This paper has provided a show case of an office building and the measure that have been taken to conserve the energy. This brings practical implication to building services engineers, consulting engineers who might want to design an office building that conserves the energy. Certainly, the Part L Building Regulations has statutory legislation in the UK, however this regulation has been amended and synchronised with the Directive on the Energy Performance of Buildings (EPBD) set up by the European Parliament and Council on energy efficiency of buildings. So this study will not be only useful for building engineers in the UK but also in the EU as well as any part of the globe which use EPBD as the basis to develop local energy code.

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Energy Analysis of Ventilated Roof

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Abstract. The thermal performance of the building envelope is an important requirement for guaranteeing both a comfortable indoor climate and building's energy efficiency.

Ventilated facades and ventilated roofs could be considered as a passive cooling system that contribute to realize low energy building.

The energy advantages provided by the ventilation of structures, during the summer, is the reduction of the cooling load due to the combined effect of the shading of the external wall and the heat removed by the air flow rate in the ventilated duct.

The objective of this study is to evaluate, the effects of the pitch angle, the intensity of solar radiation, size and shape of the cavity, on the thermal behaviour of ventilated roof. The results show the amount of the Energy Saving obtainable by the ventilation of the roof.

1 Introduction

The ventilated roof is a construction method used for roof with a pitch angle of more than 20° at least; it consists of a conventional roof structure with an air gap where it's allowed the movement of the ambient air.

In region with high level of solar radiation ventilated structure can contribute to reduce envelope gains of building both for the combined effect of shading and for the free and continuous ventilation in the air gap. The mass air flow is heated in the ventilated space by the sun , it becomes lighter (buoyancy effects) and carries away heat from the roof through natural convection especially during the peak cooling demand.

In this way, ventilation reduces the heat accumulation in the structure and at the meantime reduces the heat flux into the building.

During the winter or other times when the outdoor temperature is lower than the indoor temperature, the air gap should be shut, for the reason that heat flows goes from indoor to outdoor, on the other hand the air circulation prevent harmful condensation extending the life of the roofing system.

The aim of the work was to acquire a better knowledge on the operational characteristics of ventilated roof during summer period because this period has the largest interest in Mediterranean area.

Knowledge of the ventilated roof energy performance is very important for the development of products and construction techniques based on this technologies.

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Nomenclature

d: thickness of the air duct (m)

ES_r: energy saving rate, dimensionless

L: length of air duct (m)

I: solar radiation flux (W m^{-2})

l: width of air duct (m)

p: pitch angle (%)

p_0: air pressure into the duct at y=0 (Pa)

p_L: air pressure into the duct at y=H (Pa)

Q: heat flux incoming (W m^{-2})

Q_{tnv}: heat flux incoming in absence of ventilation (W m^{-2})

r_i: inner surface thermal resistance (m^2 K W^{-1})

R_{tnv}: total thermal resistance of the wall in absence of ventilation (m^2 K W^{-1})

T: temperature (K)

R_1: thermal resistance of the inner slab in presence of ventilation (m^2 K W^{-1})

R_{1nv}: thermal resistance of the inner slab in absence of ventilation (m^2 K W^{-1})

T_e: outdoor air temperature in the shade (K)

T_L: air temperature at duct outlet (K)

T_i: indoor air temperature (K)

T_1, T_2: air temperature of the air duct inner faces respectively of the inner slab and the outer slab in absence of ventilation (K)

T_1', T_2': air temperature in correspondence of inner's faces respectively of the inner slab and the outer slab in presence of ventilation (K)

T_0: air temperature at the inlet of the duct (K)

: thermal conductivity (Wm^{-1} K^{-1})

: air density (kg m^{-3})

2 Methodology

The study of thermal performances of ventilated roof requires a complete thermo fluid-dynamic analysis of the ventilated air gap, an accurate knowledge of the thermo-physical properties of the materials and the the modality of heat transfer.

The insulated ventilated roofs have been schematized as a two dimensional system [5] (see fig.1) consisting of two slabs (inner and outer slab) delimiting an air duct into which the air mass flows.

The modelled roof is 6 m long and 1 m wide[2,3,4].

Three typologies of ventilated roof characterised by the same value of thermal resistance (R_{tnv}=1.93 m^2KW^{-1}) but with different position of the thermal insulating, have been studied:

1. the roof *C1* has the insulation placed in the inner slab;
2. the roof *C2* has the insulation placed in the outer slab;
3. the roof *C12* has half insulation placed in the inner slab and half in the outer slab.

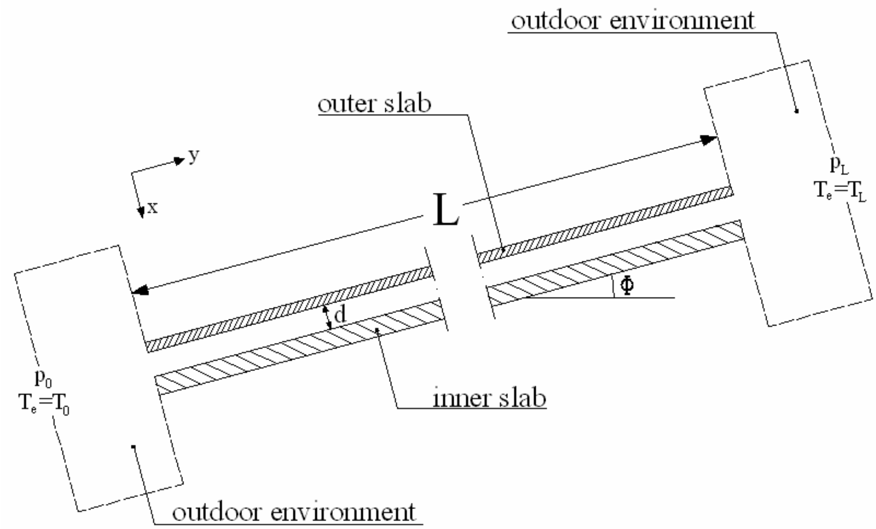

Fig. 1. Scheme of ventilated roof

Thermo-physical characteristics and geometry (thickness d, density ρ and conductivity λ) of the ventilated roofs are shown in Table 1.

Table 1. Thermophysical characteristics of ventilated roofs

No. of layer	Description of layer	Thickness s (m)	ρ (kgm^{-3})	λ ($Wm^{-1} K^{-1}$)
1 (Ext)	Brick tiles	0.035	1800	0.75
2	Wooden planking	0.01	450	0.12
3	Air (ventilation duct)	0.10	-	0.56
*4	Rigid fibreglass panels	0.04	100	0.038
5	Cement mortar	0.015	2000	1.40
6	Brick and concrete floor slab	0.30	1600	0.81
7 (Int)	Lime mortar and cement plastering	0.015	1800	0.90

*In roof C2 the insulation layer is placed under the layer 2
In roof C12 the insulation layer is equally subdivided under the layer 2 and over the layer 5.

The cooling performance of these ventilated roofs have been analysed varying both the geometric characteristics(pitch angle *p* and the air gap thickness *d*) and the operative climatic conditions (outdoor temperature T_e and solar radiations *I*).

The air mass flow rate and its thermodynamic properties in the ventilated roof is a function of the fluid dynamic in the duct geometry, the heat flux and the external atmospheric conditions (wind velocity and direction).

Numerous CFD simulations have been carried out utilising the computer code "Fluent" for predicting the air mass flow and its thermodynamic properties in the ventilated roof [1].

To simplify the study the effect of wind on the system are not considered.

A finite-difference numerical solution technique based [7] on integration over the control volume has been used to solve the model equations with appropriate boundary conditions . A non-uniform computational grid was used for the prediction of two-dimensional flow in the air gap, with dense grid cells distributed in the air gap and near the walls of the building.

The final converged steady-solutions have been obtained by solving iteratively the unsteady transport equations with very large pseudo-time steps. Convergence of the numerical solution was considered to have been achieved when the sum of normalised residuals for each flow equation was less than 10^{-3}. Convergence is typically achieved following about from 600 up to 800 iterations.

3 Thermal Performance of Ventilated Roof

During summer time a well performing roof should inhibit heat transfer from the outdoor to the indoor ambient. Therefore, in order to have a quantitative assessment of the performance of the ventilated roof it is necessary to compare the heat flux incoming for the two typologies of roof (ventilated and unventilated).

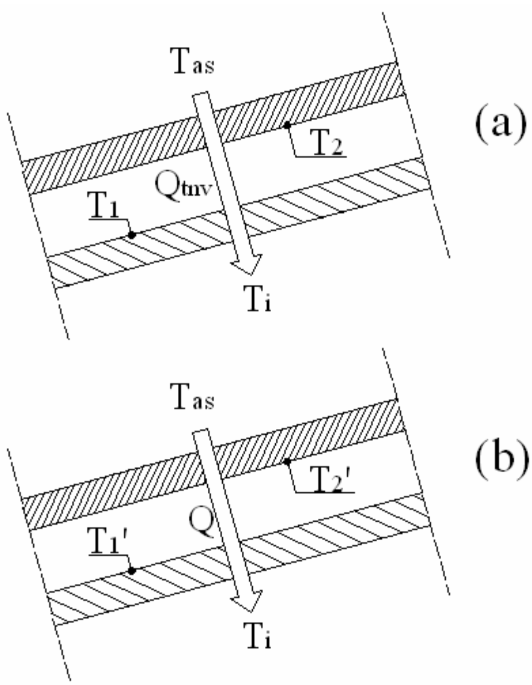

Fig. 2. Temperatures and heat flux incoming for unventilated (a) and ventilated (b) air duct

This comparison have been developed introducing the *Energy Saving rate* ES_r defined as:

$$ES_r = \frac{Q_{tnv} - Q}{Q_{tnv}} \quad (1)$$

where Q_{tnv} and Q are the heat flux, coming into the building, referred to an unventilated roof and to a ventilated roof.

Considering only the lower part of the ventilated roof (insulation layer and structural component) , the unventilated and ventilated roof have the same stratigraphy [5].
For unventilated roof the incoming heat flux (see fig. 2.a) can be calculated as :

$$Q_{tnv} = (T_1 - T_i) / R_{1nv} \quad (2)$$

For ventilated roof (see fig. 2.b) the heat flux will be calculated given by the equation:

$$Q = (T_1' - T_i) / R_1 \quad (3)$$

Therefore, neglecting variation with temperature of thermal resistance, the terms R_{1nv} and R_1 assume the same value:

$$R_i = R_{inv} = r_i + \sum_i^N \frac{s_i}{\lambda_i}$$

In consequence the ES_r can be calculated as:

$$ES_r = [(T_1 - T_i) - (T_1' - T_i)] / (T_1 - T_i) \quad (4)$$

4 Results and Discussion

The figure 3 shows the daytime temperature difference, between ventilated and unventilated roof, considering two different positions of the insulation layer(C1 and C2).

The temperature differences have a maximum at the midday when the solar radiation have the high intensity and the cooling load a maximum. It is also possible to observe that the roof C1, characterized by the insulation placed over the inner slab, shows the higher values of the temperature difference (T_1 - T_1') while the roof C2 characterized by the insulation placed under the outer slab, has lower values of the temperature difference (T_1 - T_1').

The figure 4 shows that the energy saving rate ES_r increases significantly if the incident solar radiation I increases. This effect is mainly due to the greater augment of the term (T_1 -T_i) respect to (T_1' -T_i) in the equation 4. This result indicate that the ventilated roofs have the best performance, from the point of view of energy saving, for high value of the solar radiation I.

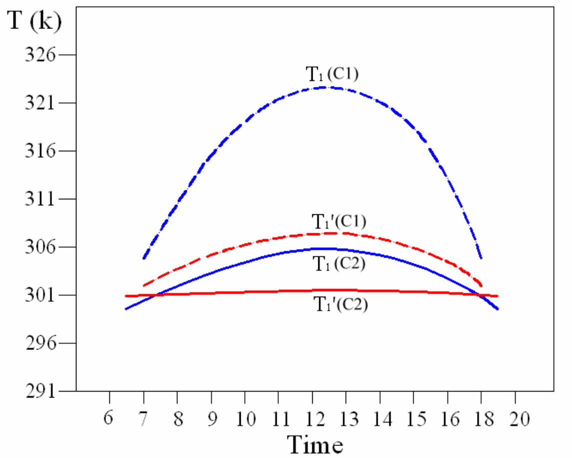

Fig. 3. Daytime temperature differences between ventilated and unventilated roof for roofs C1 and C2

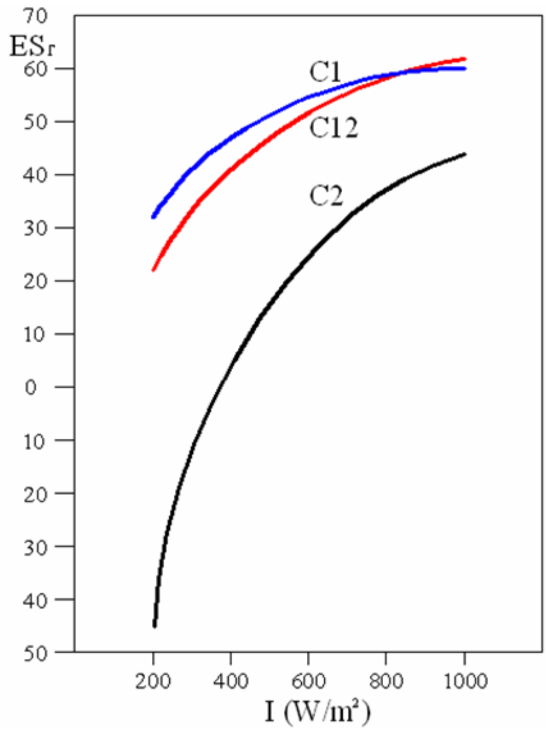

Fig. 4. Variations of energy savings rate ES_r with the solar radiation intensity I

The increase of the inlet temperature T_0 , considering the solar radiation constant, causes the augment of the terms (T_1' -T_i) and consequently causes the reduction of the energy saving rate ES_r. It is possible to observe, also for this case, that the roof C1 has the best thermal performance while the roof C2 has the worst values of the energy saving rate ES_r.

The figure 5 shows that an increase of the height gap *d* involves the augment of the energy saving rate ES_r.

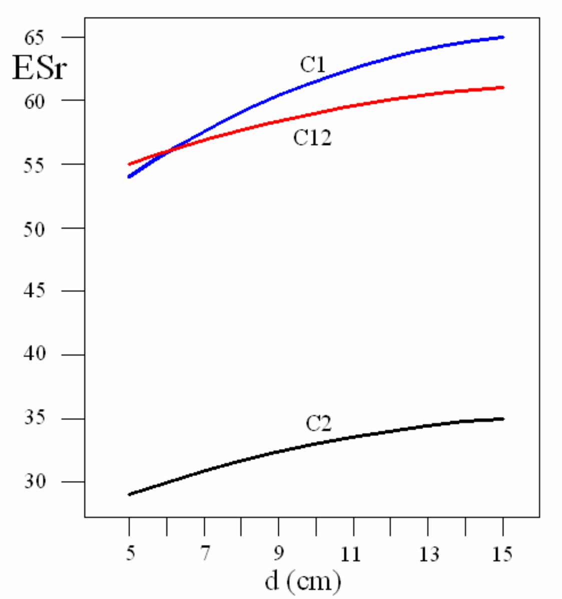

Fig. 5. Variations of energy savings rate ES_r with the air gap thickness *d*

These results appear coherent with the fact that a larger air gap permits better ventilation of the air inside the duct because the air flow becomes turbulent and consequently it enhances its capability of heat loss to the environment.

On the contrary, the increase of the air gap over 15 cm, leads to a reduction of the heat transfer due to a laminar flow of the air or at least stagnation.

Summarizing the analysis of results shows that an increase of the air gap thickness *d*, up to 12-13 cm might improve the performance of the ventilated roof in summer condition.

It is possible to observe, that the roof C1 has the best thermal performance, and the roof C2 has the worst values of the energy saving rate ES_r.

The figure 6 shows that an increase of the pitch angle *p* up to 35°- 38°, involves the augment of the energy saving rate ES_r, while for pitch angles higher than 38° there is a reduction of the energy performance of the ventilated roof.

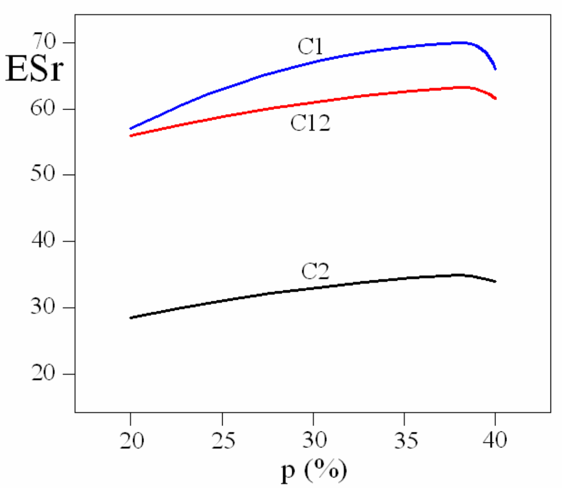

Fig. 6. Variations of energy savings rate ES_r with the pitch angle p

5 Conclusions

Numerous CFD simulations have been carried out to characterize the thermo fluid dynamic behaviour of different typologies of ventilated roofs.

The results carried out by the CFD simulations permit the evaluation of the energetic performances of ventilated roofs varying position of the insulating material, pitch angle and thickness of air gap.

The analysis of the energy saving rate ES_r allow the following considerations during summer period:

- the performance of the ventilated roof are much better than the unventilated with the same total thermal resistance;
- the better position of the insulating layer is close to the cold layer of the roof (over the inner slab);
- the increase of the external air temperature T_e causes the decrease in the energy saving rate ES_r due to the reduction of the effect of ventilation of the structure;
- an height gap d up to 12-13 cm permits the maximum of the energy saving rate ES_r;
- the pitch angle p of 38° permits the maximum of the energy saving rate ES_r.

In conclusion a tilt ventilated roof permits an energy saving up to 60% compared to an unventilated roof. These results indicate the importance to utilize in hot region the ventilation of the roof as a good and not invasive techniques of passive cooling and it could significantly contribute to a building's energy conservation during summer period.

Ventilated roof components can be a promising solution for the Mediterranean countries concerning summer passive cooling.

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An Analytic Hierarchy Process Model for Assessing Occupants' Adaptations to Thermal Comfort in Offices

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Abstract. The adaptations people utilize in response to ambient physical environmental variations are critical factors for the thermal comfort of occupants in real environments. From the adaptive point of view, thermal comfort is not solely dependent on physical thermal stimuli, but involves complex interactions between the occupants' adaptations to the physical environmental stimuli and socio-economic-cultural issues. Under certain circumstances, the adaptation of occupants to their environment may be affected by physiological, behavioural and psychological factors. The interaction of the three adaptations further affects the extent of the thermal comfort the occupants finally feel. This paper introduces a method for the evaluation of the weight of contributions of three categories of adaptations to attain thermal comfort in office environments using the Analytic Hierarchy Process (AHP). The AHP is an ideal tool for decision-making where multiple factors are involved. Through solving a pairwise comparison matrix, the weight of each adaptation category can be produced. This paper aims to develop an empirical occupants' adaptation-based thermal comfort model for office environments. The feasibility and validity of such the model has been verified by a pilot study.

1 Introduction

The adaptive theory of thermal comfort as an alternative to conventional heat balance theory was proposed in the 1970s in response to the oil shock [1]. Many field studies have been carried out worldwide in the last two decades and the weaknesses of thermal comfort assessment on the basis of heat balance theory were subsequently revealed, particularly for thermal comfort evaluation in non-air-conditioned environments. This mainly arose from the discrepancies between results for predicted and observed cases in terms of thermal sensation, satisfaction and comfort temperature [2][3][4]. Brager and de Dear [1] attributed such discrepancies to the adaptive approaches adopted by occupants. From the adaptive point of view, occupants were no longer regarded as passive recipients of thermal environmental stimuli but as active ones interacting with the person-environment

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system via multiple feedback loops [1]. Fanger extended his PMV-PPD model to thermal comfort evaluation of non-air-conditioned buildings in warm climates by introducing an expectancy factor 'e' [5]. On the basis of global field investigations into thermal comfort, which covered four continents and different climatic zones, ASHRAE [6] compiled the adaptive indoor comfort temperature zones against mean monthly outdoor temperature in the latest version of the ASHRAE standard. In response to the adaptations of the occupants, the CIBSE guide had also been extensively revised including the adaptive approach and thermal comfort criteria based on the outdoor running-mean temperature for offices in both the free-running model and for the air-conditioned model [7]. The thermal comfort defined in those standards no longer consisted of specific fixed figures, but of dynamic ranges varying with the outdoor climate. Therefore, thermal comfort is a dynamic process which is the outcome of complex interactions between people's adaptations to physical environmental stimuli and socio-economic-cultural issues.

In recent decades, many studies on the effects of occupants' adaptations in terms of physiological, behavioural and psychological dimensions on thermal comfort have been conducted [8][9][10][11]. However, they were either carried out in a climatic chamber in which the environmental parameters could be strictly controlled as the experimenters wished in order to explore some adaptation, such as thermoregulation of occupants in response to physical environmental variations [8], or regarding those adaptations as a whole and evaluating their effect in a qualitative way [9][10][11]. In other words, the interactions between each adaptation and how much each adaptation contributed to thermal comfort was not studied systematically.

In this paper, a model will be established to evaluate the weights of three categories of adaptations to thermal comfort in office environments using the Analytic Hierarchy Process (AHP) method and validating the model by means of a pilot study.

2 AHP Model Developments

2.1 AHP Method

The Analytic Hierarchy Process (AHP) developed by Saaty [12] provides an ideal tool to help decision-making that is influenced by multiple objectives. Since AHP was produced, it has been applied widely in different fields all over the world [13][14][15][16].

Three categories of adaptation and the corresponding elements that may affect the thermal comfort of the human body can be identified by establishing the AHP model (see Figure 1). These elements comprise physiological indices, the indoor environment, the outdoor environment, personal physical factors, environmental control and thermal expectation. The lack and neglect of any factors will give birth to low-level thermal satisfaction or to a growth in complaints about the thermal environment.

In Figure 1, a four-stratum hierarchy is developed to evaluate the contributions of three categories of adaptation and the corresponding elements including physiological factors, environmental factors, personal factors, environmental control factors and thermal expectation factors for thermal comfort. A number of subsets, which consist of all the elements dominated by a single element of the adjacent higher stratum, exist at different stratum levels of a hierarchy. In each such subset there is a total order in which each element is related to a dominating element in the adjacent upper level. A hierarchy is complete if each element of a given stratum is dominated by every element of the adjacent upper stratum. The elements in the lower level make contributions to the dominant element in the adjacent upper stratum, which can be considered as a criterion for assessing the corresponding contributions of the elements in the lower level. When applying the AHP method, the weight of an element in a stratum is the sum of its priorities in each of the subsets to which it belongs; each is weighted by the fraction of elements of the stratum which belong to that subset, and by the weights of the subset. The resulting set of priorities is normalized by dividing by its sum. The weight of a subset in a stratum is equal to the sum of the weights of the dominating elements in the next stratum.

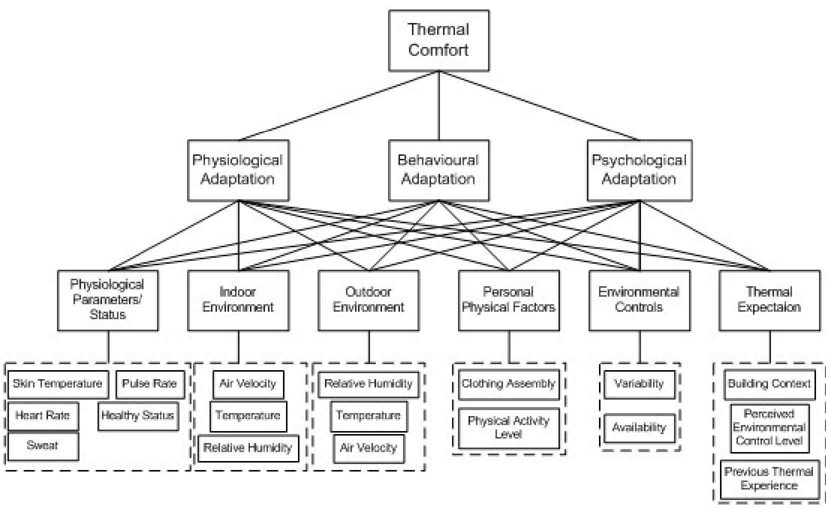

Fig. 1. AHP model for assessing the contribution of factors to thermal comfort

In the AHP method, a nine-point scale ranging from 1 (equal importance) to 9 (absolutely more important) is proposed to quantify subjects' judgments between two variables [12]. Table 1 gives the definition and explanation of each value on the numerical scale.

Table 1. Scale for importance for activities [12]

Values of a_{ij}	Definition	Explanation
1	Objectives i and j are of equal importance	Two activities contribute equally
3	Objective i is just more important than objective j	There is evidence suggesting one activity is probably more important than another
5	Objective i is much more important than objective j	Good evidence and logical criteria exist to demonstrate that one is more important
7	Objective i is demonstrably more important than objective j	Conclusive evidence shows the importance of one activity over another
9	Objective i is absolutely more important than objective j	The evidence in favour of one activity over another is absolute
2, 4, 6, 8	Intermediate values between the two adjacent judgments	e.g. a value of 8 is midway between 'demonstrably' and 'absolutely evident'

Where, a_{ij} represents the element in row i and column j of a comparison matrix. All of the information required by the AHP method is collected by a questionnaire survey.

2.2 Weights Calculation

The determination of the weight for each factor by applying the AHP method is divided into the following steps:

2.2.1 Structuring the Assessment System

The main purpose of structuring an assessment system is to quantify the information required for the development of a comparison matrix. At present, there are some acknowledged representative indices available for adaptive thermal comfort evaluation. In addition, after an extensive literature review, other indices which may affect thermal comfort are supplemented. All of these indices and corresponding elements and their interactions are depicted in Figure 1.

2.2.2 Producing the Combined Comparison Matrix

Due to the form of the pairwise comparison in the questionnaire, n $m \times m$ individual comparison matrices are obtained. After that, the next step is to incorporate those individual comparison matrices into a combined one by using the geometric mean.

2.2.3 Solving the Combined Comparison Matrix

If the comparison matrix A is a consistent matrix, the weights of each factor form the normalised eigenvector (W) corresponding to the maximum eigenvalue of m.

For the non-consistent comparison matrix, Saaty suggested the adoption of the normalised eigenvector (W), which corresponds to the maximum eigenvalue. This principle can be explained by introducing the equation below:

$$A \times W^T = B \times W^T \tag{2.1}$$

Where W^T is an unknown m-dimension column vector and B is constant. For the consistent comparison matrix, the only non-trivial solution to equation (2.1) is B=m and $W = (w_1, w_2, \cdots, w_m)$. For the non-consistent comparison matrix, let $B_{\max}$ be the greatest value in case of equation (2.1) with a non-trivial solution, which is designated as $W_{\max}$. If the non-consistent comparison does not deviate from the consistent one, the value of $B_{\max}$ should be close to m and the values of $W_{\max}$ should be close to W. That is to say, in such a case the values of W are approximated by $W_{\max}$. The results from such an approximating approach are valid and reliable only if passing the consistency test.

2.2.4 Consistency Test

In order to perform the consistency test, the consistency index (CI) should be calculated first using the equation (2.2) below:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{2.2}$$

Where $\lambda_{\max}$ is the maximum eigenvalue of the comparison matrix, which can be computed by:

$$\lambda_{\max} = \frac{1}{n \times \sum_{i=1}^{m} \frac{(A \times W^T)_i}{(W^T)i}} \tag{2.3}$$

Where, i represents the ith element in $A \times W^T$ and in W^T.

Then, calculating the consistency ratio (CR) by dividing CI by the value of the random index (RI), which can be obtained by referring to the random index table in related books, Table 2 gives the values corresponding to the values of n from 2-10.

Table 2. Values of random index (RI)

N	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

If $CR = \frac{CI}{RI}$<0.1, the conclusion that the consistency degree is satisfactory can be drawn; if $CR = \frac{CI}{RI}$>0.1, that means the degree of consistency is not satisfactory and serious inconsistencies may exist.

3 Model Validations

In order to validate the proposed AHP model, a pilot study was carried out in July 2009. There were 12 respondents participating in this questionnaire survey. All of them came from the School of Construction Management and Engineering, University of Reading, UK. After that, the information about their judgments of the importance between factors influencing the thermal comfort of occupants in offices was obtained. Table 3 shows the combined comparison matrix and the relative importance of the adaptive factors.

Table 3. Relative importance of adaptive factors

Factors	Physiological Adaptation	Behavioural Adaptation	Psychological Adaptation	EIGENVALUE
Physiological Adaptation	1.000	3.1075	0.9687	0.4509
Behavioural Adaptation	0.3218	1.0000	0.7469	0.1984
Psychological Adaptation	1.0323	1.3389	1.0000	0.3507

CI=0.0428; CR=0.0739

The normalised matrix A_{norm} is produced by dividing each element in column j of matrix A by the sum of the elements in column j.

$$A_{norm} = \begin{pmatrix} 0.4248 & 0.5706 & 0.3573 \\ 0.1367 & 0.1836 & 0.2748 \\ 0.4385 & 0.2458 & 0.3679 \end{pmatrix}$$

Then, the $A \times W^T$ can be calculated as follows:

$$A \times W^T = \begin{pmatrix} 1.000 & 3.1075 & 0.9687 \\ 0.3218 & 1.0000 & 0.7469 \\ 1.0323 & 1.3389 & 1.0000 \end{pmatrix} \times \begin{pmatrix} 0.4509 \\ 0.1984 \\ 0.3507 \end{pmatrix} = \begin{pmatrix} 1.4072 \\ 0.6054 \\ 1.0818 \end{pmatrix}$$

The value of $\lambda_{\max}$ is computed based on equation (2.3):

$$\lambda_{\max} = \frac{1}{n \times \sum_{i=1}^{m} \frac{(A \times W^T)_i}{(W^T)i}} = \frac{1}{3 \times (\frac{1.4072}{0.4509} + \frac{0.6054}{0.1984} + \frac{1.0818}{0.3507})} = 3.0857$$

The consistency index (CI) is then computed:

$$CI = \frac{\lambda_{\max} - n}{n-1} = \frac{3.0857 - 3}{3-1} = 0.0428$$

In this case, m=3, the RI=0.58, so the CR is:

$$CR = \frac{CI}{RI} = \frac{0.0428}{0.58} = 0.0739$$

The value of CR is lower than 0.10, this implies that the degree of consistency is satisfactory.

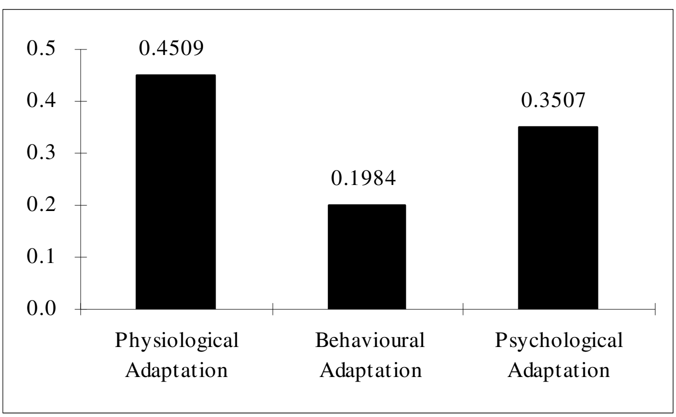

Fig. 2. Relative Importance of Adaptive Factors

Figure 2 depicts the relative importance of the adaptive factors impacting on the thermal comfort of the human body. The physiological adaptation ranks highest followed by psychological adaptation and behavioural adaptation, respectively. In order to get the weight for each system factor, similar pairwise comparisons are applied. The results are shown in Table 4.

Table 4. Weights of each System Factor

Factors	**Physiological Adaptation**	**Behavioural Adaptation**	**Psychological Adaptation**	**WEIGHT**
	0.4509	0.1984	0.3507	
P.P/S.	0.1909	0.2492	0.2398	0.2196
I.E.	0.2502	0.2682	0.2009	0.2365
O.E.	0.0903	0.0946	0.1958	0.1282
P.P.F.	0.2209	0.1024	0.1360	0.1676
E.C.	0.1778	0.1506	0.1635	0.1674
T.E.	0.0699	0.1350	0.0640	0.0809

NOTE: P.P/S- Physiological Parameters/State; I.E.- Indoor Environment; O.E.- Outdoor Environment; P.P.F.- Personal Physical Factors; E.C.- Environmental Controls; T.E.- Thermal Expectation

The results in Table 4 and Figure 3 present the weights of each system factor. Indoor environment factors and Physiological parameters/State are the two most important indices affecting the thermal comfort of the human body in offices with weightings of 0.2365 and 0.2196, respectively. The weights of environmental controls and the personal physical factor follow the top two factors being 0.1676 and 0.1674, respectively. The values of 0.1282 and 0.0809 are the weights for the outdoor environment and thermal expectation.

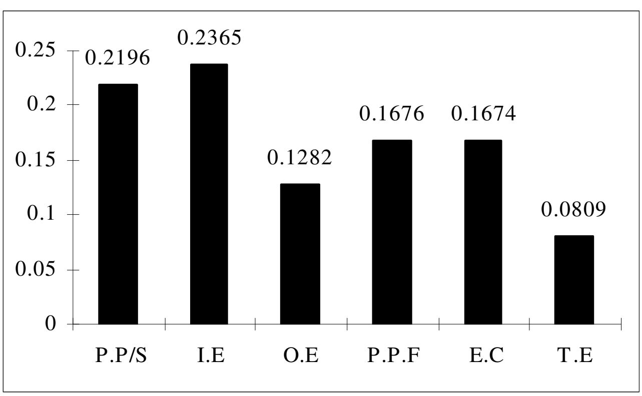

Fig. 3. Weights of each System Factor

The validation of the AHP method for assessing the contribution to thermal comfort of each adaptation and the corresponding factors is confirmed.

5 Conclusions

In this paper, a model for assessing the weight of each adaptation and the corresponding elements for thermal comfort was developed by using the Analytic Hierarchy Process method. By applying such a model, the contributions of each adaptation and their relative importance can be understood in a quantitative way. Through the pilot study, the feasibility and validity of such a method has been verified. The consistency would be achieved and further improved on the basis of a larger sample, rather than the small sample used in the pilot study.

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List of Abbreviation

AHP	Analytic Hierarchy Process
P.P/S	Physiological Parameters/State
I.E.	Indoor Environment
O.E.	Outdoor Environment
P.P.F.	Personal Physical Factor
E.C.	Environmental Controls
T.E.	Thermal Expectations

Advantages of Using Raw Materials in Ancient and Recent Buildings

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Abstract. Many of the existing buildings constructed mostly with natural raw materials, in European sites, are frequently lacking proper maintenance and, therefore, a high degree of degradation is verified in these buildings compromising their integrity and reducing their lifetime probability. Often in the rehabilitation or reconstruction of old buildings the solution adopted is the partial or integral demolition and substitution of several building components. The aims of this study are to describe the most common constructive solutions in Portuguese buildings constructed with raw natural materials, to specify the principal problems that affect each building component, and to present possible solutions to correct each defect. This study is focused on the principal elements that compose the building structures in Portugal, including load-bearing walls, wooden floor and roof structures. The architecture solution, the structure solution, the building material's identification/characterization, the sequence of structural failures and the main pathologies identification/characterization related to an early XX century Portuguese watermill were described and detailed. It may be considered as a real scale experimental model which may contribute to the rehabilitation and conservation fields of traditional Portuguese buildings. The structural failure sequence was analyzed, the corrective solutions presented and studied privileges the adoption of materials and techniques similar and most compatible with the original ones. It's also presented the structural solution savings of energy consumption and CO_2 emission. The results of this study were found to be easily extrapolated to the repairing of the Portuguese traditional buildings which are in general environmental friendly.

1 Introduction

In Portugal, the main traditional construction techniques that make use of earth are rammed earth, adobe and half-timbered. These techniques fell into disuse upon the appearance of reinforced concrete and ceramic bricks [1].

An expressive amount of the existing Portuguese buildings are old buildings which frequently reveal a certain lack of maintenance or conservation and the main reason for this fact is inherent to cost reasons. The cause of these premature pathologies may be building error, design error, inappropriate building conception, inappropriate or deficient building materials, among others and may result in

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partial or total collapses of the constructions. The occurrence of pathology may lead to others and, in the limit, may results in a progressive structural collapse [2].

A regular maintenance or conservation work is required to avoid unexpected building deterioration [3].

Based on the concept of “inform to prevent”, a research project was launched at the University of Trás-os-Montes e Alto Douro (UTAD) with the main purpose of transmitting to an expressive percentage of the population the urgency of having a sustainable attitude in all the activities and, in particular, in the construction field. Considering that, sustainable construction can be divided in four main areas which are: efficient energy use, sustainable urban planning, efficient water management and sustainable building construction.

In the context of sustainable building construction an early XX century Portuguese watermill building is used in this research work as a study case to show how a roof leaking may lead to a progressive building collapse.

A brief description of the building is done followed by an identification/characterization of the building materials. In particular, an experimental study of the structural mortar was done in the Microscopic Electronic Unit of (UTAD). The chronological partial roof structural failure sequence is presented and described, in which a pathology cause/effect relation is also done. Meanwhile, the analysis of this failure sequence may give evidence for achieving better robust timber structural roof solutions and also reinforcement repairing structures proposals for traditional Portuguese buildings that are also presented in this study.

2 Sustainability

The Earth planet must be seen as a delicate ecosystem which its equilibrium requires urgent attention. We consider that the main threats to sustainability are, by order of impact scale, the industry, human behavior and natural hazards (i.e. forest fire, volcanic eruption, among others). They may be interconnected to each other in certain ways. The sustainable system flowchart of Figure 1 is proposed.

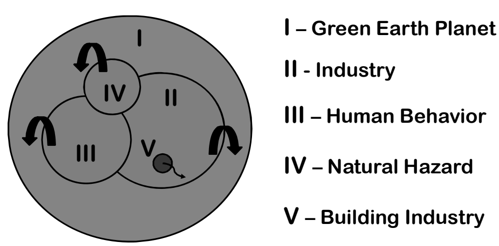


Fig. 1. Sustainable system flowchart

According to Figure 1, industry is a big field system and the main cause of CO_2 emission to atmosphere. The building industry is a set of that field system and it is the goal of this research work.

Each building material has associated a specific cost, an energy consumption and a quantity of noxious gases released into the atmosphere, which resulted from all the phases related to its life-cycle such as the extraction from the raw material, transportation, transformation, building process, maintenance, demolition and recycling.

Several research studies [4-6] have been focused on estimating the quantity of the above environmental parameters.

Table 1 shows some values of energy consumption for the building materials which are considered in this research work, [4-6]. Comparing these values it is noticed that there is an expressive difference among them. According to [6], this fact may be related to the different approaches used by each author concerning different period of time for the material life-cycle and/or different fabrication techniques.

Table 1. Energy consumption (MJ/kg)

Material	KangHee [4]	Leiden [5]	Baird [6]	Alcorn [6]
Concrete	0.52	0.48	1.99	1.95
Bar steel	38.66	-----	59.00	8.90
Mortar	0.40	0.88	2.49	1.33
Brick	2.95	0.15	2.50	-----
Earth adobe	0.06	-----	0.42	-----
Gravel	0.15	-----	0.30	0.10
Pine wood	4.44	-----	8.08	1.10
Sand	0.05	-----	0.04	0.10
Cement	3.33	-----	8.98	7.80
Earth	0.05	-----	-----	-----

3 Description of the Study Case

In this research work, the building adopted as a study case is an early XX century Portuguese watermill (Fig. 2 and 3).

The building is located in Portugal continental central region, on the coast, in the district of Coimbra, in the Municipality of Figueira da Foz, in the village of Carritos.

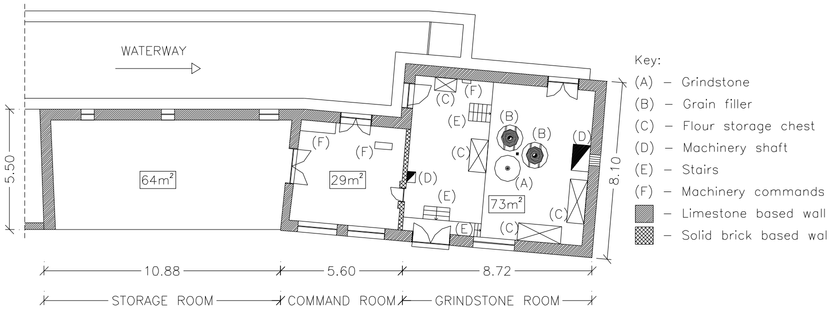


Fig. 2. Ground floor Plant, 2009 (m)

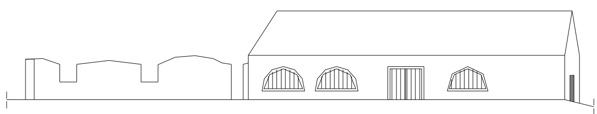


Fig. 3. Frontal view, 2009

4 Identification and Characterization of the Building Materials

The used building materials are limestone, structural mortar, timber, solid and hollow ceramic bricks, finishing plaster and ceramic tiles.

Since this region is sparse in stones, the structural stone masonries walls (exterior and interior) had been built up using irregular and small sized limestone pieces (Fig. 4, detail I) agglutinated by a structural mortar (Fig. 4, detail II). The average thickness of these walls is 0.40 m.

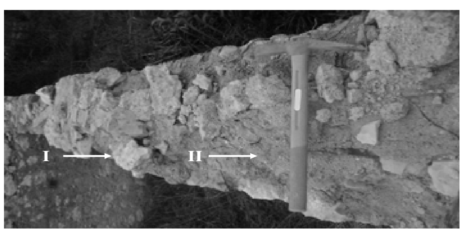


Fig. 4. Detail of the structural stone masonries walls

Timber was highly used in this building. The floor, the purling, the beams of the roof structure and over the openings (windows and doors) and the ground pavement are timber. A finishing plaster material was used in most of the walls excluding the ones of the storage room. The exterior covering of the roof is ceramic tiles.

In order to identify the type of mortar, the type of finishing plaster and the specimen of timber, experimental tests were done.

The identification/characterization of the chemical and mineralogical elementary compositions of the mortar and the finishing plaster materials was done by scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) and X-ray tests which were performed in the Microscopic Electronic Unity of UTAD. Similar tests have been already done in the framework of other research projects [7-8] to characterize the available and used materials for the local traditional constructions.

Four mortar material samples (Sample 1, 2, 3 and 4) were collected and tested. It was also tested a lime sample and a hydraulic lime sample since they are the most common binding material used in these traditional buildings.

The chemical elementary composition results obtained by the SEM/EDS test are presented in Table 2. The mineralogical elementary composition results of the X-ray test shown in Table 3.

Table 2. Chemical elementary composition results of the SEM/EDS (%).

Chemical Element	Sample 1	Sample 2	Sample 3	Sample 4	Lime	Hydraulic lime
Oxygen (O)	52.01	51.44	52.07	49.06	56.06	39.85
Sodium (Na)	-----	-----	-----	0.90	----	-----
Magnesium (Mg)	-----	-----	-----	0.68	2.01	0.50
Aluminium (Al)	6.37	6.11	8.74	6.68	3.40	0.38
Silicon (Si)	13.84	9.45	17.48	15.01	7.42	-----
Chorine (Cl)	-----	-----	-----	0.58	-----	-----
Potassium (K)	1.90	1.09	3.45	1.65	0.99	-----
Calcium (Ca)	24.92	31.17	17.36	22.51	28.01	59.26
Iron (Fe)	0.96	0.74	0.90	2.94	1.40	-----

Table 3. Mineralogical elementary composition results of the X-ray test

Sample 1	Mineralogical composition
Sample 1	Quartz, Calcite, Muscovite
Sample 2	Calcite, Kaolinite, Quartz
Sample 3	Calcite, Quartz
Sample 4	Calcite, Quartz, Plaster
Lime	Calcite,Calcium Oxide
Hydraulic lime	Calcite, Quartz, Plaster

Mortar material samples 1, 2 and 3 have similar elementary composition in particular in terms of chemical (Table 4.1). Based on these results and the above analyses we may consider that the mortar material samples 1, 2 and 3 are a mixture of local earth and lime and the mortar material sample 4 is a mixture of a local earth and hydraulic lime.

Two timber samples of the timber structural roof were experimentally identified as being *Pinus pinea* specimens. One timber sample of the ground floor pavement was experimentally identified as being *Pinus pinaster* specimen. These are both local trees specimens.

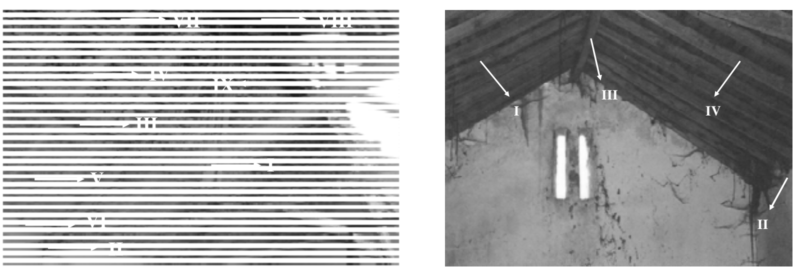
Based on the above building material description it is possible to realize that most of the used materials are natural and local and, the building itself is associated to building techniques that require small amount of energy consumption and releases an unexpressive amount of noxious gases to atmosphere [9]. Consequently, we have a remarkable example of a sustainable building solution.

According to [9], a sustainable structure like the one of this study will reveal a reduction of the energy consumption and noxious gases emissions amounts of over 60% when compared to a traditional column/beam concrete structure.

5 Structural Solution

According to Fig. 3.2 there are two types of walls. There are several limestone based masonries walls and one solid ceramic brick based wall.

The roof timber structural solution comprises two types. In the grind stone and the command rooms (Fig. 5-a) it was adopted trusses (Fig. 5-a, detail I) directly supported on the limestone based masonries walls (Fig. 5-a, detail II), these trusses support beams (Fig. 5-a, detail III) which are supporting the purling (Fig. 5-a, detail IV). On the purling there are timber boards (Fig. 5-a, detail V) supporting the ceramic tiles.



a. Trussed type roof structural solution

b. Beamed type roof structural solution

Fig. 5. Roof structural systems

The other type of roof timber structural solution was only applied in the storage room, Fig. 5-b, which includes timber beams (Fig 5-b. detail I) which were structures supported on the limestone based masonry walls (Fig. 5-b, detail II) and a central timber beam (Fig. 5-b, detail III). On these timber beams there were timber boards (Fig. 5-b, detail IV) supporting the ceramic tiles.

These are remarkable traditional timber structures built under skills based on experience.

6 Failures and Pathologies

6.1 Roof Structural Failures Sequence

The roof timber structure has been facing partial collapses throughout the last nine years. The first partial collapse occurred in 2000, in which part of the roof of the storage room was lost (Fig. 6-a, detail I). It is important to underline that the main structural timber elements which are trusses did not get damaged.

The second structural failure of the roof occurred in 2007 resulting in the completely loss of the roof of the storage room (Fig. 6-b, detail I) and part of the frontal limestone based masonry wall (Fig. 6-b, detail II).

In 2009, the third roof structural failure occurred and the roof of the grindstone room suffered a partial collapse (Fig. 6-c, detail I) In this case, the purling (Fig 6-a, detail IV) collapsed in the zone of their support (the limestone based masonry wall (Fig. 6-a, detail VI) generating a load redistribution which resulted on the collapse of the beam (Fig. 6-a, detail III). This load redistribution was possible because the roof structural solution works as a structural system [10].

a. 1st Collapse (2000) b. 2nd Collapse (2007) c. 3rd Collapse (2009)

Fig. 6. Roof's partial collapses

6.2 Pathologies

This section is focused on the pathologies associated to the above described failures. Figure 6-a in its detail II shows a local permanent deformation of the roof system of the grindstone room in its connection to the frontal wall. Some ceramic tiles were also missing there.

Meanwhile, Figure 6-a illustrates the roof's condition of the grindstone room before the above described third roof's structural collapse occurred in 2009 (Fig. 6-c). Some purling and timbers boards showed an advanced stage of deterioration in the contact zone with the structural wall. Through Figure 5-a, detail I, it is also possible to notice that these timber elements had a darker shade than the similar ones located outside of the damaged zone which indicated a leaking problem. By doing a similar analysis, Figure 5-a, details VII, VIII and IX indicate that there were some cracked ceramic tiles or the ceramic tiles/timber board direct contact solution was not the appropriated one because may increase an undesirable water moister in the timber structural elements.

An expressive vertical crack located in the junction of the two limestone based masonry wall of the storage room (Fig. 7, detail I) was formed just before the occurrence of the second roof's structural collapse occurred in 2007.

7 Reinforcement Solutions

In order to avoid the risk of leaking, a covering roof system is proposed in Fig. 8.

Fig. 7. Vertical crack, 2007

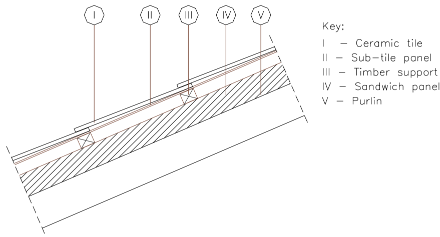


Fig. 8. Covering roof system`s detail

The option of using a sub-tile panel (Fig. 8, detail II) intended to avoid roof leaking in case of a ceramic tile cracks and to allow fixing this problem after a maintenance process. At the same time, the timber supporting solution (Fig. 8, detail III) avoids the direct contact between tile/main roof timber structure and, consequently, also it avoids the increasing of water moisture of timber structural elements which may result in either retraction effect or material deterioration.

In order to mitigate the structural failure seen in Figure 7, a structural reinforcement solution is proposed in Fig 9 which includes a steel tie (Fig. 9, detail III) and an earth based reinforcement beam (Fig. 9, detail II) as additional structural elements. It is also considered that the timber beams should have a horizontal contact surface with the wall. The structural reinforcement of the junction of the masonry walls may be done according to Figure 10 in where the lengths *a* and *b* need to be specifically calculated.

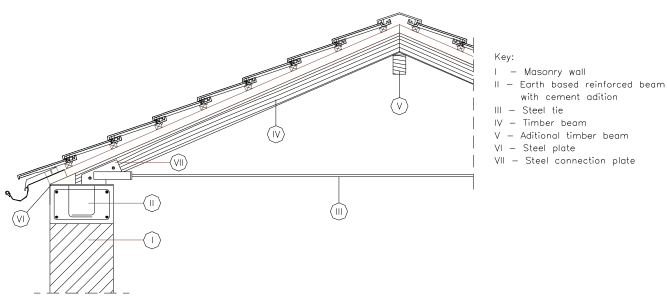
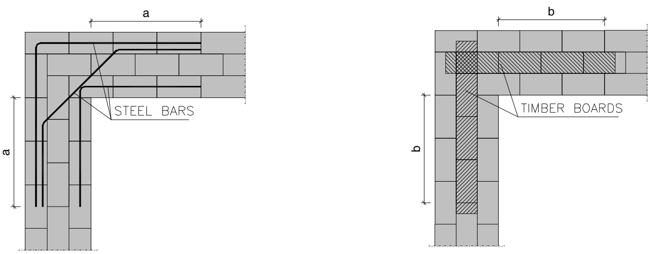


Fig. 9. Structural reinforcement solution of the roof of the storage room



a. Junction steel reinforcement b. Junction timber reinforcement

Fig. 10. Structural reinforcement of the junction of the walls

On the base of achieving a sustainable construction solution, the steel element proposed above should be a reused one.

8 Main Conclusions

A sustainable system flowchart is proposed in which the impact of the building industry is indicated.

The architecture solution, the structure solution, the building material's identification/characterization, the sequence of structural failures and the main pathologies identification/ characterization related to an early XX century Portuguese watermill were described and detailed.

The structural limestone based masonry walls adopted solution has the particularity of using small size limestone pieces connected by an earth based structural mortar which is also a sustainable and economic solution.

The reported structural failure sequence has been caused basically by roof leaking problems which have been deteriorating the timber structural elements of the roof of the watermill building. The trussed timber roof structural solution had shown a better structural behavior than the beamed timber roof structural solution because it avoids total collapse and, consequently, it is more robust.

Some reinforcement solution details were proposed based on the failures and pathologies identified in the building. These repairing solutions proposals are also sustainable based since it was suggested to apply reused materials such as steel bars. These facts may be easily extrapolated to the repairing of the Portuguese traditional buildings which are in general environmental friendly.

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Energy Saving Technologies for Conventional Dwellings – A 'Whole House' Concept

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Abstract. The concept of a 'whole house' is rarely applied to individual dwellings because each is generally regarded as a loosely connected collection of standalone systems that are provided by different manufacturers with hardly any account being given to interconnectability within the overall concept of a house as a single entity. Most houses have very basic systems for the control of major energy sources including heating and lighting. Electronic control systems requiring only basic skills to install and service can give occupants an ongoing overview of their energy use and facilitate minor changes in habit / lifestyle to allow further savings. The effects and lifetime of these control systems will be improved if they include the ability to be reprogrammed by the user to take into account future improvement projects such as upgrades in insulation or the fitting of double glazing or a change in energy supply. Lifestyle and occupation patterns will have a major effect on energy saving within domestic premises. Any proposed system must be adaptable to suit different living patterns. Interfaces between various components therefore need to be as simple as possible to allow 'mixing' of different technologies and possible future developments. It is concluded that a whole house control system that is practical, cost effective, future proof and easy to use is viable but that it could not utilise a single processor design. Instead, a hierarchical system is proposed that presents the possibility of a simple, future proof whole house control system that will accept inputs that are not specified at the time of installation.

1 Introduction

The major effect that the majority of the population of the U.K. can have on energy saving is based within their own dwelling place (e.g. Turner and Leyman, 2003; Hymers, 2006, Wilson, 2007) or new build (e.g. Anderson, 2006; Broome, 2007). In this paper we present some of the results obtained from a project to examine the hypothesis that substantial energy savings can be made in a conventionally built house by using appropriate energy production and by the application of relevant and practical electronic monitoring and control systems. Energy saving in the home is often focussed on small isolated areas within the house (Department of Communities and Local Government, 2008a,b). However, there is a need to look at home energy usage as a whole and there is potential for examining and developing a range of energy saving technologies and analysing the true potential and viability of each of the systems that are available and could be developed in the future. Substantial energy savings can be made in domestic premises by using

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existing energy system developments such as solar water heating (Martin and Watson, 2001), rainwater harvesting (National Statistics Office, 1999) and micro-wind generation[1]. There are also others currently in development and likely to be on the market in the next few years such as advanced fuel cells running on many fuel types, not just hydrogen, which produce combined heat and power (CHP)[2] Substantial additional savings can be obtained if these developments follow simpler measures such as high levels of thermal insulation and draft proofing.

For maximum efficiency and control, any new development must be able to be integrated into existing systems without the necessity and cost of 'ripping out' everything and starting again. In addition, if the energy consumption within a dwelling can be monitored and managed through a centralised control system then it should be possible to make a major contribution to efficient energy savings. However, there are problems with establishing a whole house control system.

Manufacturers usually design new systems in isolation (if not in secrecy) and they may therefore develop along quite different lines. For example, three totally incompatible designs for video tape recording were developed independently - VHS, Betamax and Video 2000. Two of these eventually disappeared but now new systems such as HD, DVD and Blu- ray are currently competing for market position. In the case of household energy efficiency the situation is more complex. To maximise energy saving requires that the use of a range of household appliances should be compatible but the likelihood of different manufacturers accepting this philosophy is extremely remote.

However, by developing methods to integrate their functionalities the systems designer can remove incompatibilities. For example, gas boilers have control systems that maintain the internal water temperature and control the gas input valves and similar functions and so to successfully incorporate this into a whole house system requires other relevant external control functions with simple interfaces that are user friendly and make efficient use of all the energy (and fuel) systems available to the house. The system needs to be intelligent enough to switch between conventional fuels and renewable energy when this is available and to be able to interface readily with them.

2 Whole House Control by a Single Central Processor

The first idea for integrating separate units and performing whole house control was to adopt a single point system. This would require a large number of input and output lines and a relatively complex main controller, such as a PC.

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[1] See for example, Warwick Wind Trials. `http://www.warwickwindtrials.org.uk/`. Accessed April 12 2010 and KR Global. `http://www.krlobal.co.kr`. Accessed April 12 2020

[2] See for example, Ceres Power. `http://www.cerespower.com/`. Accessed April 12 2010

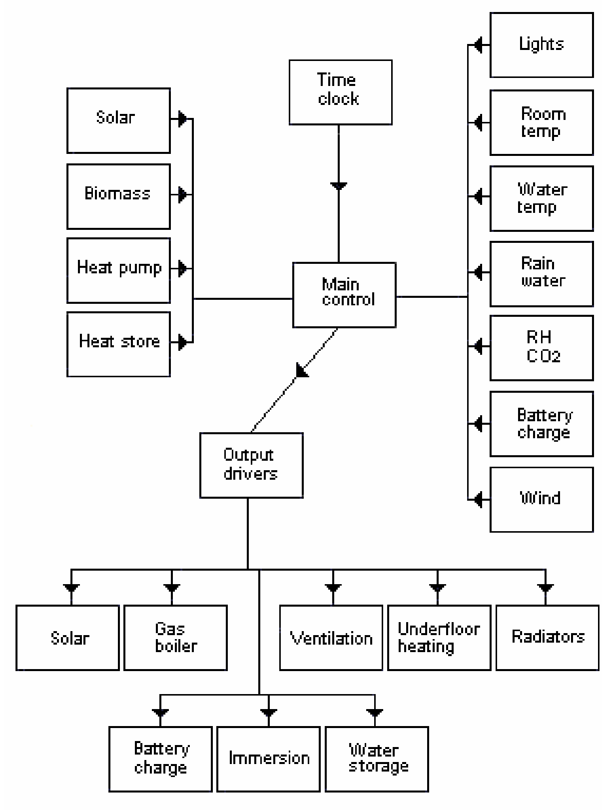

Fig. 1. Typical interaction between systems using a single processor

Figure 1 shows the interactions (rather than the actual number of connections) involved in such a single processor system. Figure 1 illustrates that there would need to be many lines of connection for this system to work. When considering the large amount of data and the actions required following the relevant analyses of this data, it became immediately obvious that this approach was totally impractical as each unit would need to be custom built. This would add considerably to the cost and complexity and would make future add-ons difficult because of the reprogramming required for each new feature.

The major priorities for any general control system design have to be its ease of use and its adaptability. The user should not need even a basic knowledge of computers to operate the system and the only actions that should be required of them should be to specify simple settings (such as the times that the heating should switch on and off and the required ambient temperature); the occasional switching off of under-floor heating in warmer weather and activating a 'holiday switch' that would put the system into background use such as frost protection when the house is not occupied for time periods outside the normal work / home lifestyle .

Although many control systems are available on the market, only one manufacturer could be found who produced anything similar to what is required of a whole house system.[3] The distributor claimed that all manufacturers looked at their products in isolation and made no attempt to try to make them compatible with others or to think of how they might be integrated into any overall control system. Their units are based on a single microprocessor and there are a range of units with different available inputs. All of these are able to take data from a number of thermostats and sensors and control a range of heat sources (such as conventional gas boilers and heat pumps). Currently there are units that can handle two and four different heat sources. However, all of the thermostats and sensors seen were bespoke and designed to work only with their system which could not accept inputs from 'standard' devices. One version has a 'weather compensating feature' which consists of an outside sensor that the processor compares with the internal temperature and attempts to pre-empt any required energy production. This feature may work reasonably well in a house that has average levels of insulation but it may not be so useful in a well insulated house where heat changes tend to be much slower.

2.1 The Control System

The commercially available (Kanmor) system comes with a number of disadvantages – it is installed and programmed by the company (or distributor) and any changes to be made require the unit to be reprogrammed. The facility to expand the system is also very limited and it is also difficult to interface with other manufacturers' input devices. These concerns were major considerations in the design of the single processor controller presented below. Further complications were generated by a desire to incorporate more control capability.

There are other underlying problems with using commercially available electronic products. Firstly, for a number of reasons the product may not be supported by the manufacturer over an extended period of time (Addy, 2006) and, although the device might continue working for many years, if the householder is reliant on the company for services such as programming then upgrades or repairs may become difficult. Secondly, all devices have a limited life span. The more complex the device the shorter its production life is likely to be, particularly if it incorporates integrated circuits. Integrated circuit manufacturers publish end of life lists. In many cases this is because a newer version pin compatible device has become available but in other cases it is because of falling sales due to advances in technology.[4]

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[3] The manufacturer is Kanmor and is distributed in the UK by Radiant Control Ltd - `www.radiantcontrol.co.uk`.

[4] See for example, component details on Microchip Technology Inc. `http://www.microchip.com/. Accessed April 12 2010.`

3 A Multi-processor Control System

With a multi processor system local decisions are delegated to secondary processors as shown in Figure 2. The main or primary processor is used to control the water heating, space heating and ventilation systems which are the main energy and comfort systems within an average dwelling. Local decisions are made on the basis of viability. As an example, with the solar delegated control the solar controller makes the decision as to whether the temperature is hot enough for use with the hot water or under-floor heating and flags the event. This flag can be polled or set as a result of main processor requesting the data. If this heat energy is not required by the main processor for hot water or under-floor heating the solar controller makes an alternative decision. This decision may be to use the heat for something such as a low temperature Stirling engine[5] or a heat store or simply to dump it. If the main processor requires heat for water or space heating it can access the various options of solar, biomass or heat store. If none of these options are available then alternative fuels (such as gas, oil, electricity or heat pump system) can be selected from a priority list set by the householder.

The design layout for a hierarchical multiple processor system (figure 2) may initially look as complex or more so than the layout of the single processor system (figure 1) however, the multiple processors allow data to be analysed at a very local level and, as only basic commands, requests and responses are transferred between processors, the main control processor does need to handle large amounts of data. Also, because of the multi processor design, a lot of data is being analysed in parallel rather than serially as in the case of the single processor system.

Figure 2 illustrates that systems such as lighting and rainwater collection can be treated as standalone and in addition, battery charging is a primary processor in its own right with interactive inputs from devices such as the wind power controller. Some secondary processors, not shown in figure 2, such as the Stirling engine controller and the solar power controller, can potentially run more efficiently if they have a direct communication / flag interaction. In the case of most input options, for example solar water heating, which sends hot water to the tank when the solar panel is hot and the tank needs heat, the energy is going out of the system i.e. into the water. In the case of the Stirling engine the energy is fed back into the system. Excess heat from the solar panels is fed to the Stirling engine to generate electricity. This electricity must be at a voltage level that is suitable for battery charging. The output of the Stirling engine is dependent on the temperature available from the solar panels. The charging voltage will depend in part on the level of charge of the batteries and if the batteries require charging. The direct interaction can allow the system to run more efficiently. The extra software required for this is very small.

[5] A Stirling engine is a heat engine with affixed amount of air or gas in a closed system. The engine has a hot side and a cold side and by moving air between the two sides the air expands and then contracts. This air expansion is then turned into mechanical movement. This type of engine is very efficient but the efficiency increase dramatically with temperature. For more information see Senft (1996).

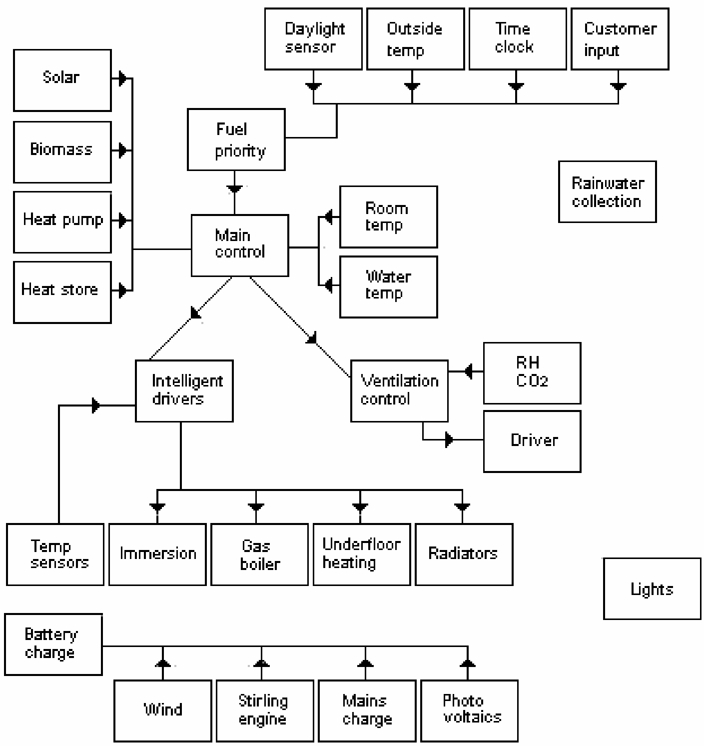

Fig. 2. Typical interaction between systems with hierarchical multiple processors

3.1 System Design

In a well designed control system, the software and firmware should allow the user to add or remove devices, inputs, outputs and preferences without any need for reprogramming. It should also have an expected life of at least that of the heating system. It may be usual for a large number of people to upgrade their PC on a fairly regular basis but heating systems are expected to run for twenty to thirty years with only minor intervention. Changing a boiler for a more efficient one should not require changing the entire control system. Thermostats, time clocks and sensors should be able to be replaced by generic devices. In addition, the controller itself should potentially be repairable by third parties and the ethical exit strategy for a manufacturing company going out of business, or changing production priorities, should be for them to make the circuit and firmware listings freely available.

As a result of the perceived problems with single processors each system was re-examined in standalone mode. The standalone systems were viewed from the point of view of their interaction with other parts of the system. Some systems, such as that for rainwater collection, require minimal intervention but others, such as hot water heating, space heating and ventilation, are totally interactive. The latter need to be able to interact not only with each other, but also with systems such as solar panels, biomass burners and heat pumps. They will also be required to make specific types of decisions such as the most efficient and cost effective fuel to use at any particular time.

The final system design was hierarchical, employing multiple microprocessors. In this case, a single central processor is used as the 'master' decision maker, while secondary processors make 'local' decisions under its overall control. It was decided to make certain processors totally autonomous but with the possibility of passing error warnings back to the main control processor. This system is relatively future proof and the addition or removal of component systems should have no affect on the running of the overall system. It was decided to use a series of Programmable Interface Controllers (PICs) as they are able to provide simple, inexpensive, easily programmed alternatives to the standard microprocessor (Smith, 2006).

Communication between the processors is on the basis of a series of simple questions and answers which can also be extended to include setting requests from secondary processors for some particular action. The question and answers would take the form of:

"Can you provide input?"
"Yes"
"I have output can you accept?"
"No"

The questions are transmitted in simple digital form, consisting of a series of bits representing 1s and 0s. The system can use a single input/output (I/O) line for each question and a single I/O for the answer. If more lines are required standard interfacing techniques can be used (see Gadre, 1998).

Standard generic devices such as thermostats and temperature sensors can be interfaced to the multiple processor system by the use of simple digital interfaces. These can be programmed by the user to feed information to the main processor on when action is needed. The use of standard thermostats means that the system appears to the user like a 'normal' central heating system.

The effects of seasonal energy price fluctuations can be optimised by incorporating the possibility for householder input for each possible fuel option. A practical hierarchical main controller is easy to implement with inputs (energy sources) in multiples of eight (the width of the standard small microprocessor buss). It is unlikely that many household will have as many as eight energy sources; therefore the undesignated inputs can be used at a later date. Undesignated inputs enable the system to be made future proof.

Intelligent drivers are a further level of the hierarchy. They are processors that respond to a single command and then have the intelligence to carry out the required function. As an example for under-floor heating the main processor provides the command for the underfloor heating and selects the fuel type. The intelligent driver then switches the correct valves and pumps and monitors the temperature of water in the secondary under floor tank and the flow and return water temperature.

4 Householder Control

The strategies outlined above mean that a relatively simple system can be designed that appears to the user to be a 'normal' heating system. It also allows for a number of options to be built in that may not be in use currently but may be included as an option in the future. The speed of the processor is fast compared to the speed of operation of the component parts of the system and the fact that non-existent options are being polled is of no detriment to the system. For example, in the time that it takes for a water valve to open or close, the processor will have undertaken of the order of 40 million clock cycles. It can be arranged for unused inputs to always return a '0'. In this case, if under-floor heating is fitted for example, a convenient switch can be employed to place the input into a 'do not use' state when it is not required - such as in summer. However, in periods of expected cold weather the system can be switched to an 'on' position as required.

The running of the system should appear to be as transparent as possible to the householder. Easy to operate and understand options for control such as time clocks and thermostats and switches or readily programmable devices for fuel selection, under-floor switch and holidays can be incorporated (see figure 3). A holiday switch is useful as a single press can put heating onto background running, switch off the ventilation (except perhaps for times when condensation maybe created by the lower air temperatures could cause a problem) and turn off rainwater harvesting in case cistern overflow occurs when the householder is away. It can also switch on security measures such as simulated occupation by switching light sequence patterns. The lights should be the low voltage type charged from one of the renewable sources. As the only input the system sees is digital then this type of function could be replaced with a time switch or operated remotely via a telephone interface so that the house system is up and running by a specific required time.

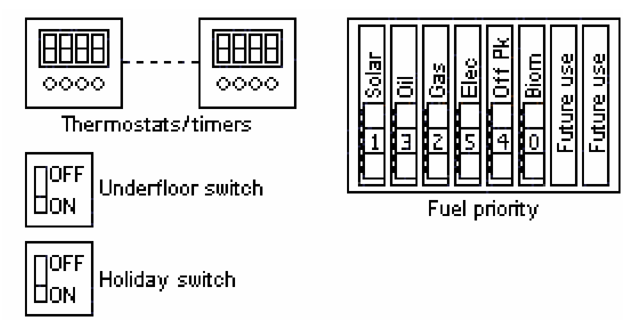

Fig. 3. The Householder's Viewpoint

The input to the processors can be in the form of thumbwheel switches with '0' to '9' positions. One switch can be used for each potential fuel. If the fuel is not available it will be switched to zero. Fuel types can then also be designated with a priority. If solar hot water is available, it will be the cheapest option and therefore first choice and designated by '1'. Different fuel types can then also be associated with other parameters that indicate cost, availability or 'greenness'. This method gives the householder a simple way of counteracting cost and availability fluctuations.

There are other opportunities for energy conservation, efficiency and/or cost savings that can be programmed in to a whole house control system. One such possibility is off-peak electricity. A time clock can be used to provide a digital output so that various options can be easily changed by the householder if times and costs of off peak electricity change. Future expansion can be included by allowing for several additional options. Those that are not fitted or not currently being used can return a '0' availability and will be passed over by the main processor.

The installer should not need intensive training for a system off this type and the only extra required should be an understanding of the placing of sensors and setting of temperature levels. Figure 3 illustrates the kind of interface that the user might have with the system. The simpler this interface is the better as it will ensure its proper and efficient use.

The system is based on hierarchical control and allows low grade and high grade heat to be used. The hot water can be preheated from a number of sources and 'topped up' from the gas boiler or immersion if not already of sufficient temperature.

5 Practical Example of a 'Typical' House Layout

A typical house layout is shown schematically in figure 4. When using a number of zoned heating areas and various forms of heat transfer such as radiators and under-floor heating together to heat the same zone there can be some difficulty deciding which source the heat originates from.

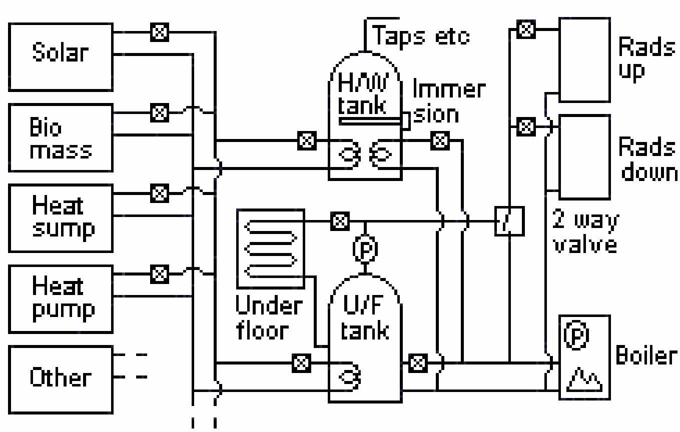

Fig. 4. Typical layout for a multi input system

The thermostats can be used to provide overall heating control but there is always a delay with under floor heating because of the heat storing mass and the transfer rate. It is possible to use sensors laid into the floor to measure the temperature of the thermal mass but unless these are laid into tubes so that they can be removed easily there can be problems if a sensor fails. Perhaps the simplest strategy is to supply the under-floor heating with low grade heat about ten degrees above the required temperature and measure the temperatures of the flow and returned water. This will mean that the under-floor heating takes longer to warm up but in a dual radiator and under floor system the latter is usually used at times when long cold spells are expected.

6 Conclusion

In this paper we have demonstrated that, when considering the energy usage of a domestic household, it is important to view the house as a whole system rather than a set of individual units. We have also demonstrated how the whole house system can best be controlled hierarchically, using a series of programmable controllers, one of which operates as a router or main controller. This offers a simple means of controlling relatively slow processes, such as energy consumption. In addition, small programmable controllers offer a number of advantages over a single, large central processor. For example, they are inexpensive, offer simple connectivity and future proofing. However, they also require much simpler power supplies and there is not need for cooling fans.

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Modifying Courtyard Wall Geometries to Optimize the Daylight Performance of the Courtyard

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Abstract. A Courtyard in a building regulates its daylight, air movement and thermal interaction with the outdoor environment. The daylight performance of a courtyard depends principally on how the daylight received and delivered into interior spaces. The current research investigates how courtyards vertical surface geometries could improve the daylight in adjacent spaces of the courtyard. The research used Radiance to investigate the impact that vertical walls, inward sloped walls, outward sloped, staggered walls and double layer walls could have on both daylight quantity and quality. Courtyards with inward sloped, inward staggered and double layer walls were found to improve the daylight quality and control the excessive light level, while outward sloped and outward staggered walls increase daylight level.

1 Introduction

Using daylighting goes beyond improving the visual environment, to improve human health, increase user productivity, reduce operating and life cycle costs, maintain sustainable development and save non-renewable energy. Daylighting has long been recognized as crucial, and a useful strategy in terms of visual comfort and energy-efficient buildings design (Lam and Li, 1998, Wittkopf et al., 2006, Freewan et al., 2008).

Psychologically, occupants prefer natural light as it offers a direct connection with outside, and enhances visual quality, human feeling, and comfort. Daylighting gives the sense of cheeriness and brightness and helps to create healthier and more attractive environments for occupants, and improves their behavior (Li and Lam, 2001, Heschong, 1999 b, Nazzal, 2001)

Lighting represents 20-60% of electricity consumption in commercial and office buildings. Using natural daylight for lighting purposes in buildings can therefore offer significant savings in energy consumption for lighting and, consequently, cooling. Daylight produces less heat per lumen compared to the equivalent amount of electric light, therefore it will be a good strategy for reducing cooling loads in buildings (Heschong, 1999 b, Moore, 2000, Johnsen, 1998).

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1.1 Courtyard

Daylight can be provided by traditional design for a perimeter zone of up to 3-5 m depth (Beltran et al., 1997). Therefore spaces without direct contact need a special design treatments, and daylight devices like courtyards, atriums, light wells or light pipes.

Courtyard is a traditional device used for ventilation, daylighting, heat gain control and social functions. Generally, it is used in large buildings to maintain a direct connection with outside. On the other hand atrium is a modern controlled courtyard used in high and large buildings. Littlefair (2002) stated the main characteristics of the atrium's shape that affect its daylighting performance. Calcagni and Paroncini (2004) investigated many variables of atrium design that could influence the daylight conditions in the adjoining space and the atrium floor.

1.2 Courtyard in Modern Housing Projects

The courtyard has become a widespread trend in housing projects and school buildings. In housing projects the courtyard is used to overcome the problem of high density housing problems by using attached or semi attached housing project. Usually large area of glazing is used in such project as the privacy is maintained and the need for natural ventilation and lighting in addition to connection with the outdoor environment. Courtyard creates a meeting point between people; increasing the qualitative value of the indoor spaces. Courtyards in such projects have small areas of 5x5m or 4x4m and floors covered with smooth tiles.

2 Research Statement and Methods

The current research is investigating daylighting performance of new courtyard' walls configurations. This paper is part of an extensive research program aims at developing new type of courtyards for new housing buildings to improve its daylight and thermal performance in summer and winter. It presents a parametric investigation on the effect of different courtyard walls configurations on daylighting.

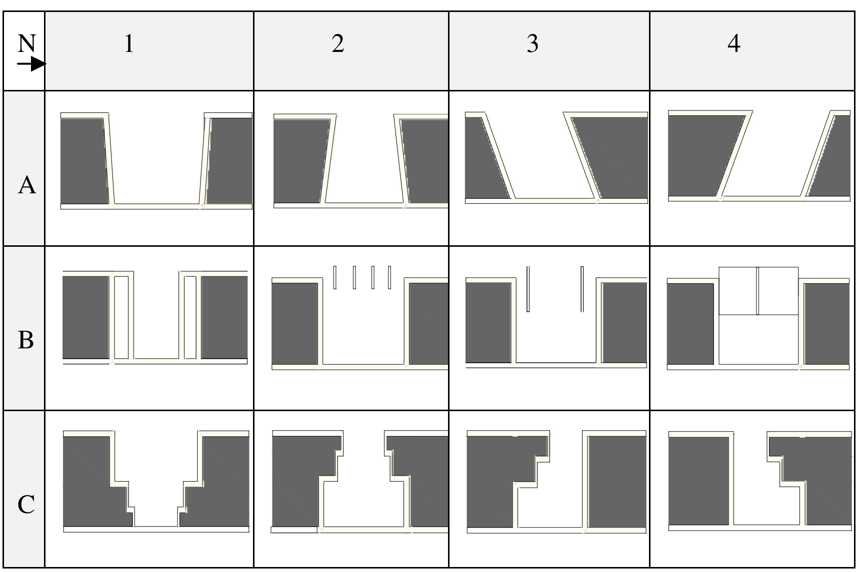
Using courtyard is providing pleasing living environment in summers as it help to control heat gain, provide buildings with natural ventilation and cool the buildings especially in the morning and evening time during daytime. On the contrary using courtyard in winter has negative impact on thermal environment of buildings. It becomes cold space and difficult to be used. Moreover courtyard has bad environment in summer specially at the noon time due to intensive direct sun rays. From daylight point of view it provide an extremely uneven daylighting distribution, causing glare problems close to the façade due to large area of glazing and smooth floor tile. The main problem is that direct sun rays, large glazing area and floor tile are creating uncontrolled excessive daylight level with uneven daylighting distribution.

2.1 Radiance

The research used computer simulations to save time and ease changing of design options. Luminous environment in the interior of a building can be studies either by using Radiosity or Ray-tracing computation method. A well known tool based on the ray-tracing technique is Radiance, which uses the back ray-tracing method. Radiance can easily deal with complex building forms and geometries, diffuse, specular and semi-specular reflection, transmission functions and also modelling advanced lighting redirecting devices like laser-cut panels. Due to its exceptional flexibility; (Greenup and Edmonds, 2004) considered Radiance a highly capable lighting simulation program currently available. Mardaljevic's (1995, , 1999) showed a good agreement between results from Radiance and actual results for; clear glazing, louvers and lightshelves as long as it use identical sky conditions. Additionally, it has been validated by different researchers in different cases and agreed well with experimental measurements (Greenup and Edmonds, 2004, Freewan et al., 2009, Ochoa and Capeluto, 2006).

The research assessed the daylight performance of the courtyard in rooms to north and south facades of the courtyard. The suggested options had been simulated using radiance in March and June under clear sky in order to increase simulations accuracy. The simulation results of each option were compared to a base case; a simple courtyard with vertical walls. Table (1) illustrates all courtyard configurations that have been studied and developed. The table shows three groups of configurations Group (A), Group (B) and Group (C). By and large the first Group depends on changing the vertical angle of the courtyard' walls to build up new courtyards. The second group depends on wall layering to configure new courtyards. Finally the third one depends on wall staggering to create new courtyards.

Table 1. Courtyard Configurations



All simulation had been conducted in Irbid_Jordan (latitude; 31.9° North, longitude; 35.9 East). In subtropical regions such as Jordan the daylight is available throughout the year during day time. Figure (1) shows two rooms which the research studied the daylight environment in. Room (A) is a room with an opening toward the north from the courtyard, while the second one (B) has an opening toward the south from the courtyard.

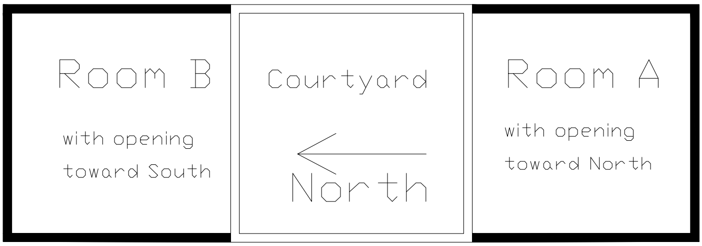


Fig. 1. Plan of the Courtyard and simulated rooms (A) with opening toward North and (B) with opening toward South

3 Results and Discussion

Figures (2 and 3) show the results of daylighting performance of the room A in different courtyard configurations in March and June. The results shows that room in buildings with courtyards; A2, B1, B3, C2, C3, and C4 perform better than

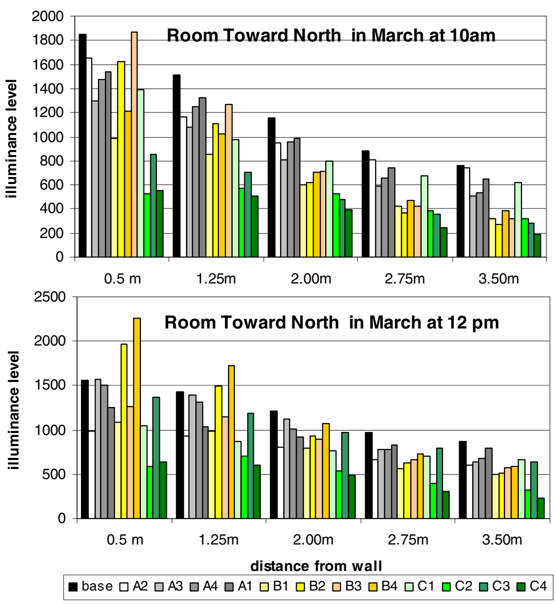


Fig. 2. Results of daylight simulations in room (A) under different courtyard configuartion in March

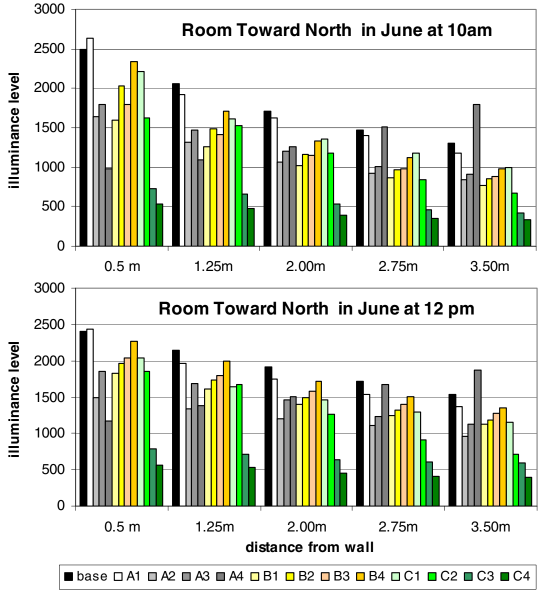


Fig. 3. Results of daylight simulations in room (A) under different courtyard configurations in June

these in buildings with other courtyards type compare to the base case, a courtyard with vertical walls. It is clear that courtyards A2, , B1, B3, C2, C3, and C4 helped to improve the daylight environment in adjacent spaces. On other hand courtyard A1 and C1 extremely increase the illuminance level in simulated rooms which negatively changed the daylighting environment compared to the original case.

On the other side the daylight analysis of the room B as seen in figures (4 and 5) showed that courtyards; A2, , B1, B3, C2, C3, and C4 could provide the room with the required illuminance level with attractive environment and view to the courtyard.

These types of courtyards improved daylight level by controlling the excessive daylight in the room. The illuminance level reduced to around 500 Lux in case of, B3, C2, C3, and C4 compared to more than 1500 Lux in the base case. Therefore the difference between the illuminance level deep in the room and near windows is reduced which help to improve the daylight quality by increasing the uniformity level.

Generally, the results show that courtyards wall configurations could be categorized, based on daylight performances, into three groups. The first group obviously helped to improve the daylight performance by reducing excessive direct light. It controlled the extreme illuminance level in summer and reduce glare compared to the base case, a courtyard with vertical walls. This group includes courtyard forms that reduce the exposed area of the courtyard floor and walls to the direct sun rays during daytime while keep a good connections to outside.

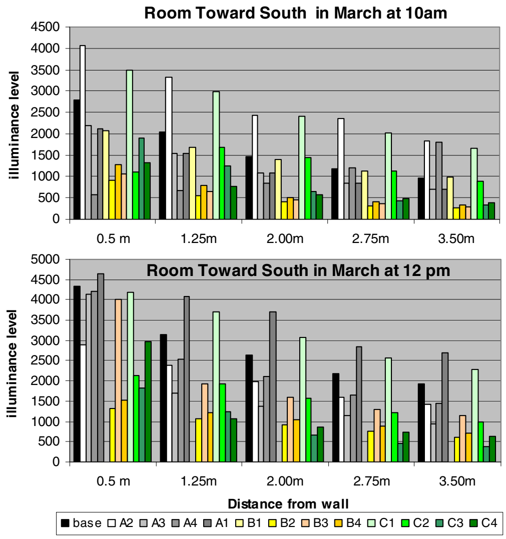


Fig. 4. Results of daylight simulation in room (B) under different courtyard configurations in March

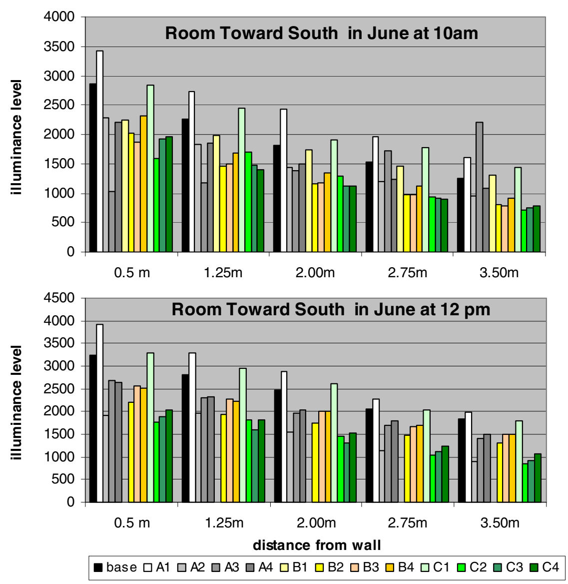


Fig. 5. Results of daylight simulation in room (B) under different courtyard configurations in June

Therefore inner spaces can be lighted through shaded area. Generally these types' walls have a horizontal part or more wall layers. The second group negatively affect the daylight performance of the courtyard by extremely increased the illuminance level and glare. These types of configurations increased the exposed area of floor and walls to the direct sun compared to the base case such as A1 and C1. The third group did not offer steady changed to the daylight performance compared to normal courtyard with vertical walls. Configurations like A3 and A4 have better performance in June than that in March.

Figure 6 shows around the year results; March, June and December for the courtyards with best performances in the first group. The figure shows how these types of configuration improve the daylight quality by reducing the differences between illuminance level across the room in both sides north and south thus improve the uniformity. It provides more shaded area in summer thus control daylight quantity and improve its thermal performance.

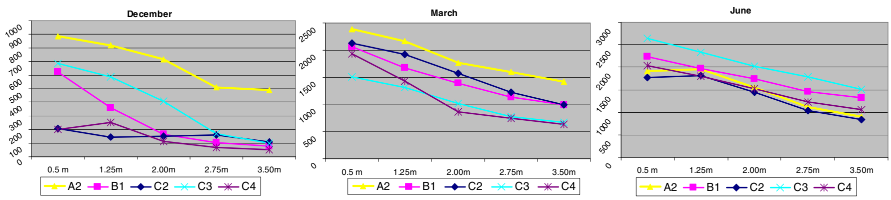


Fig. 6. Distribution of illuminance level across the midline in room (B) in December, March and June

4 Conclusion

The suggested configurations help to control the illuminance level in the adjacent rooms. Changing walls configuration of the courtyard can improve both daylight quality and quantity in addition to thermal performance of the courtyard. Configurations with horizontal elements or have more than wall layers, like; A2, B1, B3 C3 and C4, can reduce the sunny part of the courtyard in summer which helps to improve its performance from daylight standpoint. From architectural point of view this help to create attractive, pleasing and controlled outdoor space that help to increase opening area and contact with outside for interior spaces. Therefore, interior spaces will have the preferred openness without shading devices like louvers or curtain at the same time the privacy is maintained. These types of configurations are highly recommended for hot climates regions with a clear sky and direct sun rays. Courtyards like A1 and C1 can be used in regions with overcast climates or with low daylight availability as it increase the illuminance level. The results of the current research will be tuned with research program being conducted to investigate thermal performance in summer and winter as well.

More studies are needed to investigate the performance of such configuration in large building such as schools and offices.

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Research on the Current Condition of Rural Housing and Strategy of Low-Consumption in Northern China

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Abstract. The rural housing reconstruction and new construction are proceeding all over the country in northern China, but there is still so much high-energy consumption on rural housing. The rural housing may contribute to reduce energy consumption. The method of questionnaire survey to Heilongjiang Province is offered to recognize the housing current situation. The study found various influence factors of high-energy consumption. This paper presents proposal to improve the consumption of rural housing in northern China. It is suggested that energy conservation in residential buildings must be considered all-around, rather than any resolution in only one direction.

Keywords: Rural housing, Energy-saving, Factors of high-consumption, Strategy of low-consumption.

1 Introduction

New countryside construction is now in progress; the rural housing reconstruction and new construction are also proceeding all over the country. Although the housing is better than the old one on some aspects of indoor environment, layout, structural design and building materials, there is still so much high-energy consumption on rural housing. The rural housing may contribute to reduce energy consumption.

The method of questionnaire survey is offered to find out the influence factors to the high-energy consumption on rural houses. 106 families in the 27 villages are picked up at random, which are of Heilongjiang Province, Jilin Province and Liaoning Province. As part of the survey, the village heads were asked about the general situations, including the economic and the housing conditions. The chosen peasants were surveyed deeply through the methods of interview, questionnaire survey, measurement and photographs to record. The questions include the family composition, family income, basic condition of houses, willingness of housing reconstruction and new energy using and so on.

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2 Influence Factors of High-Energy Consumption

The investigation found that the influence factors of high-energy consumption are not only the rural houses, the more important is the old ideas and poor knowledge of a few peasants and officials.

(1) The peasants have clung to some old concepts, lacking of long-term planning. The northern villages contain vast area of land, and most residential planning is loose. The peasants have constructed houses and courtyards with size too large blindly [1], without consideration of family composition and further development, much less energy conservation. 41.4% of surveyed houses area was more than 100 m^2, 66% of the household with large area has less than 4 members (Table 1). Other operations and equipment facilities have not been reformed in the new houses, following the old ideas.

Table 1. Cross tabulation of Floor area and the number of family members

		Floor Area (Unit: m^2)					**Total**
		<70	70~100	100~130	130~160	>160	
The Num. of Family Members	1~2	4	7	3	1	0	**15**
	3	4	19	9	5	3	**40**
	4	2	11	4	0	4	**21**
	5	2	10	3	4	3	**22**
	>5	1	2	5	0	0	**8**
Total		**13**	**49**	**24**	**10**	**10**	**106**

(2) There had been many defects in early stages of design and construction, which may lead to energy waste and cost increase in the course of living. The old rural houses were almost built by the peasants themselves. The experience of building has been inherited from traditions. The construction level was so backward [2]. Lack of organized knowledge in design and construction lead the poor quality of houses. Many drawbacks existed in the design of plane, elevation, section and envelop enclosure, the choice of materials and the construction site. Therefore, bad living environment and massive energy waste formed the situation gradually. (Figure 1).

Fig. 1. The house on the construction

(3) The thermal insulation performance of exterior wall materials is taken into consideration only in some houses, while the performance of building envelope system is ignored. Some peasants and government officials generally believed that the good thermal insulation performance of exterior wall materials was equal to the performance of the whole house. They put all effort into development of new materials, and ignored the performance of windows, roofs, floors and so on.

(4) The rebuilt projects of the existing rural houses were ignored. In many villages, the point of the new countryside construction is demolishing the old houses and building the new ones. 74.5% of rural houses surveyed with good load-bearing structure were suitable for living in (Figure 2). 81.5% of them had non-insulation layers on the exterior walls (Table 2). Therefore, some repair or replace of components such as windows may be needed, which would be considered as energy-saving rebuild. If there were no rebuild of the existing rural houses, they should still be the sources of high-energy consumption.

Fig. 2. The existing rural house

Table 2. The situation of the external wall insulation in survey

		The Num. of Houses	Percent (%)	Valid Percent (%)
The External Wall Insulation	Insulation	15	14.1	18.5
	Non-insulation	66	62.3	81.5
	Total	**81**	**76.4**	**100.0**
Missing		25	23.6	
Total		**106**	**100.0**	

(5) The successful experience of new countryside construction was copied, not following the actual situation. Some government officials used the practical achievement blindly, without the deep analysis and understanding about successful experience. This practice caused to equipment facilities stagnation. For example, the household biogas system in some villages of Northeast had been put into use. However, they didn't consider about the factor of low temperature in winter. The biogas system had been forced to stop finally, which showed the efforts wasted.

(6) Certain government officials considered the new countryside construction just as a task. They rushed to complete tasks of building new houses and peasants living in new houses, did not consider the energy conservation (Figure 3). This attitude caused to new energy-saving houses not energy saving.

Fig. 3. The new house with aluminum alloy door

(7) New energy resources and renewable energy resources have been rarely used in Northern China, and the understanding on them need be strengthened. Most households still depended heavily on single traditional energy, abundant new energy resources not being used. The equipment was so simple and inefficiencies, with few safety measures. 61.1% of surveyed peasants had expressed the willingness of increasing a little investment and using green energy resources and efficient equipment (Table 3).

Table 3. The willingness of using new energy resources and renewable energy resources

		The Num. of Household	Percent (%)	Valid Percent (%)
Rated	Willing to do	58	54.8	61.1
	Do not matter	12	11.3	12.6
	Do not want to do	25	23.6	26.3
	Total	**95**	**89.6**	**100.0**
Missing		11	10.4	
Total		**106**	**100.0**	

3 Strategy of Low-Consumption

This paper presents proposals to improve the rural housing high consumption of energy in northern China. It is advocated that the peasants, governments, architects of working on energy conservation tripartite joint collaboration to point out the trend of construction.

(1) The residential planning overall should be compact and reasonable following the rule of economizing on land. To leave space for sustainable development in the villages' future, the old loose planning should be changed into compact one. The

idle land and residential base should be diminished in size appropriately. The houses of centralized models should be designed like Shuangpin and platoon style. The two or more storey buildings may construct in better-developed rural areas. The distance between houses should be reduced on the basis of appropriate spacing of sunshine.

(2) The heat delivery surface should be reduced in housing design (Figure 4). The shape coefficient of buildings and the area of external walls outside surface should be reduced. The shape coefficient may be less than 0.6 to the low-density residential buildings in severe cold area of China[3]. Houses adopt multi-depth layout to decrease the heat dissipation and the exterior wall surfaces of rooms in the South. The traditional dwellings have a long history with some reasonable layout. The patterns of plan have been modelized. The daily life spaces are in the South, and the ancillary spaces are in the North. As protections, the storage rooms adjoin the houses, making temperature transition.

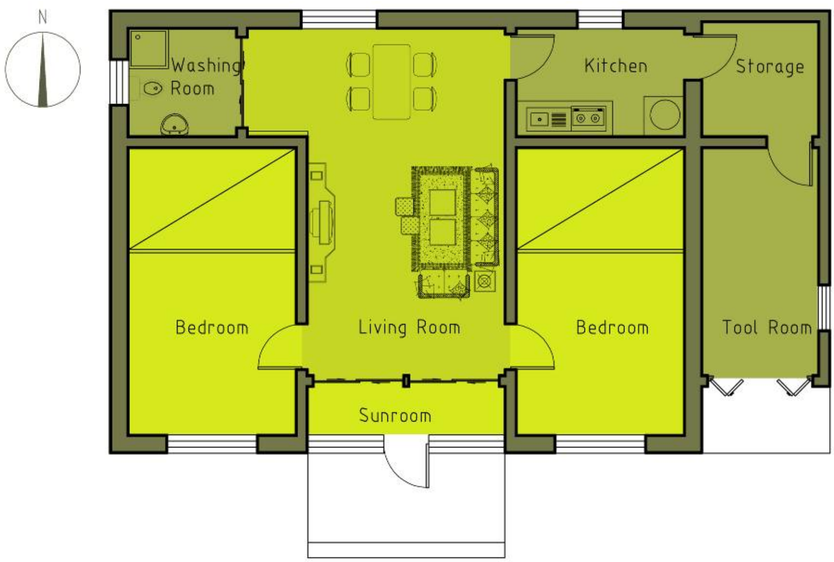

Fig. 4. Plane of rural house

(3) Needless thermal loss should be reduced. Improve the thermal insulation performance of each building element, such as roof, exterior wall, ground, entry door and window and so on. Strengthen the thermal insulation performance of components connections, avoiding the thermal bridge [2]. The building envelope should be considered as an entire system. For example, the appropriate window-wall ratio may be helpful for energy saving.

(4) In line with local conditions, the local green energy resources should be used actively. The experts may work together with the governments to develop new type green building materials, which are made from local and reclaim materials. They may reduce the cost of general material mining and transportation. For example, the straw-bale, which is an ecological and renewable green insulation material [4], sets a building envelope system and fine insulation in it (Figure 5). The agricultural waste such as rice hull, straw, plant and so on, may be roof insulation materials with low cost.

Fig. 5. The straw-bale and the solid brick

The local renewable energy sources should be also used positively. The single traditional energy form should be changed into energy mix with high efficiency and different combination modes. This method would reduce the consumption of non-renewable energy resource. Local governments would work together with specialists in resources, exploiting the natural energy resources and advantages fully, discussing the effective energy combination methods jointly, developing the new technologies and popularization to villages. The new energy resources and technologies should be suitable for the regional and economic conditions. In addition, they would provide reliable and sustainable energy resources and technical support for the future village construction.

(5) Enhance the specialty and preciseness of field construction. The old unorganized construction teams should be changed into special ones, which should be trained by the professional. They may acquaint with condition. The knowledge of building houses and renovating equipment should be popularized among special construction teams. The experience may be an important part of home and comfort improvement. The knowledge and the specialty may avoid poor quality housing and high-energy consumption.

(6) The peasants, governments and experts of working on energy conservation tripartite lay the foundation for the collaborative relationship. The experts should strengthen the advocacy of energy saving and sustainable development to the grassroots cadres and masses. The governments may set up schemes to reward those who build energy-saving houses.

Local government officials would establish correct energy-saving ideas, and carry through the importance to the peasants. To help the peasants to set up the awareness of energy conservation for the future production and living, the experts and officials would use the plain language they deserve. Financial prizes would be granted to a certain contribution of energy conservation.

Local authorities may establish some special advisory and consultative committees. The consultants may be the specialists of rural housing construction or the skilled local farmers. They could lead the peasants to solve the problems and direct the construction on site. The committees may be the rating agencies, which rank the reconstruction or new rural houses.

(7) The government and the research institutes would design and construct the rural ecological demonstration projects together, then popularize the suitable ones. The demonstration projects would help to spread the energy-saving houses as good models. The houses not only meet the function needs of daily life, but also satisfy the sustainable development demand in the future. More important is they should save more energy than ever before.

At beginning of design, the architects should survey the needs, the preferences and the living habits of the local peasants comprehensively. They must design the energy-saving houses according the actual natural and economic environment with keeping the traditions. The authorities should be efforts to tie in with the architects, providing detailed information and data.

Kinds of houses would be built with different area or different layout. The process of designing, choosing materials, construct of building, heating methods and energy resources used may take into consideration according to the local conditions.

The construction of demonstration houses must be based on construction drawings strictly. The local government officials and experts should supervise the whole process of construction. It may avoid a negative impact because of bad construction.

It is necessary to compare a normal rural house with the energy-saving one, including indoor thermal comfort, energy consumption, construction cost and so on. The peasants could choose one demonstration house according to the results of comparison. Funds would be granted to the people who may construct or rebuild their houses. Furthermore, the process would help them build their awareness of energy-saving and sustainable development.

(8) The existing rural houses should be rebuilt. Simple repair and components replace would improve the energy situation. There are many methods, such as increasing the insulation layers for the non-insulation, replacing the windows of better insulation performance, using high-efficient equipment and so on.

4 Conclusions

It is suggested that energy conservation in residential buildings must be considered all-around, rather than any resolution in only one direction. Saving energy should be considered from the effective ways of residential plan, housing design, structural joint and construction, adjusting measures to local conditions and reducing energy consumption on the basis of function. Functionality, durability, aesthetics, safety, housing costs and operation consumption of rural houses should be evaluated comprehensively. The propaganda of energy saving policy and practice of conservation demonstration projects also should be taken into accounts. The government, the peasants and the experts would establish the well cooperative relations, which ensure substantial energy conservation housing implementation.

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The Design Study of Energy-Saving Rural House in Rural Areas in Heilongjiang Province, China

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Abstract. This paper takes Heilongjiang province, the coldest province in China, as an example to study one energy-saving rural housing form which is suitable for rural areas in Heilongjiang province. In order to make the rural housing becomes more comfortable, healthy, energy efficient and environment friendly. Through the calculation of the computer software, this energy-saving and sustainable housing which is built according to this research can reduce the energy consumption by 53.4%. This will promote the sustainable development of rural housing in the severe cold region of China.

Keywords: the severe cold region; energy-saving and sustainable rural housing design; Heilongjiang province.

1 Introduction

Heilongjiang province is one of the coldest provinces in China. It located in China's northeast frontier, belongs to temperate and cold temperate monsoon climate. In Heilongjiang province the winter is very long and cold, while the summer is short and cool. The average temperature is -32 ~-17℃ in January and 16-23℃ in July [1]. Meanwhile, agriculture is the major industry in Heilongjiang. There are 0.99 million hectares of arable land, accounting for 21.7% of the total area in the province. According to census, the number of rural permanent population would reach 17.96 million in the end of 2008. The number of rural population would take up 46.97%. Due to the limitation of the geographical and climatic conditions, most of villages are underdevelopment. The topic which is how to enhance the rural living quality and save the consumption of the house is always been discussed and studied. Recent years, Heilongjiang province proposes a lot of policies to respond the call of the State that "building a new countryside". Most of these policies are beneficial to the villagers. Hence, in Heilongjiang province, it is necessary to design the house which is comfortable, energy-saving, and sustainable.

2 Investigations

Through the investigation of local typical traditional rural housing in Heilongjiang Province, the traditional rural housing has following characteristics:

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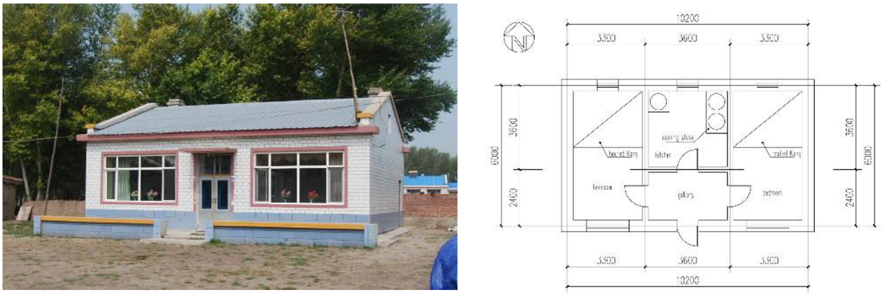


Fig. 1. Local typical traditional rural

2.1 Site

One-storey and single-family living form is very common in the rural areas in Heilongjiang province (figure 1). And the common plan of the traditional rural house is shown in the figure 1. But the basic functions of the housing are not perfect. In recent years, some villagers begin to rebuild their house themselves. They build bathroom in their houses just like the house in the city. But after a while, the function of bathroom has been changed into storage or shower room. (figure 2) That is because the drainage facilities are imperfect, and the hygienic conditions are very poor.

Fig. 2. The indoor bathroom

Fig. 3. The kitchen

In the kitchen, straw which is the basic cooking and heating fuel lay in a heap on the floor. This condition can not only cause fire easily, but also impact the living environment of the room. (figure 3)

2.2 External Envelope Structures

Traditional housing uses panels of brickwork for the wall. The total thickness of the wall is 500mm, and there is no insulation. The thickness of internal wall is 240mm or 120mm.There is no insulation on the roof and floor. Timber is often used for window frames and front doors. There are two windows or two doors in each opening to reduce the heat losses as much as possible.

2.3 Heating System

The common heating methods in Heilongjiang are heated-Kang (figure4, 5), heated-wall (figure6) and local heater (figure7). Compared with the urban heating system, in rural areas in order to improve the indoor temperature, the villagers always heat the heated-Kang and heated-wall. This method belongs to intermittent heating, and the indoor thermal stability is not very good, especially to those houses without insulation structures.

Fig. 4. Heated-Kang

Fig. 5. Cooking stove

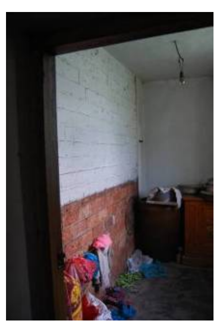


Fig. 6. Heated-wall

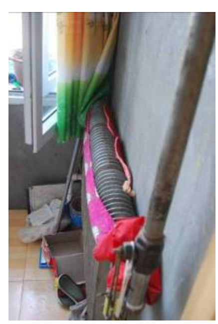


Fig. 7. Local heater

3 Design Study

3.1 Site Selection

The location of building is a major contributor to internal climate control. Many aspects must be considered, including building orientation, building interval, main prevailing wind direction in winter and the external climate. Heilongjiang locates in severe cold region, so it is crucial to keep house warm in winter. As mentioned previously, the location of building also affects the internal climate. The building faces south, and make sure there is nothing blocking the sunlight by makes a good control of the building interval. To reduce the effect of the prevailing wind on the internal climate of building, windows are usually not set in the west and east, and control the windows areas which are in the north. Meanwhile, the placement of the landscaping is also very important to sustainable building design. Also control the distance between vegetation and the main buildings. The ideal condition is that the vegetation can block out some sunlight in summer and don't in winter. Plants also can be used as windbreaks that are placed toward the north, west, and east. It can cut the costs of heating. (figure 8~9)

Fig. 8. The bird's-eye view of the whole energy-saving sustainable building

Fig. 9. Perspective view

3.2 Plan Design

Due to the living pattern of the villagers is very different from the people who live in the city, the habits and customs of the villagers, the relative of each room, and the indoor thermal environment of different room must be considered thoroughly when doing the energy–saving and sustainable hosing design in rural areas. In designing it is important to take all factors into consideration to reasonably place the function subarea via different thermal environment. Each room has its different requirement of the thermal environment. The rooms which require lower thermal comfort temperature can be placed in the north of the building, such as kitchen, storage and corridor. Those rooms make a transitional space to reduce the effect of cold air which infiltrate from windows, doors and external walls in the north. Simultaneously, put the rooms, such as bed room, living room, which need higher thermal comfort temperature in the south to make sure they get more sunshine to keep the room warmer enough in the winter and reduce the heat loss at the same time. This plant design can not only make a comfortable indoor thermal climate and maximize the energy efficient. (figure 10)

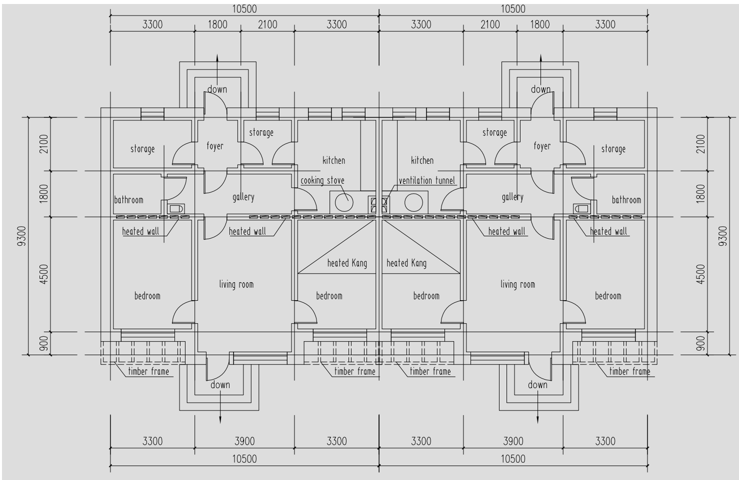


Fig. 10. The first plan of the energy-saving house

3.3 Shape Coefficient

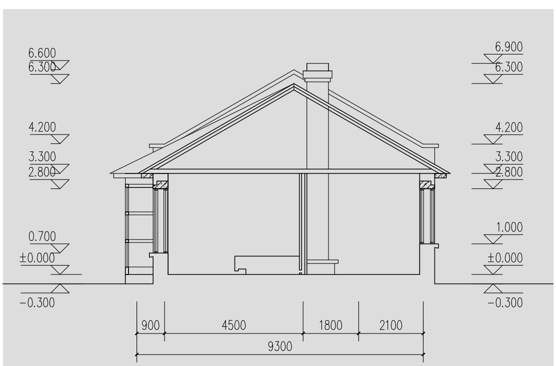


Fig. 11. Sectional drawing

The shape coefficient is one of the most important factors which affect the energy consumption of the buildings. Some studies indicate that huge shape coefficient is very adverse to energy-saving. To do the sustainable rural housing design, the town-house form is chosen and increased the depth of the building. Through the calculation and the simulation of the PKPM, this house's shape coefficient is 0.54. It conforms to the requirements of the standard of energy consumption.（figure 11~12)

Fig. 12. Elevation views (left: the south face of the building; right: the north face of the building)

3.4 Heating System and the External Envelope Insulation Structures

In the severe cold region of China, buildings consume 30%~40% of the nation's energy. The heating consumption accounts for 56% of the building. [2] It is very important to choose appropriate heating methods and external envelope insulation structures.

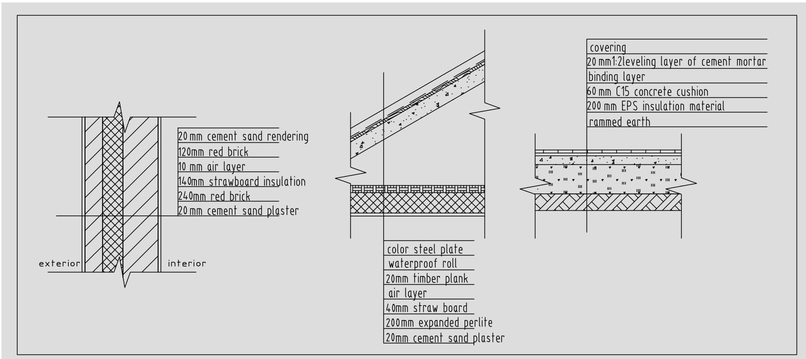
Heating System. Choose the common traditional heating methods: heated Kang and heated wall.

External Envelope Insulation Structures. The external envelope insulation structures mainly include external walls, doors, windows, roof and ground. Some studies indicate that the external walls account for 40% of the thermal losses, 20% of the roof[3]. So the external envelope insulation structures are the critical item in building energy-saving.

External Walls. External walls are the largest heat losses areas of building. Instead the traditional single-material walls, the energy-saving building choose compound-material walls. In rural areas villagers heated the heating facilities three times one day. This belongs to intermittent heating system. And villagers always go out frequently every day. So the indoor temperature should be limited it in 14℃~18℃[4].The specific practice of construction is that make the insulation layer (140mm strawboard which is local material in Heilongjiang) enveloped the main structure. And add 120mm brick to protect the insulating layer. This method can improve the energy-saving efficient and the effect of the insulation is very well. (figure 13-1)

Windows and Doors. In designing, the high-performance windows with double glazing can reduce leakage and increase energy efficient. A foyer is very necessary too.

Roof and Ground. The insulation of the roof (figure 13-2) and ground (figure 13-3) is also very important.



13-1: the detail drawing of external wall 13-2: the detail drawing of roof

Fig. 13. The detail drawing of the external walls, roof, and ground

3.5 Renewable Energy Sources

Compared with urban, solar energy resource in Heilongjiang rural areas is very rich. The design of energy–saving and sustainable rural hosing must consider the utilization of the renewable energy sources.

Due to economic reasons and technologies of the Heilongjiang's rural areas is limited, passive solar heated ways is chosen. The most common way is using the sunshine directly: The rooms which located in the south of the house can take advantage of the direct sunlight. During the day, the floors, internal walls and furniture get and store energy from the sunshine. When night is coming, the temperature of the rooms begins to drop. At that time, the components begin to release energy to improve the inner temperature. Another effective method is set up an additional sun room out the south face of the building. It can effectively reduce the effect of the cold air in winter night.

In this design, expand the windows' areas in the south face, while reduce the north's. And place the additional sun room which is detachable out of the bedroom. In summer, in order to avoid the temperature is too high in the south, the glasses or transparent plastics can be removed. Liana can be planted near the frames, and make these plants climb on the timber frames. It can not only beautify the external environment of the building, but also shield sunshine to reduce the inner temperature. (figure 14) In winter, glasses or transparent plastics can be installed on the timber frames. It becomes a sun room which can improve the inner thermal comfort and save the energy efficient. (figure 15)

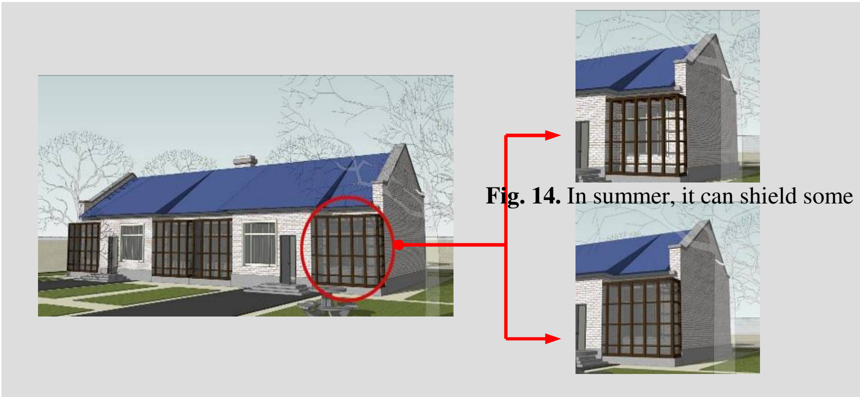


Fig. 14. In summer, it can shield some

Fig. 15. In winter, it becomes a sun room to keep warm

3.6 Calculation of Energy Efficient

Calculate the energy efficient of the sustainable rural hosing, via the computer software PKPM, to verify the effectiveness and rationality of it.

Energy Consumption Calculation of the Building. According to the parameters of the buildings and *the Standards of energy-saving design for civil construction (part of heating residential building) (JGJ26-95)*, and the calculation and simulation of the computer, the amount of annual energy consumption of the local typical traditional rural housing and energy-saving sustainable rural housing can be seen as table 1:

Table 1. Energy Consumption Calculation of the Building

Build Mode	Energy Consumption Indicator	Total Energy Consumption	Unit Energy Consumption
Local traditional rural housing	Heat Consumption	5983.57	97.77
	Coal Consumption of Heating	5073.51	82.9
Energy-saving and sustainable rural housing	Heat Consumption	8901.65	46.54
	Coal Consumption of Heating	7547.77	39.46

Assessment of the Building Energy Efficient. The design indicator of the local traditional rural house and energy-saving ones can be seen as table 2:

Table 2. The results of the Building Energy Efficient

Results	Build Mode	Heat Consumption	Coal Consumption of Heating
Design Indicator	Local traditional rural housing	97.77	82.9
	Energy-saving and sustainable rural housing	46.54	39.46

Energy Consumption. It can be clearly seen that compared with the local traditional rural housing, the energy consumption of the sustainable house can be saved 53.4%, and it has already reached the national standard requirements. This building not only saves energy, protects the natural environment, but also satisfies the basic living requirements of the villagers. It is worth to popularizing in the rural areas of Heilongjiang province. (figure 16)

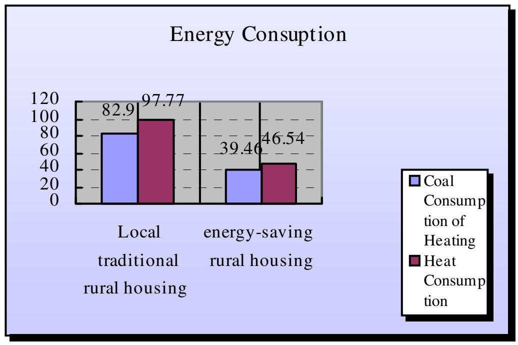


Fig. 16. Energy consumption

4 Conclusions

This mode of sustainable rural housing can save energy efficiently. Through the calculation and simulation of the PKPM, it can be seen clearly that if the rural hosing is designed by this way, the heat consumption will be reduced more than 50%. Simultaneously, the residential environment might be more comfortable and healthy. It also can reduce the of construction costs. Compared with the traditional rural housing, the total cost of the energy-saving housing increases less than 10%. This will promote sustainable and energy-saving development of rural housing in the severe cold region of China.

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Numerical and Experimental Study of the Natural Convection in a Tall Closed Cavity

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Abstract. One of the heat transfer mechanisms in the cavity of the hollow concrete block is the natural convection. The cavity formed by concrete blocks placed in walls, has a geometric ratio of 20:1 for common blocks of 0.1 m width. The thermal gradients applied are representatives of the boundary conditions in a wall exposed to weather conditions in a desert climate. Experimental and numerical convective heat transfer coefficients are presented and compared. The numerical flow and temperature pattern, obtained with CFD software Fluent 6.3 are discussed.

1 Introduction

The envelope of a building or house controls the indoor environment in terms of light, temperature and sound. From the standpoint of heat, its characteristics determine the magnitude of heat that will flow into the interior. One of the materials most used in construction of walls is the hollow concrete block, which once placed form a vertical tall closed cavity which presents the heat transfer by natural convection.

There are studies in the literature of natural convection in tall closed cavities, which are described briefly next. Pérez-Segarra et al. (1995) numerically studied a two-dimensional tall cavity with an aspect ratio of 30, using different variations of the k-ε turbulence model. Shunichi y Wakitani (1998) conducted a numerical study of two-dimensional turbulent natural convection of air in a differentially heated tall cavity. The results were obtained using the finite difference method for a wide range of Rayleigh number ($10^3 \leq Ra \leq 10^6$) and aspect ratio ($10 \leq A \leq 24$), covering the transition from a unicellular to a multicellular flow pattern in the steady state. Betts y Bokhari (2000), made an experimental study of natural convection of air in a differentially heated closed tall cavity (2.18 m high, 0.076 m wide and 0.52 m depth), the results obtained with temperature differences between the

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vertical walls of 19.6°C and 39.9°C, corresponding to Rayleigh numbers based on the width of $0.86x10^6$ y $1.43x10^6$. Zhu and Yang (2003) studied the transient natural convection in a tall cavity with laminar flow, the aspect ratio of the cavity was 16 and the Prandtl number of the cavity was 0.71; is reported the presence of multicellular flows for various values of the Rayleigh number. Manz (2003) analyzed the heat transfer by natural convection of air in vertical rectangular cavities, such as those found in double facades of buildings, with aspect ratios of 20, 40 and 80 using the numerical code Flovent; comparison with experimental correlations for the Nusselt number showed deviations less than 20%. Zhou et al. (2004) conducted a numerical study of transient turbulent natural convection in an elongated cavity closed with two different Rayleigh numbers ($Ra=0.86x10^6$ and $Ra=1.43x10^6$), results were obtained with the software PowerFLOW using the Lattice-Boltzmann algorithm and were compared with experimental data reported in the literature with a good approximation. Xamán et al. (2005) numerically studied the laminar and turbulent natural convection in a two-dimensional tall cavity with different aspect ratios, reporting Nusselt number correlations for each aspect ratio. Wright et al (2006), studied experimentally the natural convection of air in a vertical tall cavity using smoke patterns and interferometry, covering Ra numbers between $4850 \leq Ra \leq 54800$ which concluded that the core flow becomes chaotic and acquired characteristics of three dimensional flow for $10^4 \leq Ra \leq 5x10^4$. Xamán et al. (2008) quantified the effect of surface thermal radiation on turbulent natural convection in tall cavities, a parametric study was conducted by varying the Rayleigh number in the range 10^9-10^{12}, the aspect ratio of 20, 40 and 80 and the emmisivity between 0.0-1.0; they found that surface radiation does not significantly influence flow patterns in the cavity. Chico et al. (2008) performed numerical simulations for the prediction of turbulent flow by natural convection in cavities, using different turbulence models with two equations, the study was intended to show the generality, precision and characteristics of each model for natural convection.

This paper presents numerical and experimental heat transfer by natural convection in a closed tall cavity with aspect ratio of 20, as presented in the building systems based on hollow concrete blocks. Due to the size of the system being considered in this study, it is considered that the flow regime of the fluid (air) in the system is turbulent.

2 Physical Model

The study of heat transfer by natural convection will be carried out in a closed tall cavity with a height (H) of 1.00 m, length (L) of 1.00 m and width (W) of 0.05 m, the cross section is presented in Figure 1. The system consists of a vertical wall that receives a uniform and constant heat flux (q''), while the opposite wall is maintained at a uniform and constant temperature, the four remaining walls are thermally insulated. The thermal fluid is air.

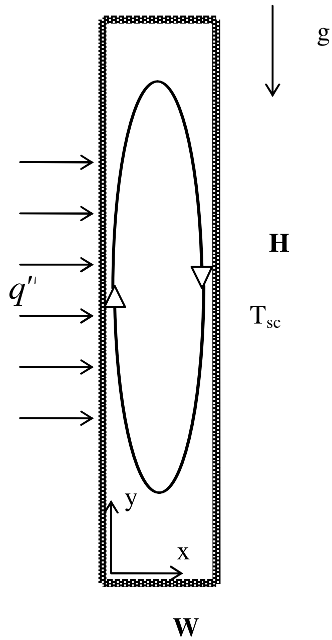


Fig. 1. Physical model of the closed tall cavity

3 Description of the Experimental Setup

An experimental setup was built to perform calorimetric tests based on standard ASTM C-177, using a test box with adiabatic cover and air-tight seal (Figure 2). The device consists of the following components:

a) Heat removal system. It consists mainly of two parts, a plate heat exchanger placed inside the test cabinet and a Cole-Parmer temperature bath model 1197P that uses water as working fluid.
b) Heat supply system. It consists of a flexible electrical resistance with a silicone cover, with dimensions of 36 "(91,44 cm) x 39.75" (100,965 cm), the resistance is in contact with a aluminum plate for better distribution of heat across the hot face of the cavity. The electrical resistance is connected to Agilent power supply model E3632A that allow varying the heat flux in the wall.
c) Temperature monitoring and data acquisition system. The temperature values were obtained with type K thermocouples. They were connected to an Agilent acquisition system model 34970A and a personal computer. The sensors monitor the temperatures of hot and cold surfaces of the cavity.

Fig. 2. Experimental setup

4 Numerical and Experimental Methodology

The numerical results were obtained with the CFD software Fluent 6.3, it is based on the finite volume method to numerically solve the fluid dynamics governing equations. The SIMPLEC algorithm was applied to couple momentum and continuity equations. The k-ε standard turbulence model was used (Ince and Launder, 1989). The convective terms were discretized with the MUSCL scheme (Van Leer, 1979).

In order to determine the appropriate mesh size for the parametric study into the cavity, a mesh independence study was conducted considering the following conditions: heat flux of 150 W and a cold wall temperature of 288 K. The value of average Nusselt number in the cavity becomes independent of the size of the mesh using 100 nodes in the vertical direction and 50 nodes in the horizontal direction (5000 nodes in total).

To obtain experimental results, the cavity was instrumented with nine thermocouples on an aluminum foil attached to the electrical resistance (hot surface) and nine thermocouples on the heat exchanger coated with aluminum (cold area), plus two thermowells within the polystyrene envelope. The experiments started by setting a constant temperature of 15 °C in the water bath and a constant heat flux with the power supply, five experimental heat fluxes were applied (16.6, 37.6, 66.8, 104.5 and 150 W). The steady state is achieved within 24 hours when the standard deviation of the last hundred data is within ± 0.06 °C per channel.

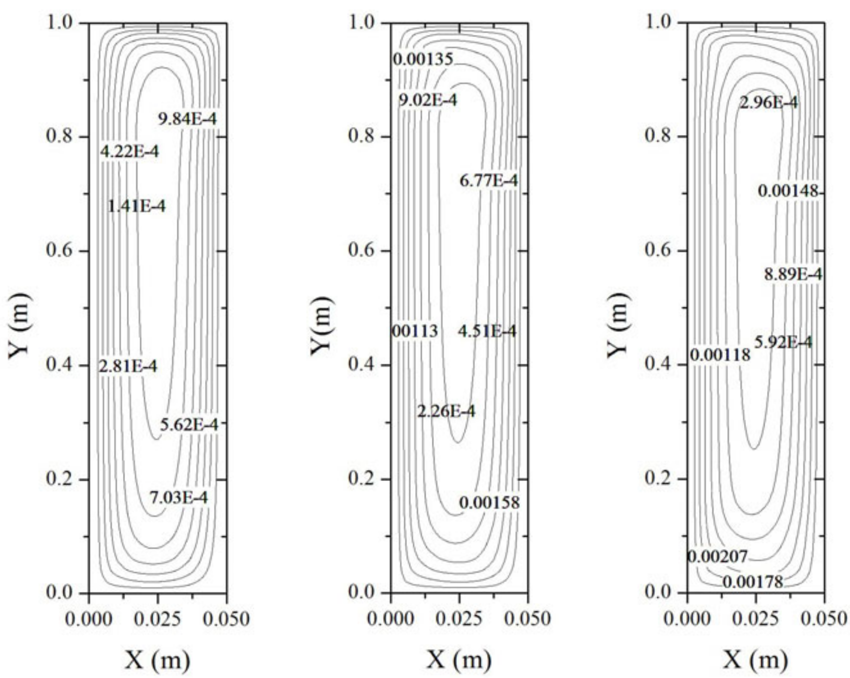
The uncertainty of the experimental results was obtained in accordance with the standard NMX-CH-140-2002. The formulation incorporates the uncertainty of every variable and is given by:

$$u_h = \sqrt{\left(\frac{\partial h}{\partial V} u_V\right)^2 + \left(\frac{\partial h}{\partial I} u_I\right)^2 + \left(\frac{\partial h}{\partial W} u_W\right)^2 + \left(\frac{\partial h}{\partial L} u_L\right)^2 + \left(\frac{\partial h}{\partial \bar{T}_{SH}} u_{\bar{T}_{SH}}\right)^2 + \left(\frac{\partial h}{\partial \bar{T}_{SC}} u_{\bar{T}_{SC}}\right)^2 + \left(\frac{\partial h}{\partial \theta_\sigma} u_{\theta_\sigma}\right)^2}$$

The terms in brackets are the sensitivity coefficients of the dependent variables with regard to the independent variables (measurements), multiplied by the uncertainty associated with them. The last term represents the influence of random errors in the estimation of uncertainty, estimated in terms of repeatability and reproducibility of the experiment.

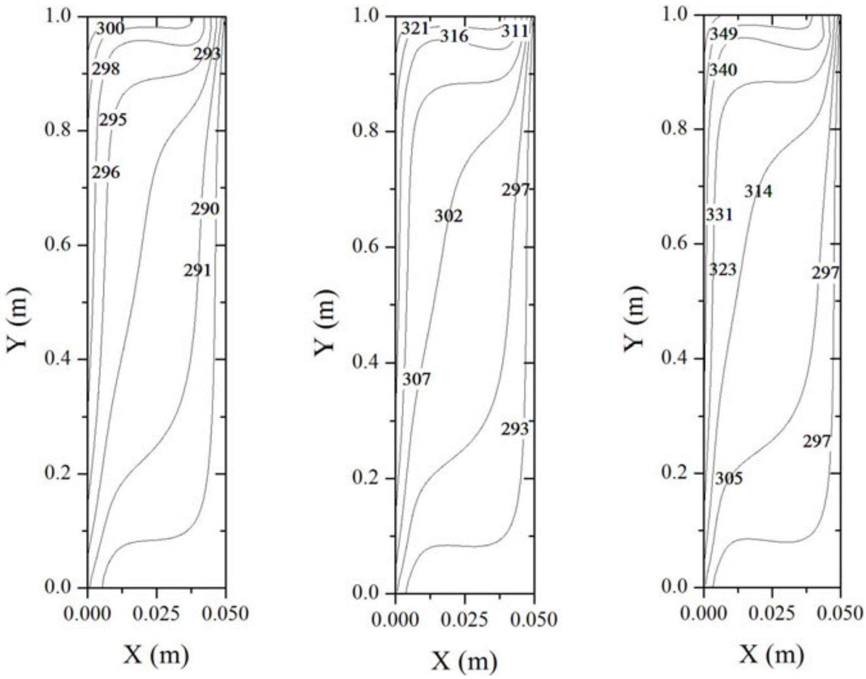
5 Results and Discussion

The numerical results were obtained reproducing the experimental conditions. Figure 3 shows the flow patterns (streamlines) in the central plane of the cavity for three different heat fluxes: 16.6 W, 66.8 W and 150 W, it can be seen that the flow



16.6 W 66.8 W 150.0 W

Fig. 3. Streamlines



16.6 W 66.8 W 150.0 W

Fig. 4. Isotherms

pattern for the three heat fluxes is very similar, the fluid flows along the shape of the cavity in the clockwise direction, forming a elliptical vortex, the values of the streamlines indicate that the fluid in the center of cavity is almost stagnated. Figure 4 shows the temperature field (isotherms) in the central plane of the cavity for the three heat fluxes considered, it is shown that are very similar for three cases, a pattern that indicates the formation of thermal boundary layers on the vertical walls vertical, with nearly vertical isotherms in the center of the cavity, indicating that in this region that heat transfer occurs mainly by diffusion. The temperature values increase with the heat flux.

The corresponding Rayleigh numbers (Ra) together with the experimental and numerical average Nusselt numbers (Nu) and convective coefficients (h) are reported in Table 1. The Rayleigh number values are in the range 7.75×10^{10}-4.73×10^{11}, indicating a turbulent flow regime inside the tall cavity. However the maximum percentage difference between experimental and numerical Nusselt numbers is 9.7 % (for 16.6 W) whereas the minimum is 3.02 % (for 104.5 W). A set of correlations for the average Nusselt number as a function of Rayleigh number was obtained:

$Nu_{exp}=42.6409+1.228\times10^{-4}\,Ra^{1/2}$ $(r^2=0.997)$

$Nu_{fluent}=34.2041+1.298\times10^{-4}\,Ra^{1/2}$ $(r^2=0.993)$

The comparison between the experimental and numerical heat transfer convective coefficients (considering the experimental uncertainty) is shown in Figure 5. It can be seen that only one numerical value is outside the experimental uncertainty.

Table 1. Average Nusselt numbers and convective coefficients for different Rayleigh numbers and heat flux

Heat flux (W)	Ra	Nu_{exp}	Nu_{fluent}	h_{exp} (W/m^2K)	h_{fluent} (W/m^2K)
16.6	7.75×10^{10}	76.2	68.8	1.98	1.79
37.5	1.63×10^{11}	93.1	89.6	2.42	2.33
66.8	2.64×10^{11}	106.5	100.0	2.77	2.6
104.5	3.71×10^{11}	115.8	112.3	3.01	2.92
150	4.73×10^{11}	127.7	123.8	3.32	3.22

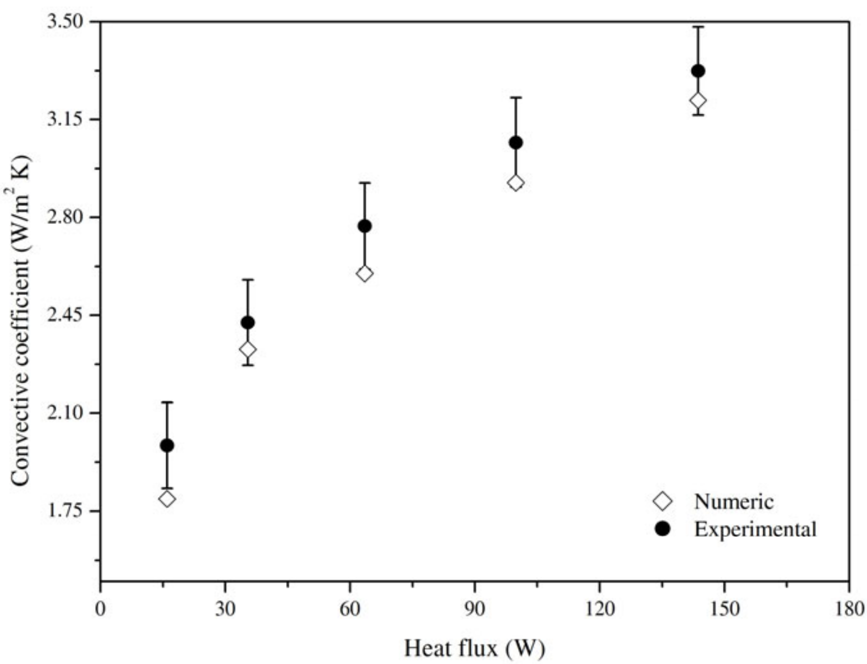


Fig. 5. Comparison between experimental and numerical convective coefficients

6 Conclusions

In this paper the heat transfer by natural convection in a tall closed cavity was studied. It can be concluded the following:

1. The flow pattern predicted by the numerical simulation show an elliptic vortex inside the cavity with a fluid core almost stagnated.
2. The numerical temperature field indicates the formation of two boundary layers near the walls with heat flux and constant temperature. Also a central region with almost vertical isotherms.
3. The percentage differences between the experimental and numerical average Nusselt numbers are in the range 3.02 % (for 104.5 W) and 9.7 % (for 16.6 W).
4. The numerical average convective coefficients are close to the experimental values when the experimental uncertainty is considered.

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Numerical Study of Heat Transfer by Free and Forced Convection in a Ventilated Cavity

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Abstract. In this paper the heat transfer by free and forced convection in a ventilated cavity is studied. The cavity is used to model a room, where a wall is receiving a uniform heat flux (like the one supplied by sun). In order to obtain the numerical results, the CFD´s software Fluent 6.3 was used and because the turbulent nature of the flow in the cavity, the k-ε turbulence model with a nonuniform grid was applied. Different values of heat flux and inlet air velocities are tested and the flow patterns and thermal fields are discussed. The heat transfer coefficients for engineering calculations are presented in nondimensional form.

1 Introduction

In the thermal design of buildings, passive cooling is a strategy that seeks to provide comfort conditions inside homes and buildings using natural ventilation, with a consequent saving of energy to reduce or avoid the use of artificial air conditioning. However it is known that a set of physical environmental variables determine the thermal sensation of a man, these variables are the temperature, speed of the air and humidity, by measuring these parameters in a room, it is possible to operate the climate control system by establishing the right conditions in order to the majority of people feel a comfortable thermal environment (Fanger, 1972). There are a variety of commercial sensors for measuring individual physical variables that determine the comfort designed to meet the requirements of international standards relating to thermal comfort. Particularly the measurement of air velocity is complex for low values, such as those existing in the interior of conditioned rooms. The computational numerical studies are helpful to simulate the global behavior of thermal systems and consequently optimize the process of localization of a climate sensor inside buildings. There are numerical studies in the literature corresponding to ventilated cavities, which are briefly described next.

Raji and Hasnaoui (1998) studied the heat transfer by mixed convection in a ventilated cavity with a uniform heat flux from the side, the proposed mathematical model was solved for ranges of $10^3 \leq Ra \leq 5x10^6$ and $5 \leq Re \leq 5000$; the

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relative height of the openings is kept constant (B ~ h'/ H' ~ 1/4). The effect of these parameters on heat transfer and fluid flow was examined, and useful correlations are proposed by considering air as the working fluid (Pr = 0.72). Sinha, et al. (2000) obtained the temperature and velocity profiles in a cavity heated by a flow of warm air, introduced at various positions, considering a steady laminar flow, and incompressible fluid under the Boussinesq approximation. Raji and Hasnaoui (2000) numerically studied the mixed convection heat transfer in ventilated cavities submitted to a constant heat flux using the Navier-Stokes equations with the Boussinesq approximation; results in terms of streamlines and isotherms are produced for different values of the governing parameters, the Rayleigh number $10^3<Ra<10^6$ and the Reynolds number $5<Re<5000$, results of the simulations show that the maximum interaction between natural and forced convection occurs for couples (Ra, Re) which can be correlated as $Re=aRa^b$. Raji and Hasnaoui (2001) analyzed the interaction between mixed convection and surface thermal radiation in a ventilated cavity with grey walls; the effect of the thermal radiation on the streamlines and isotherms is shown for different values of the Rayleigh number ($10^3 \leq Ra \leq 10^6$), the Reynolds number ($50 \leq Re \leq 5000$), and the emissivities of the surfaces ($0 \leq \varepsilon \leq 1$). Singh and Sharif (2003) made a numerical study of the mixed convection in two-dimensional cavity with differentially heated walls; the main objective was to optimize the inlet and outlet positions, in order to find the most effective way to removal of heat in the cavity. Saha et al. (2006) studied numerically the combined free convection and forced convection in a rectangular enclosure with side openings, whereas the bottom of the cavity has a uniform heat flux; three values of the Reynolds numbers, were chosen as Re = 50, 100 and 200, and steady, laminar results are obtained in the range of Richardson number as $0 \leq Ri \leq 10$ and a fixed Prandtl number of 0.71, the computational results indicate that the heat transfer coefficient is strongly affected by Reynolds number and Richardson number. Rahman et al. (2007) conducted a numerical study of the mixed convection in a vented enclosure were an external fluid flow enters the enclosure through an opening in the left vertical wall and exits from another fixed opening in the right vertical wall, various inlet port configurations are extensively studied with the change of governing parameters it is found that with the increase of Reynolds and Richardson numbers the convective heat transfer becomes predominant over the conduction heat transfer and the rate of heat transfer from the heated wall significantly depends on the position of the inlet port, higher Nusselt number is observed at very large Prandtl number. Raji et al. (2008) made a numerical study of the mixed convection heat transfer in a ventilated cavity by solving the mixed convection equations with the Boussinesq approximation, results are presented in terms of streamlines, isotherms and heat transfer for different combinations of the governing parameters namely, the Reynolds number ($10 \leq Re \leq 5000$), the Rayleigh number ($10^4 \leq Ra \leq 10^6$) and the relative height of the openings (B=1/4), the numerical results show the presence of a maximum interaction between the effects of the forced and natural convection and the existence of different flow regimes, the latter are delineated in the Ra–Re plane and the values of Re separating the different regions are determined and correlated versus Ra. Saha et al. (2008) carried out a numerical study of the mixed convection in a rectangular enclosure, four different placement configurations of the inlet and outlet openings were considered, a constant heat flux on one vertical wall was applied with air as a thermal fluid; results were obtained for a range of the Richardson number from 0 to 10, at Prandtl number of 0.71 and Reynolds number of 100 with constant physical properties, the results indicate that the average Nusselt number and the dimensionless surface temperature depend on the positioning of the inlet and outlet. Bilgen et al. (2008) studied numerically the cooling strategy in a square enclosure with ventilation ports and a discrete heat source at its optimum position considering three different ventilation ports arrangements, It was found that the heater position is at off center in all cases, its optimum position is insensitive to the variation of Ra and Re; it solely depends on the ventilation ports arrangement.

In this paper the heat transfer by free and forced convection in a three-dimensional vented cavity is studied. The cavity is used to model a room, where a wall is receiving a uniform heat flux (like the one supplied by sun). The effect of varying the heat flux and inlet air velocity is reported. The flow pattern and thermal field are discussed. Finally the heat transfer coefficients for engineering calculations are presented in nondimensional form.

2 Physical Model

The heat transfer study will be carried out in a cubic ventilated cavity with a height (H) of 1.00 m, which cross sections are presented in Figure 1. The system consists of a vertical wall (x=0) that receives a uniform and constant heat flux (Q), while the opposite wall (x=1 m) is maintained at a uniform and constant temperature of 293 K, the four remaining walls are thermally insulated. Three square inlet openings (0.1 m x 0.1 m) are placed in the bottom of the wall with uniform heat flux, whereas three square outlet openings (0.1 m x 0.1 m) are located on the top of the isothermal wall. The thermal fluid is air, which enters to the cavity at 298 K.

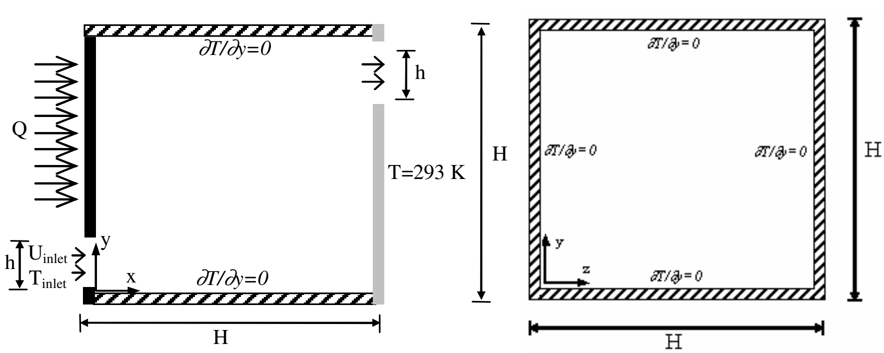

Fig. 1. Cross sections of the ventilated cavity: z=0.5 (left) and x=0.5 (right)

3 Numerical Methodology

The numerical results were obtained with the CFD software Fluent 6.3, which is based on the finite volume method to numerically solve the fluid dynamics governing equations, in this case under the Boussinesq approximation. The SIMPLEC algorithm was applied to couple momentum and continuity equations. The k-ε standard turbulence model was used (Ince and Launder, 1989). The convective terms were discretized with the second order upwind scheme.

In order to determine the appropriate mesh size for the parametric study into the cavity, a mesh independence study was conducted considering a heat flux of 300 W and an air inlet velocity of 0.5 m/s. The value of average Nusselt number in the cavity becomes independent of the computational mesh when a 50x50x50 (125000 nodes in total) nonuniform grid was applied.

4 Results and Discussion

The numerical results were obtained for two different heat fluxes on the heated wall: 150 W and 300 W, and three values of the inlet velocities: 0.1 m/s, 0.25 m/s and 0.5 m/s.

The fluid motion in the cavity is illustrated with velocity vector graphs in the cross section corresponding to z=0.5 m (Figure 2). It can be observed two main movements: the ascending fluid by the heated wall driven by the buoyancy force (free convection) that turns to the top aperture after reaching the top wall, turning again to descend by the isothermal wall and the entering air that moves by the bottom wall (forced convection). However the fluid motion induced by free convection is stronger that the corresponding to the forced convection, as a consequence the incoming air after collides turns toward the inlet aperture. Also it is shown a vortex in the left bottom corner.

Figure 3 shows the temperature fields (isotherms) in the central plane of the cavity (z=0.5 m); in all cases the presence of temperature gradients near the vertical walls is observed, on the left wall caused by the free convection whereas on the right wall by the ascending and descending fluid motion. On the other hand when the heat flux increases, the maximum temperature in the cavity varies between 319 K (46°C) for 100 W and 333.5 K (60°C) for 300 W. The increases of the inlet velocity promotes the formation of a thermal stratification in the top section of the cavity, mostly for Q=150 W and U_{inlet}=0.5 m/s. For the Q=150 W the variation of the velocity inlet varies the maximum temperatures from 319 K (U_{inlet}= 0.1 m/s) to 310 K (U_{inlet}= 0.5 m/s) and for Q=300 W from 333.5 K (U_{inlet}= 0.1 m/s) to 312 K (U_{inlet}= 0.5 m/s).

In Figure 4, are presented the temperature fields in the plane perpendicular (x=0.5 m) to the previously discussed. In all cases a symmetric temperature pattern can be observed. For Q=150 W the increase of inlet velocity reduces the temperature values in the cavity, until for U_{inlet}=0.5 m/s approximately two thirds of the cavity has the inlet temperature. When Q=300W, the same tendency of forming a thermal stratification can be observed for the maximum inlet velocity, also that the relative importance of forced convection is increasing.

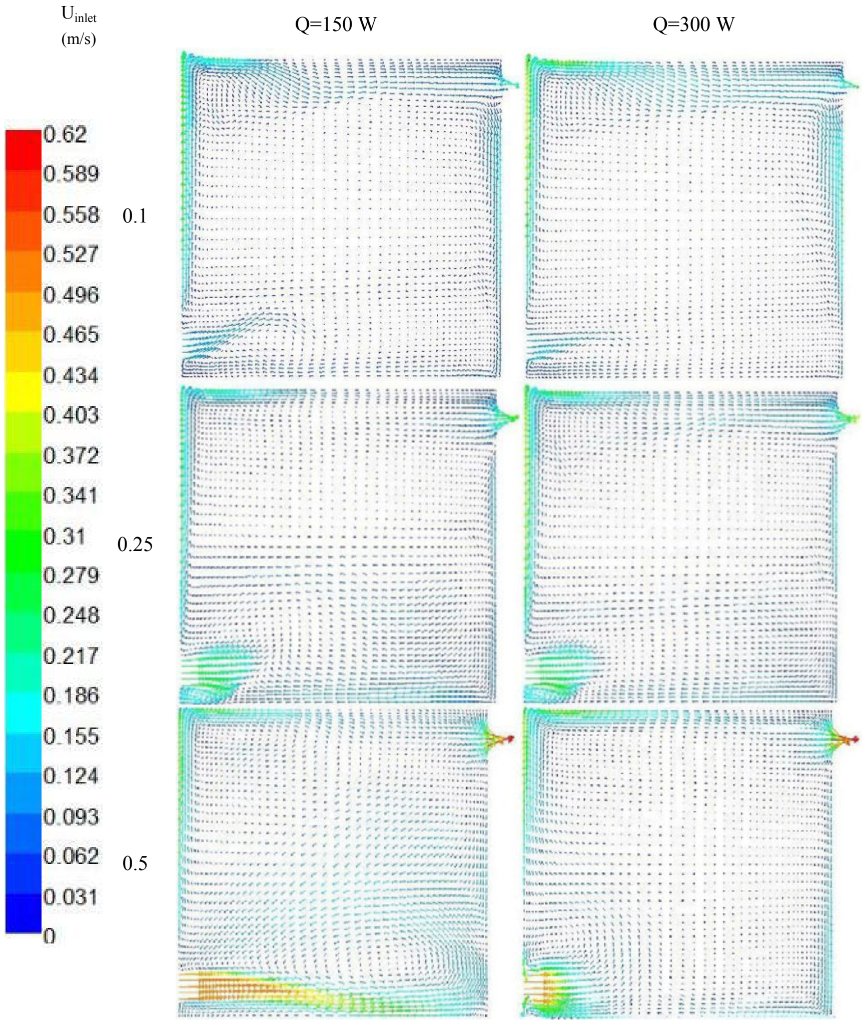

Fig. 2. Vector fields in the ventilated cavity for plane z=0.5 m

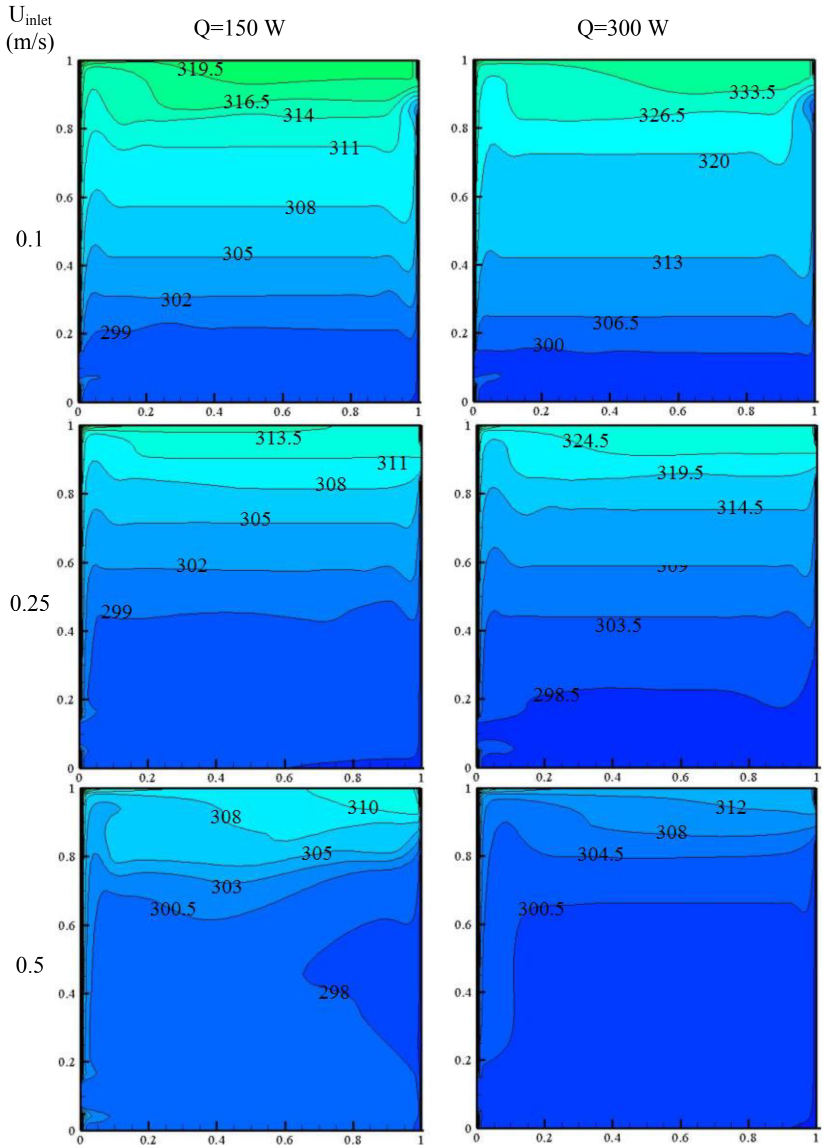

Fig. 3. Temperature fields in the ventilated cavity for plane z=0.5 m

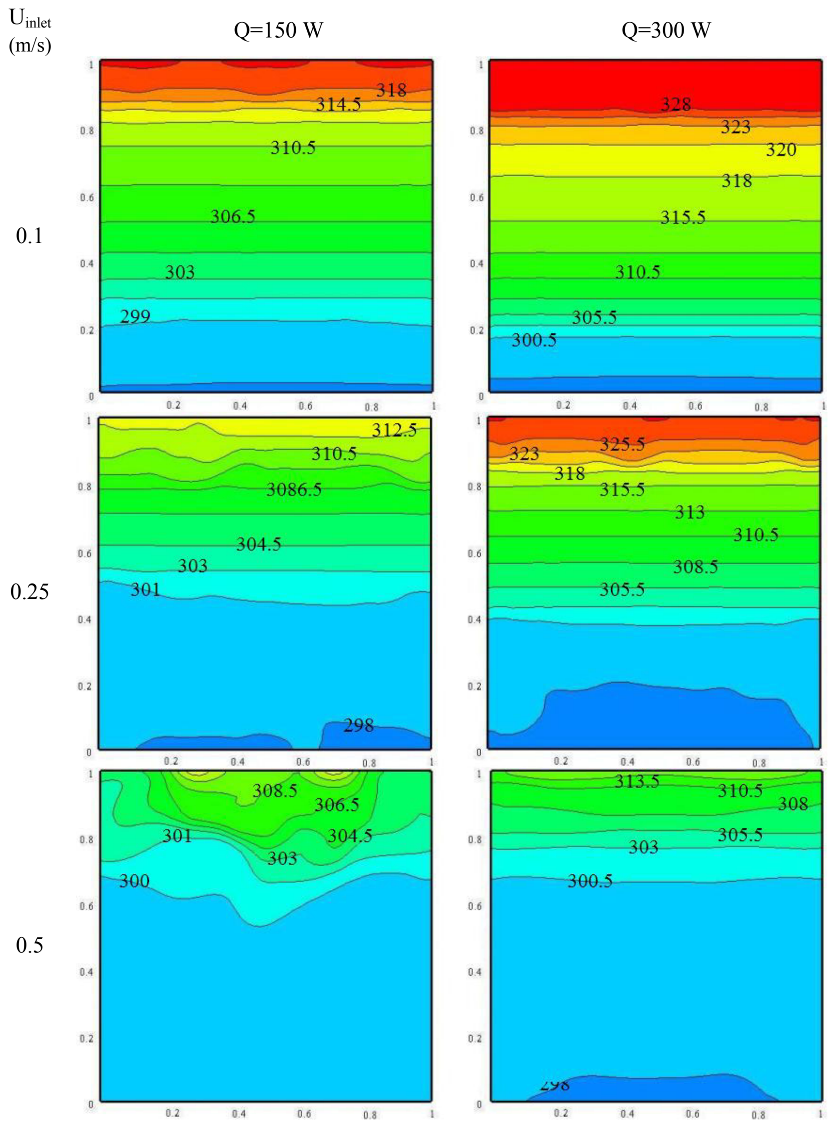

Fig. 4. Temperature fields in the ventilated cavity for plane x=0.5 m

The corresponding average Nusselt numbers (Nu) on heated wall together with Rayleigh (Ra) and Reynolds numbers are reported in Table 1. The Nusselt numbers increases with the Rayleigh and Reynolds numbers.

Table 1. Average Nusselt numbers on the heated wall for different Rayleigh and Reynolds numbers

Q (W)	U_{inlet} (m/s)	Ra_H	Re_h	Nu
150	0.1	$5.22\text{x}10^{11}$	629.1	82.43
150	0.25	$5.22\text{x}10^{11}$	1572.9	107.98
150	0.5	$5.22\text{x}10^{11}$	3145.7	119.90
300	0.1	$1.04\text{x}10^{12}$	629.1	130.33
300	0.25	$1.04\text{x}10^{12}$	1572.9	133.87
300	0.5	$1.04\text{x}10^{12}$	3145.7	140.40

5 Conclusions

In this paper the heat transfer by mixed convection in a ventilated cavity was numerically studied. It can be concluded the following:

1. The fluid motion driven by the buoyancy force (free convection) is dominant for the considered parameters in the ventilated cavity.
2. When the inlet velocity increases the temperature values reduce and for U_{inlet}=0.5 m/s a thermal stratification in the top of cavity is formed.
3. The Nusselt number on the heated wall increases with the Rayleigh and Reynolds numbers.

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Model Predictive Control of Wind Energy Storage System for Frequency Regulation

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Abstract. This paper presents a method to regulate the power frequency at a nominal value using a battery energy storage system (BESS). A control system model is proposed to simulate the BESS for frequency control application. A controller based on model predictive control (MPC) is designed for the optimal operation of the BESS for primary frequency regulation. A frequency prediction model based on Grey theory is also designed to optimize the performance of our controller. The method is tested using real measurements from a real power grid in the presence of multiple and realistic physical system constraints. The effectiveness of the proposed frequency regulation scheme is demonstrated with a simulation example.

1 Introduction

Energy storage technology has become an attractive option to cover a wide spectrum of applications ranging from short term power quality support to long term energy management. Various technologies such as Battery Energy Storage Systems (BESS), Compressed Air Energy Storage (CAES), Pumped Storage, and Superconducting Magnetic Energy Storage (SMES) are used for this purpose. The devices such as batteries, ultracapacitors, super inductors, flywheels, and fuel cell systems are normally utilized for storage purposes [1].

As the world is moving towards renewable energy sources such as wind and solar. In particular, wind energy is becoming the fastest growing energy technology in the world. It provides a clean and cheap opportunity for future power generation and many countries have started harnessing it [2]. Due to the intermittent nature of these sources, significant problems such as frequency control, voltage support, excessive peak loads on transmission lines, and power quality may arise [3]. Therefore, energy storage is critical to act as a buffer for the grid. The role of energy storage is also significant in load frequency control (LFC) [4] in order to meet the demand of electric power reliably with good quality. Energy storage systems can also be used to satisfy the spinning reserve or frequency regulation requirements.

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In this paper, our focus will be on BESS associated with the frequency control problem. Indeed the battery energy storage can provide the frequency regulation [5], [6], [7]. The basic principle of BESS is that it discharges the energy into the grid when the system frequency is below a nominal value and absorbs the energy when the system frequency is above that value. The important factor associated with BESS is the total cost, therefore, cost can be reduced either by minimizing the capacity of the storage unit [8] or by optimizing its operation. We propose a simple control algorithm based on Model Predictive Control (MPC) for the optimal operation of BESS. A principal diagram of BESS is shown in Fig. 1.

MPC has gained popularity in the industry since the 1990s and there is a steadily increasing attention from control practitioners and theoreticians. MPC has been a major success story in the modern control engineering. Thousands of industrial applications have been reported in the literature, especially in the petrochemical area; see e.g. [9, 10]. The advantage of MPC is mainly due to the fact that today's processes need to be operated under tight performance specifications and more and more constraints need to be satisfied. These demands can only be met when process constraints are explicitly taken into account in the controller design. MPC is an effective solution for that due to its intrinsic constraints handling capability.

Clearly BESS has certain constraints to satisfy in order to regulate the frequency at a nominal value. The constraints associated with BESS are expressed in terms of the battery life, the battery capacity, and the charging/discharging rate; see e.g [11] for CSIRO UltraBattery requirements. For the frequency control, certain constraints need to be satisfied as specified in the grid code; e.g. nominal frequency, maximum frequency deviation and non-critical window of frequency. Therefore, a method based on MPC is selected to regulate the frequency with optimal operation of BESS.

In this study, we propose a control system model to simulate the BESS and design a controller. As a case study, the controller has been tested with real data from a power grid. In addition, a frequency predictor based on the Grey model has been designed to improve the performance of the controller. The prediction model involved is capable of predicting frequency multi-step ahead which is used in the optimization part of the controller and for the adjustment of BESS storage state.

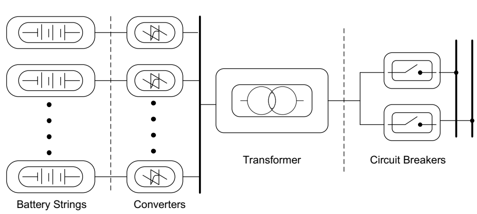

Fig. 1. A principal BESS

2 Existing Frequency Control Techniques - An Overview

An overview of a power system analysis can be found in [12]. The power system from a control perspective and its stability is discussed in [13]. In general, six major classes of control techniques have been identified for frequency control applications, including classical techniques, digital control schemes, adaptive methods, optimal control, robust approaches, and intelligent strategies.

The application of artificial neural networks for the solution of frequency problems can be found in [14] whereas [15] discusses the applicability of fuzzy logic technique. Adaptive control technique is described in [16]. For description of other methods like H^{∞} control, optimal control, and robust control; see e.g. [17], [18]. The storage based approaches are reported in [7], [19]. For a detailed survey of frequency control strategies; see [4] and references therein. However, in this study our focus is on model predictive control [20].

3 Problem Statement

The power production and consumption must be matched instantaneously and continuously in the power system. However, some factors as discussed in Section 1 may cause a deviation of system frequency from a set-point value and reduce the power quality. Therefore, a sufficient amount of active power is maintained in reserve to compensate for the mismatch. This is known as primary frequency control reserve and BESS serves this purpose. As soon as frequency deviation occurs, the controller must respond instantaneously within a few seconds to regulate the frequency back inside the allowed tolerance band around the nominal frequency value as specified in the grid code by utilizing the BESS power. For specific rules and requirements, the reader is referred to the Union for the Co-ordination of Transmission of Electricity (UCTE) handbook [21].

A basic schematic diagram of system is shown in Fig. 2. The objective of this study is to propose a control system model and to design a controller for the frequency control application using BESS under variety of constraints imposed by both BESS and the grid. The control algorithm should be such that it can optimize the operation of BESS so as to minimize the total BESS installation cost. A number of constraints, as outlined next must be satisfied. First the BESS should operate between desired state of charge (SOC) levels. Secondly, the rate of charge/discharge of battery should be within the range in order to ensure maximum lifetime of battery. A reliable operation of the controller should follow the power-frequency (p-f) characteristics of BESS as shown in Fig. 3.

4 Proposed Model

In this study, our proposed model consists of a control system model, MPC based controller, and a frequency predictor. The control system model approximates the operation of BESS facility for frequency regulation. The controller guarantees the

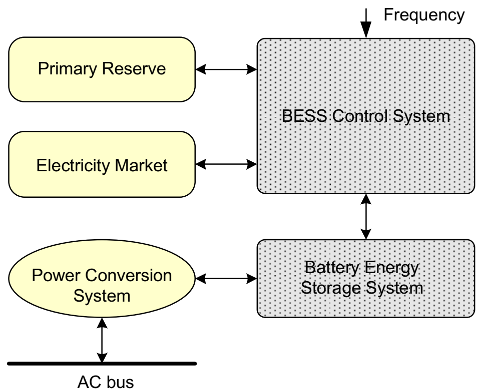

Fig. 2. Schematic diagram of the system.

reliable operation of BESS facility in presence of constraints and the purpose of frequency predictor is to optimize the performance of the controller using multi-step ahead predictions. Adaptive selection of storage state of BESS is also based on the frequency prediction. All elements are described in detail in the following sub sections.

4.1 Control System Model

Consider the following control system model for primary frequency control,

$$\begin{aligned} x_1(k+1) &= f(k) - k_1 u(k) \\ x_2(k+1) &= x_2(k) + u(k) \end{aligned} \tag{1}$$

$$y(k) = x_1(k) \tag{2}$$

with the following cost function,

$$J = \sum_{k=0}^{M-1} (x_1(k) - F_{nom})^2 \;\rightarrow\; \min \tag{3}$$

subject to following set of constraints,

$$F_{nom} - tol \leq y(k) \leq F_{nom} + tol; \;\; k = 0, 1, \ldots, M-1 \tag{4}$$

$$c_{1_{\min}} \leq u(k) \leq c_{1_{\max}}; \;\; k = 0, 1, \ldots, M-1 \tag{5}$$

$$r_{1_{\min}} \leq u(k+1) - u(k) \leq r_{1_{\max}}; \;\; k = 0, 1, \ldots, M-1 \tag{6}$$

where $f(k)$ is the real frequency, $x_1(k)$ is the controlled frequency, $x_2(k)$ is the change in battery power, M is the control horizon, tol is the given frequency tolerance, F_{nom} is the nominal frequency, c_1 and r_1 are the constraints imposed by the system, and the integer k represents the time instant.

The constraint (4) keeps the frequency regulated inside the non-critical frequency window, the constraint (5) is chosen such that it prevents the overcharging of the battery as well as avoids the negative load on the battery, the constraint (6) is associated with BESS charging/discharging rate.

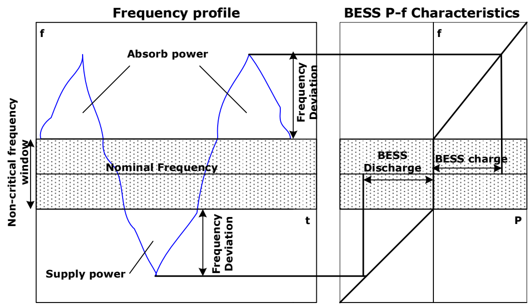

Fig. 3. Power-frequency characteristics of the BESS frequency controller

4.2 Controller Setup

MPC is based on the solution of an on-line optimal control problem where a receding horizon approach is utilized in such a way that for any current state $x(k)$ at time k, an open loop optimal control problem is solved over some future interval taking into account the current and future constraints. The MPC algorithm calculates an open loop sequence of the manipulated variables in such a way that the future behavior of the plant is optimized. The first value from this optimal sequence is injected into the plant. The procedure is repeated at time $(k+1)$ using the current state $x(k+1)$. In this study, the proposed model is standardized such that techniques in [10] can be applied, where the optimal solution of the form,

$$U^{Opt} = [\bar{u}^{OPT}(0), \bar{u}^{OPT}(1), ..., \bar{u}^{OPT}(M-1)]^T \quad (7)$$

can be numerically solved as static-optimization problem of the form,

$$U^{OPT} = \arg \min_{\substack{U \\ LU \leq K}} U^T W U + 2U^T V \quad (8)$$

with constraints expressed in the form,

$$LU \leq K \quad (9)$$

by using standard Quadratic Programming algorithms.

4.3 Frequency Predictor

The purpose of frequency predictor is to optimize the controller performance. As the Grey predictor models have been involved in many prediction applications. Therefore, in this study, we are focusing on *GM (1, 1)* model [22] for frequency prediction. The brief procedure of the *GM (1, 1)* model is as follows, the first order accumulated generating operation (AGO) series is generated in the first stage i.e.

$$F^{(1)}(k) = \sum_{t=1}^{k} F^{(0)}(t) \quad \forall k = 1, ..., \mathrm{n} \tag{10}$$

where $F^{(1)}$ is the accumulated data series and $F^{(0)}$ is the original frequency data series. In the second stage, the model's differential equation that relates its dependent variables with the independent ones is formulated. This differential equation is known as the Grey dynamic model. For the traditional *GM (1, 1)* model, this differential equation is represented by one independent variable and no dependent variables and can be expressed as follows,

$$\frac{dF^{(1)}}{dt} + aF^{(1)} = b \tag{11}$$

where F represents the independent variable for the traditional *GM (1, 1)* and (a, b) are the model parameters. These parameters can be determined by the method of least squares as follows,

$$A = \begin{bmatrix} a \\ b \end{bmatrix} = \left[\beta^T \beta\right]^{-1} \beta^T Y \tag{12}$$

where

$$\beta = \begin{bmatrix} -Z^{(1)}(2) & 1 \\ -Z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -Z^{(1)}(n) & 1 \end{bmatrix} \tag{13}$$

$$Y = [F^{(0)}(2) \; F^{(0)}(3) \; \ldots \; F^{(0)}(n)]^T \tag{14}$$

and

$$Z^{(1)}(t) = \frac{F^{(1)}(t-1) + F^{(1)}(t)}{2} \tag{15}$$

The following equation calculates the predicted values of the AGO series $\hat{F}^{(1)}$ at each time step,

$$\hat{F}^{(1)}(t+1) = \left(F^{(0)}(1) - \frac{b}{a})\right) e^{-at} + \frac{b}{a} \tag{16}$$

where $F^{(0)}(1)$ represents the first data in the original time series. Finally, the predicted AGO series of data is transformed back to its original form using the inverse accumulated generating operation (IAGO) mathematically represented as

$$\hat{F}^{(0)}(1) = \hat{F}^{(1)}(1) \tag{17}$$

$$\hat{F}^{(0)}(t+1) = \hat{F}^{(1)}(t+1) - \hat{F}^{(1)}(t) \;\; \forall t = 1, 2, 3, ... \tag{18}$$

5 Data Bases

This paper is based on real frequency measurements from a real power grid. The data has a 6 sec resolution and covers the calendar year 2005. Exact name and location of the site is not mentioned due to confidentiality issues. Normalized results are presented where possible. Measured frequency for one of the days is shown in Fig. 4.

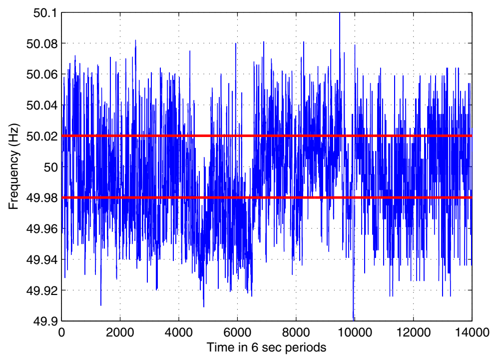

Fig. 4. Measured frequency for a typical day showing non-critical frequency window

6 Results and Discussion

A simulation study has been carried out to check the validity and effectiveness of the proposed approach. As regards the prediction model, Fig. 5 shows the prediction performance of our prediction model, where the frequency prediction is based on the historical frequency measurements.

On the controller side, all constraints are chosen based on physical limitations of the system, where nominal frequency is chosen to be 50 Hz, a non-critical frequency window is also shown in the figures where maximum frequency deviation is set to be ±20mHz.

It can be observed from Fig. 6 that designed controller faithfully regulates the frequency inside the non-critical frequency window. The corresponding battery storage is depicted in Fig. 7 along with the real frequency. It can also be observed that BESS follows the p-f characteristics exactly as shown in Fig. 3.

In this study, some facts about the real data under study are not presented intentionally to avoid any commercial confidentiality issues. However, the presented methodology is straight forwarded and may be extended.

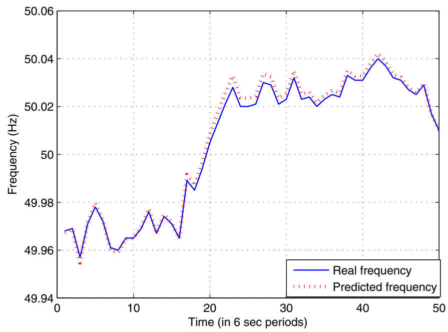

Fig. 5. Prediction performance

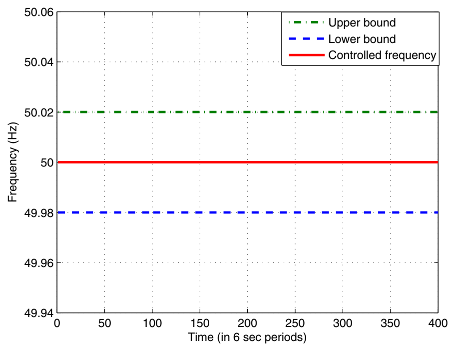

Fig. 6. The regulated frequency at a nominal value

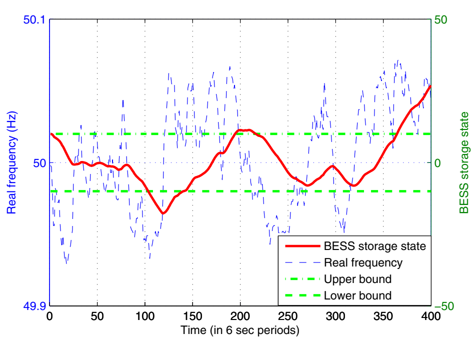

Fig. 7. BESS storage state along with real frequency following the p-f characteristics

7 Conclusion and Future Work

In this study, a linear dynamic model is proposed to approximate the operation of a BESS facility for frequency regulation application. An MPC based controller was proposed and implemented for the optimal operation of the BESS for the frequency control problem. Controller optimization is achieved using a frequency predictor based on the Grey model. Despite considering a BESS in this paper, the idea and concepts may be easily extended to other storage technologies.

The detailed study of the robustness, uncertainty, and noise effects will be the focus of future study. We will apply methods and ideas of the modern robust state estimation theory; see e.g. [23, 24, 25].

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Development of a Simulation Tool to Predict Urban Wind Potential

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1 Introduction

Since energy production is no longer limited to decentralized systems, but brought into the urban environment, where a huge amount of energy consumption takes place, new technologies are emerging and already known technologies are used in another context. One of these technologies is wind energy. Even though the wind energy is significantly lower in urban districts wind turbines are currently erected and new design of wind turbines could possibly be designed rather cost effective. Several trials and studies in different countries were conducted, where small-scale wind turbines were attached to building walls or mounted on rooftops [1, 2, 3, 4]. The used wind turbine configurations were various, including lift-driven horizontal axis wind turbines, drag-driven vertical axis wind turbines, but also completely new concepts. One essential part for a promising integration of wind energy in an urban context is a well designed wind turbine; well designed for the wind condition it is going to be exposed to.

Within this work the development of a simulation tool to predict urban wind potential is presented. Wind conditions around buildings can basically be determined in three ways. The most accurate way is to take measurements over a one year period directly at specific sites. Another way is to build down-scaled models of the areas of interest and expose the models to different wind conditions in a wind tunnel and measure punctually at locations where e.g. a wind turbine is intended to be positioned. The third method is to model the vicinity to a certain extent in a so called computational domain and solve the flow field which will emerge by the influence of the buildings. Whereas with the first two methods wind velocities are measured at only few points at the same time, the third method resolves the whole wind field so that data can be extracted at every position. A drawback is the uncertainties involved in CFD (computational fluid dynamics) simulations.

Due to the fact that the whole wind field can be captured with CFD simulations and the fact that the first two methods are rather costly, this work is based on simulations. The used flow solver code, EllipSys [5,6,7], was developed at Risø, DTU, DK. For this study a RANS (Reynolds-Averaged Navier-Stokes) solver

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scheme with a k-ε turbulence model is applied to examine the wind conditions around and within simplified building arrangements and to evaluated areas with respect to a local wind energy maximum. The simulated building arrangements are oriented on characteristic set-ups within urban areas, defined by Badde & Plate in 1994[8].

2 Method

In this work a simulation tool is introduced to determine the wind energy potential in urban districts. The idea is to be able to rebuild typical building configurations within a CFD simulation environment. In a domain, consisting of 8x14x4 cubes of the same size, single cubes can be set to solid and thus simulate a building. In this way the tool is flexible, but at the cost of a detailed representation of the buildings. A roughness length of z_0=0.2m applied to the buildings surface accounts for the neglect of balconies, blinds, oriels or roof rails etc. The physical dimensions of a single cube are 12.5m x 12.5m x 12.5m. With that a district can be rebuild with building heights of 12.5m, 25m, 37.5m and 50m.

2.1 Computational Domain

Three dimensional CFD is based on finite-volume discretization. That means that the continuous fluid medium, here it is air, is subdivided into small cells, forming a grid. The applied computational code is then solving the governing equations at the center of every single cell. In areas with large gradients of e.g. velocity, a finer resolution is needed than in areas where the flow is undisturbed and homogeneous. But since the computational time is increasing with increasing numbers of cells, a satisfying trade-off between accuracy and computational time has to be found. The domain of the tool designed here consists of 1024 blocks. Each of the blocks contains 24^3cells, which makes approximately $15x10^6$ cells in total. In Fig. 1a) the round ground plate of the whole domain is shown, where the lines are showing the arrangement of the blocks. The circular shape was chosen to use the same domain for different inflow angles. In the center, an area is located consisting of 8x14x4 equally sized cubes, which can be set to solid obstacles, representing buildings. The distance between inlet and this area, D, is around 25 times the height of the tallest building possible to be built. In this way the wake provoked by the obstacles is expected to be fully developed within the domain. In order to reduce the block number and to keep cells as less skewed as possible, the domain is built up as a hemisphere. Fig. 1b) shows the side-view of the domain, where no cubes are set to solid and an inflow boundary condition of a logarithmic inflow profile in y-direction is applied. The colors show the velocity distribution. The height of the first cell above any possible solid object is set to 0.16m in order to capture a roughness length of 0.20m and higher.

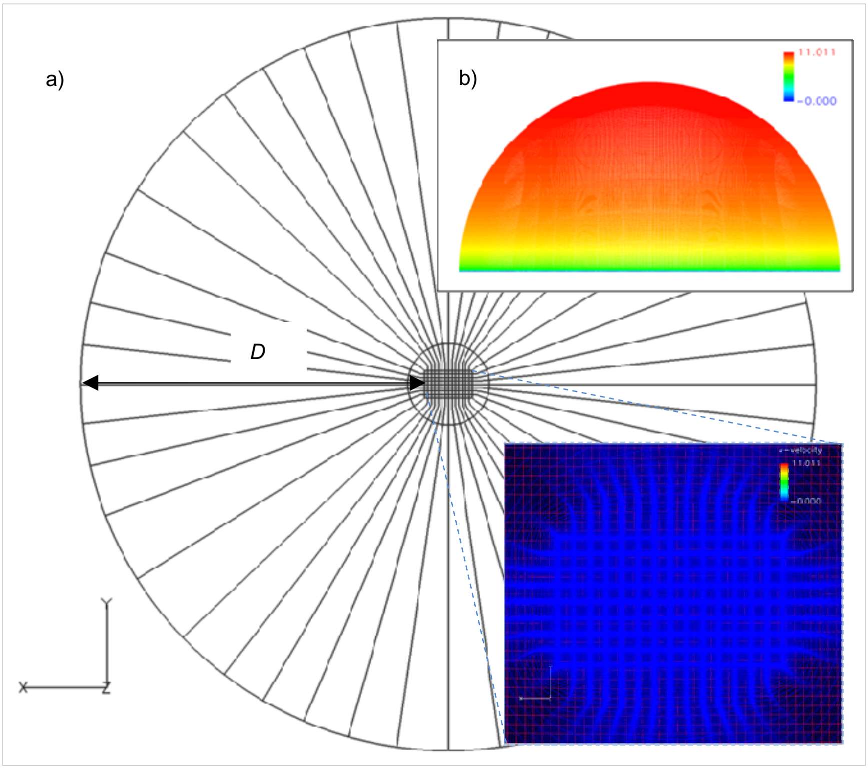

Fig. 1. Hemispherical computational domain a) top-view with block outlines and detail-view of the center-located block arrangement and in b) side-view with colored legend, indicating the applied logarithmical velocity distribution on the domain surface

2.2 Simulation Settings

A RANS solver in combination with a k-ε turbulence model is applied with the following settings:

Medium density:		ρ=1.225kg/m^3
Kinematic viscosity:		ν=1.5x10^{-5}m/s^2
Inflow friction velocity in	x-direction:	u^*=0.0m/s
	y-direction:	v^*=0.5m/s
	z-direction:	w^*=0.0m/s
Roughness length:		z_0=0.2m

The boundaries of the computational domain are defined as:

WALL on the ground plate and the block surfaces, if they are set to solid
INLET on hemisphere surface depending on the inflow direction
OUTLET on hemisphere surface, changing correspondingly to inflow direction

The shape of the inflow profile defined at the inflow boundary is set to logarithmical and is described as

$$U_{\log}(z) = \frac{U^*}{\kappa} \ln(\frac{z + z_0}{z_0}) , \quad (1)$$

with U_{log} as the velocity depending on the height z, U^* as the friction velocity and the Karman constant, which is $\kappa = 0.4$.

2.3 Validation

To verify the CFD settings within the flow solver, eight cubes were set to solid, forming one single cube in the middle of the domain. With that the cube height was h_C=25m. The results from the simulation were compared with results found for a cube mounted on a plate in a wind tunnel experiment [9]. Three different simulation cases where conducted, where the roughness length was varied with z_0=0.2m; 0.5m; 0.825m. The wind tunnel experiment settings where z_0/h_C=0.02, which correspond to a roughness length of z_0=0.5m for the CFD set-up. Fig. 2a) shows plots of the velocity profiles found on top of the cube center, half cube height behind the cube and one and a half cube height behind the cube. For comparison reasons the velocities are normalized with a reference velocity, U_r, defined as free-stream velocity at $z=10h_C$. In Fig. 2b) the pressure coefficient, C_P, found along the cube sides is plotted. The pressure coefficient is defined as

$$C_P = (p_s - p_\delta) / ½\rho U_h^2 , \quad (2)$$

where p_s is the surface static pressure, p_δ is the static pressure in the free stream at a height of $z=10*h_C$ and U_h is the velocity in the undisturbed flow at cube height. This validation of the tool showed good agreement, see Fig. 2.

Earlier simulations in a test domain showed a Reynolds Number independency, which arises from the aerodynamic behavior of bluff bodies as soon as a critical Reynolds Number, Re, is exceeded. Castro and Robins stated for this set-up a Reynolds Number independency for Reynolds Numbers beyond $4x10^3$[9]. The Reynolds Number in this case is based on the free-stream velocity at cube height and the cube height as characteristic length. Such independency means on one hand that for a certain building set-up, areas of high and low wind velocities respectively will be at the same location independent of the incoming wind velocity. On the other hand it means that the cube size is scalable, as long as the roughness length is scaled correspondingly.

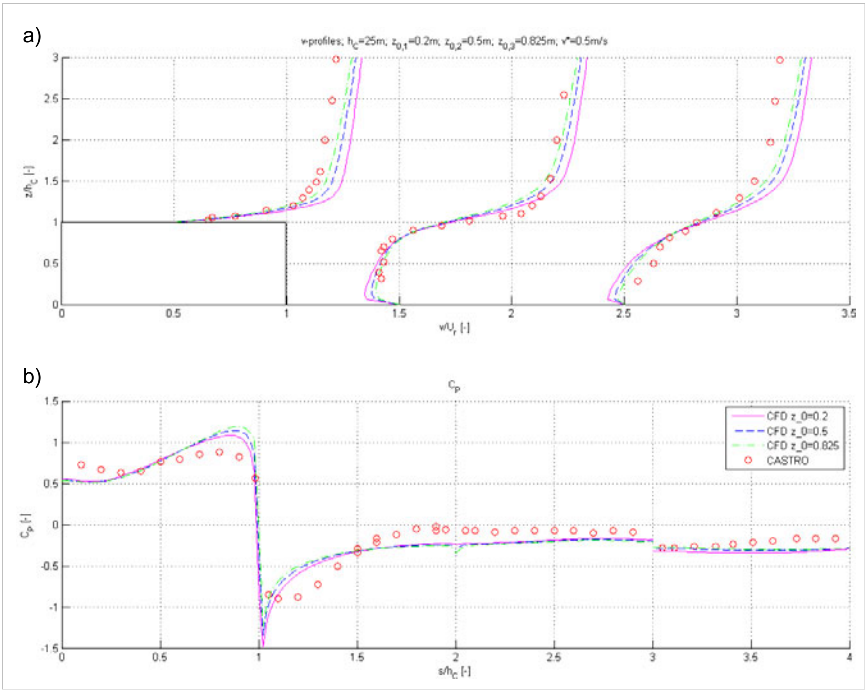

Fig. 2. Comparison of results from experiment conducted by Castro and Robins [9] with results from CFD simulations (z_0=0.2; 0.5; 0.825). In a) velocity profiles plotted on top of the cube center, $h_C/2$ behind the cube and at $3h_C/2$ behind the cube. In b) C_P found along cube sides, starting with the front side $C_P(x=0;\ y=-h_C/2;\ z=0\text{-}h_C)=C_P(s/h_C=0\text{-}1)$, continuing over the roof $C_P(x=0;\ y=-h_C/2\text{-}h_C/2;\ z=h_C)=C_P(s/h_C=1\text{-}2)$, moving downwards on the rear side $C_P(x=0;\ y=h_C/2;\ z=h_C\text{-}0)=C_P(s/h_C=2\text{-}3)$ and finally upwards along a side wall $C_P(x=h_C/2;\ y=0;\ z=0\text{-}h_C)=C_P(s/h_C=3\text{-}4)$.

2.4 Showcases

Typical building configurations as commercial and industrial areas, city center areas including parks, high-rise buildings and public facilities were parameterized in a work by Badde & Plate in 1994 [8]. They defined 10 different configurations in terms of mean building height, $\overline{H}$, relative standard deviation of the building heights, $\sigma_H/\overline{H}$, mean length to mean width ratio $\overline{L}/\overline{B}$, mean length to mean height ratio and two more coefficients; λ_{ar}=sum of all areas covered by building/total urban area; λ_{fa}=sum of average building areas normal to the wind/total urban area. Four configurations are rebuilt following these parameters and are shown in Fig. 3. In the following the configurations will be referred to as *CASE1* (Fig. 3a)) representing areas of one family buildings one to two stories high, *CASE2* (Fig. 3b)) representing residential blocks regularly aligned three to five stories high, *CASE3* (Fig. 3c)) representing city center areas including parks, high-rise buildings and public facilities and *CASE4* (Fig. 3d)) representing commercial and industrial areas two to five stories high. The roughness lengths announced in the figure legend are values for the influence of the buildings themselves. That means that they could be removed and be replaced by a roughness length of that value.

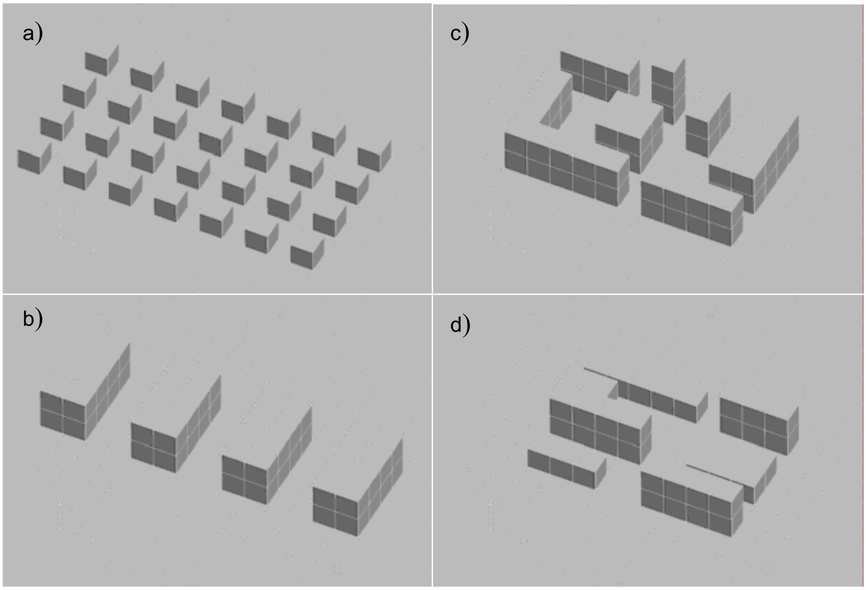

Fig. 3. Picture of chosen building configurations oriented on parameters defined by Badde & Plate [8]. In a) *CASE1*: one family buildings 1-2 stories; z_0=1.3m. In b) *CASE2*: residential blocks regularly aligned 3-5 stories; z_0=1.5m. In c) *CASE3*: city center areas including parks, high rise buildings and public facilities; z_0>2m. In d) *CASE4*: commercial and industrial area 2-5 stories; z_0=0.6m.

To respect the neglect of balconies, blinds and the like a roughness length of z_0=0.2m is applied on the surface of the blocks, but also for the incoming wind. In this way the configurations are placed in a cultivated or natural area with high crops or crops of varying height and scattered obstacles at relative distances of 12 to 15 obstacles heights for porous objects (e.g. shelterbelts) or eight to 12 obstacles heights for low solid objects (buildings), following the Davenport classification of effective terrain roughness [10]. That is not representing real conditions, since city centers are very unlikely to be positioned in such an environment, but for an initial study a regular roughness length was chosen.

2.5 Evaluation

In order to evaluate the wind conditions found around and within the building arrangements with respect to wind energy applications, the velocities and turbulence kinetic energy, *tke*, are studied. In the results figures are shown where the acceleration coefficient, *ac*, is plotted. It is defined as

$$ac = U(x,y,z)/U_{log}(z) \qquad (3)$$

where $U_{log}(z)$ is the inflow profile and calculated corresponding to equation 2. $U(x,y,z)$ is the local velocity including all velocity components, that means that

$$U(x,y,z) = \sqrt{u(x,y,z)^2 + v(x,y,z)^2 + w(x,y,z)^2} \qquad (4)$$

does not include information about directions, but is more a measure of energy. In areas where $ac>1$, the buildings presence cause an acceleration, whereas in areas of $ac<1$, the buildings cause a deceleration compared to the free-stream profile. The other variable of importance is *tke* and is characterized by measured variances of the velocity components.

$$tke = ½(\langle u'\rangle^2 + \langle v'\rangle^2 + \langle w'\rangle^2)\,. \qquad (5)$$

The obstruction of the flow by the buildings provokes an increase in turbulence, which has an impact of the performance of wind turbines and their fatigue loads.

3 Results

For the implementation of wind turbines (WTs), areas as roof-tops, house corners and location beside or in between buildings are interesting. Fig. 4 shows *ac* for *CASE1* and *CASE2* at the physical height of z=5m. In Fig. 5a) the same but for *CASE4* can be seen. Due to the huge amount of visual information, the illustration of the method is limited to one example, *CASE4* (see Fig. 5), where further *ac* cuts are chosen at 13.5m,.which corresponds to 1m above the first roof-level and 8% of cubes height respectively, at 28m, corresponding to 3m above second

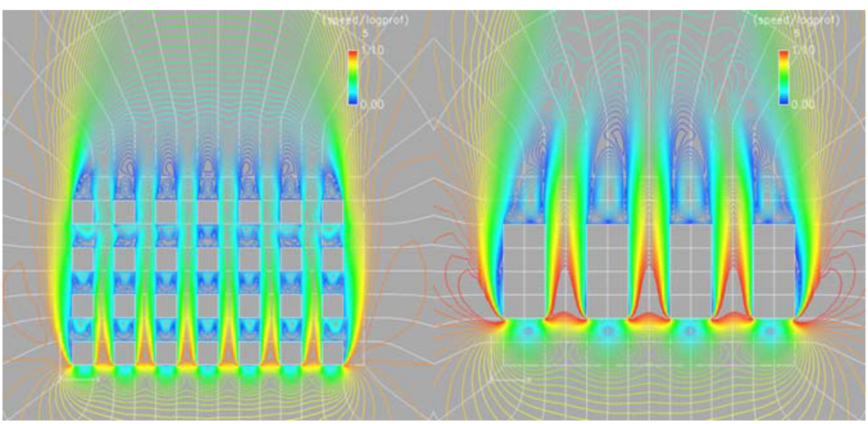

Fig. 4. Parameter *ac*=0.0-1.1 plotted at *z*=5m; to the left: *CASE1* and to the right: *CASE2*

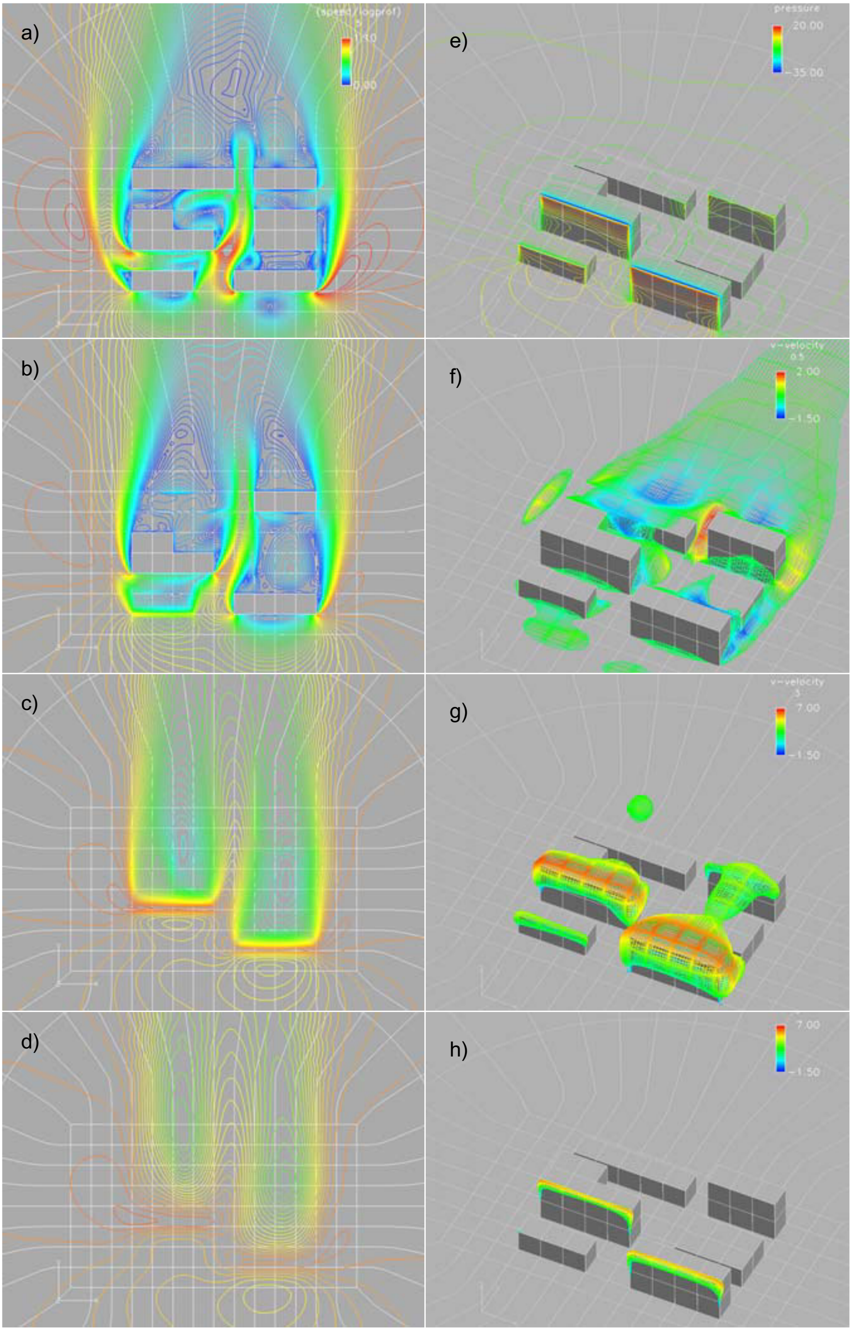

Fig. 5. *CASE4*: a)-d) *ac* plotted at z=5; 13.5; 28; 32m. In e) the static pressure distribution is plotted and f)-h) shows *tke* iso-surfaces (*tke*=0.5; 3; 6m^2/s^2) with velocity component v on them.

roof-level and 12% of two cubes height respectively and at 32m, which is 7m above second roof-level height and with that 28% of two cubes height. Especially in low regions high *ac* values are present. The plots do not show the actual velocity, but regions with velocities higher than 3m/s at 5m were found for an inflow velocity of $U_{log}(z\text{=}10\text{m})\text{=}4.9\text{m/s}$. 3m/s is a threshold value for many wind turbines to start electricity production. It is interesting to see in Fig. 3.2c) and d) how the region of high *ac* values broadens with increasing height. That might support the decision making of the wind turbine size. On the roof-top edge a horizontally orientated vertical axis wind turbine (VAWT) could be mounted, close to the roof-top with a smaller diameter than further away, where a bigger diameter might be chosen. Besides velocity, turbulence is a driver for a successful implementation of WTs. Fig. 3.2f)-h) depicts *tke* iso-surfaces. The highest *tke* values appear at areas where high pressure gradients are present. See Fig. 3.2e) for pressure distribution on the block surfaces.

4 Discussion

The tool is very useful to get an overview of the wind situation for certain building arrangements. Quantitative conclusions can then be obtained by exploring the areas of interest. General statements can be made like increased turbulence is present at areas of high pressure gradients, buildings higher than the mean height of an area, bear the potential of higher wind velocities, where buildings located in the wake of another building of the same height or below are facing increased turbulence and lowered wind velocities. The fact that the clusters were exposed to an undisturbed wind profile has to be kept in mind. If other buildings surround the quarter, a higher roughness length and a displacement height have to be considered for the inflow conditions. Furthermore, the results are representing the situation for only one wind direction. To predict the most favorable placing of a wind turbine, all directions have to be taken into account. The Reynolds Number independency is not verified for the showcases and therefore has to be assumed, but carefully.

5 Conclusion

Comparing the simulations of a single cube using the CFD tool with wind tunnel tests shows very good agreement. An important conclusion from this study is the independency of Reynolds Numbers on flow patterns around buildings. This means that despite of changing wind speeds the flow patterns are maintained. Using the tool for a certain configuration of buildings illustrates the methodology to analyze the wind energy potential on different positions on buildings to identify the most appropriate positions in terms of both wind energy potential and low fluctuations in the wind, i.e. low turbulence kinetic energy. With this information, future mounting of wind turbines in urban districts can be based on quantitative potentials rather than on qualitative estimations. The perspective for further development is to apply the local wind rose as inflow boundary conditions to obtain a more complement picture of the local average wind energy potential.

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Direction Dependent Power Curves for Wind Power Prediction: A Case Study

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Abstract. This paper describes the significance of empirical direction dependent power curves for wind power prediction at a wind farm site. The results, based on empirical studies, demonstrate that use of directional power curves for wind farm power prediction can lead to an accuracy improvement in the final power prediction of the wind farm. In general, the influence of wind direction on power output is less significant as compared with wind speed due to the fact that turbines are directed to face the wind during its operation. However, maximum wind power potential could not be achieved due to the specific site conditions and important factors like wake effects, environmental effects, hysteresis, and curtailments in the wind farms. Therefore, it is important to model the local conditions of the wind farm; directional power curves are one of the techniques to maximize the expected power production. This case study is based on real-world measurements from a selected wind farm site in Australia.

1 Introduction

The world is moving towards renewable energy sources such as wind and solar. In particular, wind energy is becoming the fastest growing energy technology in the world. It provides a clean and cheap opportunity for future power generation and many countries have started harnessing it [1]. However, the drawback is that wind is a highly fluctuating resource. The maximum penetration of wind power in electricity networks is limited by its intermittency. However, a large fraction of wind power can be absorbed in the electrical systems using an efficient prediction system. Hence, the value of the prediction is determined by it's accuracy. Accurate prediction of the wind turbine's power output is useful for generators, schedulers, transmission operators, network managers, and energy traders [2].

Different methods of wind power prediction are used now a days, see e.g., [3] and references therein. One method for the prediction of wind power is to predict the wind speed and covert it to the predicted wind power output by means of a power curve. The power curves (i.e., wind speed-power relation) can be modeled by means

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Fig. 1. Location of Woolnorth wind farm in Australia

of different methods based on either physical or statistical tools. However, another important factor in modeling the power curves is the selection of suitable data that could possibly influence the accuracy of prediction. Therefore, our focus is on data region for power curve modeling.

For example, the wind power generation is influenced by wind direction. In general, the influence of wind direction on power output is less significant as compared with wind speed due to the fact that turbines are directed to face the wind during its operation [4]. However, some power deviation may be observed based on the specific site conditions and general factors like wake effects, environmental effects, hysteresis, and curtailments associated with wind farms. Therefore, the need of new strategies is obvious in order to minimize the effect of well known factors and to get

Fig. 2. The Woolnorth wind farm at cliff

the maximum benefit from available wind potential. Hence we analyzed and tested the use of direction dependent power curves for wind power prediction.

As a case study, data from one turbine from Woolnorth wind farm site in Tasmania, Australia as shown in Fig. 1 has been analyzed and tested. A picture of the wind farm is also shown in Fig. 2. The wind farm is situated at a coastal site on a cliff which gives the site a very high wind resource with extreme variations [5].

2 An Overview of Existing Approaches

In general, some of the research models for wind power prediction are Kalman filter [6], autoregressive models [7], autoregressive moving average (ARMA) models [8], neural networks [9], and Grey predictor [10]. There are also some other hybrid approaches that combine the two models in order to join the advantages of both to improve the prediction. The persistence model is used as a benchmark model. The state-of-the-art nature of prediction models can be found in numerous publications, (see e.g. [11]). The outputs (i.e., speed and direction predictions) from these models may be utilized at the input of our direction dependent power curves to improve the prediction.

2.1 The Persistence Model

This is the simplest model also known as naive predictor. This model is presently an industry benchmark for very short-term wind power prediction. It assumes that the power at time step $t-1$ is the same as the power at time step t.

$$P_t = P_{t-1} \tag{1}$$

In other words, the persistence is based on the assumption of a high correlation between the present and future wind values.

2.2 Power Curve Model

The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds, i.e.,

$$\hat{P}_{out} = f(\hat{w}) \tag{2}$$

where $\hat{P}_{out}$ is the predicted wind power output based on predicted wind speed ($\hat{w}$). Normally a machine power curve is provided with a particular wind turbine to convert wind speed to wind power. In fact, this deterministic power curve is different from the empirical power curve obtained in the real operation at a wind farm [12], i.e., for a specific site the wind turbine will not perform in accordance with the manufacturer's power curve and such behavior should be learned from the data. Hence, only empirical PC's are being considered and focused in this study.

3 Proposed Approach

This brief case study is based on the use of direction dependent power curve models for wind power prediction using the predicted wind speed and direction from different models. The idea is to use the separate power curve models for each dominant wind direction at the given site to improve the prediction accuracy. The empirical modeling of the power curves for each direction sector is based on the historical measurements at that site using standard techniques. We analyzed the approach empirically using the inputs from different prediction models (i.e., persistence, Grey predictor, etc), with and without using the directional power curves to check the effectiveness of proposed idea. The analysis may be based on annual, seasonal and even on monthly basis provided that data for each determined direction sector is rich enough to represent the complete power curve relation for the given site. However, we presented the results based on annual data analysis.

4 Data Bases

The wind farm observation data used in this paper is measured at hub height at each of the 37 turbines in the Roaring 40s Woolnorth wind farm in Tasmania, Australia. The locations of individual 37 turbines are shown in Fig. 3. The data has a 10 min resolution for wind speed, wind direction and wind power and covers the calendar year 2006. The data is properly filtered by removing noise and any outliers.

5 Case Study Results and Discussion

In this case study, data from one turbine from a given wind farm site has been analyzed and tested. A detailed empirical study was carried out based on computer simulations. A wind rose showing the dominant directions at one of the turbines at Woolnorth for the calendar year 2006 is shown in Fig. 4. The corresponding power curves for two of the directions are shown in Fig. 5 where significant deviation in the power has been observed at the same wind speed for two direction regions. The power curves can be modeled using standard techniques [13] with the condition that the data for each defined direction sector should be rich enough to represent the complete speed and power relation. The number of direction sectors depends on the given site conditions. The idea is to use the separate power curves for dominant directions.

It has been observed that $1-2\%$ accuracy improvement in the power output could be achieved at the turbine level. The significance of this result, as applied on one turbine, is that our method may be employed in a wind farm to each turbine in order to achieve significant accuracy improvements for the entire wind farm output. The proposed method is compared with the persistence model (i.e. the benchmark model) with respect to the mean absolute percentage error.

In this study, some facts about the real data under study are not presented intentionally to avoid any commercial confidentiality issues. However, the presented methodology is straight forwarded and may be extended.

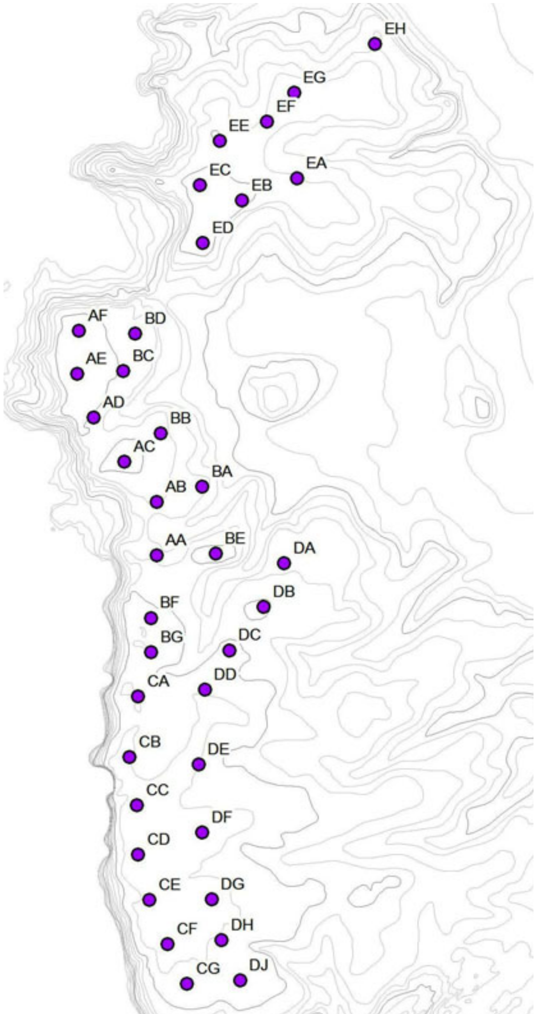

Fig. 3. The locations of individual turbines at Woolnorth

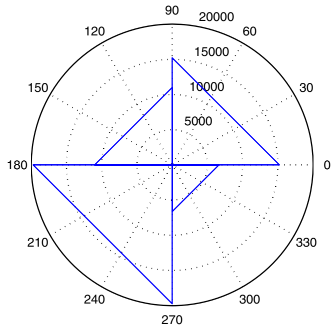

Fig. 4. Wind rose

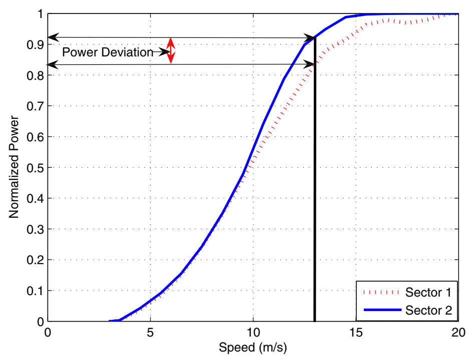

Fig. 5. Directional power curves

5.1 Conclusion and Future Work

The use of direction dependent power curves for wind power prediction has been analyzed in this paper. The benefits of the proposed approach for wind power prediction are based on the use of separate power curves for each dominant direction at the wind farm site, as distinct to only employing one average power curve. The analysis and simulation results demonstrate that a slight accuracy improvement can be achieved using the proposed approach. In addition, the use of directional power curves can minimize the effect of well known adverse factors associated with wind farms.

Indeed, the information of prediction uncertainty is required in order to optimize the performance of prediction-based decision making processes. Therefore, the detailed study of the robustness, uncertainty, and noise effects will be the focus of future study. We will apply methods and ideas of the modern robust state estimation theory; see e.g. [14, 15, 16].

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Tools and Techniques for Intelligent Characterization of Fuels

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Abstract. The on-going adoption of biofuels is presenting problems for automotive diesel engine systems, due to the differing mixture preparation and combustion properties of the widely varying fuel blends in the vehicle tank. Diesel engine management has improved enormously, yet it still relies largely on look-up tables and 'reactive' exhaust treatment technologies. 'Intelligent Fuel Characterization' facilitates a 'proactive' engine management role by gathering, processing and making available information about the precise fuel blend which is about to be combusted in the engine. The engine management system can then use this information to optimise engine system operating points for the exact blend of fuel. This paper introduces the concept of Intelligent Fuel Characterization and presents ideas for its implementation, including promising sensor and data analysis technologies.

1 Introduction

The state of the art in diesel engines

In recent years, there has been a strong drive for adoption of 'greener' diesel engine fuels, such as biodiesel and pure plant oil. However, this can present problems for current diesel engine management systems, due to the different physical, chemical and thermodynamic properties of these new fuels. Even mixtures of fuels, designed to reduce incompatibilities between engines and biofuels, don't completely solve the resulting poorer combustion.

Concurrently, there has been phenomenal progress in improving all aspects of automotive diesel engine performance. However, the basic principle of engine management has remained largely unchanged: the principal operating parameters are stored as look-up tables in memory, and closed-loop control systems provide further capacity for optimisation of output power and emissions. After the look-up tables, the engine management is providing a 'reactive' function, reacting to the results of recent combustion events. An in-depth guide to current practice in diesel engine management may be found in a fine book by Bosch [1].

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Intelligent Fuel Characterization

The novel principle in the proposed 'Intelligent Fuel Characterization' is that the engine management is given a more 'proactive' role, in addition to the existing reactive one. An intelligent system gathers information about the fuel which is about to be inducted and burned within the engine, and provides this information to the main engine management system. The engine management system may then make immediate adjustments to engine operating points to allow for the particular formulation of fuel in the fuel system, i.e.: 'fossil-fuel diesel', biodiesel, pure plant oil or mixtures thereof.

2 Fuel Parameters That Could Affect Combustion Quality

Three main categories of fuel are currently used in automotive diesel engines, as shown in Table 1. At the time of writing, even pure diesel fuel is allowed to contain up to 5% Fatty Acid Methyl Esters (FAME), which is the main component of biodiesel. FAME is typically produced by the chemical reaction of alcohols and sodium hydroxide with plant oils, to yield a more 'engine-friendly' fuel than the original pure plant oil. However, unmodified pure plant oil is also used by a minority of road users, some of whom run older engines which can cope with the more viscous oil without modification; other such users risk engine or injection system trouble by not modifying their fuel delivery system to cope with inherent deficiencies of pure plant oil.

It is clear that there is a widely varying range of possible fuel blends that may be in a diesel engine road vehicle at any given time, and that is the point of this project, which seeks to characterize and improve performance of such vehicles under today's conditions.

Table 1. Current Fuels for Diesel Engines

Fuel	Applicable Standard	Features
'Diesel' (Fossil) Fuel	EN590	<=5% Fatty Acid Methyl Ester (FAME)
Biodiesel	EN14214	>5% FAME
Pure Plant Oil	DIN v 51605:2006	Pure Vegetable Oils

For the purposes of this current project, pure plant oil is not being considered – the focus is on the effects of progressively changing from diesel to biodiesel only.

The effects of various fuels on diesel engine exhaust emissions have been well-documented, but often with widely varying results and conclusions; Lapuerta et al. have presented an exhaustive summary and statistical analysis of the increasingly weighty literature, thus allowing overall conclusions to be drawn, at least for changing from diesel to biodiesel [2]. Table 2 shows some of these conclusions, with the most significant results highlighted. It may be *generally* concluded that changing from diesel fuel to biodiesel causes increases in fuel consumption and NOx emissions, no change in thermal efficiency, and decreases in: output power and particulate, hydrocarbon and carbon monoxide emissions.

Table 2. Summary of Reported Effects of Changing from Diesel to Biodiesel (After: [2])

Changes in Parameters (Given a Change from Diesel->Biodiesel)	Numbers of Publications Citing Stated Results			
	Increases	Same*	Decreases	Synergies
Effective Power (Full Load)	-	2	**96**	2
Brake Specific Fuel Consumption	**98**	2	-	-
Thermal Efficiency	8	**80**	4	8
NOx Emissions	**85**	10	5	-
PM Emissions	3	2	**95**	-
THC Emissions	1	3	**95**	1
CO Emissions	2	7	**90**	1
Note: *Some references report that differing engine load and temperature operating conditions and the engine type can result in increases and decreases.				

The observed phenomena shown in Table 2 arise from the differing physical and chemical properties of the two fuels, as illustrated in Table 3. In this table, arguably the most significant, and hence most often discussed, property is ‘viscosity’. Pure plant oil and the derived biodiesel exhibit higher viscosities, hence thicker consistency, than diesel fuel. Needless-to-say, there is an infinitely variable continuum of mixtures, hence properties, of the two fuels in any given fuel tank.

Table 3. Ranges of Specifications of Fuels used in Lapuerta’s Reviewed Studies (After: [2])

Property	Units	Biodiesel Limits		Diesel Limits	
		Lower	*Upper*	*Lower*	*Upper*
Density @ 15°C	kg/m^3	870	895	810	860
Viscosity @ 40°C	cSt	3.5	5.5	2.0	3.5
Cetane Number	-	45	65	40	55
Cold Filter Plugging Point	°C	-5	10	-25	0
Cloud Point	°C	-5	10	-20	0
Pour Point	°C	-15	10	-35	0
Lower Heating Value	MJ/Kg	36.5	38.0	42.5	44.0
Water Content	mg/kg	0	500	-	-
Acid Number	mg KOH/g	0	0.60	-	-
Ester Content	% w/w	96	-	-	-
Glycerine Content	% w/w	0	0.25	-	-
Sulphur Content	mg/kg	-	-	15	500

3 New Sensor Technologies for Diesel Engines

This paper reveals the results of an extensive literature survey, in which a variety of different sensor and data analysis technologies have been investigated for possible use in the aforementioned application, given the usual cost-sensitivity of the automotive industry. Some of the sensors are also believed to be fairly new to mainstream automotive applications, therefore the paper also serves as a general guide to new sensor technologies for possible adoption by the automotive industry.

Industrial Viscosity Sensors

The term ‘viscosity’ refers to the friction existing internally within chemicals and it gives a metric of the resistance experienced when the molecules of the chemical are subjected to physical forces, [3]. Viscosity sensors and their measuring equipment are available commercially, such as the Sengenuity sensor [4]. This type of sensor is packaged in the form of a threaded bolt, designed to be screwed into the wall of the vessel containing the liquid test sample. Based on ‘crystal technology’, the sensor is readily available, has no moving parts, and is: shock, flow, immersion and vibration proof. It also appears to be a semi-intelligent device, regularly outputting a reading every second; also rugged enough for under-bonnet deployment, even if it is too expensive a solution for mass application. A picture may be seen on the Sengenuity website [4].

Fuel Viscosity Sensing using the Fuel Pump Current Profile

Where an electric fuel lift pump is fitted, the current waveform profile may yield information about the viscosity of the fuel in the line, using an experimental set-up similar to that shown in Figure 1. This technique, if successful, could be much cheaper and simpler than an industrial viscosity sensor. Conversely, this viscosity sensing technique may be susceptible to seasonal changes in viscosity due to temperature and variation in fuel additive packs; also, some diesel injection systems use mechanical instead of electrical pumps.

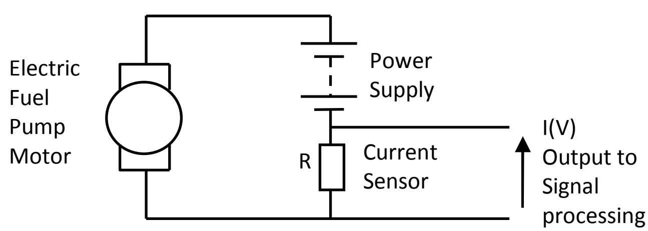

Fig. 1. Measurement of Viscosity using the Fuel Pump Current Profile

Concentration Sensors

A MicroElectroMechanical Systems concentration sensing chip device was originally conceived for methanol-water concentration monitoring in Direct Methanol Fuel Cell applications [5]. The sensor was also found to be suitable for other water-based solutions, and for distinguishing between gasoline, E85, diesel and biodiesel fuels. High-stress vibration and temperature operating conditions, commonly found in automotive applications, were found to be acceptable for the sensor. The technology was 'resonant microtube', with on-chip temperature sensor, for reliable density measurements – change in temperature produced a small linear change in the resonant frequency of the microtube. The response of the sensor was demonstrated to be very linear within operating limits, in the intended application. However, the technology was a laboratory prototype at the time of writing.

Gas/Vapour Sensors

Diesel fuel and biodiesel are organic compounds that liberate vapours which, to some degree, may be used to identify their constituents. Gas/vapour sensor technology is mature – there is a wide-range of packaged sensors available for specific, and ranges of, hydrocarbon gases and vapours. However, packaged sensors can be expensive or unavailable for the exact target gas/vapour in a given application. Unpackaged gas sensors for special purposes may be custom fabricated as thin/thick film devices but need specialist construction. Cosandey et al. [6] offers substantial information about implementation and applications for gas sensors.

Electronic Nose

The Electronic Nose is a logical progression from gas sensors in that several different gas sensors are concurrently used to perform chemical analysis of a sample which is in the gaseous/vapour phase. An Electronic Nose comprises of: a sample delivery system (gas handling system), a detection system (gas sensor array), and a computing system (often principal component analysis or a neural network). The principle is often compared with Gas Chromatography. The benefits of many gas sensors and linked intelligence are combined into one system, but the resulting system is rather complex; in addition, sensor temperature, sample gas temperature and flow rate / mixing must be well-controlled for consistent results [7].

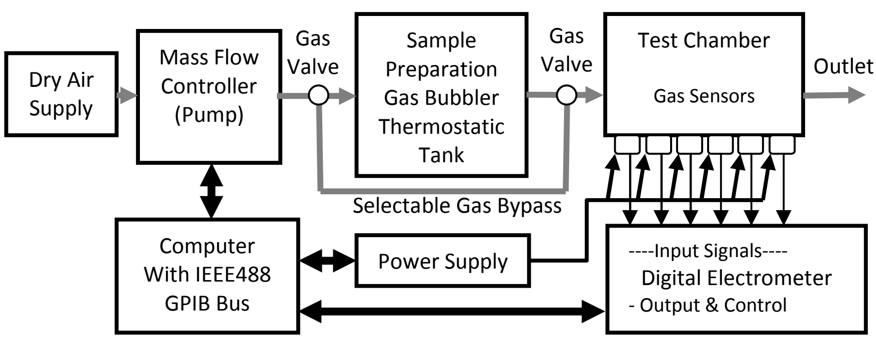

Fig. 2. Implementation of an Electronic Nose (After: [7])

Electronic Tongue

The Electronic Tongue operates in a similar fashion to an Electronic Nose but the sensor array is in direct contact with a *liquid-phase* chemical test sample. Suggested applications are usually in the food and beverage industries, yet there is no reason why a non-human tongue cannot be used to taste dangerous or unpalatable fluids, as in the current application. There are similar benefits to those of the Electronic Nose, with less sample delivery problems. Conversely, there are still similar temperature and mixing requirements to those of the Electronic Nose. A 'flow-through' Electronic Tongue may be implemented [8], which may lend itself to the current application. Figure 3 shows the working principle of an electronic tongue.

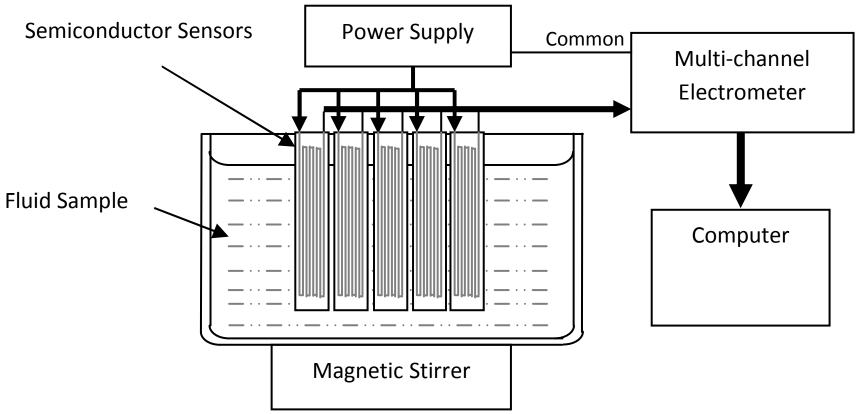

Fig. 3. Operating Principle of an Electronic Tongue

Electrical Impedance Tests

There are a few papers available under this heading; the Electrochemical Impedance Spectroscopy of Ulrich et al. is a good example, in a related field of application: simultaneous estimation of soot and diesel contamination in engine oil [9]. It was found that soot affects entire test frequency band whereas diesel affects low frequencies only. Some electrical impedance tests are quite straightforward, in principle; however, operating temperature is a consideration and bulky laboratory-precision equipment, with complex electro-magnetic compatibility arrangements tends to be specified – which could be difficult to implement in vehicle. The liquid sample shown in Figure 4 was actually 0.2mm thick, which could be difficult to maintain in a clean state in a fuel system.

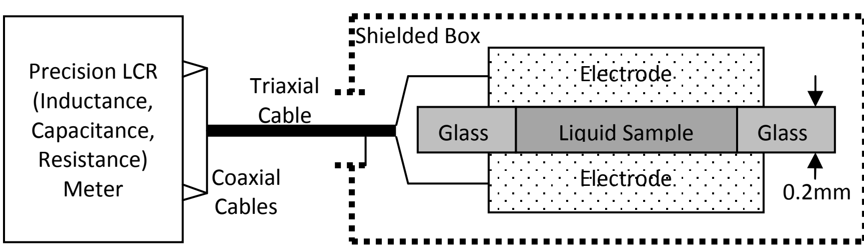

Fig. 4. Electrochemical Impedance Spectroscopy (After: [9])

Fibre Optic Sensor

The Fibre Optic sensor shown in Figure 5 was used to determine the degree of adulteration of petrol and diesel by kerosene [10]. Adulteration of the base fuel caused a change in the refractive index and evanescent wave absorption in samples. The technique had stated advantages of: simplicity, safety, and sensitivity, whilst being possible to implement as a compact test system. On the downside, cost might be an issue on mass vehicle application.

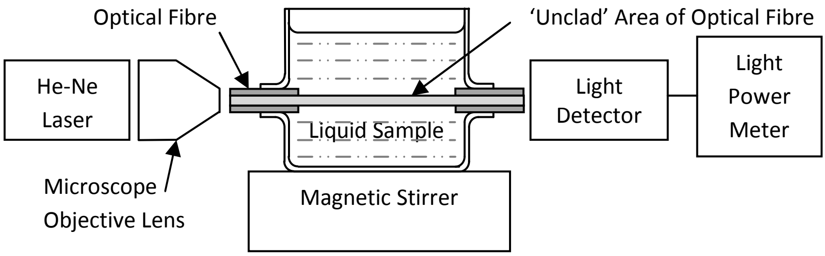

Fig. 5. Fibre-optic Sensor (After: [10])

4 Analysis and Fusion of Complex Data

Principal Component Analysis

Principal Component Analysis is the rotation and scaling of data to reduce the dimensionality of data. The result is enhanced visualisation and simplification of complex data, both for human and computer interpretation; the relative importance

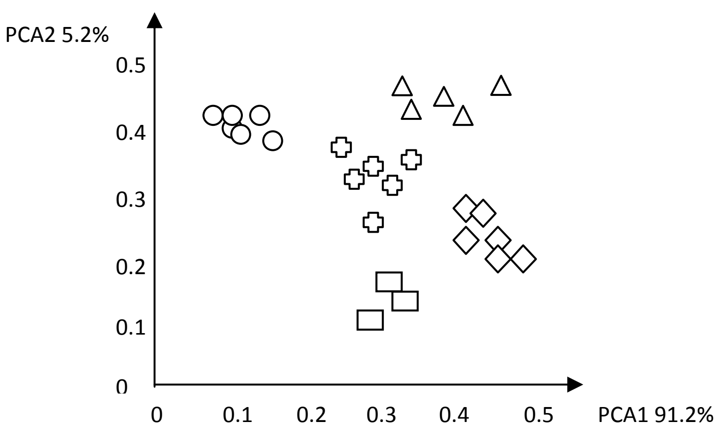

Fig. 6. A Simulation of PCA in Action

of the simplified data is also stated. There are few disadvantages to the use of PCA, apart from the obvious loss of some data which was arguably not required anyway. Figure 6 shows a simulation of PCA in action, where the first two principal components would have been extracted from complex multi-dimensional data; the displayed two dimensions are responsible for 91.2% and 5.2% of the variation in the complex data, and the 'useful' five data clusters may now be clearly seen in just two dimensions.

Data Processing and Fusion by Neural Network

A neural network can perform a highly useful reduction of dimensionality in electronic nose and tongue systems, which inherently produce multi-dimensional data. In addition, other sensors may contribute information by way of data fusion, i.e. adding data from other sensors to extra inputs to the neural network. The neural network can effectively add 'intelligence' to sensing systems by undertaking a decision-making process which automatically reduces dimensionality of the input data. For safety-critical operation, neural networks are not generally suitable due to their operation in high-dimensional feature space; this is because their operation can only be visualised if dimensionality of input is less than, or equal to, three dimensions. Figure 7 depicts the architecture of the most commonly encountered type of neural network: a Multi-Layer Perceptron, [11], [12].

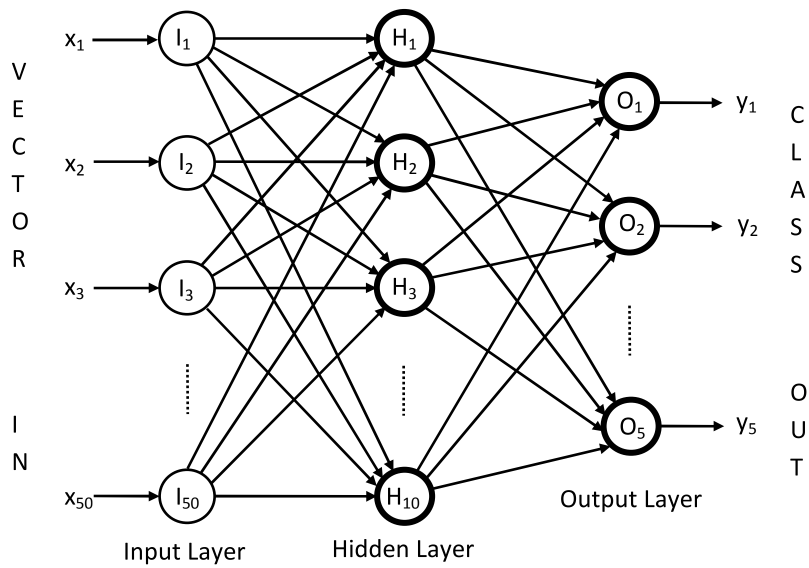

Fig. 7. A Multi-Layer Perceptron Neural Network (After: [11], [12])

5 Implementation

In respect of implementation of Intelligent Fuel Characterization, three questions need to be answered: (1) Which sensor(s), (2) Which fuel delivery method, and (3) Which signal processing to use?

Experimental work has commenced and sensors are being evaluated, initially as separate data sources. On completion of this phase of the work, the need for data processing, and data fusion, as applicable, will be investigated. The choice of sensor(s) is expected to determine the fuel sample delivery method, to a large extent. The sensor(s) could be contained in a chamber in the fuel line or built into the fuel tank for measurement of the bulk fuel properties; either way there may be maintenance issues, depending on the sensor(s) used. Figure 8 depicts a possible Intelligent Fuel Characterization system employing data fusion in combination with three sensor groups.

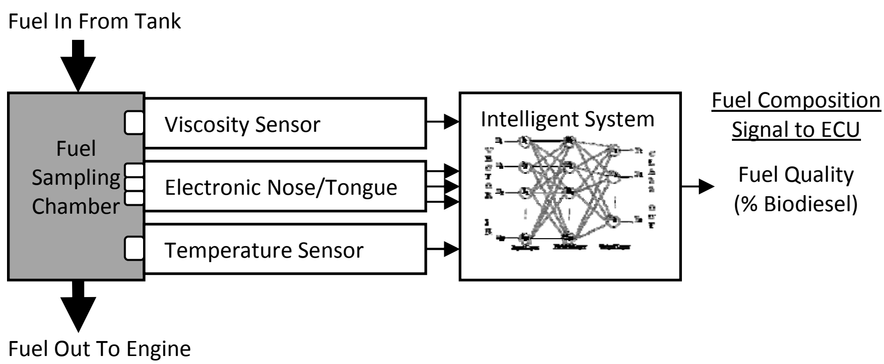

Fig. 8. A Possible Intelligent Fuel Characterization System

6 Conclusions

- This paper has introduced the concept of Intelligent Fuel Characterization; a means by which an internal combustion engine may be made aware of the physical and chemical properties of the fuel that it is about to combust.
- A range of potentially suitable modern sensor and data analysis technologies for this application have been briefly described.
- A future paper will present results of evaluation experiments which are being undertaken.

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Use of Super-Capacitor to Enhance Charging Performance of Stand-Alone Solar PV System

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Abstract. The battery charging performance in a stand-alone solar PV system affects the PV system efficiency and the load operating time. The New Energy Center of National Taiwan University has been devoted to the development of a PWM charging technique to continue charging the lead-acid battery after the overcharge point to increase the battery storage capacity by more than 10%. The present study intends to use the super-capacitor to further increase the charge capacity before the overcharge point of the battery. The super-capacitor is connected in parallel to the lead-acid battery. This will reduce the overall charging impedance during the charge and increase the charging current, especially in sunny weather. A system dynamics model of the lead-acid battery and super-capacitor was derived and the control system simulation was carried out to predict the charging performance for various weathers. It shows that the overall battery impedance decreases and charging power increases with increasing solar radiation. An outdoor comparative test for two identical PV systems with and without super-capacitor was carried out. The use of super-capacitor is shown to be able to increase the lead-acid charging capacity by more than 25% at sunny weather and 10% in cloudy weather.

Keywords: stand-alone solar PV power; solar charging; battery charging; super-capacitor charging.

1 Introduction

The battery charging performance in a stand-alone solar PV system affects the PV system efficiency and the load operating time. New Energy Center at National Taiwan University has been devoted to the development of a PWM charging technique to continue charging the lead-acid battery after the overcharge point to increase the battery charge capacity [1]. The present study intends to use the super-capacitor to further increase the charge capacity before the overcharge point of the lead-acid battery. The super-capacitor is connected in parallel to the lead-acid battery. This will reduce the overall charging impedance during the charge and increase the charging current, especially in clear weather. A charge control system (Figure 1) is thus developed and tested outdoor.

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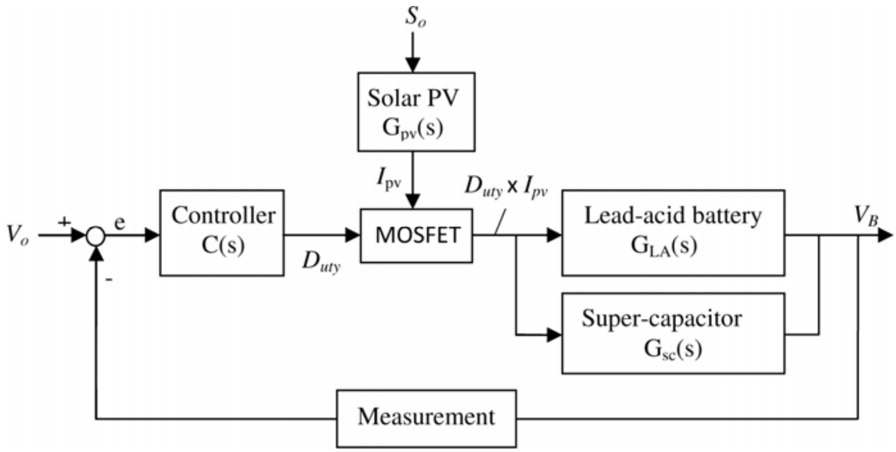

Fig. 1. Solar charging control system

2 System Dynamic Model of Super-Capacitor and Lead-Acid Battery

In order to design a feedback control system for solar charging control with lead-acid and super-capacitor batteries in parallel, the system dynamic model of super-capacitor and lead-acid batteries have to be determined first. In the present study, the size of the lead-acid battery used is 100Ah/12V and the super-capacitor is 120F/2.3V.

Derivation of System Dynamic Model of Super-Capacitor

The electrical performance of a super-capacitor is equivalent to a capacitor connected in series to a resistor. The system dynamic model of super-capacitor thus can be written as

$$\frac{V_{sc}(s)}{I_{sc}(s)} \equiv G_{sc}(s) = k_1 + \frac{k_2}{s} \tag{1}$$

The time response of super-capacitor voltage $v_{sc}(t)$ can be derived as:

$$v_{sc}(t) = k_1 i_{sc}(t) + k_2 \int i_{sc}(t)dt \tag{2}$$

$$\frac{dv_{sc}(t)}{dt} = k_1 \frac{di_{sc}(t)}{dt} + k_2 i_{sc}(t) \tag{3}$$

By inputting a step current to the super-capacitor and measuring the voltage time response $v_{sc}(t)$, the parameters k_1 and k_2 can be determined. The capacity of the super-capacitor is 0.077Ah. Figure 2 shows the time response of voltage under the step inputs of 1C current (0.077A) and 2C current (0.154A). Right after step current input, $di_{sc}(t)/dt=0$, and eqn(3) can be rewritten as

$$k_2 = \frac{1}{i_{sc}(t)} \frac{dv_{sc}(t)}{dt} \tag{4}$$

Therefore, k_2 can be determined from the magnitude of step current and the voltage response slope. Table 1 shows the results.

Table 1. Dynamic test results of super-capacitor

Step current, A	$dv_{sc}(t)/dt$, V/s	k_2
1C (0.077A)	0.00067	0.0087
10C (0.77A)	0.00562	0.0072
average		0.0080

The parameter k_1 can be determined from the initial condition of the step response test. From eqn(2), at $t=0^+$, the integral part is still zero and

$$v_{sc}(0^+) = k_1 i_{sc}(0^+) \ \ or \ \ k_1 = \frac{v_{sc}(0^+)}{i_{sc}(0^+)} \tag{5}$$

Table 2 presents the determination of k_1 from the test results.

Table 2. Determination of k1

Current step size	Voltage jump, V	k_1
1C→ 2C	0.039	0.51
2C→ 1C	0.036	0.47
1C→ 3C	0.065	0.43
3C→ 1C	0.063	0.40
average		0.45

The system dynamics model of the super-capacitor is then derived as, using the average values of k_1 and k_2 :

$$G_{sc}(s) = 0.45 + \frac{0.08}{s} \tag{6}$$

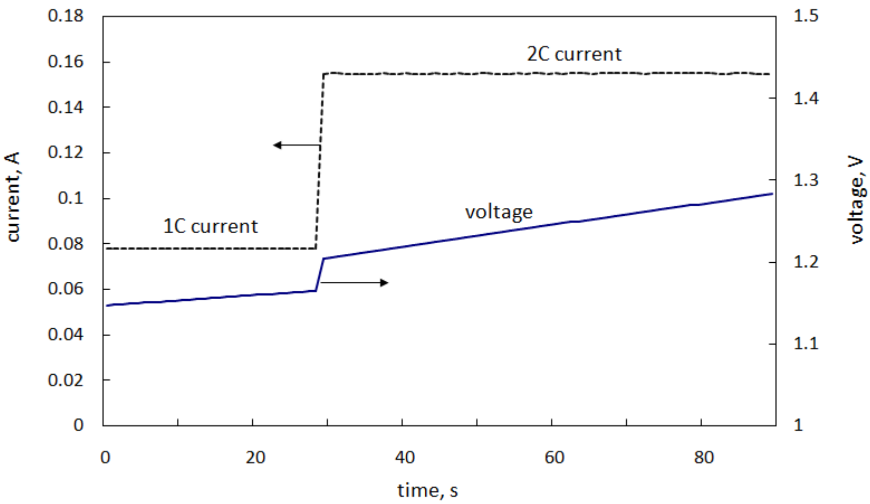

Fig. 2. Voltage time response under step inputs of current

Derivation of System Dynamic Model of Lead-acid Battery

The derivation of the system dynamics model of the lead-acid battery follows the same method described in [1]. For the lead-acid battery (Pilot, 12V/100Ah) used in the present study, the system dynamics model is derived as

$$\frac{V_{LA}(s)}{I_{LA}(s)} \equiv G_{LA}(s) = \frac{2.6861}{s + 3.5693} \tag{7}$$

3 Design of Solar Charging Control System

To charge the battery to its full capacity, a three-stage charge algorithm can be utilized (Figure 3). Phase 1 is to directly charge the battery from solar PV until the battery voltage reaches its overcharge point. Usually, the battery is charged in full load without controlling the charging current in Phase 1. Thus, only 50~80% state of charge (SOC) can be achieved at Phase 1. Phase 2 is to maintain the battery voltage at the fixed overcharge point to replenish the remaining capacity. Phase 3 is to reduce the charge voltage to avoid overcharge and maintain 100% SOC for the battery. In both Phase 2 and Phase 3 the charging current generated from PV needs to be reduced in order to maintain at a set voltage. A feedback control system based on the system dynamics model of battery (Figure 4) was developed using pulse width modulation (PWM) technique to control the charging current from PV in Phase 2 and Phase 3 [1]. The system dynamics model for the lead-acid battery connected in parallel to the super-capacitor ($V_{LA}=V_{sc}$) is

$$\frac{V_B(s)}{I_B(s)} \equiv G_{bat}(s) = G_{LA}(s) + G_{sc}(s) \tag{8}$$

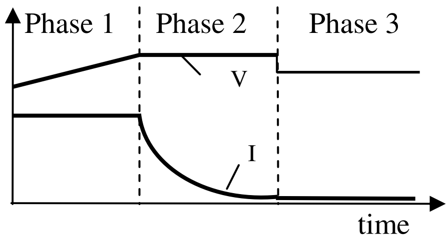

Fig. 3. Battery charging process

The PI controller was used in the present study. The control system will switch to the PWM mode when the battery reaches overcharge point (Phase 2 and Phase 3). During Phase 1, the feedback system sets the PWM duty cycle as 1.0 to charge the battery in full speed. The controller design for the lead-acid battery using SIMULINK simulation results in the following results:

$$C(s) = 9\left(1+\frac{1}{s}\right) \tag{9}$$

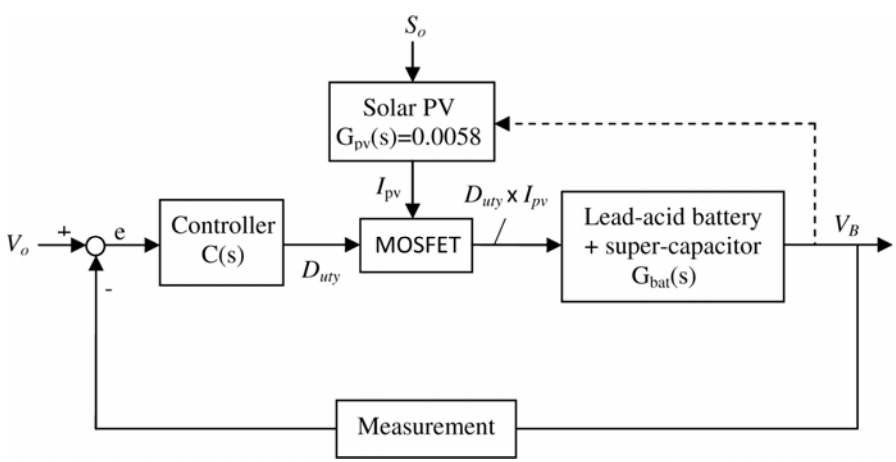

Fig. 4. Feedback control system based on the system dynamics model of battery

The control system was developed using the microprocessor PIC16F877A. The overcharge point is set at 14V and the lowest discharge voltage is set at 11V. The discharge power to LED for lighting starts at 18:30PM until the lowest discharge voltage reaches.

4 Outdoor Performance Test of Solar Charging System

Two solar PV modules (MSX-60) and a 25W LED lighting fixture were installed in a solar charging system for the long-term outdoor test of solar charging performance with and without super-capacitor. The super-capacitor used in the solar charging system consists of seven super-capacitors with 120F/2.3V each connected in series. The system dynamics model then becomes

$$G_{sc}(s) = \frac{1}{n}\left(0.45 + \frac{0.08}{s}\right) \tag{10}$$

Where n is the number of super-capacitor connected in series, (n=7 in the present study).

Two identical solar PV systems (with 25W LED) were installed at the same location to compare the performance. First of all, the control system simulation results using SIMULINK are compared with the test results and shows very small errors as shown in Table 3.

Table 3. Comparison of simulation and outdoor test results

Date (2009)	4/23	4/15	4/14	4/17
Daily total solar irradiation (MJ/m^2)	13	10.8	4.9	2.6
weather	sunny	sunny with cloud	cloudy	rainy
	daily total charged energy (Wh)			
simulation	399.3	296.6	162.9	77.1
outdoor test results	392.5	293.9	156.9	72.9
Simulation error (%)	1.7	0.9	3.7	5.4

The outdoor test has shown that the use of super-capacitor in parallel connection with the lead-acid battery can increase about 25% battery charge capacity in sunny days and more than 10% in cloudy days, as shown in Table 4. All the test results show that the lead-acid battery without super-capacitor operates mostly in Phase 1, before the overcharge point (14V), usually 13.8V at most, since the charging power is relatively lower without the aid of super-capacitor. The state of charge (SOC) of the lead-acid battery is always lower than 80%. For PV system with super-capacitor, the operation of lead-acid battery will easily lie in Phase 2 and the PWM charging control [1] is activated. In this case, the SOC is always higher than 80%. This is due to the fact that the use of super-capacitor will move the lead-acid battery operating line closer to the MPP (maximum power point) of the solar PV (Figure 5) which creates a larger power generation.

Table 5 shows the internal resistance and charging power of the lead-acid battery at different time. At 12PM, the internal resistance of the lead-acid battery reaches the lowest (3.21Ω) for the solar system with super-capacitor, while it becomes 4.93Ω for the system without super-capacitor, about 35% higher. Figure 6 presents the instantaneous solar radiation variation on 2009/4/23. It shows that around 12PM, there is a time variation of solar radiation which will cause the super-capacitor to become a temporary energy storage device at the instants of high radiation when the lead-acid battery is not able to be charged at high power due to internal resistance. This stored energy in super-capacitor is then released during the low solar radiation periods to charge the lead-acid battery. This explains the increase of charged energy due to the use of super-capacitor.

Table 4. Outdoor performance test under various weather

Date (2009)	4/23	4/15	4/14	4/17
Daily total solar irradiation (MJ/m^2)	13	10.8	4.9	2.6
weather	sunny	Sunny with cloud	cloudy	rainy
Simulation results of daily total charged energy (Wh)				
System with super-capacitor	399.3	296.6	162.9	77.1
System without super-capacitor	331.3	261.8	143.5	81.8
Increase of charge (%)	20.5	11.0	13.6	-5.7
Outdoor test results of daily total charged energy (Wh)				
System with super-capacitor	392.5	293.9	156.9	72.9
System without super-capacitor	315.2	257.0	140.8	79.8
Increase of charge (%)	24.5	14.4	11.4	-8.5

Table 5. Internal resistance and charging power of lead-acid battery at different time

system time (4/23)	With super-capacitor		Without super-capacitor	
	LA battery resistance (Ω)	Charging power (W)	LA battery resistance (Ω)	Charging power (W)
8AM	9.99	17.4	11.53	14.2
10AM	6.30	28.6	6.98	24.7
12PM	3.21	59.1	4.93	35.9

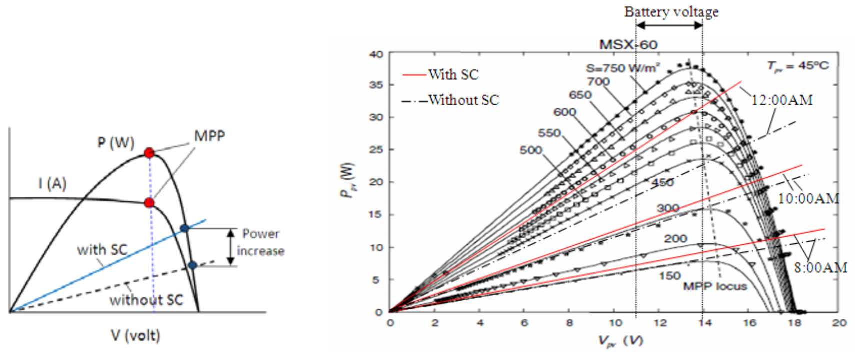

Fig. 5. Operating line of lead-acid battery with and without super-capacitor

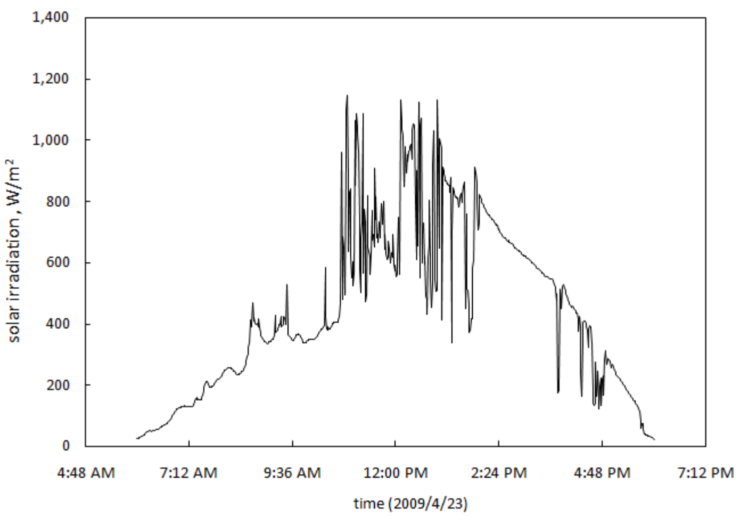

Fig. 6. Variation of solar radiation on 2009/4/23

5 Conclusion

The battery charging performance in a stand-alone solar PV system affects the PV system efficiency and the load operating time. The New Energy Center of National Taiwan University has been devoted to the development of a PWM charging technique to continue charging the lead-acid battery after the overcharge point to increase the battery storage capacity by more than 10%. The present study intends to use the super-capacitor to further increase the charge capacity before the overcharge point of the battery. The super-capacitor is connected in parallel to the lead-acid battery. This will reduce the overall charging impedance during the charge and increase the charging current, especially in sunny weather. A system dynamics model of the lead-acid battery and super-capacitor was derived and the control system simulation was carried out to predict the charging performance for various weathers. It shows that the overall battery impedance decreases and charging power increases with increasing solar radiation. An outdoor comparative test for two identical PV systems with and without super-capacitor was carried out. The use of super-capacitor is shown to be able to increase the lead-acid charging capacity by more than 25% at sunny weather and 10% in cloudy weather. For PV system with super-capacitor, the operation of lead-acid battery will easily lie in Phase 2 and the PWM charging control is activated. In this case, the SOC is always higher than 80%. This is due to the fact that the use of super-capacitor will move the lead-acid battery operating line closer to the MPP (maximum power point) of the solar PV which creates a larger power generation. In addition, the time variation of solar radiation will cause the super-capacitor to become a temporary energy storage device at the instants of high radiation when the lead-acid battery is not able to be charged at high power. This stored energy is then released during the low solar radiation periods to charge the lead-acid battery. More research is needed to clarify how to design a proper super-capacitor to best mach the solar PV system.

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Nomenclatures

i_{sc}	current through super-capacitor, A
v_{sc}	voltage across super-capacitor, V
s	Laplace transform variable, complex variable
v_{sc}	voltage across super-capacitor, V
I_{pv}	solar PV current, A
V_{pv}	voltage across solar PV, V
V_B	voltage across the battery, V
V_o	overcharge point of lead-acid battery, V
$I_{sc}(s)$	Laplace transform of super-capacitor current
$V_{sc}(s)$	Laplace transform of super-capacitor voltage
$I_{LA}(s)$	Laplace transform of lead-acid battery current
$V_{LA}(s)$	Laplace transform of lead-acid battery current
$G_{sc}(s)$	transfer model of super-capacitor
$G_{LA}(s)$	transfer model of lead-acid battery
$G_B(s)$	transfer model of battery bank in solar PV system

Displacement of Conventional Domestic Energy Demands by Electricity: Implications for the Distribution Network

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Abstract. Using off-peak electricity for domestic loads instead of burning fuel can reduce CO_2 emissions. Two loads are considered: electric vehicles, which displace petrol and diesel, and electric space and water heating, which displaces natural gas.

The paper uses experimental evidence based on case studies, together with estimates based on existing information, to calculate the extra electricity demand which might result from changing to electricity. The resulting figures are used to estimate how much demand could be met without reinforcement of the distribution infrastructure, and what reinforcement might be needed if all the demand is to be met by electricity.

It is shown that charging of electric vehicles can be accommodated, in most cases without reinforcement of the distribution network. However, electric domestic space and water heating would require reinforcement, unless very stringent efficiency improvements can be achieved.

1 Introduction

With an increasing proportion of electricity coming from renewable and from other low-carbon-dioxide sources, probably including nuclear in the future, it becomes attractive to look for a displacement of existing energy-consuming activities, both in the home and for activities associated with the home, away from fossil fuel burning appliances and towards electricity. However, this can be justified only if the increased electrical load is genuinely met from low-CO_2 sources. In practice, this probably means using as large a proportion as possible of the 'new' loads at night, using base-load generation. This paper will look at the implications of such a policy, not for the generation of electricity, but for the final stage of distribution to the consumer. Two aspects will be considered, electric vehicles and electric space and water heating. These are chosen as being, at present, the two most significant home-based activities which are fossil-fuel based.

2 Electric Vehicles

Although biofuels, and especially biodiesel, are becoming important in some markets, there is a limited amount of recyclate feedstocks such as waste frying oil, and

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the production of new feedstocks involves the displacement of arable land from food production to fuel production. Hydrogen has been proposed as an alternative to hydrocarbons, for spark-ignition engines and for fuel cells, but fuel storage as a compressed gas is potentially dangerous, and storage as a cryogenic liquid, though easy on a large scale, is difficult on a small scale because of surface-to-volume considerations. Moreover, whatever their fuel, fuel-burning engines suffer from the limitations of the second law of thermodynamics, so their efficiency is inevitably poor unless they can be combined with a use for the waste heat, which is difficult in a vehicle except for the relatively small heat requirement of warming the car and demisting the windows. There is thus an obvious advantage in moving away from fuels and towards electricity.

To begin, we must try to put a figure on the energy requirements of a typical electric private car. There are at present almost no hard figures available. Recently [1,2] a project has begun in the West Midlands to discover the pattern of use and the energy consumption of electric cars, which may provide reliable figures in the reasonably near future. For this paper, however, we need a way of getting an estimate.

The present author has been fortunate to have a rough estimate from a neighbour in Lichfield, Staffordshire, who has a Citroen Berlingo Electrique van. His typical uses are for short runs around the West Midlands, the largest distance being a trip to Birmingham, a round trip of perhaps 35 miles. According to this owner, the charging takes typically 3-4 hours overnight at 2 kW, making a daily requirement of only 6-8 kWh per day. For owners living in metropolitan areas, this relatively small figure may well be typical.

To get a more generally applicable estimate, we can use figures for the annual mileage of cars. In the USA this figure (for the year 2007) is 12,334 miles per year [3], while the figure for the UK is probably a little less, at about 10,000 miles per year. To convert that into fuel, we need a miles-per-litre figure. That does of course depend on the nature of the vehicle and of the terrain in which it is used. The author's own car does about 10 miles per litre of petrol. For the UK average of 10,000 miles at 10 miles per litre, we get 1000 litres per year. With a density of 0.7 kg per litre [4] (the figure for *n*-octane) we get 700 kg per year. To convert this to kilowatt-hours we can use a conversion figure of 1 tonne of oil = 12,000 kWh [5] so 700 kg = 8400 kWh. An alternative, and higher, conversion figure can be obtained from the higher (or gross) calorific value of petrol, given [6] as 48 MJ/kg. This leads to a conversion figure of 700 kg = 9300 kWh, but it must be borne in mind that the higher calorific value assumes use of the latent heat of condensation, which is not likely in a petrol engine. As a compromise, we shall assume an effective conversion figure of 700 kg = 9000 kWh. However, we also need to allow for the fuel efficiency of the car at the point of use. A typical petrol engine probably reaches no more than 20% efficiency, while an electric car might be expected to reach 80% efficiency. Assuming those two figures to be accurate (which is not by any means certain), an electric car is some 4 times as efficient at point of use as a petrol car. That reduces the annual requirement for 10,000 miles per year to 2250 kWh. If we now assume that the car is used 4.5 days a week for 50 weeks of the year, that is 225 days a year, we get 10 kWh per day. That is not too much greater than the figure for the Berlingo van that we looked at above.

It appears, therefore, that an *average* night-time charging requirement of about 10 kWh per night is a reasonable estimate for the average domestic vehicle.

3 Electric Space and Water Heating

Space heating in the UK accounts for some 58% of all domestic *energy* use [7], and water heating for a further approximately 15% (see figure 1). Getting figures for the *power* needed to heat a 'typical' household is more difficult, as it is very sensitive to weather and to occupancy. However, figures obtained by Sernhed [8] for houses in Lund, in southern Sweden, indicate heating consumption of between 2 and 5 kW over a 24 hour period, see figure 2.

If this is regarded as reasonable, we would need to have energy available of between 48 and 120 kWh for each day of 24 hours. Sweden, even in the south, is of course colder in winter than most of the UK, but the houses there are usually better insulated, so the Swedish figures may be at least reasonably applicable to houses in the UK.

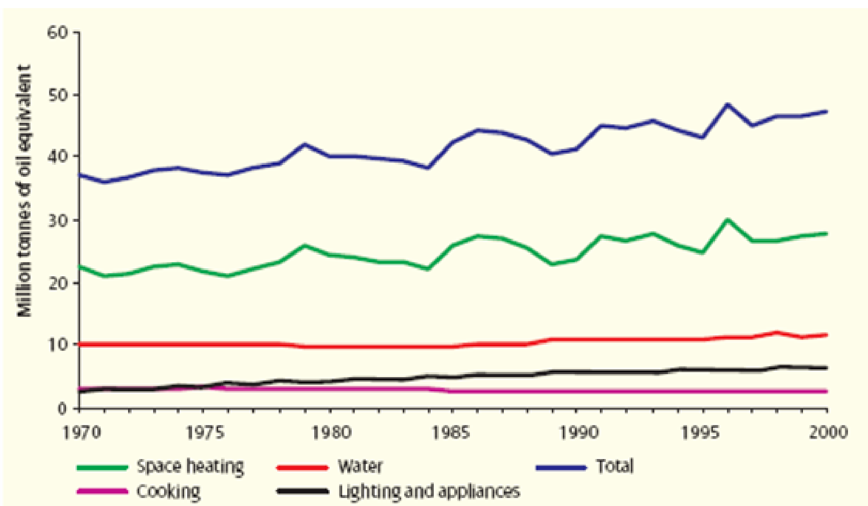

Fig. 1. Domestic final energy consumption. Measurements from Building Research Establishment, original diagram from UK DTI, Energy Consumption in the United Kingdom.

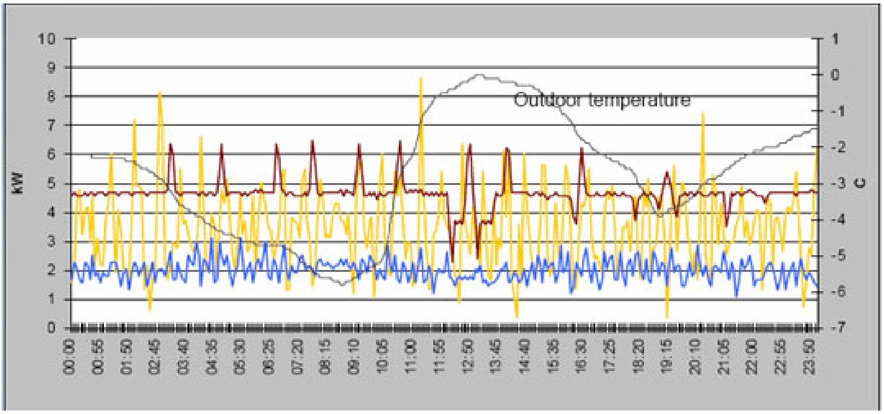

Fig. 2. Power consumption of houses in Lund, Sweden. Diagram from Kerstin Sernhed, Household load patterns and peak load problems, EEDAL 06.

4 Existing Supply Infrastructure

The electric power distribution system is installed on the assumption of *diversity* of demand, that is, not all loads in each house, and not all loads in a group of houses, will be at their maximum at any one time. The diversity factor is defined as the ratio of the sum of the individual maximum demands of the various parts of a power distribution system to the maximum demand of the whole system. The diversity factor is always greater than unity. However, a commonly used figure is the demand factor, defined as the ratio of the maximum demand of a building for electric power to the total connected load. This is always less than unity. Either way, the result is that there is no need to install capacity sufficient to meet the total load of a house.

In typical suburban housing developments in the UK, it has been customary to install enough distribution capacity to supply an average of 2 kW to each house. Of course, the maximum demand will be significantly greater, and the usual domestic fuse rating is 40 amps, which equates to about 10 kW. But the 2 kW average figure is usually found to be adequate except where a new development has electric heating, which is quite unusual in this country, though it is common in Scandinavia.

We can see the effect of this policy in the way the popular media cover renewable energy projects. A wind power project is described as ‘enough to supply 10,000 homes’. The technical media, covering the same project, might describe it as having a rated output of 20 MW. Clearly, the ‘Home’ is a unit of power equal to 2 kW. This relationship may well be derived from the figure of 2 kW used for the diversified demand of a residential development.

It must be noted that older residential areas in the UK, up to perhaps the early 1960s, were cabled at the much lower level of 1 kW per house. The extent to which this older practice is still extant is not known.

5 Supplying New Loads

At night in the UK a typical house probably has almost zero electricity consumption. Even if heating is kept on at night, this is typically fired with natural gas or oil, so the only electrical loads are the pump and boiler, which are very small. Thus the whole of the 2kW average demand is potentially available to supply new loads. And at night, only the most efficient and lowest cost power stations are on load, which hopefully may also be the ones with the lowest CO_2 emissions, such as nuclear and wind power sources. The power industry has recognised for more than 40 years the desirability of encouraging the use of this off-peak availability. Numerous preferential tariffs are available, the most widely known of which is 'Economy 7', which provides for 7 hours of low-price electricity from about 2300 to 0600 or midnight to 0700. To give some idea of the financial benefit available, the Scottish Power (formerly Manweb) tariff in North Wales is 4.839 p/kWh at night rate and 12.195 p/kWh at day rate, that is, night rate is 40% of day rate. These prices pertain to the latter part of 2009.

We noted earlier that the charging requirements of electric cars are around 10 kWh per night. With a 7-hour charging period, this averages to 1.4 kW, well within the 2 kW capacity of the typical suburban distribution network. Moreover, there is a considerable margin for error, so even if the earlier estimates of charging requirements are low, the new load of electric cars can easily be accommodated.

More problematic is the requirement for space and water heating. We have noted earlier that the requirement is between 48 and 120 kWh per day. If this is to be stored during the off-peak period of 7 hours, this would make for an off-peak load of between 7 and 17 kW. That is well in excess of the 2 kW available.

In order to make electric heating a widespread replacement for natural gas, we could look at supplying the energy over 24 hours, as it is required, rather than by overnight storage. That is unlikely to be realistic, as the demand is likely to be very 'peaky' with peaks in the early morning and in the early evening, as that is when people in this country turn on their heating. More likely is the use of thermal storage, not as a means of using night-rate electricity, but as a means of peak-lopping. If that is done, the lower figure for heat requirement of 48 kWh is just about met by a constant load of 2 kW.

What would such a heating system look like? Domestic heating in the UK is dominated by hydronic systems with pipes and radiators. Any replacement heating must continue to look and feel like the present one if it is to be accepted. The most likely replacement would use the existing pipes and radiators, supplied by an enlarged version of the ordinary hot water storage tank, heated by immersion heaters. Such equipment already exists for supplying hot water from stored overnight electric heat. However, it tends to be large. A thermal store of around 450 litres occupies a cupboard of 700 x 700 x 2500 mm [9]. Such a store, if filled with 450 litres (450 kg) of water with a specific heat of 4.18 J $g^{-1}\ {}^{0}C^{-1}$ used over the range 90 - 60 ^{o}C (30 ^{0}C range), can supply 450 x 30 x 4.18 = 56430 kJ of heat, equivalent to 15.7 kWh , which is nowhere near the 48-120 kWh per day which space heating appears to need.

Instead of water, a thermal storage substance is needed. In the 1960s a number of thermal storage heating units were manufactured using refractory bricks as the storage element. Most of these went on to supply hot *air* rather than hot water to heat the house. Although perfectly satisfactory as a means of heating, this is likely to face resistance from UK households used to hydronic heating. Some hot brick storage units were made with a heat exchanger to heat water, so meeting that requirement. As an alternative, it might be possible to use a substance which melts at a suitable temperature, and which stores heat in the latent heat of melting. Suitable substances can be either ordinary chemicals such as magnesium nitrate, melting point 95 ^{0}C [10], or specially formulated substances such as ethylenediammonium ditetramethoxyborate [11], melting point 78 ^{0}C.

Another possible approach is to use heat pumps rather than direct electric heating. A heat pump [12] exploits the second law of thermodynamics, using refrigeration technology to take heat from a low-temperature source such as air, water, or pipes buried in the ground, and to supply it at the temperature required for central heating. The Coefficient of Performance for Heating (COP_h) is the ratio of heat supplied to power consumed, and is typically around 3. Thus 3 kW of heat are supplied for each 1 kW consumed. If a heat pump is used, the available supply of 2 kW can supply around 6 kW of heat, which on a 24 hour basis is 144 kWh, well in excess of the larger heat requirement figure of 120 kWh. However, it must be noted that the COP_h figure for a heat pump is very sensitive to the temperature at which heat is supplied. If used to heat a store, the temperature may well be higher than if used to heat a house directly, and so the COP_h may be significantly less than the value of 3 used above. Heat pumps are thus likely to be at their best if used with 24 hour electricity rather than with a thermal store.

6 Can Energy Efficiency Help?

With the present-day preoccupation with energy efficiency, it might be thought possible to accommodate the new loads by cutting down on existing loads, through energy efficiency measures, or just by doing without certain energy consuming activities. We must examine, therefore, how far this can help.

Proposing the reduction or elimination of ‘standby’ consumption is fashionable. The red light on the front of the television set has been blamed for all manner of woes. Looked at rationally, however, this is a very small amount of energy per consumer; it is only because of the enormous scale of public electricity supply that the total energy figure is significant. And recent advances in technology have reduced the figure considerably. Most of the energy used by the standby function of the older type of television set with a cathode ray picture tube went to keep the picture tube cathode hot, so as to give a quick start when required. With modern flat-screen television sets there is no requirement for such a system, so the standby power can be greatly reduced. The same applies to computer displays, which are now almost entirely of the flat-screen type. It appears, therefore, that standby power in most homes is not a significant load, even on a national scale, and its elimination cannot possibly provide any useful capacity in the local distribution network.

Another fashionable proposal is to turn off street lighting late at night. There is no doubt that street lighting is a significant load. To take an example, the county of Essex has 120,000 street lights, which together use 44 GWh per year [13]. This equates to 366 kWh per year for each lamp, or an average of 1 kWh per lamp per day. If we now look at the street (not in Essex) where the author lives, there are 17 houses and 4 street lamps. If the Essex average figure of 1 kWh per lamp per day is used for this street, the total elimination of street lighting would liberate an average of only about 0.25 kWh of energy per household.

Another possibility sometimes aired is the use of more efficient light sources. Indeed, an American web site claims that changing to more efficient lamps such as light-emitting diodes [14] would reduce the energy requirement by 50% or more. This is at variance with a recent paper [15] which suggests that white LEDs have a luminous efficacy of up to 150 lumens per watt compared with 100-200 lumens per watt for low-pressure sodium lamps as used in many suburban areas in the UK. The efficiency improvement achievable by using LEDs may be only marginal, therefore.

Thus, although reducing the amount of street lighting, or perhaps using more efficient lamps, would significantly reduce national energy consumption, it would do almost nothing to free up capacity in the local distribution network.

Where energy efficiency measures might indeed help is if the heating requirement of houses can be reduced. In the discussion of space heating, we assumed a requirement of 48-120 kWh per day per house, and we noted that 24-hour electricity was needed to supply that requirement. If these figures could be reduced to one third, an off-peak period of 7 hours could very nearly supply the requirement. It seems unlikely, however, that such a drastic saving of heating could be achieved easily.

7 Demand-Side Management

Demand-side management (DSM) can be used to improve the use made of existing infrastructure (generation and transmission as well as distribution) by reducing the peak demand. It achieves this by dividing the demand into high-priority loads such as lighting, which are always met, and low-priority loads, such as water heating by an immersion heater, which can afford to wait because it incorporates an element of storage. With the exception of storage heating with off-peak tariffs, DSM is not widely used in the UK at present.

New loads such as vehicle charging and space heating are ideally suited to the technology, since they can be designed at the outset to use DSM. In practice this cannot be done at the level of the individual home, because each house can easily cope with an increase in short-term load. Instead it needs to be done at the level where the problem exists, which for the present purpose is the local distribution substation. For this reason the new American standard for charging vehicles, SAE J1772 [16], which is said to enable ‘smart grid’ technology, may be a way forward.

What DSM cannot achieve, however, is the liberation of significant distribution capacity over a large fraction of the off-peak period.

8 Reinforcement of the Distribution Network

It appears, therefore, that supplying space and water heating requirements electrically is feasible, but cannot be done using the existing 2 kW infrastructure unless it is done with 24 hour electricity supply. That loses both the price advantage of night-rate electricity and also the CO_2 advantage of using only the most efficient and lowest CO_2 power generation. If we wish to use off-peak electricity for space heating, we must reinforce the distribution network.

The thought of digging up the streets of our towns is unattractive. However, we have done it at least twice, and in some places three times before. Historically, the gas industry in the UK used first coal gas and then a type of coal gas substitute made by cracking petroleum naphtha. In the 1960s natural gas became available. The existing distribution network was unsuitable for this new gas, and all the gas pipes in all the towns and cities of Britain were dug up and replaced, and the streets were then reinstated. More recently, in the 1990s, there was a major campaign to lay optical fibres for cable television and broadband internet. Again, the streets were dug up and then reinstated. And in some places the water supply pipes have been renewed. So we can contemplate doing a similar scale of work to reinforce the electricity distribution network, especially if ‘trenchless’ technology can be used.

Installing new additional cables, rather than replacing existing cables, would allow the simultaneous installation of kerbside charging points for residential areas which lack garages or private car parking areas. Such points are already seen in some European cities, and are already being planned for new public car parks in the UK.

As well as reinforcing the cables, the local distribution substations would need to be upgraded. In contrast to the requirements of cables, the substations are concentrated in a few locations, often in buildings or in small fenced-in enclosures. Upgrading would involve craning out an existing transformer and craning in a new, larger one, or possibly adding a second transformer to supplement the existing one. Either way, it is a much easier problem to solve than reinforcing the cables.

In contrast, there is likely to be less need to reinforce the existing incomers into individual houses. Most houses have a single-phase incomer which is easily capable of meeting the fuse rating of 40 amps, and indeed is probably capable of much more. This is more than enough to satisfy the requirements of the new loads, especially if demand-side management methods can be used.

It must be emphasised that the problem discussed is primarily a problem of the suburbs. In city centres the domestic load may be small in comparison to the total load because commercial or even industrial premises dominate. In the off-peak period, the commercial load is likely to be small, so there will be ample distribution capacity to supply an increased domestic load. In rural areas of the UK, the usual arrangement is to supply individual houses or small groups of houses through an 11kV single-phase transformer rated at close to the expected maximum demand, so there is little risk of overload at night unless the transformer has a really low rating. Interestingly, the practice in urban and suburban areas in the United States and in countries under its influence is to run distribution lines overhead rather than underground, at medium voltage around 12 kV, and to install local transformers on poles overhead rather than in buildings or enclosures, in a similar way to the rural practice in the UK, so the problem discussed in this paper may be less significant in such countries.

9 Conclusions

This paper is based on a number of assumptions which are believed to be reasonable but are not hard fact. Based on these assumptions, it is clear that the existing suburban distribution network in the UK can cope with a night-time load of private electric vehicles, at least in those areas where a 2 kW average demand has been catered for. It is also clear that a change from fuel-burning space heating to electric cannot be coped with unless 24-hour electricity is used, which would lose much of the advantage of lower CO_2 emissions, or unless there is an extreme reduction in heating demand to about one-third of the present level, an improvement which is unlikely to be achievable easily. Other energy efficiency measures are unlikely to achieve enough saving to make a worthwhile difference to that conclusion. Thus it appears that reinforcement of the distribution network is necessary if electric space heating is to be used extensively.

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Experimental Investigation of CI Engine Operated Micro-Trigeneration System Fuelled with Karanj Methyl Ester-Diesel Blend

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Abstract. A Micro-Trigeneration system based on Karanj Methyl Ester-Diesel Blend fuelled CI engine is designed and realized in laboratory. Experimental investigations are carried out to evaluate the performance and emissions of the original single generation system as well as the Trigeneration system developed. The test results show that the total thermal efficiency of Trigeneration reaches to 87.28% at the engine full load compared to only 33.21% for that of the original single generation. CO_2 emission in kg per unit (kWh) of useful energy output from Trigeneration is 0.1348 kg CO_2/kWh compared to that of 0.3184 kg CO_2/kWh from single generation at the engine full load. Percentage reduction in CO_2 emissions in kg/kWh with Trigeneration as compared to single generation throughout the load range is from 57.65% to 87.37%. The experimental results show that the idea of realizing a Karanj Methyl Ester-Diesel blend operated Micro-Trigeneration is feasible and effective to utilize the resources more efficiently.

1 Introduction

Increased energy demand, limited resources and the environmental pollution due to exploitation of energy, have emphasized the need for utilizing these resources efficiently. Trigeneration has been emerged as the effective technique for achieving the goal of energy conservation. It is more efficient and less polluting than electricity generated from central power plants. This makes Trigeneration the cleanest, most environmentally friendly and economic method to generate electricity.

Cogeneration is defined as simultaneous production of power and heat. Trigeneration is simultaneous production of power, heat and cooling or refrigeration. This is also referred as combined cooling, heating and power i.e. CCHP. [1,2] Trigeneration is advantageous over single electricity generation and cogeneration. It has higher total energy efficiency, lower emissions of CO2 and the other waste gases and it has more choices for useful energy outputs [1-15].

These systems range in size from large units designed to electrify and heat entire town, to small units that can serve a single home. In addition to the ability to utilize the by-product heat, Trigeneration also has the advantage of lower transmission losses and increased energy security from natural disasters, over

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consumption of power and even terrorist acts. Large industrial plants, universities, hospitals, and office buildings have successfully implemented Trigeneration systems. This technology is maturing and typically utilizes natural gas micro-turbines integrated with adsorption / desiccant coolers to take advantage of by-product heat in warm seasons. The new frontier of Trigeneration is in the residential and small building sector. Applying Trigeneration technology to smaller scale residential and small commercial buildings is an attractive option because of the large potential market. Many manufacturers are developing small scale Trigeneration systems or micro-CHP units. These small-scale power plants typically range in size from 1 to 15 kWe. These generators utilize an internal combustion engine, Stirling cycle engine, or fuel cell as the prime mover. Prime mover drives a generator which produces electrical power. The waste heat from the prime mover is recovered and used to drive thermally activated components such as an absorption chiller or desiccant dehumidifier, and to produce hot water or warm air through the use of heat exchangers. Fossil fuels are mainly used world over for providing energy to the prime movers. However the fossil fuels are depleting very rapidly. Moreover, the increased use of petroleum products will intensify local air pollution and enhance the global warming problems. This situation has compelled scientists and technologists in both developed and developing countries to look for economically and environmentally sound alternatives to fossil fuels. The vegetable oils can be used as an alternative fuel for the C. I. engines. Vegetable oil based fuels have been proved as potential alternative greener energy substitute for fossil fuels. The vegetable oils are renewable in nature and have comparable properties with Petro-Diesel. These are biodegradable, non-toxic, and have potential to reduce the harmful emissions. One of the best methods to use the vegetable oils in the diesel engine is the conversion of vegetable oil into Biodiesel by transesterification process. The transesterification process has been proved as the most effective method and widely utilized [16-20].

Several researchers have conducted experimental and simulation based investigations on Trigeneration systems [1-15]. Most of the studies are related to computational based simulation techniques or experimental studies on large scale Trigeneration systems [6,7,9,15]. Little work has been done in the field of experimental studies on Micro-Trigeneration systems utilizing alternate fuels for their prime movers. The investigations showed a significant impact on raising the energy efficiency and reducing greenhouse gas emissions responsible for global warming [3,4,8].

The objective of this study is to investigate the feasibility to develop a Micro-Trigeneration system working on alternate fuels and to carry out experimentations to investigate the performance and exhaust emission of the system. The Trigeneration system designed and realized in laboratory for the present research work is based on a CI engine as prime mover. Biodiesel-Diesel blend has been used as an alternate fuel for the CI engine. The waste heat from engine cooling system and engine exhaust system has been utilized to generate hot water through a heat exchanger and cooling or refrigeration through a vapor absorption refrigerator.

2 Experimental Setup and Procedure

The schematic layout of the experimental setup for the present investigation is shown in Fig.1. It consists of a test-bed, having a diesel engine, electric dynamometer, heat exchanger for heating the water, exhaust heat driven absorption refrigerator, fuel tank, air box, operation panel having controls and displays for different thermocouples, tachometer and flow meters. Fuel supply is measured using burette flow meter. NOx, CO, CO_2 and HC measurements were done with the help of AVL DITEST (AVL DiGas 4000 light) gas analyzer. Envirotech APM 700 Smoke meter was used to measure exhaust smoke. Calorific value of the fuel used was evaluated by Bomb calorimeter.

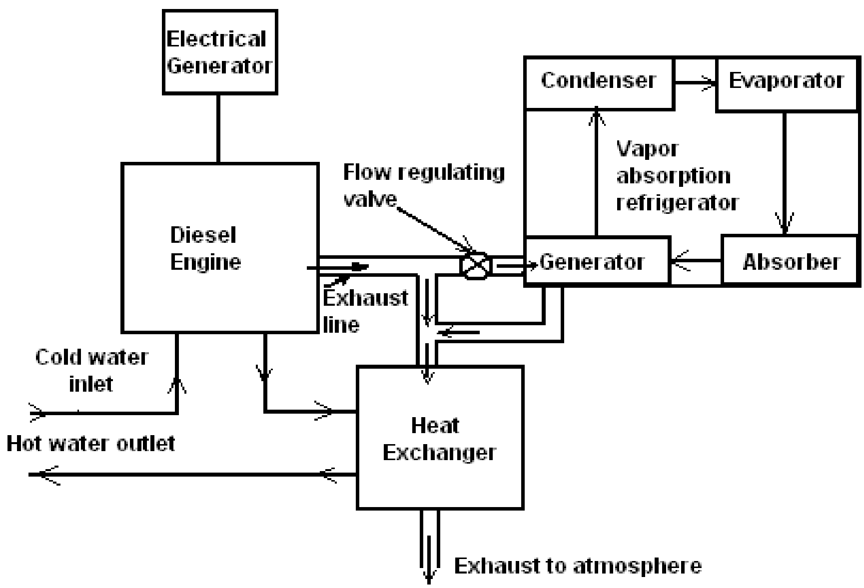


Fig. 1. Schematic layout of Experimental Setup for Trigeneration system

2.1 Diesel Engine Generator Set

A typical engine system widely used in the agricultural sector of India has been selected for present experimental investigations. A stationary single cylinder, four stroke, constant speed, water cooled, direct injection Kirloskar make diesel engine (Model-AV1) with electric generator was used for the experimentations.

2.2 Heat Exchanger

A heat exchanger was designed and fabricated for the experimental tests to recover heat from the engine exhaust gas according to the maximum heat output from the exhaust gases. The heat exchanger is a cross flow, multi-flattened tube and finned, compact, and made of brass tubes and copper fins. The size of the heat exchanger designed was obtained as: Height 0.34 m, Width 0.3 m, Thickness 0.05 m.

2.3 Absorption Refrigerator

An Electrolux vapor absorption refrigerator was used for creating the refrigeration effect. It was a commercially available, NH_3-H_2O pair based, electrically operated refrigerator with a capacity of 41 liters and heat input of 95 Watt. Generator of the refrigerator was modified to utilize the waste heat of exhaust gases. Due to small amount of heat available from the engine, the generator was modified to make the refrigerator, a direct exhaust fired refrigerator instead of a hot water fired or steam fired refrigerator. For the above purpose, a counter flow, double pipe type heat exchanger was designed, fabricated and installed.

2.4 Experimental Plan

A plan was designed for the experimental investigation of the performance of the Trigeneration system which is given as following:

2.4.1 Performance of Engine Generator Working on Single Generation System

A series of tests were designed and conducted to evaluate the engine generator performance when it runs on a single generation system working on B-20 as well diesel for baseline data. The fuel used in the study is blend of diesel and Biodiesel based on Karanj oil which is an inedible vegetable oil and renewable in its nature. The botanical name of Karanj tree is Pongamia Pinnata. It is chiefly found along the banks of streams and rivers or near the seacoast of India. It is known that the pure vegetable oils create operational problems in engines due to its high viscosity and low volatility. So it was then decided to use Biodiesel of Karanj oil i.e. Karanj methyl ester as blending fuel in Diesel to obtain Karanj Methyl Ester-Diesel blend. The blend of 20% Karanj methyl ester and 80% fossil diesel by volume was selected as fuel for the existing diesel engine. The Biodiesel of the Karanj oil was produced by Transesterification process. The fuel blend so obtained is named as B-20. While varying the engine load between idle to full load the relevant data were recorded such as the engine generator power output, fuel consumption, engine exhaust temperature, emissions etc.

2.4.2 Performance of Trigeneration

A series of tests were also designed and conducted to evaluate the performances of Trigeneration. In these tests, the engine load was varied between idle to full load (similar to that of single generation) and the required parameters were recorded in order to evaluate the total useful output (power + heat recovered from coolant and exhaust + refrigeration effect), total thermal efficiency etc.

3 Results and Discussion

The main physico-chemical properties of the selected fuel were evaluated and were found to be equivalent to that of fossil diesel. There was no abnormal combustion phenomenon in the engine and the engine was running smoothly. The performance and emission of the diesel engine with B-20 were nearly same as compared to that with fossil diesel. The diesel engine generator system fuelled with B-20, performed satisfactorily on the single generation system as well as on the Trigeneration system mentioned above. There was no engine operational problem during the experimentations. The test results for averaged values of three tests for each parameter are shown in the following sections:

3.1 Engine Generator Performance and the Comparison

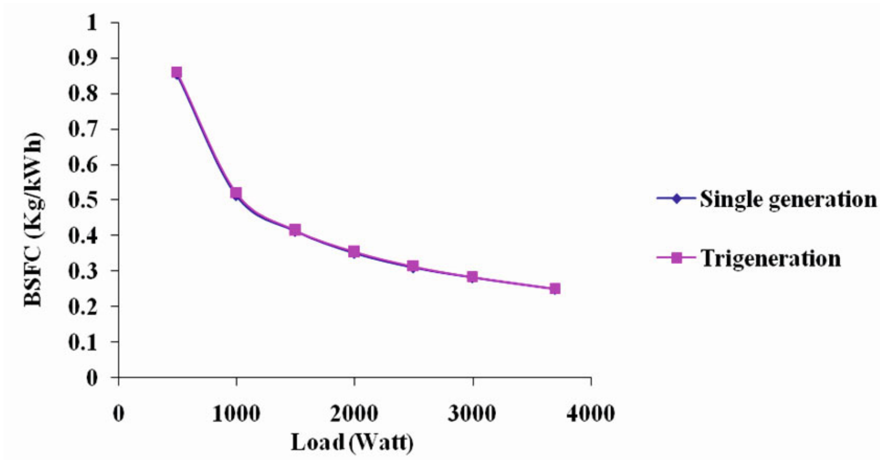
The test results for BSFC of engine generator on Single generation and Trigeneration systems are shown in Fig.2(a). The results show that the BSFCs of Single generation and Trigeneration are nearly equal. The test results for the brake thermal efficiency of engine generator on Single generation and Trigeneration are shown in Fig.2(b). The test results show that the brake thermal efficiency of engine generator on Single generation and Trigeneration are nearly the same. The results show that the integration of the Trigeneration components to the engine generator does not influence the performance of the engine generator significantly.

3.2 Engine Emissions

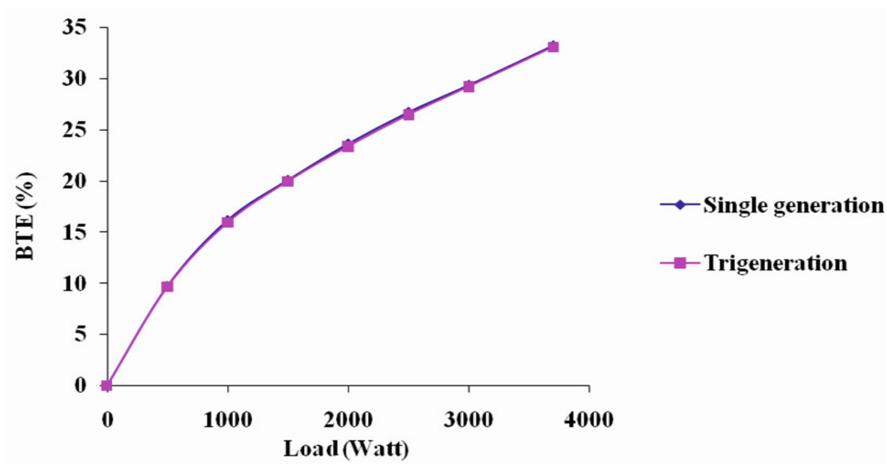
The emissions of smoke, CO, HC, NOx, and CO_2 from the diesel engine on Single generation and Trigeneration are shown in Fig.3. The results show that the differences are mostly very small.

3.3 Performance of Vapor Absorption Refrigerator

The parameters of the performance of refrigerator were recorded and evaluated during the Trigeneration operation on different engine loads. The test results for the exhaust gas fired refrigerator shows that at the full load, the generator temperature is 118^{0}C. The final evaporator inlet temperature is -3.2^{0}C; at food chamber is 3.2^{0}C. The heat input to the refrigerator Q_G is 100.13W; the refrigeration effect Q_E is 42.1 W; and the coefficient of performance of the refrigeration system is 0.4204. The test results for DC power electric heated refrigerator show that the refrigeration effect is 30.165 W with COP equals to only 0.3175. The refrigeration effect was calculated by placing a known quantity of water inside the food chamber and noting down the change in temperature of the chamber and time taken by it to reach steady state. The linearity of the fall in temperature was confirmed and UA value for the evaporator chamber was calculated to determine the refrigeration effect. These results show that the COP of the refrigerator driven by exhaust gas is higher than that of electric power heated refrigerator.



(a)



(b)

Fig. 2. Variation of (a) BSFC and (b) BTE with engine load and comparison of single generation with Trigeneration

3.4 Performance of Trigeneration System Compared to That of Single Generation System

The parameters of the performance of refrigerator were recorded and evaluated during the Trigeneration operation on different engine loads. The test results were validated by comparing it with the test results of experimental study on a small household size Trigeneration carried out by Lin Lin et.al [4]. Percentage changes in the values of performance parameters of Trigeneration over the single

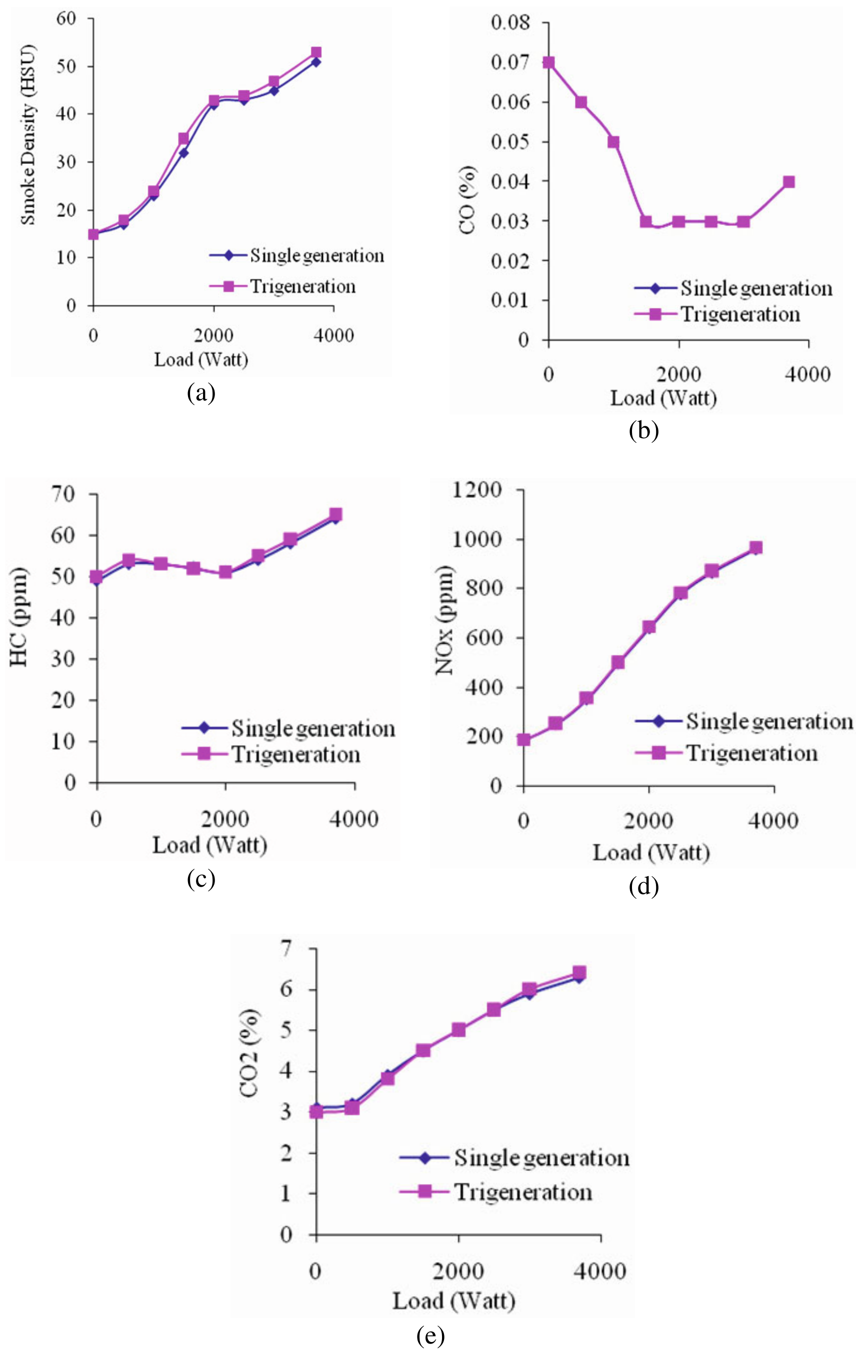


Fig. 3. Variation of (a) Smoke density (b) CO (c) HC (d) NOx and (e) CO_2 in exhaust with engine load and comparison of Single generation with Trigeneration

generation for the two studies are quite comparable. The detailed test results of the whole Trigeneration system from the engine no load to full load, are shown in Fig.4. From the figure, it can be seen that

- the useful energy output varies from 2370.06 W at the engine no load to 8873.23 W at the engine full load;
- the thermal efficiencies of Trigeneration varies from 52.13% at the engine no load to 79.38% at the engine full load;
- the specific fuel consumption varies from 0.1315 kg/kWh at the engine 500 W load to 0.1044 kg/kWh at the engine full load;
- the CO_2 emission varies from 0.1775 kg CO_2/kWh at the engine 500W load to 0.1348 kg CO_2/kWh at the engine full load.

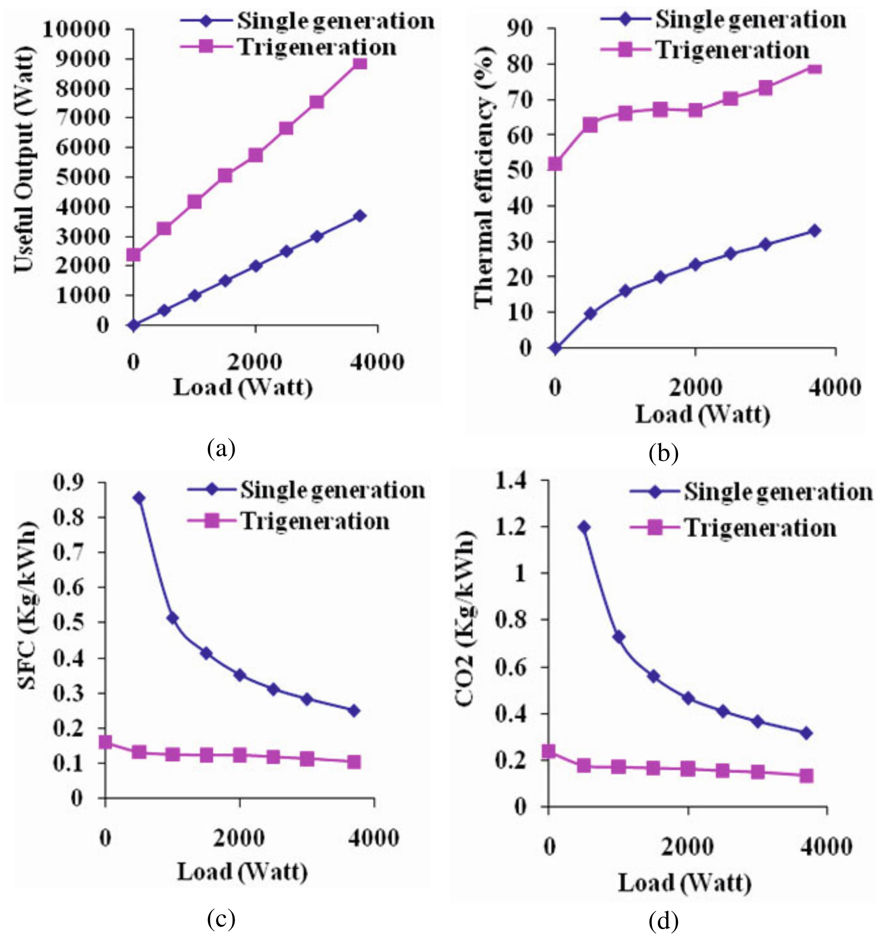


Fig. 4. Variation of (a) Useful energy output (b) Thermal efficiency (c) SFC and (d) CO_2 for Single generation and Trigeneration and their comparison

Fig.4 also shows the comparisons of the useful energy output, total thermal efficiency, specific fuel consumption and CO_2 emission between Trigeneration and single generation. From the results, it can be seen that the useful energy outputs from Trigeneration are much higher than that of single generation. The increase in useful energy output is 139.92% at the engine full load. The total thermal efficiency of Trigeneration is from 139.03% higher than that of single generation at full load. The fuel consumed by Trigeneration is much less than that of single generation. The specific fuel consumptions for single generation are from 0.8540 kg/kWh at the engine 500W load to 0.2497 kg/kWh at the engine full load. The decrease in fuel consumption for Trigeneration over single generation is from 58.16% at the engine full load. The CO_2 emissions for single generation are from 1.1968 kg CO_2/kWh at the engine 500W load to 0.3184 kg CO_2/kWh at the engine full load. The CO_2 emission per unit (kWh) of useful energy output of Trigeneration is reduced by 57.65% at engine full load, compared to that of single generation. This shows that the CO_2 emissions from Trigeneration are much lower than those from single generation.

4 Conclusions

In this study, performance and emission of a Micro-Trigeneration system based on Karanj Methyl Ester-Diesel Blend (B-20) operated CI engine are evaluated. The performance of the engine with B-20 is nearly equivalent to that with Diesel. When the engine generator runs as a single generation or in a Trigeneration, the brake power output, brake thermal efficiency and the fuel consumptions for the two systems, are nearly the same. The increase in useful energy output from the Trigeneration as compared to single generation is from 139.92% under different engine loads. The total thermal efficiency of Trigeneration is from 139.03% higher than that of single generation at full load. The saving of fuel consumption for Trigeneration over single generation is 58.16%_at full load. The CO_2 emission per unit (kWh) of useful energy output from Trigeneration is reduced by 57.65% as compared to that from single generation at full load. This research work shows that the idea of realizing a household size Trigeneration is feasible and the design of the Trigeneration is successful. The experimental results show that the Micro-Trigeneration is able to generate electricity, to produce heat and to drive a refrigeration system simultaneously from a single alternate fuel (B-20) input. The Trigeneration is more efficient, less polluting and more economic than the single generation.

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Renewable Energies in the EU Energy Policy: Model of Territorial Distribution of Efforts to Meet the Strategic Goal for 2020

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Abstract. First, we analyzed available data on renewable energy consumption and the share in the European Union, taking 2005 data, total and per capita general energy consumption and per capita income during 2000-2006 as references. Afterwards, a nonlinear methodology for territorial distribution of the EU-27 goal for reaching a 20% share of renewable energy in the gross final consumption of energy is proposed. This methodology is applied to the year 2020 on the NUTS0 territorial level, that is, to members of the European Union, according to the EUROSTAT Nomenclature of Territorial Units for Statistics (NUTS). Weighting is done based on the share of energy from non-renewable sources in gross final consumption of energy, energy from non-renewable sources per capita, energy from non-renewable sources per GDP and GDP per capita. Finally, a multicriteria formula was applied, weighting the variables used in this study.

Keywords: EU energy policy, Energy from renewable sources, National overall targets.

1 Introduction

There is worldwide concern about high fossil-fuel energy consumption, climate change and global warming and its possible long-term consequences (Omer 2008a; Vera and Langlois 2007), forcing us to seek safer and cleaner energy resources, in keeping with the search for sustainable development (Dincer 1999; Dincer and Rosen 1998; Rosen 1996). The use of energy from renewable sources (RES) is closely bound to sustainable development, more so when society requires a sustainable supply of energy resources and their effective and efficient use (Dincer 1999; Omer 2008a). RES are sustainable and available in the long term (Charters, 2001; Dincer 1999), and both their generation and consumption have a minimum negative impact on human health or the healthy functioning of vital ecological systems (Omer 2008b).

European energy policy incorporating energy efficiency, renewable energies and energy savings in its work programmes is in agreement with governmental policies instituted worldwide (Andrews-Speed, 2009). In this regard, the European

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Union, which has a renewable energy market with an annual turnover of EUR 15 000 million, equivalent to half the world market (EU, 2006), has set a goal of a minimum 20% share of its energy mix from renewable resources in the gross final consumption of the European Union by 2020. This is one of the general strategic goals of the energy policy for 2020, called the 20/20/20 goal (Council of the European Union, 2007; Bouquet and Johansson, 2008).

To meet this general goal, Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, established binding national targets for the share of energy from renewable sources in the gross final consumption (GFC) of energy by 2020. Although this new directive was far more detailed and gave the Member States clear targets, it remains unclear how these national quotas were set. Data are rational, but there is no information on how they were arrived at. In the Presidency Conclusions from the European Council (Council of the European Union, 2007), the 20/20/20 goals were approved, and the starting point for these EU-27 strategic energy policy goals was set as the year the Green Paper on Energy Efficiency was published (2005).

The purpose of this paper is to present a clearer distribution methodology for quotas and efforts, which takes into account the actual state and the specific characteristics of the different States involved (which are extremely heterogeneous).

2 Analysis of Renewable Energies During 2000-2006 and in the Starting Year (2005)

This section analyses the situation of renewable energies in Europe in two scenarios, the European Union of the 15 (EU-15)[1] and the European Union of the 27 (EU-27)[2], to identify the differences in behaviour of the more industrialised countries (EU-15) from those that have joined the EU since 2004. First an analysis of their development is given, and then the main indicators related to the RES in the starting year (2005): share of renewable energy resources, RES in GFC per capita and per GDP, and GDP per capita, and NRES in GFC per capita and per GDP

During 2000-2006, the EU-27 increased its overall share of RES in GFC by 1.69%, and the EU-15 by 1.68%. Of the Member States, Denmark, Czech Republic and Germany increased their share most during this period (Fig. 1), by 5.41, 4.38 and 4.06%, respectively. Countries like Latvia, Slovenia, Lithuania, France, Greece and Finland reduced their share in this period, but except for Greece, they are still higher than the European mean. Malta is the only Member

[1] The European Union 15 is composed of: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

[2] The European Union 27 is composed of: EU-15 plus Bulgaria, Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia.

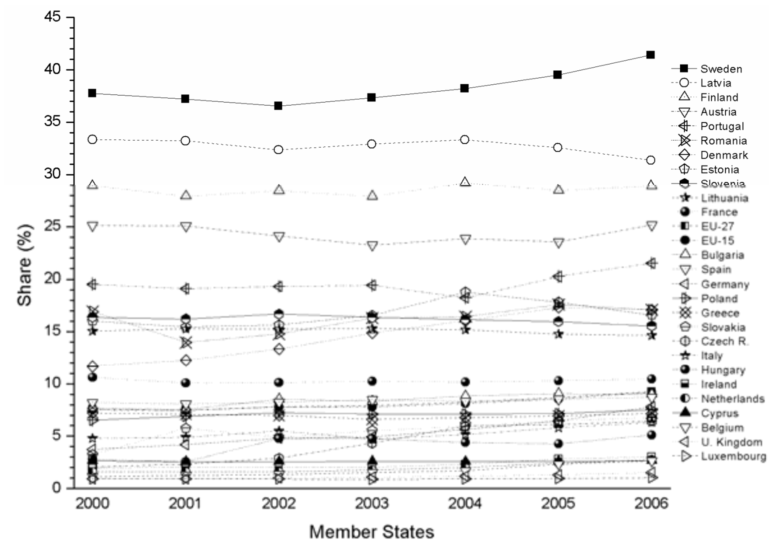

Fig. 1. Share of RES in GIC.in 2000-2006

State that has neither reduced nor consumed RES during this period. The trends are irregular among the member countries, and are much higher in the EU-15. The EU-15 consumed 84.21% of RES in the total EU-27 GIC.

The overall share of the EU-27 was 8.53% in 2005, where Sweden, with 39.80%, is the Member State with the highest share of RES in GIC. Only five countries surpassed the EU minimum share of 20% (Sweden, Latvia, Finland, Austria and Portugal). Luxembourg, United Kingdom, Belgium, Netherlands and Cyprus stand out with shares of less than 3%. The shares of the member countries are observed to be very heterogeneous (Fig. 2). The RES in GFC per capita are also significantly different. The EU-27 mean was 2.10 toe inhabitant¯1, where Sweden, Finland and Austria stand out with their high means of 15.56, 14.15 and 7.94 toe inhabitant^{-1}, respectively. The United Kingdom, Cyprus and Netherlands, were the lowest. No direct effect of population was observed in the results due to the differences in RES in GIC.

In the RES in GFC per GDP analysis, it is observed that most of the countries that have joined the EU since 2004 have higher means than the EU-15. Latvia, Romania and Estonia were the countries with the highest RES in GFC per GDP, with 109.72, 86.60 and 61.29 toe M€$_{00}^{-1}$. Significant differences in GDP per capita were observed among the Member States. The highest is Luxembourg, which surpasses almost 25 times the ratio of countries like Bulgaria and Romania, the last countries to join the EU, and practically triples the EU-27 (20 495.86 000 €$_{00}$ per inhabitant). The mean GDP per capita of the EU-27 countries is 18.53±13.14 000 €$_{00}$ per inhabitant.

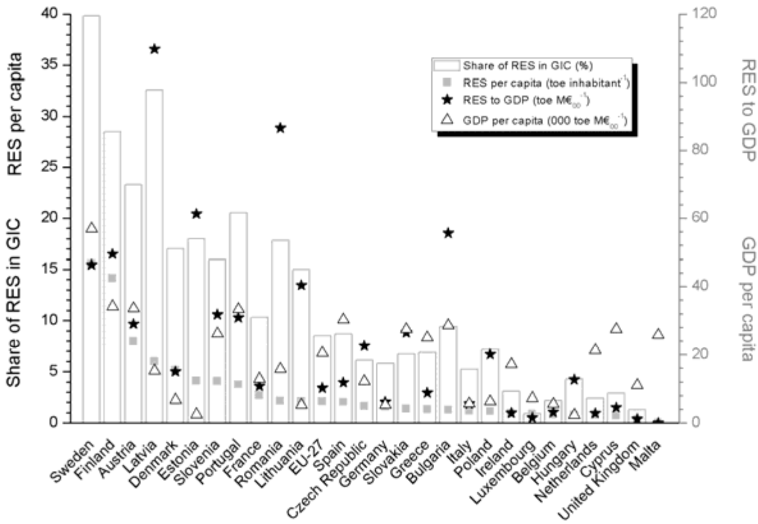

Fig. 2. Indicadores relacionados con las energías renovables en 2005

Luxembourg, Belgium and Finland had the highest NRES in GFC per capita, with 95.76, 36.65 y 35.49 toe inhabitant^{-1}. The mean for the EU-27 was 22.55 toe inhabitant^{-1} (Fig. 3). The most heavily populated countries in Europe, the United Kingdom, Germany, France, Italy and Spain, were around the European mean, 25.71, 25.62, 23.51, 21.97 and 21.37, respectively.

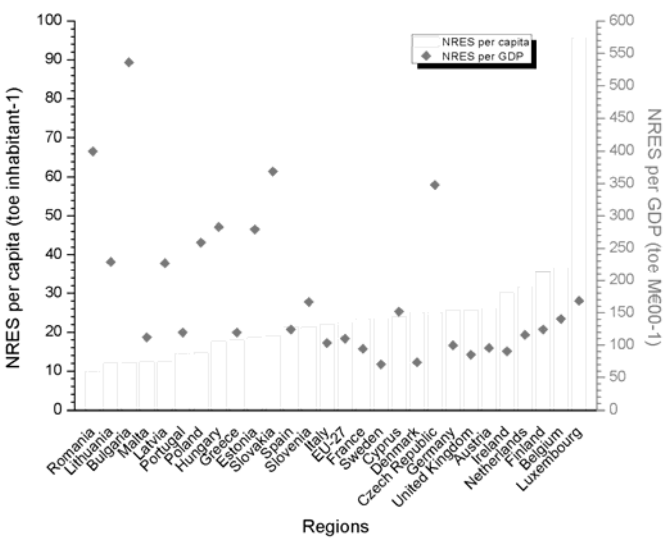

Fig. 3. NRES in GFC per GDP and RES in GFC per GDP in 2005

A direct effect of the GDP was observed on the NRES in GFC per GDP indicator, as it was higher in the countries that have joined since 2004, in all of which it was over the EU-27 mean of 110.07 toe $M€_{00}^{-1}$. Sweden is the Member State with the lowest NRES in GFC per GDP with 70.16 toe $M€_{00}^{-1}$, followed by Denmark and the United Kingdom, with 73.35 and 85.20 toe $M€_{00}^{-1}$, respectively.

3 Method

This general methodology is based on scientific fact and may be easily modified to take other characteristics of the States into account. This distribution methodology may also be used on other territorial aggregation levels, such as the decentralized States of Germany or Spain (NUTS2). The proposed model is based on the use of statistical data (EC 2009a, 2009b), general distribution functions and minimum and maximum limits. We applied our method under the following premises:

1. Effort is distributed territorially on the EUROSTAT NUTS0[3] level for the current 27 countries in the European Union.
2. The EU-27 must meet a minimum of 289 Mtoe of RES in GFC in 2020, which is 20% of the RES in GIC according to data published by the EU in the Renewable Energy Technology Roadmap document (EREC 2008). This would be an increase of 183.7 Mtoe over 2005 (105.3 Mtoe). Therefore, the coefficient of increase of the EU-27 is 2.744.
3. All the countries must meet a minimum share of energy from renewable sources in their gross final consumption of energy for 2020. This minimum can be modified[4] as the final criteria are changed: Minimum overall share of renewable energy.
4. All the countries must improve their renewable energy share even if they have previously reached the final target set by a general distribution method: Minimum improvement rate.
5. Effort is distributed by a nonlinear function (in our example, we use a quadratic distribution function), whereby the countries that started out in the worst situations are asked to do the most.
6. Each State is assigned a single value generated by a weighted multicriteria formula that takes the distance to the final overall goal into account (computed as the complement of the renewable energy share) and the GDP per capita. The first component implements the fact that those countries with the lowest renewable energy share must make the strongest effort, the second component shows how the European Union can ask a little more from those countries with more economic potential. These values include current knowledge.

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[3] Nomenclature of Territorial Units for Statistics.

[4] In this study the minimum overall share was 10%, assigned to Malta in Directive 2009/28/EC.

The reduction coefficients are weighted according to four relative indicators (*Ri*): Share of NRES in GFC, NRES in GFC per capita, NRES in GFC per GDP and GDP per capita, in the starting year of 2005, and in each geographic unit (*i*). The four hypotheses considered in this study were:

- Hypothesis 1. The countries that have a high share of NRES in GFC must make the greatest effort to increase their RES share.
- Hypothesis 2. The countries that consume the most NRES in GFC per inhabitant must make the greatest effort to increase their RES share
- Hypothesis 3. The countries that consume the most NRES in GFC per euro GDP must make the greatest effort to increase their RES share.
- Hypothesis 4. The countries with the most material wealth per inhabitant must make the greatest effort to increase their RES share.

The formula for finding the coefficients for modulated increase in the RES in GFC (*E*), for each member state (*i*) was:

$$c_i = f\left(Ri_{(2005)}\right) = a * \left(Ri_{(2005)}\right)^2 \qquad (1)$$

where a is the weighting factor that modulates the coefficients of increase c_i, as a function of the relative indicator (*Ri*). The coefficient multiplied by the RES in GFC in 2005 ($Ei_{(2005)}$) gave us the absolute minimum that must be met by each Member State in 2020 ($Ei_{(2020)}$). *A* was calculated using the expression:

$$a = \frac{E_{(2020)}}{\sum_{i=1}^{i=n} E_{(2005)} i * \left(Ri_{(2005)}\right)^x} = \frac{(c) * E_{(2005)}}{\sum_{i=1}^{i=n} E_{(2005)} i * \left(Ri_{(2005)}\right)^x} \qquad (2)$$

where c is the coefficient of increase of the total geographic area ($c_{EU\text{-}27}$ = 2.744), $E_{(2005)}$ and $E_{(2020)}$ are the result of the summation of the RES in GFC of the Member States for 2005 and 2020, respectively; and *Ri* is the relative indicator selected.

Since in 2020, no country can reduce its RES in GFC, and this share must be at least 10%, the countries that do not meet these parameters after applying the formula were applied the premise of: $b+10$, where b is the share of RES in GFC in the starting year. Then a second iteration was done excluding countries with shares below 10%.

In the second iteration, $E_{(2005)}$, corresponded to the summation of RES in GFC of the countries that were not excluded in the first iteration. Due to the change in the total geographic area, a new c was calculated called c^*. The new coefficient c^* was found from the relationship between the sum of $E_{(2005)}$ and ΔE, and $E_{(2005)}$. The increase in RES in GFC (ΔE) is equal to the difference between the expected amount of RES in GFC for 2020 ($E_{(2020)}$) and the summation of the RES in GFC for 2020 of the countries in the second iteration. Successive iterations were done until the criteria set were met.

Finally, the formula was applied with S as a multicriteria equation: $S=\lambda_1*S_1+\lambda_2*S_2+\lambda_3*S_3+\ldots$, weighting relative indicators S, so the sum of the coefficients that weight them is equal to 1, $(1=\lambda_1+\lambda_2+\lambda_3+\ldots)$. The weighting coefficients used in this study were 0.25, 0.25, 0.50 and 0, for the share of NRES in GFC, RES in GFC per capita RES in GFC per GDP, and GDP per capita, respectively. GDP per capita was not used because the GDP and population variables are already included in other indicators. Weighting was done in this way give more weight to relativisation by the GDP, according to Directive 2009/28/EC.

4 Results

The values presented below are for orientation only, as the GFC predictions for 2020 may vary, depending on political, economic, environmental or social situations in each country, within the European Union or worldwide. By analysing the results, it is hoped to open discussion on the possibilities for setting EU energy policy thresholds depending on the parameter or indicator used. In 2020, the EU-27 share of RES in GFC would be 21.10% in all the hypotheses considered in this study. The results found for the four hypotheses are shown in Figure 4.

In all of the Hypotheses, Malta is assigned a 10% share for 2020 as specified in Directive 2009/28/EC. Its coefficient of increase is infinite because its RES share in 2005 was 0%.

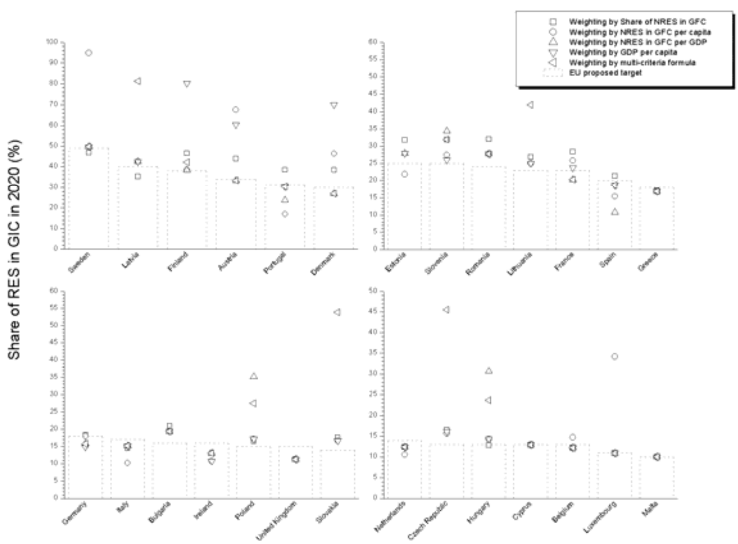

Fig. 4. Renewable energy share under the four hypotheses and in the multicriteria formula

The results as a function of the share of NRES in GFC (Hypothesis 1) show that the countries with the largest share of NRES in GFC in 2005 should have the highest coefficients of increase. Therefore, Luxembourg and the United Kingdom should make the greatest effort with coefficients of increase of 13.881 and 8.816. These countries should increase their share of RES in GFC from 0.90 and 1.30% in 2005 to 10.90 and 11.30% in 2020, respectively. Shares range from 10.00% in Malta to 46.96% for Sweden. Comparing the shares found with those set by the EU, there is less pressure on the final share in the countries that had a lower share of NRES in GFC in 2005 (Fig. 4). Luxembourg, the United Kingdom, Belgium and Netherlands would have shares lower than those set by the EU (10.9 vs. 11.0%, 11.3 vs. 15.9%, 12.2 vs. 13.0% and 12.4 vs. 14.0%, respectively), even though they are the countries with the highest coefficient of increase.

As a function of NRES in GFC per capita, differences are wider than those found as a function of share of NRES in GFC (Fig. 4). In general, no direct relationship is observed between the coefficient of increase and the NRES in GFC per capita. But most of the countries do respond positively to the hypothesis posed with shares similar to those set by the EU. Luxembourg, with 43.557 would have the highest coefficient of increase and Portugal, Finland and Estonia have the lowest (1.000, 1.517, y 1.660, respectively.) The countries that should have the highest shares in 2020 are Sweden, Austria, Denmark and Latvia (94.95, 67.58, 46.32 and 42.60%, respectively). The shares calculated for Finland are contrary to the hypothesis, since in spite of being the country which consumes the second highest NRES in GIC per capita, it would have the second lowest coefficient of increase. Its high share of RES in GIC in 2005 explains this result, because when the the formula is applied, the coefficient would increase its share over 100%. No direct effect of the population was observed due to the differences in absolute RES in GIC in 2005.

In Hypothesis 3, weighting as a function of NRES in GFC per GDP, Slovakia would have the highest share for 2020 (75.67%), followed by the Czech Republic (61.94%) and Lithuania (53.41%), as shown in Fig. 4. Luxembourg, Slovakia and the Czech Republic should have the highest coefficients of increase (13.881, 13.354 and 11.881, respectively), and on the contrary, Sweden (1.380), Portugal (1.406) and Finland (1.515) should make the least effort. The shares found with this hypothesis are mostly similar to those of the EU, except for Lithuania, Spain, Poland, Slovakia, Czech Republic and Hungary. Most of the EU-15 should make the least effort. The heterogeneity of the absolute RES in GFC and GDP do not allow any direct effect of the GDP to be observed.

Luxembourg, the country with the highest GDP per capita in 2005, should have the highest coefficient of increase for 2020 (1.881) under Hypothesis 4 (as a function of GDP per capita.) Sweden (1.380), Portugal (1.795) and Latvia (1.965) are the countries that should increase the least under this hypothesis. Sweden's low coefficient of increase is the result of the high share of RES in GFC in 2005, in spite of having one of the highest per capita incomes. No direct relationship is observed between the GDP per capita and the coefficients of increase found due to the heterogeneity of the RES in GFC. The shares found under this hypothesis are the most similar to those set by the EU with the exception of Finland, Austria and Denmark, which should have shares of over 50%.

As a function of the multicriteria formula, the shares are in the range of 86.21 to 10.00%, corresponding to Latvia and Malta (Fig. 4). The countries that should increase the most are Luxembourg and Slovakia (13.881 and 9.511, respectively). This is a result of the high NRES per capita, NRES per GDP and share of NRES in GFC in 2005. On the contrary, Sweden and Austria are the Member States with the lowest coefficient of increase (1.380 and 1.600 respectively), with NRES per capita above the European mean in 2005, but lower NRES per GDP and share of NRES in GFC. The widest differences between the shares set by the European Union and those found under this hypothesis are observed for Latvia, Lithuania, Poland, Slovakia and Hungary, because of their poor indicators in 2005, penalising them somewhat for their inefficient energy consumption (understood as a synonym of energy consumption intensity). In general, the results found agree with those set by the EU.

5 Conclusion

The analysis of the development of renewable energies in final gross energy consumption highlighted the heterogeneity and differences in the progress made by countries in the EU. The share of renewables has stagnated somewhat in most of the countries, but the EU-27 has increased its overall share of renewables in the final gross energy consumption.

Application of the model for the territorial distribution of dynamic targets seeks to give Policy Makers a broader view of the achievement of the EU overall energy policy goals. The model proposed is simple and its results are for orientation, so they should not be taken as absolute, but as a reference for formulating energy efficiency policies.

Finally, it was noted that the heterogeneity of the results of each of the different hypothesis evaluated reinforces the need to include as many perspectives as possible in the formulation of energy policies, taking the specific characteristics of the realities in the different regions and countries into account. Proposed specific goals can thus be pragmatic and affordable.

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Future-Proofed Design for Sustainable Communities

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Abstract. This research investigates 'best practice' design and decision-making processes for achieving sustainable buildings and communities over the long-term. Amongst the core objectives of strategic urban planning for sustainable communities is to accommodate future changes, however this is not explicitly integrated into the planning and design processes. A framework of future-proofed building design is proposed, which aims to bridge the gap between the traditional short-term outlook and the need for resilient and flexible buildings over the long-term. An overview of design principles for sustainable urban communities and buildings within them is followed by an examination of decision-support techniques and tools. Insights regarding how new developments should address these objectives are captured. The research represents a shift away from the short-term mindset that still dominates design and construction practices, and provides a critical review of assessment methods for improving and incentivising sustainable urban design over the long-term.

Keywords: future-proofing, sustainable communities, decision-support techniques and tools, building assessment methods.

1 Introduction

Sustainable development is a concept that has increasingly gained the attention of stakeholders in the built environment. Global population growth, rapid urbanisation, and climate change are amongst the key challenges. Strategic urban planning aims to reveal how such challenges can offer opportunities for transformational change via policies that address the dual goal of sustainability, namely: human development together with low ecological impact [1]. While buildings account for up to 40% of total energy consumption in many countries, they are essential for sustaining economic activity, since people spend around 80-90% of their time indoors [2]. It is expected that around 70% of the world's inhabitants will live in metropolitan centres by 2050 [3]. The business-as-usual scenario highlights the need for a shift away from current consumption rates through multi-stakeholder collaboration, systems thinking, and innovation.

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The present research lies under the umbrella of sustainability in the built environment and aims to reveal features of future-oriented building design and their effect on the development and maintenance of sustainable urban communities. Little research has been conducted into ex-ante design and assessment techniques that explicitly aim to accommodate future trends and uncertainties. In addition, mainstream assessment methods focus mostly on single-buildings overlooking interrelationships at wider scales. This paper considers a community-level integrated design approach. Initially, a framework of future-proofed building design is developed based on insights gained from a literature review on sustainable communities and 'green' buildings. Thereafter, an overview is provided of decision-support techniques and tools that can enhance long-term thinking from the early planning stages.

2 Research Scope and Methodology

This research covers the neighbourhood scale, as community-level schemes present opportunities for integrated solutions rather than ones developed in a piecemeal fashion [4] and can provide the economies-of-scale needed for novel technologies [5]. The term 'sustainable communities' refers to exemplar urban sites that exhibit a holistic approach to sustainability, which may include: 'green' buildings; reduced motor vehicle dependence; walking and cycling routes; green and public spaces; cultural heritage preservation; flood risk management; biodiversity; the proximity of community facilities; and local employment [6]. A scrutiny of multi-stakeholder perspectives, 'green' building elements and site-level details in leading European sustainable communities can contribute to the formulation of a future-proofed design framework and create the grounds for knowledge and technology transfer to mainstream practice. Such a framework can facilitate the selection and optimisation of technologies and policies for the regeneration of brownfield sites or the development of greenfield sites.

3 Framework of Future-Proofed Design

3.1 Definition

According to the Brundtland Commission, sustainable development is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' [7, p.43]. From this broad definition, it can be argued that future-proofing is a key ingredient in the pursuit of sustainable development or sustainability[1] over the long-term. Future-proofing can be defined as strategic planning and design that responds explicitly to the temporal dimension of sustainable development, and aims to limit the risks inherent in long-term decision-making by accommodating future uncertainties. Neighbourhoods and

[1] In this paper sustainable development and sustainability are used interchangeably.

buildings that are designed to be adaptable may prove more resilient and durable over the long-term than those tailored to meet a particular short-term need.

The future performance of buildings has received little consideration due to the short-term mindset and conservatism that still prevails in much of the property and construction sectors. Currently, many buildings and infrastructure have long life cycles and high up-front capital costs with a risk-averse characteristic of investing further in novel technologies [8]; hence they are not easily able to adapt to changing socio-economic and environmental conditions. Furthermore, there are 'shifting goal posts' caused by amendments in political systems, modifications in building regulations, establishment of new incentives, innovation in research and development, and commercialisation of new technologies.

Future-proofing will add value to buildings and property developments within communities by facilitating informed and sustainable responses regarding the choice of technologies and policies and embracing a whole design approach (rather than a measure-by-measure approach), which will consider issues of embodied energy and specific planning for decommissioning. The primary objective is to identify appropriate management responses to the more predictable and, in particular, the uncertainty dimensions of the long-term future. A more context-specific understanding of future-proofing is the consideration of the life cycle of buildings by entailing an adaptable interior layout or a durable structure that can last through a number of cycles. There is no prescriptive way to future-proof a design, as choices are site-specific. Nonetheless, two categories of approaches can be distinguished, namely:

- *'Soft' future-proofing*: design response to mitigate the negative outcome of an identified high impact future trend, which can be quantified to a high degree of certainty via statistical analysis. An example is the uptake of renewable energy sources or whole building design as a means to address future climate change concerns.
- *'Hard' future-proofing*: design response to accommodate more uncertain future developments, which are not realised to date. An example is the use of flexible or adaptive designs to prepare for difficult to predict society changes, natural constraints or policy developments.

3.2 Design Considerations

A review of consultation reports and policy documents on sustainable or 'green' design reveals a set of aspirational criteria for various types of buildings not all of which are explicitly long-term focussed [9]. Leading examples apply sustainability criteria for planning and design at the neighbourhood or community scale and also address non-technical criteria, such as: the need for stakeholder participation or collaboration [10]; and/or funding mechanisms and incentives. Table 1 summarises aspects for future-proofed planning and design, which aim to ensure that adaptability and durability are considered in addition to specific 'green' design criteria, such as energy efficiency and innovation [11].

Table 1. Criteria for future-proofed planning and design at a community-level

Category	Criteria
Space, density and accessibility	Flexibility in size and allocation of internal space Multi-purpose spaces Medium to high-density development for centralised energy provision Human comfort and well-being Social acceptability and accessible buildings and neighbourhoods for an ageing population
Tenure types and house affordability	Range of tenure choices: private, social housing, co-housing, co-operative housing, and self-build Incentives for novel heating and electricity technologies
Energy and climate change	Diversification of energy mix due to finite resources Fuel poverty due to increasing energy costs Whole life cycle costing Embodied energy calculations Energy efficiency and shift to decarbonised energy • Centralised energy systems (e.g. district heating) • Renewable energy technologies • Emergency management plans for natural hazards, such as flooding • Inhibit the need for cooling

The buildings in exemplar sustainable communities contribute to their 'future-proof' by achieving, for example, zero or low carbon standards, or following specific utility management plans and carbon emissions monitoring [5]. Design pre-requisites for achieving this are: a building envelope that utilises solar thermal gains, good insulation and glazing, optimum air-tightness, natural cooling, low energy lighting and appliances. Table 2 illustrates design responses to aid future-proofing,

Table 2. Design responses for future-proofing at a building-level

Layout and Technologies	Materials, Waste and Water
Integrated solutions, such as green roofs for energy and water management Flexibility via a combination of low or zero carbon solutions Passive solar building design Real-time monitoring systems Space for energy storage systems Modern methods of constructions Smart facades	Low embodied energy steel, cement, aluminium and insulation materials Phase change materials Closed-loop networks to make obsolete the concept of waste (recycling) Rainwater and waste-water are resources; 'doing more with less' concept

which do not aim to point at specific technologies but rather to facilitate the process of a sustainable development strategy that all new developments should establish. These principles should be case-by-case specific and follow an iterative approach at successive development stages, informing planning and design activities.

A future-proofed design should proactively consider layout and space needs, and possible modifications in the operation of buildings that may be needed to accommodate the installation of new systems and technologies in the future [12]. Optimising the building envelope at the outset can cost-effectively enhance energy efficiency [8]; however the adoption of novel low or zero carbon technologies and innovative materials is more challenging. Even where new solutions are market-ready, high costs and the lack of skilled labour hamper their widespread uptake. At present, commercially viable low or zero carbon technologies at community-level are: large wind turbines located outside built-up areas and waste heat or biomass-fuelled combined heat power (CHP) plants [8, 13]. Cost-effective integrated building technologies are: solar thermal collectors; and ground source heat pumps [ibid]. Solar panels and micro-wind generation or micro-CHP still require large improvements in their market penetration and performance [8].

4 Decision-Support Techniques and Tools

4.1 Sustainability Assessment Techniques and Tools

This section begins with a general overview of decision-support techniques and tools used to inform stakeholder decision-making towards sustainability. Commentators agree that there is still no single, truly holistic sustainability assessment method [14], thus underpinning the need for improvements, which will address sustainability in its entirety [15]. Sustainability assessment techniques and tools have generally evolved under three main 'umbrellas', namely: (i) auditing or reporting against indicators or indices, (ii) product-related (e.g. life cycle or 'green' certification schemes), and (iii) impact assessment techniques or analytical tools [16]. This paper explores ex-ante design and decision-making; hence the first category is not of direct relevance. Research findings demonstrate that assessment methods can be differentiated by the following factors [16-17]: timing (ex-post or ex-ante assessment), coverage of sustainability themes (social, economic, and bio-physical issues), degree of integration of the themes or disciplines involved, level (projects, plans, programmes or policies). Table 3 illustrates four families of methods: *impact assessment techniques*; *analytical assessment tools*; *Life Cycle Assessment (LCA)*, and *futures techniques*. The latter category of tools has not been developed with sustainability in mind; however their orientation is of direct relevance to future-proofing. Nevertheless, scientific research on climate change highlights the use of scenario building as a well-established method for addressing the complexity and uncertainty embedded in long-term challenges.

Table 3. Decision-support techniques and tools to promote sustainable development

Family	Techniques or tools and key features	
Impact Assessment Techniques Prediction tools used to aid policy-making.	Strategic Environmental Assessment (SEA): well-established ex-ante environmental assessment of proposed policies at a more general policy, programme and plan (strategic) level.	
	Environmental Impact Assessment (EIA) Health Impact Assessment Social Impact Assessment	Theme-specific ex-ante assessment of impacts at project level aiming to reduce negative effects [16-17].
	Sustainability Assessment or Appraisal (SA): integrated ex-ante social, economic and environmental assessment at strategic regional level. It derives from EIA and SEA but promotes a more comprehensive approach towards sustainability. There is little consensus regarding the nature of SA, since it is an evolving concept that is used to a wide variety of approaches in various jurisdictions [17].	
Analytical Tools Narrowly-focussed tools which deliver particular types of analysis.	Uncertainty Analysis: proactive assessment of potential damages [16]. • Vulnerability Analysis • Risk Assessment	
	Cost-Benefit Analysis: ex-ante assessment technique applied for weighting the costs across various themes against the expected benefits [17]. It is a systematic and quantitative appraisal of economic and biophysical costs and benefits of alternative projects, strategies and policies [18].	
	Multi-Criteria Analysis: appropriate for addressing complex problems with high uncertainty, conflicting objectives, various data and information, multiple stakeholder interests, and the accounting for complex and evolving biophysical and socio-economic systems [17, 19]. Suitable for including intangible values into the decision-making. • Analytical Hierarchy Process (AHP): specific tool that can incorporate both qualitative and quantitative data into the process and may range from complex modelling to basic 'scoring'. AHP evaluates alternatives via a matrix of pair-wise comparisons, giving the highest score to the best alternative [ibid].	
	Stakeholder Analysis: a systematic qualitative approach to identify and analyse the various interests and perspectives involved in the decision-making process. • Social Network Analysis: particular tool that links stakeholder analysis with communication network theory [20].	
Life Cycle Assessment (LCA) A 'cradle to grave' environmental assessment of a product, process or activity [16].	Life Cycle Costing (LCC): economic approach in summing up the total costs of product or service over its lifetime	
	Life Cycle Cost Accounting Full Life Cycle Accounting	The only two life cycle costing tools that include assessment of environmental costs
Futures Techniques A new and unregulated research field which incorporates tools for understanding trends and drivers, identifying risks, and critical uncertainties and proactively formulating robust strategies that will prove to be resilient under plausible futures.	Scenario Planning: the main method for strategic future thinking. • Forecast • Normative (Backcasting) • Explorative Most future work is based on explorative scenarios, which do not aim to predict the future or to find the single best answer but rather to explore a range of plausible futures [21-22] Delphi Method: consultation process involving a wide group of independent experts seeking for consensus through rounds of predefined questions.	

Sustainability assessment techniques and tools give emphasis to particular themes, most often environmental, and are often used to describe a specific cause-effect relationship [17]. A key finding of this overview is the increasing interest in delivering new generation integrated assessment techniques and tools which combine standard impact assessment or analytical tools (e.g. Multi-Criteria Analysis) with futures techniques (e.g. scenario planning) for appraising sustainable futures [23-24]. It is argued that methods to aid future-proofed design responses should adopt a combination of the aforementioned techniques and tools.

4.2 Limitation of Existing Building Rating Tools

The literature demonstrates a large number of tools for evaluating the environmental performance of buildings, known as Environmental Assessment Methods (EAMs) [15]. These tools cover various: building components and building types; life cycle stages (e.g. design, construction or operation); scales (e.g. global, national or local); end-users (e.g. policy-makers, academics, consultants, developers or building owners); and environmental aspects of the building performance (e.g. indoor environmental quality or total energy consumption) [25]. In addition, the tools can be differentiated by the ‘scoring’ or rating method that is used [2]. In general, EAMs are distinguished in: *knowledge-based tools*, such as design briefs; *performance-based tools*, namely LCA or simulation decision-support tools [25]; and *building rating tools* which are mostly considered in this section, i.e. checklists and credit rating calculators for identifying design criteria and performance, such as BREEAM (Building Research Establishment Environmental Assessment Method in the UK), LEED (Leadership in Energy and Environmental Design in the US), CASBEE (Comprehensive Assessment System for Building Environmental Efficiency in Japan), SPeAR™ developed by Arup, GBTool in Canada, Green Globes™ US, HK-BEAM, etc.

The overview of existing building rating tools reveals a number of limitations, which hamper their effectiveness as tools to support sustainable design, in general, and future proofing, in particular. These, together with recommendations, include:

- Most rating tools are strongly linked to the environmental performance of buildings, underestimating or even overlooking social and economic aspects of the sustainability agenda [15].
- Few integrate a whole life cycle approach, calculate the embodied energy and give specific planning for decommissioning; either refurbishment or demolition. Furthermore, most of them do not consider real-time consumers’ behaviour into the evaluation process.
- They are not sufficiently flexible or user-friendly. Increase in flexibility will deliver tools applicable for various building types and adaptive to changing circumstances, whereas usable tools will present results in various formats [26]. For instance, user-friendly building guides with non technical language will facilitate a dialogue between developers and building occupants.
- There is not enough emphasis given to educate the building industry in terms of life cycle assessment, building design and impact on capital costs and household bills, innovation, and future uncertainties. Hence, post-construction

auditing and performance reporting should be instituted preferably to annual performance reviews. Apart from better appraisal on building's performance, annual reviews will create a database which will set the grounds for new research on future building design [15].

- They are mostly voluntary, and since legislation has always been of the strongest tools for adopting sustainable polices, policy-makers should consider more stringent schemes as an option to increase market penetration of rating tools [26]. Higher carbon reduction targets could assist in the commercialisation of emerging technologies and lead to the establishment of dynamic energy price regimes and/or the roll-out of smart metering.
- They do not effectively integrate the impacts of external environment into the building design, thus they could be expanded to assess the performance of the building stock within a neighbourhood or community [15].

5 Concluding Discussion

Future-proofing refers to strategic design for buildings or communities, which manages uncertainty and enhances sustainability over the long-term. Such design exhibits adaptability, resilience and durability, which are translated into criteria for internal space flexibility, accessibility by different consumer groups, housing tenure choices, and carbon reduction.

The overview of existing decision-support techniques and tools that are able to enhance efficient long-term thinking underlines the following aspects for their future development:

- Sustainability decision-support techniques and tools, in general, should increasingly adopt mixed (hybrid) approaches combining mainstream impact assessment or analytical methods with futures techniques.
- Building assessment tools, in particular, should adopt a whole life cycle approach, by calculating the embodied energy and monitoring the energy behaviours in the assessment process. Furthermore, these tools should have multiple forms, varying from advanced modelling for designers to non technical checklists for the lay-person to effectively educate both the construction industry and the general public. Lastly, the next generation of tools should evaluate community-based settlements, thus appraising the building stock holistically at a neighbourhood scale.

The above-mentioned considerations aim to orientate mainstream construction practice towards both value creation in buildings and property developments and informed decision-making for sustainable urban design.

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Enabling Low Carbon Living in New Housing Developments – A Triple Bottom Line Analysis

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Current approaches to the design and planning of new housing developments in the UK do not sufficiently contribute to the necessary carbon emission reductions that will be required to meet UK Government targets and to avoid dangerous climate change. A tool (the Climate Challenge Tool) has been developed, which allows house builders to calculate whole life carbon equivalent emissions and costs of various carbon and energy reduction options for new developments. These cover technical and soft measures; energy used within the home, energy embodied in the building materials and emissions from transport, food and waste treatment. The tool has been used to assess the potential of various carbon reduction options for a proposed new housing development in Cambridgeshire. It was found that carbon reductions can be achieved at much lower costs through an approach which enables sustainable lifestyles rather than one which purely focuses on reducing heat lost through the fabric of the building and improving the heating and lighting systems. Furthermore a triple-bottom line analysis shows additional social and economic benefits from many of the measures.

1 Introduction

The UK Government has set an 80% carbon emission reduction over 1990 levels by 2050 (Milliband, 2008). Intermediate targets of 30% by 2020 have also been set. These targets are ambitious and policies currently planned for the next ten years are considered insufficient for the 2020 target to be met (AEA Energy and Environment, 2008; DTI, 2007). UK policy focuses largely on technical solutions such as energy efficiency and renewable energy. For example, the potential from behavioural changes is not explicitly mentioned in the Energy White Paper (DTI, 2007), neither are policies that encourage such behavioural shifts.

The Government tends to gradually improve the carbon emissions of new homes, to achieve a 25% emission reduction over Part L by 2010, 44% by 2013 and a final leap to "zero carbon" by 2016 (OPSI, 2008). A zero carbon home is defined as a home that produces no net CO_2 emissions from energy used by the people living in the home (i.e. to heat and light the home). This however does not include energy used in the construction of the dwelling, energy embodied in the construction materials, energy embodied in goods consumed in the home or

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transport energy. There are currently no specific national policies that limit, or require an assessment of carbon emissions from these other ways in which energy is consumed by households.

Desai (2004) estimates the contribution of the energy used in a home built to 2002 Building Regulation specifications to the overall footprint of a UK resident using a consumer based accounting methodology. He found that only 11 per cent of the carbon emissions generated by a typical UK resident living in a new home is created through direct energy use (heat and power) in the home itself. This raises the question as to whether there is anything that a house builder can do to encourage emission reduction in the other categories which amount to 89 per cent of emissions UK consumers are responsible for.

Whilst there is significant potential for energy and carbon savings through technological measures such as building insulation, use of high performance glazing, and efficient heating systems (Performance and Innovation Unit, 2002), there is also significant potential for savings through behavioural and lifestyle changes (Oxford University Environmental Change Institute 1997) both within and outside the home. Many of these can be influenced by the design of dwellings and the developments within which they sit. For example, the location of a new housing development (in particular its proximity to services and facilities, including shops and public transport) can influence travel choices and thus the amount of energy used for travel, as can soft measures such as the production of a travel plan (Titheridge 2004). Some of measures can be incorporated into new housing developments through the land use planning system i.e. through transport and environmental assessments, and by applying certain planning conditions.

Given that our dwellings last decades, if not hundreds of years, it makes sense to take a more holistic approach than currently being adopted through the building regulations; an approach which allows behavioural and lifestyle factors to be taken into account alongside technological fixes, when assessing options for reducing carbon emissions from new housing developments.

In order to make the right choices we need to fully understand a number of factors including: the carbon equivalent emissions implications over the lifetime; the impact of the measure upon the residents; the cost implications of different measures; and the wider sustainability implications of the different measures beyond those experienced by the residents.

2 Methodology

A tool (the Climate Challenge Tool) has been developed that will enable developers to compare carbon emission reduction potential for a wide range of measures that can be designed into new housing developments. The measures included in the tool cover both technical solutions such as building integrated renewable energy and soft measures that reduce carbon emissions through encouraging environmentally responsible behavioural changes.

The tool assesses options from a triple bottom line perspective by quantifying carbon as an indicator for environmental impact and costs as an indicator for economic impact. Social acceptability and any impacts on the residents of the housing development are incorporated as qualitative indicators for social impact. The tool was developed in Microsoft Excel and uses a database of carbon emission reduction measures, their potential for carbon savings and their cost, to calculate the tonnes of carbon equivalent emissions avoided per £ invested. The tool then ranks the measures being compared on the basis of cost effectiveness, defined as £ per tonne of CO_2 saved. This information is displayed alongside information on the social impacts of each measure. A five point scale is then used to indicate which measures may be most appropriate. On this basis developers can make informed choices on how to deliver carbon emissions reductions and other sustainability measures.

Within the tool, capital costs are offset against any monetary savings. These saving were discounted over the lifetime of the measure using net present value (NPV) calculations. In addition to capital costs energy savings and maintenance costs plus replacement costs were taken into account. The NPV was calculated using a 3% discount rate. Available secondary data was used to build the database of carbon reduction measures. Where reliable data on carbon savings potential and cost was not available best estimates were used. Multiple data sources were used to increase the reliability of the estimates. This data came from, for example, BRE good practice publications, academic literature, government statistics, empirically determined emission reduction achievements from Bioregional and Camco, Spons and quotations from suppliers. Data from the EPA's WARM Tool was used to assess life cycle emission abatement potential of different waste management measures. In addition input was sought from a range of relevant stakeholders to gain insight on the potential for carbon emissions reduction from soft measures that rely on behavioural change. The social acceptability and other social impacts of the measures were determined based on the findings of a consumer preference survey by Ipsos MORI (2006) and a focus group workshop conducted with sustainability and building consultants from Camco International and property developer Crest Nicolson.

The tool works from a lifestyles-based view. In other words, the aim was to include within the tool emissions generated as a result of a occupying households' lifestyle and behavioural choices, from the energy they use within the home, to the travel they make, the food they buy and the amount and way in which they dispose of waste. Such a lifestyles-based view has the potential to allow business to target those products and services which have highest overall carbon emissions. Business should then be able to proactively reduce carbon emissions throughout the supply chain in a way that also delivers financial benefits over time. This point of view also means that it is easier to estimate the effect of a decision upon occupant behaviour and therefore permits including both emission savings from technical solutions and from behavioural shifts. Furthermore, policy makers should be able to formulate sensible policies which both take into account the end consumer (i.e. the occupants of the development once it is completed) and the overall carbon emissions implication of their policies.

Five categories of measures are considered within the tool. These categories have been chosen to reflect areas which are significant generators of carbon emissions and can, to some extent, be influenced by the house builder or developer. These categories are:

1. **Household energy:** the carbon emitted by a home's occupants through consumption of energy (electricity and fossil fuels such as gas) within the dwelling, for example for heating and lighting. A house builder can influence these emissions through energy efficient design and building-integrated renewable and low carbon energy sources.
2. **Building materials:** carbon is generated in the production and transport of the building materials, construction on site and disposal at the end of the life of the building. A developer can influence this through, for example, by choosing locally produced material, building materials that require little energy in their manufacture (e.g. timber), and by avoiding or recycling construction waste.
3. **Transport from commuting:** the carbon emitted from cars, and public transport. A house builder can influence this by choosing a site where people can live close to where they work and by provision of low carbon (car sharing, public transport) and carbon free (attractive cycling paths and walkways) transport solutions, or by creating jobs locally, for example through incorporating commercial space into the development.
4. **Food:** the embodied carbon in food from agricultural machinery, transport, packaging material, storage and supermarket energy can be influenced by the developer by providing allotments to grow food, promoting low carbon/ethical food, or by creating local amenities which offer local and ethical produce.
5. **Waste:** providing recycling and composting facilities reduces waste send to landfill sites where it emits methane, a very strong greenhouse gas. In addition replacing virgin products with recycled products often means a lower carbon footprint in the manufacture of the product. A house builder can influence recycling rates by including good recycling provisions and by raising awareness (James and Desai, 2003).

To illustrate the potential of the tool, it was used to examine carbon saving measures for a proposed development on the edge of Cambridge of approximately 2000 houses containing a mixture of houses and flats.

3 Results

3.1 Environmental and Economic Assessment

The quantitative analysis assesses the cost and carbon implications of various household energy (energy efficiency and renewable energy) options, building material choices, sustainable transport options, and actions for reducing emissions from waste and food.

Figure 1 below displays one of the outputs of the tool: life cycle carbon abatement costs for energy efficiency measures applied to the case study development. Energy efficiency measures are ordered according to their net present value over tones of CO_2e saved ratio. A number of measures save carbon and have a negative NPV; this is because the value of energy savings is greater than the initial capital outlay even after discounting. It therefore makes most sense to incorporate these measures into a housing development, in terms of both reducing emissions and saving costs over the life time of the dwellings. Other measures save carbon at widely varying costs. Note, not all these measure are included in the UK building regulation's SAP assessment (BRE, 2009). For example, the water reduction measures and A-rated appliances are not regulated. Similar ranking was also performed for renewable energy options, waste options, building material choices, and sustainable food propositions.

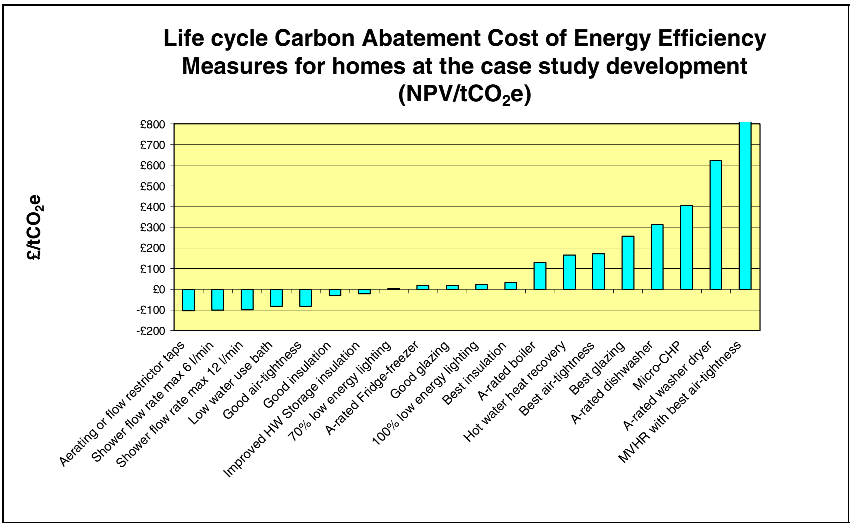

Fig. 1. Life cycle carbon abatement costs of energy efficiency measures for homes within the case study development (£per tonne CO_2e saved)

Figure 2 displays a number of options to reduce carbon emissions through encouraging sustainable lifestyle choices at the case study site. A number of measures cost less than £100 per tonne of CO_2; these are site location, mix of uses on site, awareness-raising through an on-site sustainable living officer, and provision of communal facilities (indoor and outdoor). There are also a number of cost effective measures relating to energy efficiency and building material choice. The majority of carbon emission reduction measures however do involve additional costs. The difference in costs per unit of CO_2e saved varied significantly.

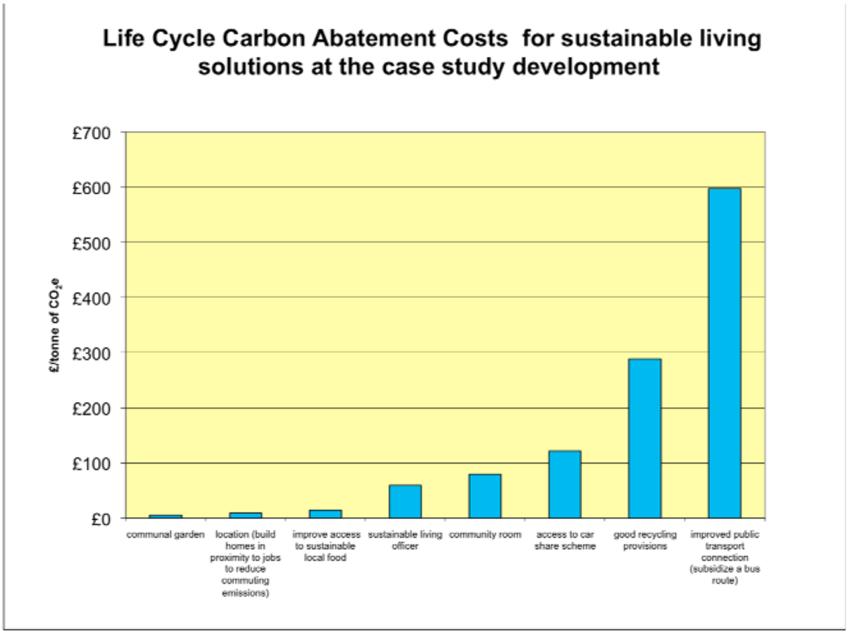

Fig. 2. Life cycle abatement costs for sustainable living solutions at the case study development

Based on analysis reported elsewhere (Broer and Titheridge, 2010), a home built to the current energy efficiency standards required under part L of the building regulations would have a household carbon footprint of about 2.9 tonnes CO_2 per household per year. The analysis shows that the extra costs of achieving a similar level of CO_2e emission reduction as would be required to move from current new build standards to a zero carbon home using the lifestyle approach for the case study site would amount to approximately £4000 per home. Sensitivity analysis reveals that costs would be similar for other housing developments of similar scale and may range between £3k per home and £10k per home. The additional capital cost of building a zero carbon home compared to building to current standards was estimated to be in the order of £20-£36,000 (op. cit). . Table 1 shows s a range of measures for the case study development and the emissions savings which were calculated to be achievable from each.

Table 1. Estimated CO_2e savings per household at the case study development for measures that go beyond current building regulations

Measures	**Annual CO_2e reduction (tCO_2e/household/yr**
Low cost energy efficiency measures (air tightness, low e lighting, low flow tabs and showers)	0.3
Solar hot water	0.3
20% increase in waste reduction and recycling through good provisions and awareness raising	0.5
15% carbon emission reduction of food carbon footprint through awareness raising and advice on organic veggie box schemes, once a week local farmers market	0.6
25% reduction in commuting transport emissions though choosing a location with jobs close to the homes, increased cycling, car share scheme and public transport	0.6
Low cost building material with low embodied carbon is chosen (timber frame, timber and tile flooring, timber cladding, site construction waste reduction, minimizing the use of concrete and lead)	0.3
Sustainable living officer achieves 10% uplift in recycling rates, sustainable food uptake, uptake of sustainable transport options and home energy management	0.3
Total	3.1

3.2 Social Assessment

The social assessment covered the customer acceptability and the social impact upon the residents. Table 2 presents a summary of the analysis that was carried out, with various measures bundled into themes. From the analysis it was clear that many of the measures which are outside the normal set considered by developers, especially those relating to transport and food, can significantly add to the wellbeing of the residents, something which many of the traditional low carbon solutions to reduce household energy consumption cannot achieve.

Table 2. Summary of the impact of various measures upon residents

Theme	Residents impact	Judgement
Energy efficiency measures	Improve thermal comfort and day-lighting	positive
Renewable energy generation	Some renewables have little or no impact upon the residents (e.g. solar hot water, heat pumps); others have negative impacts (e.g. biomass reduces air quality and can be less reliable, wind has visual impact)	neutral or negative
Building materials	Impact can be positive or negative depending on taste and choice of materials. Use of timber is becoming increasingly popular. Timber framed houses can be noisier.	neutral
Transport	Building mixed-use developments that match the needs and wishes of the future residents can hugely improve the livelihoods of the residents. Reducing the commute creates time for other activities.	highly positive
Waste	Residents need extra space for recycling bins in their home and need to spend time separating the waste. A space where residents can leave useable things they no longer want for others to take, will benefit those on low income most.	neutral
Food	Making ethical and healthy food easily accessible can improve the health of the residents and support local farmers	highly positive

3.3 The Triple-Bottom Line Assessment

The results from the quantitative analysis of environmental and economic impacts were combined with the results from the qualitative assessment of social impacts to produce a rating for each measure based on its appropriateness (a combination of the three elements of assessment) for the case study development. Table 3 is an example of this analysis; it shows the results for a selection of the renewable energy options that were investigated. The scoring system used in the Table 3 below

Table 3. Example of renewable energy measures assessment

Renewable energy source	**Description, practical implications, acceptability and residents impact**	**Capital cost and environmental cost/benefit ratio**	**Recommendation**
Wind turbine	One medium-large scale wind turbine could be located on the edge of the site or close by. Residents are impacted visually. Noise can be an issue; turbines are available that cannot normally be heard from 10 metres. This is economically viable in the UK where high wind speeds prevail. Planning permission can be difficult to obtain as local opposition can be high.	Capital costs:£160 per dwelling Environmental cost/benefit ratio: £9 per tonne of CO_2e	**** Recommended if planning permission can be obtained
Solar water heating	Solar hot water panels can provide a visual statement. Solar hot water panels are non intrusive, and therefore have neither a positive nor a negative impact upon the residents. They are normally sized to provide 50% of annual hot water demand. On their own they would not meet the 10% renewable energy target. It is a simple and low cost technology with minimal maintenance requirements. The cost calculation assumes that all homes will have individual solar hot water panels. Communal systems could be installed with lower capital costs but potentially higher maintenance costs resulting from the need for O&M, metering and billing.	Capital costs: £1,860 per dwelling Environmental cost/benefit ratio: £268/tonne of CO_2e	***** Highly recommended

indicates our judgment of appropriateness. We are basing this on a sliding scale ranging from * indicating unsuitable to ***** indicating highly appropriate. Costs should be read as generic guidance only and will fluctuate according to specific setup and the detailed design of the site. Please note that this analysis is site specific for the development in Cambridgeshire. Many aspects will be similar for other developments as well; however local resources (such as wind speeds) will affect the recommendations. The renewable energy measures were assumed to be sized to meet a 10% household energy carbon emission reduction target.

4 Discussion and Conclusions

The Climate Challenge Tool presented in this paper allows a wide variety of different measures to be compared on the basis of not just their cost and carbon savings potential but also on their social acceptability and wider impacts. This will enable developers to incorporate a range of measures into their housing developments that will not just reduce carbon emissions and meet the energy efficiency requirements of the building regulations but will also appeal to potential purchasers of the properties.

It has been shown through a triple-bottom line assessment of a case study housing development in Cambridgeshire that carbon emission reductions can be achieved at much lower costs through an approach that enables sustainable lifestyles, rather than focusing purely on reducing the emissions of the building in its use. In addition many of the low carbon lifestyle solutions have greater additional benefits to the residents than energy efficiency and renewable energy measures. Good low carbon transport provisions (walking, cycling, public transport, car-share schemes); access to jobs, amenities and low carbon consumables; convenient recycling facilities, and a sustainability officer who supports implementation and community cohesion, may be more valuable to the local residents and the wider local economy, than renewable energy and energy efficiency measures only.

Whilst the findings are specific for this site, similar outcomes are expected for other developments in the UK. Changes would result from changes in household size and composition, environmental resource parameters, local transport networks, local amenities and overall size of the development. Findings show that many carbon reduction measures, such as building integrated renewable energy, currently required by many local planning authorities, cost far more per tonne of carbon saved than other unregulated solutions. Many of the lifestyle option have additional benefits to the residents and may even without additional policy incentives be a viable option for progressive house builders.

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Aspects of Life Cycle Investing for Sustainable Refurbishments in Australia

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Abstract. Refurbishing existing buildings to reduce greenhouse gas (GHG) emissions is important in meeting Australian government aspirational targets of a minimum of 25% by 2020. Previous studies of such refurbishments tend to provide only general upgrade, cost and investment advice because they apply generic building attributes and location criteria. They also ignore life cycle aspects such as component assets being replaced at the end of their service life and sustainability investments are over-and-above these 'normal' investments. This research investigates an appropriate methodology for more realistic evaluations of refurbishments and life cycle investment to upgrade buildings to 5 to 6-stars on the NABERS Australian energy rating system. The methodology is presented and discussed as a suite of inputs, simulation tools, and outputs. Preliminary results from ongoing work illustrate the outputs and their interrelatedness.

This work focuses on façade improvements because they can have a major influence on the energy consumption and upgrades based on HVACs alone are often insufficient in achieving the required energy savings.

'Sets of improvements' are introduced as a means of controlling the variables by way of façade improvements and related changes to mechanical and electrical systems required because of the interconnectedness of building envelopes and these services.

1 Introduction

International research indicates that reducing energy consumption and greenhouse gas (GHG) emissions is vital for the mitigation of climate change (Stern 2006; IPCC 2007). Australian research shows that its per capita emissions are among the highest in the world (Garnaut, 2008). This is a reason for the Australian Government to commit to cut the GHG emissions by a minimum of 25% by 2020. As buildings contribute approximately 23% of GHG emissions (RAIA, 2008) buildings will be important in achieving these reductions. An implication of a 25% cut is that commercial buildings will need to achieve an average energy rating of 4.5-stars on the Australian National Australian Building Energy Rating System (NABERS) (formerly Australian Building Greenhouse Rating - ABGR) in order to achieve the necessary abatement of CO_2 emissions.

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New, more sustainable buildings can be more energy efficient but these additions to the building stock constitute as little as 2% annually (McNamara, 2008). Furthermore, the global financial crisis has severely curtailed such investments making existing buildings' refurbishment even more important in achieving reductions by 2020. Therefore, a big challenge in Australia is the refurbishment of the existing building stock directed towards reduced operational energy and associated GHG emissions.

In addition, government measures to abate Australia's greenhouse gas emissions, such as the mandatory disclosure of energy consumption for buildings (Australian Government, 2008), threaten obsolescence for existing buildings; particularly lower grade, B & C-grade, office buildings which make up approximately 80% of the Australian office building stock (Langdon, 2009). Furthermore, many owners of these office buildings are ill-equipped to do the research necessary to make decisions to invest in sustainability in their particular circumstances.

Previous studies into ways of improving energy consumption of existing buildings are of two types – improvements to building management, for example Warren Centre (2009), or refurbishment of the physical asset.

There are four critiques of existing investment approaches to sustainability refurbishments. These are:

1. Studies of costs (and capital expenditure) for these refurbishments vary wildly, with figures from as high as $962/m^2 (Langdon, 2008) to as little as $6/m^2 (Arndt, 2009). In part, this is because they ignore the particulars of building attributes and locations – which they must as generic studies;
2. The use of techniques, such as payback periods, that are acknowledged as crude because they ignore the time-value of money;
3. Assumptions that the investment would not otherwise be undertaken, and consequential to this;
4. Ignoring the fact that investments occur as part of normal building life cycles where component assets – parts of HVACs, lifts and the like – are replaced at the ends of their service lives. This means that a sustainability refurbishment may be only an increment relative to what is already occurring.

Clearly, different real-life circumstances for buildings may require different refurbishment and investment strategies, but which to consider and what to do is problematic for building owners in light of generic figures. This necessitates building owners attempting to make their own sense of such information in how it applies to their own, idiosyncratic situation, or, as may be the case, deciding not to make an upgrade sustainable, as it is more difficult and deemed not worth the effort.

This work focuses on façade improvements because they can have a major impact on the operational energy and upgrades based on HVACs alone are sometimes insufficient in achieving the required energy savings. Given the research focus is on façade refurbishment the façade technology for simulation was selected using a systematic approach to façade design (Hertzsch, 1999). Because of the interconnectedness of facades and aspects of building services, such as HVAC & lighting, a ‘set of improvements’ were derived consequential to and consistent with the façade technology. These sets of improvements are a technique to control the number of possible variables available as refurbishment options in this investigation of a methodology of analysis rather than absolute results on all possible refurbishment options.

2 Aims

The research investigated an appropriate methodology for more realistic evaluations of refurbishment options and life cycle investment strategies to upgrade buildings to 5 or 6-star NABERS energy rating. Such ratings exceed the 4.5-star average noted above but are necessary in achieving that average to compensate for buildings that are unable to be successfully upgraded to that level, for example, heritage buildings. The successful development of such a methodology would give greater precision and more sophistication to understanding refurbishment costs and their optimal timing, as a life cycle investment which is a more appropriate, holistic approach given sustainability issues require a long-term perspective.

The project, as a whole, aims to addresses a number of aspects: 1) Building use; 2) Building attributes; 3) Location and resultant climatic conditions; and 4) Life cycle investment strategies. To allow these to be managed in the research process the methodology is presented here.

This paper addresses a more limited range of these aspects and presents a few refurbishment options from our ongoing project to illustrate the efficacy of the work.

3 Methods

One Melbourne office building (21 stories plus a 9-level carparking podium) was chosen to represent a specific building use. The building’s owner provided access to energy consumption data, plans, specifications and equipment schedules. From this an electronic building model was constructed to allow energy simulation using ‘Design Builder’ to simulate the effects of the improvements. These improvements formed the basis for analyzing the resultant expenditures as investments. A total of 9 scenarios were developed for analysis to represent the range of variables that need to be examined in order to compare refurbishment costs and consequential investment strategies from this single building study.

The first three scenarios are life cycle investment only analyses as base case examples of ‘normal’ asset investment strategies that employed an Excel spreadsheet-based ten-year life cycle asset management model developed by Dr Frank Bromilow and taught in the University of Melbourne’s Faculty of Architecture, Building and Planning. The investment analysis model included in its input data set issues such as:

- Asset value at commencement and termination of the analysis period;
- Life cycle investments in renewal of component assets such as HVAC systems at the end of their service life, and the like;
- Income; and
- Taxation of income and depreciation allowances available under the Australian taxation system.

The next six scenarios were sustainability upgrades. The second group of three scenarios examined, in order, an HVAC upgrade, a façade upgrade and a combination of the two because of the interconnectedness of these two aspects of building science. The third set of scenarios replicates the second set of three scenarios above in Brisbane. It was theorized that the sets of improvements would differ because of Brisbane's sub-tropical climate. During the course of the research a number of sub-scenarios emerged, for instance, two different façade refurbishments.

The refurbishment scenarios introduced the concept of 'sets of improvements' focused on, in this study, façade technologies, either singly or in combination with consequentially required refurbishment of HVAC, and lighting systems. In general, energy consumption improvements can be made from looking at the following building elements and technologies: Façade type, daylight use, shading, artificial light fittings, passive cooling strategies, energy sources, heat recovery, heat pumps, HVAC system, building automation, rainwater collection, building material ecology, and others. It is important that the list is not understood as a 'shopping list' with a 'use as many as possible' approach to minimize operational energy demand. Rather, what is needed is to maximize the consumption reduction with the minimum of technologies and building components that take advantage of the outdoor environment as much as possible.

Costs related to these sets of improvements (both capital expenditure for the refurbishment and consequential operational expenditures) were then analyzed using the same investment analytical techniques used for the base case. In the results presented here the costs of the upgrades were included as an investment in the first year of the analysis period, but investment to coincide with normal asset component renewal also needs to be simulated.

4 Modeling the Analysis

The analysis method used here represents a significant increase in sophistication over those often seen in many analyses of sustainability refurbishments, for instance, Davis Langdon (2008), Kelly & Hunter (2009), and others. This necessitates modeling of the analysis in order to understand the interlinking of inputs, simulation tools and outputs.

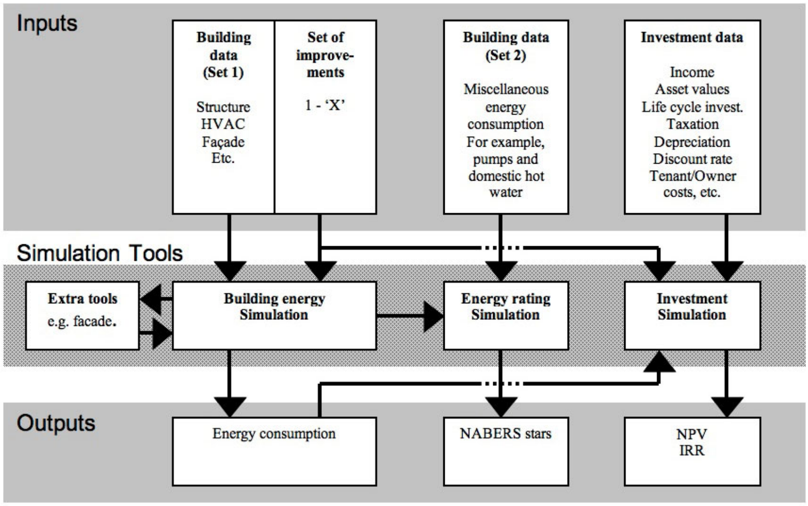

Fig. 1. Modeling the methodology for analyses and simulations of one building

The methodology consists of three phases of inputs, simulation tools and outputs, some of which provide inputs for other simulations. The fundamental input data consists of:

- Building data (Set 1) which are the building attributes by way of construction materials (structure), floor area, height, HVAC, lighting and façade technologies, location, and more, that are necessary to simulate the buildings energy performance;
- The 'sets of improvements' that constitute the scenarios' refurbishment options for further building simulation and provide costs for investments as capital expenditure in the investment analysis;
- Building data (Set 2) are, primarily, further energy consumption data necessary for completing the energy rating simulation, for example, services pumps, lifts, domestic hot water; common lighting, and carpark lighting; and
- Investment data, such as those noted above in the Methods section.

Three core simulation tools were used:

- Building Energy Simulation (Design Builder), which calculates outputs of energy consumption data which in turn provides an input to the investment analysis as the reduction in energy use and a change, consequentially, in operational expenditure;
- Energy Rating Simulation (NABERS in this instance). The output from this was the NABERS 'star rating' that was important performance target here; and
- Investment Simulation which was based on a 10-year life cycle producing both Net Present Value (NPV) as a discounted sum of cashflows over the analysis period and Internal Rate of Return (IRR) as a measure of the investment value of the asset.

A fourth, subsidiary set of simulation tools were included as an adjunct to the Building Simulation Tool to bring additional refined data into that simulation. Certain building elements in old buildings may not be included in the libraries of new simulation tools, thus these tools can provide a more precise reflection of the elements' impact on the energy consumption by including detailed simulation of the façade, or façade elements, such as framing and its edge effect.

5 Set of Improvements

An appropriate set of improvements were derived using the 'systematic approach to façade design' (Hertzsch 1999). It considers the magnitudes of principle impacts to derive the minimum set of functions for the maximum savings in the operational energy demand and takes into consideration the need for façade 'responsiveness' due to outdoor environmental conditions and internal heat gains for the respective building and location.

The scenarios' sets of improvements were:

- A null set as a base case;
- A 'normal sustainable refurbishment' that reflects the Australian 'state of the art' upgrade that concentrates on HVAC alone (and some related technologies). In this study we added heat recovery, variable speed drives to air-handling unit fans, and perimeter lighting control to the car park;
- 'Façade Option A': changed window-wall-ratios (WWR) due to an added spandrel panel, an extra glass layer creates a 'double glazed unit (DGU)', internal shading system connected to the BMS, additional perimeter lighting control to office levels and the carpark; and
- 'Façade Option B': Same WWR as façade scenario 'A', a good DGU used with low-e coating, external shading connected to the BMS as well as the same perimeter lighting controls as in façade Option 'A'

The façade Option 'A' and 'B' are compared with the base case in Figure 2.

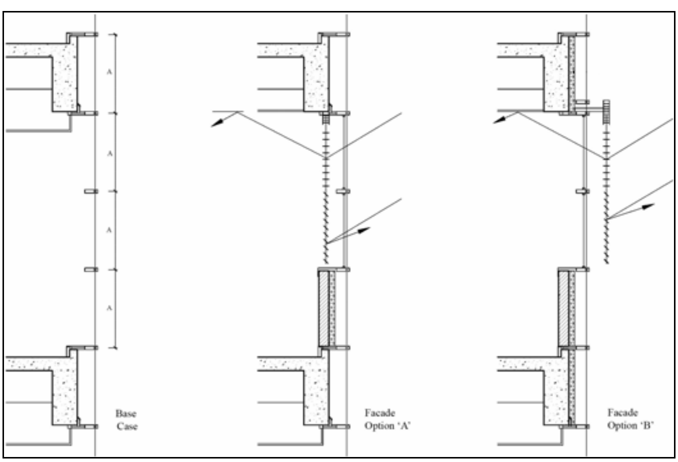

Fig. 2. Diagrammatic sections of base case (left) and façade refurbishment 'A' and 'B'

6 Results

The results of this analysis are in three forms (Table 1):

- Technical results for reduction in the energy consumption from the modeled refurbishment options;
- The consequential Energy rating; and
- Results of the life cycle investment analysis as NPVs and IRRs.

These results from the first run of simulations show that the sets of improvements produce marked reductions in energy consumption and a consequential improvement in the NABERS energy rating. However, none of the sets of improvements alone came close to achieving the targeted 5 to 6-star rating. This suggests that any set of improvements needs to include upgrades to both HVAC and facades as either alone is insufficient.

The investments were also progressively larger through Simulations 2 to 4. These reflect in the changes to NPV and IRR simply as a result of how these calculations are affected by large capital expenditures (as here) early in the period of analysis. The usefulness of IRRs is in comparing this investment with an investment hurdle rate. The incremental change is less important than whether the result is more or less than the hurdle rate. In this research we are unfamiliar with the asset owner's rate, but the decline in IRR values is, never-the-less, disturbing for any asset owner.

Table 1. Preliminary results of simulations

	Reduction in energy consumption		NABERS rating	Capital expenditure	Net Present Value (NPV)	Internal Rate of Return (IRR)
	mWh p.a.	mJ p.a.	Stars	('000s)	('000s)	(%)
Simulation 1 *(Base case)*	0	0	2.5	0	-$6,646[1]	11.0
Simulation 2 *HVAC*	744	20	3.5	$492	-$6,516	11.1
Simulation 3 *Façade Option A*	933	904	3.5	$10,811	-$14,200	7.2
Simulation 4 *Façade Option B*	1,238	3,219	4.0	$15,800	-$17,736	5.4

[1] This negative NPV is largely a factor of the initial asset value being considered high and large capital expenditures in Year 1 of analysis required to replace aged component assets. The terminal value is also influential. These asset values need to be examined further.

A number of investment data have not been considered here, for example:

- Whether there was any rental premium available due to the upgrade;
- Effects of obsolescence in the base case due to lower than desirable sustainability levels in the rental market;
- Effects on tenant expenses such as power, and particularly lighting costs; and
- Timing of the investment to reflect life cycle capital expenditures. For instance, we know that for this building the asset management plan includes HVAC upgrades in the second year of our analysis period.

7 Discussion

The refurbishment of HVACs together with a building automation/management system (BMS) and energy efficient lighting have recently become a norm, of sorts, in Australia. In part this is because of the threat of compulsory disclosure of buildings' energy consumption. However, the results clearly show that this 'normal sustainable upgrade' seems insufficient in achieving the targeted 5 to 6-star NABERS rating. Additional, more dramatic and costly, refurbishments (such as the façade refurbishments here) are likely to be needed in order to reach government targets of 25% reductions in GHGs by 2020.

This work shows that the refurbishment of existing buildings to reduce GHGs is a complex problem at the intersection of technical, building science solutions and investment decisions by asset owners. The latter occur in particular national circumstances of:

- Norms of space occupation. For instance, Australia has owner-tenants as the norm while elsewhere owner-occupiers may be more common; and
- Taxation relief available to asset owners.

Yet, the target of achieving significant energy reduction, in this study 5 to 6-star NABERS, is universal.

We have critiqued existing approaches to this complex problem as inadequate; often being simplistic by overlooking the particular circumstances of actual buildings. To address this critique we propose a more sophisticated approach through a methodology integrating several simulation tools, each of which allows sophisticated analysis of their input data.

While the results presented here belie the sophistication inherent in the methodology we believe it a relatively straight-forward process to model a number of significant technical and investment variables, such as:

- Reconsidered sets of improvements to reduce capital expenditure;
- Rising energy costs in different energy efficiency scenarios;
- Obsolescence by way of changes to rental levels and terminal yields;

- Taxation incentives, such as accelerated depreciation allowances, to support the viability of owners' capital expenditures, which on these results are not viable; and
- Investment timing to match end-of-service life asset renewal programs.

Despite the methodology's sophistication a number of important energy sustainability benefits are not considered here including:

- Improvements in indoor environmental quality and productivity, the benefits of which flow to the tenant occupants, and despite arguments that these benefits should be monetizable through uplifts in rentals that flow into capitalized asset values, this rarely seems to occur at present. This is part of sustainable built environments' 'viscous circle of blame' (Cadman, 2007);
- Increases in usable areas, if not net lettable areas. In this study's building it was observed that because of the façade design – full height glazing – occupant desks were arranged away from the façade as a buffer against excessive internal surface temperatures, localized heat gain and glare.

8 Conclusion

This paper establishes the viability of a sophisticated methodology useful for analyzing sustainable refurbishments as life cycle investments. The methodology has been developed by integrating a suite of simulation tools spanning from building energy performance to life cycle asset management.

While the results reported here come from a limited number of simulations, those calculations used actual building data as inputs and are based on a selection of realistic variables; variables that could be expanded to examine the effects of changes to other technical, building aspects and investment data. The, albeit limited, results here show that sets of improvements to make buildings sustainable at 5 to 6-star NABERS levels should include façade and HVAC refurbishments.

Further research is required to examine a greater selection of variables and multiple buildings to provide more generalizable results and more widely applicable guidance to asset owners in making decisions about investments to reduce their assets' GHG emissions.

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Advent of Climate Change and Resultant Energy Related Obsolescence in the Built Environment

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Abstract. By 2050s the UK is expected to experience: increase in average summer mean temperatures (predicted to rise by upto 3.5^{o}C) and frequency of heatwaves / very hot days; and increases in winter precipitation (of up to 20%) and possibly more frequent severe storms. Also, in 2050s approximately 70% of UK buildings will have been built before 2010, which due to aforesaid climate change factors will suffer from various types of obsolescence – including energy related obsolescence. Thus, if sustainable built environment is to accommodate climate change and the investment in these buildings (which was approximately £129 billions in 2007 in the UK alone) is to be protected, action needs to be taken now to assess the vulnerability and resilience of the existing UK built environment; and plan adaptation / mitigation interventions, that allow to continue to support the quality of life and well-being of UK citizens. The situation with other countries around the globe is not dissimilar, although there may be some variation in nature and quantity of climate change, and the way climate change impacts manifest themselves in relation to the resources and governance of a given country. Failure to act now will mean that the costs of tackling climate change in future will be much higher, jeopardising not only environmental but also economic sustainability. In view of these concerns, this paper will focus on obsolescence that is associated with energy and climate change. The climate change factors that shall be specifically covered include global warming, flooding, carbon emissions, carbon cut targets, environmental legislation and building regulations. Obsolescence types are categorised into direct and indirect obsolescence groups. Moreover, although the paper will mention both generation and consumption of energy, the later shall be more specifically addressed due to accelerating demand of power as well as

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pressures for efficient energy consumption in buildings to cut carbon emissions. Finally, in light of to date literature review, the paper will emphasise requirement of a fundamental framework for identification and categorisation of energy related obsolescence in the built environment, which shall attract interests for further investigation from both researchers and practitioners.

1 Introduction

Any constituent (such as a building or infrastructure) of built environment grows to become obsolete or suffers increasing obsolescence over time. There is a host of factors which play a role either alone or collectively to cause obsolescence. Examples of these factors are not only conventional such as aging, wear & tear, but also, rather contemporary factors including energy consumption efficiency, environmental pressures such as reduction of carbon emissions, legislation / regulations, change of use, clean and waste water management, water quality and resources, land use, land contamination / soil quality, changing occupier / end user demands, sustainable waste management, ecological concerns, health & safety, and climate change. These factors can be categorised in different groups from various perspectives. However, the main focus of this paper is those factors which can be addressed under the banner of climate change category in the context of climate change mitigation and / or adaptation. However, the paper's scope is not a specific constituent type of built environment (e.g. a certain building type or infrastructure class) or a specific constituent itself (e.g. a given commercial building, a given hospital, a specific stretch of railway or road network, etc.). The paper is to consider obsolescence in a broad sense around various climate change phenomena and yet with focus to energy.

Currently, the most widely accepted climate change scenarios or projections predict increases of between 1 to 3.5^{o}C for the global annual average temperatures (Crawley, 2010). On the top of global warming as a result of climate change, over the past few decades, there has been a significant trend towards increasingly larger urban areas. This concentration of transportation infrastructure and buildings often results in urban heat islands – increasing of the cooling loads on buildings. For example, London Heathrow, Los Angeles, and Phoenix have all seen average temperature increases of at least 1^{o}C over the past few decades (Crawley, 2010). Further more, floods, storms, droughts, and extreme temperatures strike communities around the globe each year. The top ten disasters of 2004, in terms of the number of people affected, were all weather and climate-related. These types of disasters have occurred throughout history but with total damages amounting to US$130 billion from just these ten events, it is clear that the necessary steps to reduce disasters have not yet been taken (CRED, 2005a; 2005b). As climate change begins to manifest itself—in the form of increased frequency and intensity of hazards such as floods, storms, heat waves, and drought—the need for communities to address climate risks is becoming urgent. The coming decades are likely to bring, among other changes, altered precipitation patterns so that many areas will experience more frequent floods and landslides, while others will experience prolonged drought and wildfires (IPCC, 2001; IATF, 2010). This simply will also lead to increase degree of obsolescence both in buildings as well as infrastructures of our built environment around the world.

Specifically for the UK, by 2050s the UK is expected to experience: increases in average summer mean temperatures (predicted to rise by up to 3.5^{o}C) and frequency of heat-waves / very hot days; and increases in winter precipitation (of up to 20%) and possibly more frequent severe storms (Hulme et. al., 2002). Also, in 2050s approximately 70% of UK buildings will have been built before 2010. Thus, if the investment in these buildings, which was approximately £129 billion in 2007, (UK Status online, 2007), is to be protected, action needs to be taken now to assess the vulnerability and resilience of the existing UK built environment, and plan adaptation and mitigation interventions, that allow to continue to support the quality of life and well-being of UK citizens. Failure to act now will mean that the costs of tackling climate change in future will be much higher (CBI, 2007). The UK will also miss out on the commercial opportunities that will emerge on the pathway to a low carbon economy (CBI, 2007). Thus, there is a growing need for long-term investors, managers and other stake holders to be able to assess how resilient their real estate assets are to new regulations and changing occupier demands (Goodland, 2008), which, in fact, reflect on various types of obsolescences, including the energy related and climate change induced obsolescence.

The biophysical properties of the urban environment are distinctive with a large building mass (350kg.m^{-2} in dense residential areas) and associated heat storage capacity, reduced greenspace cover (with its evaporative cooling and rainwater interception and infiltration functions) and extensive surface sealing (around 70% in high density settlement and city centres) which promotes rapid runoff of precipitation (Handley, 2010). Climate change amplifies this distinctive behaviour by strengthening the urban heat island (Gill et. al. 2004). This correspondingly leads to amplify climate change induced obsolescence in built environment (as explained with examples in Section 4.0). So it can be safely presumed as a general rule that the more the density of a built environment, correspondingly there is to be more the obsolescence, irrespective of drivers and reasons. For instance, London is one of the top most parts of the total UK built environment in terms of a range of elements such as geographical size, value, economy, human population, diversity, ecology and heritage. Furthermore, London is the capital of the UK and located near the North Sea, stretching around an estuary, and the River Thames running through it, thereby further adding significance and sensitivity to the city in hydro-logical context e.g. increased potential of pluvial, fluvial, tidal and coastal floods. Collectively along these wide-ranging elements, the overall London share in the total obsolescence over time in total UK built environment, most probably is to be larger than anywhere else in the UK, and probably one of the largest shares throughout the world.

2 Obsolescence Definition and Types

2.1 Financial Obsolescence and Functional Obsolescence

In the context of built environment, obsolescence can be defined as depreciation in value and / or usefulness due to an impairment of desirability and / or function caused by new inventions, current changes in design, improved processes of production, or external factors that make a property or infrastructure less desirable and valuable for a continued use. Thus, irrespective of reasons / causes, financial obsolescence means loss in value where as functional obsolescence is loss of usefulness, effectiveness, efficiency or productivity. The financial obsolescence is also termed as social or economic obsolescence, and functional obsolescence as technical obsolescence. (Cooper, 2004; Montgomery Law, 2010; Leeper Appraisal Services, 2010; Richmond Virginia Real Estate, 2003; Nky Condo Rentals, 2010: SMA Financing, 2009; Landmark Properties, 2010).

2.2 Internal Obsolescence and External Obsolescence

Irrespective of whether obsolescence is in value or function or both, internal obsolescence in a component or built asset is due to factors that exist with in the component or built asset. For instance, general wear and tear, fatigue, corrosion, oxidation, evaporation, rusting, leaking of gas / water or any other fluid like coolant, breaking, age, etc. Where as external obsolescence is temporary or permanent impairment in value or usefulness of a built asset due to factors outside the system (where the boundaries of the system may not necessarily be physical but virtual) such as change in existing or advent of a new environmental legislation; carbon cut targets, carbon-social forces / pressure groups; arrival of new technology; enrichment of knowledge e.g. asbestos is no longer allowed to be used in the built environment; fluctuation in demand; inflation of currency; political stability / instability of a country; etc.

2.3 Climate Change Induced Obsolescence

Irrespective of whether an obsolescence is internal or external and financial or functional, if a given obsolescence is due to impacts of climate change (e.g. more intense and more frequent rainfall, stronger and more frequent hurricanes, heatwave, flooding, etc.) is referred to as Climate Change Induced Obsolescence by the authors. More examples of climate change impacts are listed in Section 4.0. Those examples also demonstrate that climate change related obsolescence is predominantly external, rather than internal.

2.4 Energy Related Obsolescence Induced by Climate Change

Irrespective of an obsolescence in the built environment is internal or external, financial or functional, if the obsolescence is induced due to climate change either directly or indirectly and is around systems, components or processes that are associated with energy at generation end, distribution or consumption end, is termed as energy related obsolescence induced due to climate change. This kind of obsolescence is the main focus of this paper.

3 Energy Related Obsolescence

3.1 European Perspective

Energy related issues in terms of sustainable generation, consumption efficiency and environmental protection are not only national but also international. For instance, from European perspective, buildings are responsible for 40% of energy consumption and 36% of EU (European Union) CO_2 emissions. The Directive of Energy Performance of Buildings (2002/91/EC) is the main legislative instrument at EU level to achieve energy performance in buildings (EU, 2002; EC 2010). Under this Directive, the Member States must apply minimum requirements as regards the energy performance of new and existing buildings, ensure the certification of their energy performance and require the regular inspection of boilers and air conditioning systems in buildings. Thus, at European level energy performance of buildings is key to achieve the EU Climate and Energy objectives, namely the reduction of a 20% of the greenhouse gas emissions by 2020 and a 20% energy savings by 2020. Many scientists and pressures groups are now calling for 40% reductions. For that to be achieved the built environment would have to take on a larger share of the burden. Improving the energy performance of buildings is a cost-effective way of fighting against climate change and improving energy security (EC, 2010; RUDI Ltd., 2010; Bell, 2004; EU, 2002). Although steps are being taken to cut carbon emissions from other areas such as road travel, reducing waste and water consumption, but the building sector as well as energy sector are becoming key areas of focus for carbon cuts which means growing potential of energy related obsolescence in European built environment. The situation is likely to become more challenging when the demand for energy has been always escalating. For example, demand for power has increased by 24% since 1990 and is predicted to grow by 2030 (DTI 2010, BIFM, 2007)

3.2 UK Perspective

The Department of Energy and Climate Change (DECC) in the UK has successfully taken three bills through the Parliament, which are now the Energy Act 2008, the Climate Change Act 2008 and the Energy Act 2010. Where as other Acts introduced by the Government which cover energy issues include Planning Act 2008 (which is of considerable importance for energy infrastructure projects) and the Planning and Energy Act 2008. (DECC, 2010a). Furthermore, Building Regulations which are made under powers provided in the Building Act 1984 and apply in England and Wales, are mainly found in The Building Regulations (2000 as amended) and The Building (Approved Inspectors) Regulations (2000 as amended). These legislation apply to new as well as existing buildings whether domestic, commercial or industrial; and specifically addresses energy efficiency in buildings. (DCLG, 2010). All these legislation together cover not only the consumption end of energy but also distribution as well as the generation end of energy. These legislation are deriving the UK towards energy conscious and efficient built environment via carbon cuts, climate change mitigation and adaptation, renewable energy exploitation, and efficient energy consumption in UK built environment.

On the other hand, desired and required energy related improvements still have not picked up pace yet. For instance, Sustainable Development Commission (SDC) has said that the government had reported a 6.3% decrease in carbon emissions from its offices since the year 1999-2000, an insufficient reduction for it to hit a target of 12.5% reductions by 2011-12. And it was not nearly enough to contribute to the legally binding national goal to cut emissions by 80% by 2050 (Guardian, 2009). While there is a long way to go and yet in short space of time, carbon cuts are increasingly becoming more stringent. DECC stated in one of its white paper in the year 2007 that carbon emissions need to be cut by 60% by 2050 to meet energy challenge and yet without new nuclear power stations (DTI, 2007). While the Climate Act 2008 legally binds the UK to at least 80% reduction by 2050 and 34% by 2020 (DECC, 2010b). Although not a legal binding, the UK Green Building Council has stated that the UK can and must slash carbon emissions from the built environment by 50% by 2020, thus, even tighter car cut target (RUDI Ltd., 2010).

Similarly, the Merton Rule, which was / is named after the council in the UK that adopted the first prescriptive planning policy of the Rule, states that new commercial buildings over 1,000 square metres require to generate at least 10% of their energy needs using on site renewable energy equipment. It was implemented and overseen by the then leader of Merton Council, Andrew Judge. The rule was developed and adopted in 2003, and its impact was so great that the Mayor of London and many other councils have also implemented it. Now it has also become part of national planning guidance. In 2008, the UK government published its central planning guidance Planning Policy Statement – Planning and Climate Change – PPS1 that requires all UK local planning authorities to adopt a “Merton Rule” policy. Receiving Royal Assent in November 2008, the Planning and Energy Act 2008 enables all councils in England and Wales to adopt a Merton Rule as well as specify energy efficiency standards over and above that of building regulations. (Wikipedia, 2010). These legislation and other instruments becoming more and more stringent by the day indicate how energy related obsolescence in built environment is at the verge of becoming substantially noticeable. Happening of this is expected throughout the energy ‘pipeline’, that is, generation end, distribution and consumption end.

4 Impacts on Maintenance / Refurbishment

There is growing evidence that climate change is real, already observable, and threatening to undermine development. Therefore, climate adaptation continues to rise on the agendas of researchers, practitioners and decision-makers. On the other hand, the onus of adaptation to climate change directly lies with or impacts on maintenance and refurbishment of existing built environment. Even future developments are not safe from climate change unless adaptation is not integrated into not only in their design but also maintenance and refurbishment cycles, both in the form of practice as well as costs. Thus, any effective planning and development process will need to take climate adaptation into account throughout all stages from design through to decommissioning, including maintenance and / or refurbishment.

While climate impacts are increasingly observed, the debate over managing adaptation has progressed very slowly. However, climate change adaptation is expected to accelerate rapidly and exponentially soon. One of the reasons of the acceleration shall surely be increased realisation which is yet to fully catch up with the reality. Relatively current slow realisation is in part due to confusion about relationship between adaptation and development – a definitional problem that has hindered not only project design, but also the allocation of funding to adaptation efforts. Notwithstanding the difficulty in developing a concise operational definition, failure to clarify this relationship has meant that funding mechanisms create redundancies or leave gaps in the landscape of critical adaptation, development, maintenance and refurbishment activities (WRI, 2010). Being specific to energy related obsolescence, the picture is not dissimilar to this.

Common examples of climate change factors (both causes and / or affects) that have already begin to cause energy related obsolescence to the built environment (both directly or indirectly) and have substantial potential to further increase climate change induced obsolescence in future, are:

- Flooding (fluvial, tidal and pluvial due to e.g. more frequent and more intensive rainfall);
- Coastal flooding due to sea level rise;
- Over-heating (due to global warming as average annual global temperature is rising);
- Corrosion (due to acidic rain, more frequent and more intensive storms / hurricanes);
- Coastal corrosion;
- Drying out of water bodies such as lakes;
- Ultra-violet (UV) sun rays due to ozone layer depletion;
- Resources depletion e.g. deforestation;
- Wildfire;
- Drought;
- Landslides;
- Hurricanes;
- Environmental pollution e.g. greenhouse gas emissions;
- Environmental and legislative pressures e.g. to reduce carbon emissions;
- etc. etc.

Below are a few examples described to indicate how climate change impacts are causing and / or have potential to cause energy related obsolescence either directly or indirectly and add burden on maintenance and refurbishment:

Enhanced cooling / air conditioning in buildings

The1990s was the warmest decade in central England since records began in the 1660s. Summer heat-waves are now happening more frequently and in winter there are fewer frosts. Globally, over the past century, the average temperature of the atmosphere near the earth's surface has risen by 0.74°C. Eleven of the 12 hottest years on record occurred between 1995 and 2006. The scientific consensus is that global temperatures could rise between 1.1 and 6.4°C above 1980 – 1999 levels by the end of 21st century. The exact amount depends on the levels of future greenhouse gas emissions. (Directgov, 2010). This happening phenomenon is already demanding our current residential and commercial built environment for extra cooling (consequently more energy consumption) to achieve comfort zone during heat-waves in particular. This could also affect our road infrastructure for heat-waves could have adverse affect on roads charcoal and quality. Various industrial processes may also be affected due to ambient temperature rise. All of these scenarios are resulting and will increasingly result in obsolescence, thus demanding more maintenance and refurbishment incurring more costs and energy consumption as well as greenhouse gas emissions. Global warming has already started and has further potential to cause energy associated obsolescence in buildings in different ways e.g. cooling systems becoming out of date / obsolete to whatever degrees. This can be deemed as directly climate change related obsolescence.

Flooding risks to residential and commercial properties

UK coastal waters have warmed by about 0.7°C over the past three decades. In addition, the average sea level around the UK is now about 10 cm higher than it was in 1900. Globally, sea level could rise by 18 to 59 cm by the end of the century. Rising sea levels would swamp some small, low-lying island states and put millions of people in low-lying areas at risk of flooding (Directgov, 2010). Consider an existing residential area near by a coastal line or along a tidal river stretch. Given that these residences would be containing items such as electric cookers, microwave oven, refrigerators and freezers, washing machines, dishwashers, tumble dryers, carpets, vacuum cleaners, cars, radio and CD players, CDs / DVDs, Hi-Fi stereo, video equipment, televisions, telephones and answer machines, computers and peripherals, toys, power distributions and accessories, sentimental value items, etc. (Cooper, 2004). Climate change includes more rain and more flooding. Thus, if a pluvial, fluvial or coastal flooding occurs, all these listed items if subjected to flood water are to become obsolete. Not to mention damage that flooding will cause to the fabric of buildings and houses. Thus, if refurbishments take place post-flooding, the cost could be incredible, depending not only on degree of flooding intensity but also other factors such as how dense the residential area is, how well planned it is, etc. In the context of adaptation, a number of steps could be taken either at individual property level or communal level, for examples, raising and strengthening flood banks and their regular maintenance to control their obsolescence. In planning applications for various developments, Environment Agency in England and Wales is consulted on flood risk assessments seeking implementation of flood resistant and resilient approaches (ODPM, 2001; 2005;

2006; DCLG, 2007; DEFRA, 2005a; 2005b). Whereas if a given development is new and in planning stage finished floor levels can be set above 1 in 100 year flood level plus allowance for climate change and 300mm freeboard for hard flood defences and 500mm for soft flood defences (ODPM, 2006; DCLG, 2007). The same discussion also implies in principle to commercial properties though additional losses due to flooding include disruption of businesses. Thus, flooding is a potential source of external obsolescence directly increasing maintenance and refurbishment requirements and costs.

All the aforesaid items that may be either completely damaged and / or partly due to flooding, will require either replacement or repair. Also, electrical wires need to be fed from top-to-down and electrical appliances as well as power points / switches need be set above flood level. All these activities require energy either on-site and / or off-site where different products are produced and supplied to end users in the flood affected areas. In energy context this kind of obsolescence can be seen as directly associated with climate change.

Acid Rain

The term ‘acid rain’ refers to both wet and dry deposition of acidic pollutants that may damage material surfaces including corrosion of metals and deterioration of paint and stone (such as marble and limestone). These materials constitute our built environment. Thus, acid rain effects can significantly reduce the societal value of buildings, bridges, cultural objects (such as statues, monuments, and tombstones) as well as leading to increased maintenance and refurbishment costs (EPA, 2007). Since air emissions are escalating and correspondingly more acid rain, therefore maintenance and refurbishment costs are likely to be much higher in future than they are now to keep built environment constituents from suffering from external obsolescence directly related to climate change. Similarly, acid rain also adversely impacts vegetation or plant life. This means open space green areas as well as any other vegetation in the built environment can also be affected by acid rain, thereby increasing their maintenance amount, frequency and costs. Whether it is repainting or treating (external) building fabric surfaces, will require energy which is increasingly becoming an expensive commodity.

Sea ports

Climate change can impact ports in a variety of ways. For instance, increases in power and duration of storm surges; coastal flooding and changes to erosion pattern can impact infrastructure and dredging requirements; wave attack at higher sea levels can increase the vulnerability of structure over time, as can increase in frequency and duration of storms (Shipping Industry News, 2009). All such potentials and incidents if happen have strong likelihood to cause obsolescence to various degrees which may require increased levels and frequencies of maintenance. Such maintenance activities simply means transport of equipment and materials to and from the site, arising of waste and disposal, etc. which all require energy to accomplish one way or another. Thus, even more greenhouse gas emissions.

5 Discussion and Concluding Remarks

Irrespective of reasons or causes of obsolescence, the prime affect of it is reduction in performance and, consequently, not appropriately meeting demands, requirements and expectations of the end user of a given building, structure, infrastructure or any other constituent / unit of built environment. It is maintenance and refurbishment which attempts to eradicate obsolescence, to whatever degree this may be, to avoid rebuilding / redevelopment. Consequently, as the afore-listed climate change impacts (Section 4.0) intensify and become more frequent over time, the climate change induced obsolescence correspondingly will increasingly lead to substantially more expensive maintenances and refurbishments and yet more often, thereby reducing maintenance and refurbishment cycles' length and escalating frequency and costs. Furthermore, if enough measures / interventions are not implemented in time, this could even lead to redevelopment i.e. demolition and fully rebuilding at the same place or even geographical relocation of the new resultant development, which could raise additional siting / relocation issues in a whole host of sustainability seeking efforts. Whether obsolescence compromises performance of a system, or increases maintenance and refurbishment amount and frequency, or even result in rebuilding / redevelopment, in all cases it requires energy (which generally means additional greenhouse gas emissions) and eventually all these stress finances and economy of an organisation. Thus, further research is needed to relate climate change induced obsolescence factors (both causes and affects) with in-time maintenance and refurbishment cycles (including energy demand, supply and efficient consumption); such that the given built environment scenario does not loose its performance both as a physical built asset as well as operational, and continues performing efficiently with cost-effective maintenance and / or refurbishment. In the literature review, no evidence has been found of such a holistic framework which could assemble all these aspects together under one umbrella.

The ongoing research study reported in this paper is investigating how climate change is to cause obsolescence and consequent affects on built environment, which predominantly comprises buildings and infrastructures. The former category includes offices / commercial buildings, structures (e.g. tunnels, bridges, dams, etc.), residential buildings (e.g. houses, flats, etc.), schools, churches, factories; and the latter predominantly comprises utilities, energy and transportation. Thus, built environment is not only physically built assets but also contains other aspects such as facilities, products, materials, commodities, services, energy, comfort, health & safety, and operational facets (McClure and Bartuska, 2007; Wikipedia, 2009). All such aspects and facets of a unit / constituent (e.g. a given building or an infrastructure) of a built environment are collectively termed as overall performance of the unit / constituent, by the authors. That is performance comprises both a given built asset itself (e.g. fabric of a building) as well as various operational / functional elements such as cooling / heating in the building. Both of these require and consume energy one way or another, either directly or indirectly. The focus of this research is energy related obsolescence either directly or indirectly driven by climate change impacts.

As stated earlier, this underway research project is establishing causes and effects regarding energy related obsolescence and specifically in the climate change context. Then those factors (both causes and affects) shall be further investigated to find which crucially relate to the overall performance of built environment (inclusive of both, buildings and infrastructures). Thus, the project is to address not only physical aspects of the built environment but also operational facets. The identified factors shall be categorised in a holistic set of logical groups and subgroups particularly along the sustainability dimensions i.e. social, environmental and economic. Later the project shall investigate which of these factors are more frequent and influential / sensitive for various scenarios e.g. a certain aspect of maintenance / refurbishment like boilers / heating system, a certain industry like oil refinery, a certain set of buildings such as houses, etc. From the review of literature and models to date (e.g. Allehaux and Tessier, 2002; Jones and Sharp, 2007; Acclimatise, 2009) it is established that especially from the perspective of climate change related factors and subsequently growing pressures for efficient energy consumption in built environment, there is lack of knowledge, models, and holistic approaches towards integrating maintenance and refurbishment cycles with the performance and life-cycle of a given built asset / building or infrastructure. On the other hand, in 2005 built asset maintenance and refurbishment accounted for approximately 45% of the total UK construction output (DTI, 2006); employed 1.17 million individuals and represented approximately 6.2% of the UK's Gross Added Value (Dye and Sosimi, 2006). In view of such facts, in summary, this research is identifying knowledge gaps to establish bases for future research to develop a holistic framework to assist obsolescence assessment around climate change impacts, then a knowledge-base procedure, which shall be translated into a computational methodology and then probably eventually an expert system. This framework will be flexible to be narrowed down to climate change induced obsolescence and yet specifically in context of energy.

The research project is not to consider only causes and effects of climate change induced obsolescence in the built environment, but also more or less account for how maintenance and refurbishment can be designed, developed and delivered so that the resultant built environment following the maintenance and refurbishment does not constitute to climate change. For instance, for a given building the air conditioning aspect is considered for maintenance / refurbishment. This cooling system should be maintained and refurbished not only with the purpose to render the building cooler in order to be climate change resilient to outweigh the rising average global temperature (i.e. climate change adaptation). But, this should be achieved in such a sustainable / green manner that the cooling system does not consume too much energy to prevent additional greenhouse gases and thereby not additionally contributing to the average global temperature rise. In other words, low carbon cooling systems and approaches to combat the global temperature rise, should be designed, developed and employed (i.e. climate change mitigation). Thus, the care needs to be taken at both ends, i.e. render the built environment (buildings and infrastructures) climate change resilient but at the same time without causing any escalation in, rather reduction if and where possible to, climate change already happening. In view of this, it can be said that not only climate change mitigation but adaptation as well are expected to accelerate soon not only due to continually growing evidence of climate change and impacts but also escalating realisation as evident from the way carbon cut targets are becoming stringent.

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Environmental Attitudes and Energy Initiatives within the Greek Hotel Sector

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Abstract. This paper describes the Greek hoteliers' attitudes about energy initiatives and their implementation to their facilities. The aim of this paper is to demonstrate the interaction between the users' behaviour and the way energy is consumed in Greek hotels in a long-term period. This paper is part of a wider research project that explores the energy consumption in several Greek hotels. Through interviews with open-ended questions, their responses reveal their opinions and the level of information they have on the existing legislation-Greek and European- on energy use in buildings. Further than that, two scenarios are developed, using the Long Range Energy Alternative Planning software (LEAP). Each one of them exhibits different findings proposing significant but easy to apply alterations to hotels. The first one is the Business as Usual scenario, and it is developed based on the current trends in energy use in hotels. The second is the Policy scenario which is developed based on the existing legislative framework, Greek and EU.

1 Introduction

The Greek hotel sector is examined in this paper, in conjunction with the effect of the existing legislation on it, in the long-term. Every hotel has its own distinctive energy characteristics. There are differences in the way energy is consumed in each facility since they are located in islands or mountainous areas or in city centers, they vary in size and in number of rooms. In addition, the high amounts of electricity and oil consumption in hotels, along with the absence of renewable energy technologies indicate the need to promote a *green* way of energy use. Hence, it is important to examine and evaluate possibilities that would reduce the energy consumption in hotels, evaluating also the effectiveness of the policy on them. Simultaneously, the attitudes of hotel owners' or managers play an important role on the application of the policy framework in their facilities. Their opinions are examined.

2 Energy Overview in Greek Hotels

Hotels represent about 0.26% of the total Greek buildings. Despite their small percentage comparing to the total building stock, they are responsible for the 29% of the energy consumption in the private sector. This is explained by the AC space

R.J. Howlett, L.C. Jain, & S.H. Lee (Eds.): Sustainability in Energy and Buildings, SIST 7, pp. 225–235.
springerlink.com

heating and cooling equipment, hot water needs, facilities and services offered and the number of the tourist arrivals during the hotels' operation (Gaglia, 2006).

Various types of fuels used, such as electricity, gas, diesel fuel, natural gas. Still, the main energy source used is electricity, generally for air-conditioning, heating, lighting, lifts, kitchen equipment and many static and portable appliances. This explains that the energy cost in hotels is high (Mavrotas, 2003).

Heating is responsible for the highest amount of energy consumption in hotels, since the main fuel used is oil. Natural gas is lower in use, but this is possible to change in the next years as it is expected to replace oil use. (Santamouris, 1996).

A series of policies not only Greek but also European could be implemented in the hotel sector, aiming to improve its energy performance. The legislative framework refers to the National Climate Change Programme for Greenhouse Gas Emissions Reduction; the National Action Plan for Energy Efficiency; the European Action Plan for Energy Efficiency and the Directives embraced in it. The Building Directive 2002/91/EC, the Directive 2006/32/EC for Energy End-use Efficiency and Energy Services and the Directive 2005/32/EC for Eco-design requirements for energy-using products.[1]

3 Energy Analysis

This section analyses the two energy scenarios, Business as Usual and Policy using the Long Range Energy Alternative Planning (LEAP) energy modelling tool. The total sample of 28 hotels is divided in 14 four star hotels and 14 five star hotels. The following figures display the energy consumption in each cluster and the changes that occur from the assumptions considered.

3.1 Four Star Hotels

3.1.1 Business as Usual Scenario

This scenario is developed under the current trend of energy use in 4 star hotels. During the data collection was observed that the efficient lighting is commonly used in this sample, with a possible growth in use 5 to 10% per year by 2020, as hoteliers declared. Furthermore, the use of natural gas is expected to increase the next decade, with the level of penetration to be almost 20% by 2020, as the Ministry of Development estimates (2008). Generally, it concerns commercial buildings, and hotels as part of this sector, would be affected as well. In addition, the Ministry of Development (2008), gave estimates about fuels consumption and growth in use for the commercial sector. It is expected that by 2020, electricity use would increase by 1.5% per year and oil consumption by 3.5% per year. In addition, the use of hot water and heating services to increase in terms of use and consumption, with 3% increase of fuels used for this service. In Figure 1, the activity of each service in the building is displayed.

[1] See *Maleviti, E. (2009), The Influence of Various Factors on Hotels' Carbon Footprints under the Implementation of the EU and Greek Legislative Framework, Sustainability in Energy and Buildings: Proceeding in the International Conference in Energy and Buildings, Brighton, 2009* for detailed analysis of the policy framework.

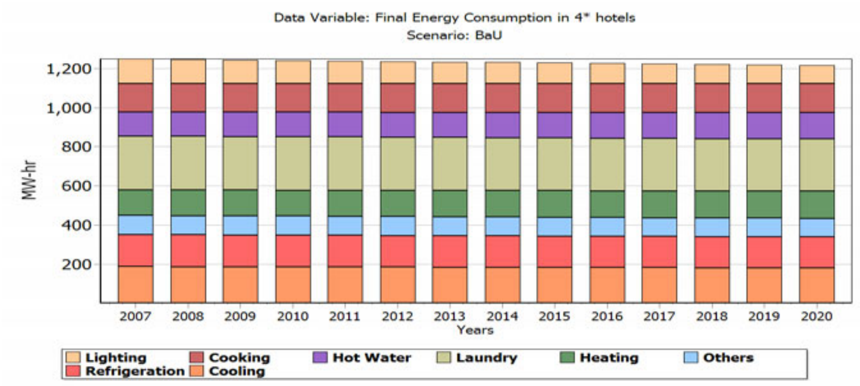

Fig. 1. Final energy consumption in 4* hotels in the Business as Usual scenario

Figure 1 displays that if the current trend is followed, the final energy consumption could be remain similar levels by the year 2020. This scenario has been developed considering that the occupancy rates are following the same trend as in the past 5 years. Therefore, the Business as Usual scenario is not negative in terms of energy use. This indicates that if the use of efficient lighting and efficient equipment increase, then energy consumption would be reduced without major alterations.

3.1.2 Policy Scenario

This section analyses the effect of the Greek legislative framework on the four star hotels, with a detailed result of the effect of each one of the measures, on every specific service of the hotels.

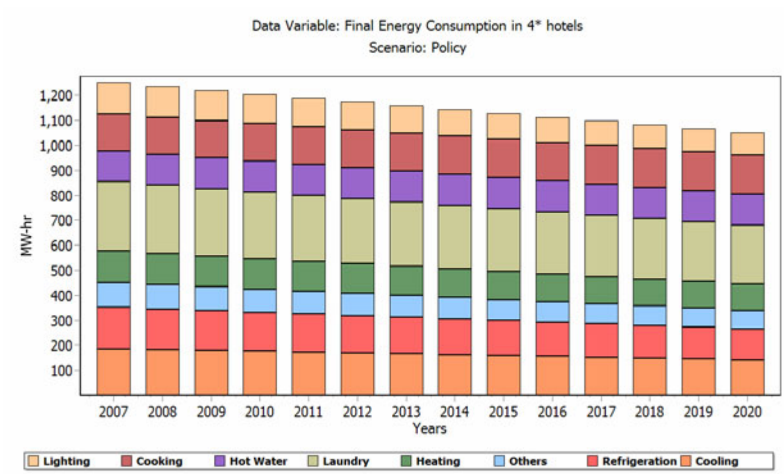

Fig. 2. Final Energy Consumption in 4 star hotels in the Policy scenario

Figure 2 displays the effectiveness of the policy framework. The measures could reduce the total energy consumption from the year 2007 to the end year 2020, by 150MWh. The electricity consumption in lighting could be decreased by 35MWh by the year 2020 under the policy measures. According to that measure, it is possible 50% of the conventional lighting to be replaced with efficient lighting.

In addition, the use of efficient electrical equipment is expected to increase by 15% to 20% per year, such as refrigeration and cooling services. The replacement of efficient mini-bars in rooms and the equipmnet in areas, such as bars and restaurants, where autonomous units are used, could reduce electricity consumption by 30MWh by the year 2020.

The same assumption is used in laundry facilities which are responsible for the highest electricity consumption, among the other services, and that the electricity consumption is 280MWh. These measures could decrease this amount by 60MWh by 2020.

Hot water is used in rooms for customers use, in kitchen and laundry services through the facilities of each case, and in few cases of four star hotels for leisure facilities such as showers in gyms, or spa areas. Hot water is responsible for the 12% of the total energy consumption in the hotels of this category. The assumptions and measures considered are shown in Table 2.

In four-star hotels of this project, only 15% of the total energy used for hot water is covered form solar thermal panels. However, the policy framework does not include specific information on how many kW of solar thermal panels needs to be installed, and what are the needs that are going to be covered.

Heating is responsible for 120MWh. It is very important to find measure to apply them in order to reduce the energy use for that service. The policy framework includes measures for improved thermal insulation, which could reduce the energy consumption in the building by 2% per year. In addition, the installation of solar thermal panels could reduce the energy consumption in heating by 10% per year. Energy consumption in heating services could be reduced by almost 25MWh by 2020. According the policy framework, the use of solar energy is expected to replace the 50% of oil and LPG use. In addition, the use of natural gas is expected to grow replacing also a significant share of oil consumption.

Cooling services, are responsible for 187MWh of electricity consumption in total, in the four-star hotels of the project. The measures concern the use of efficient equipment, thermal insulation and information about rational use of energy in the building. Following these measures, the electricity consumption could be reduced by almost 30MWh.

3.2 Five Star Hotels

3.2.1 Business as Usual

This section displays the Business as Usual scenario for the five star hotels of the selected sample of the research. The alterations considered in the facilities are the use of efficient lighting with a low level of penetration, the use of efficient electrical equipment and replacement of obsolete and inefficient, and increase of natural gas use replacing other fuels that are more expensive and with high environmental effects, such as oil, LPG and electricity. In addition in the following results, assumptions concerning the use in services and the growth in fuels are included, and they are displayed in Table 1.

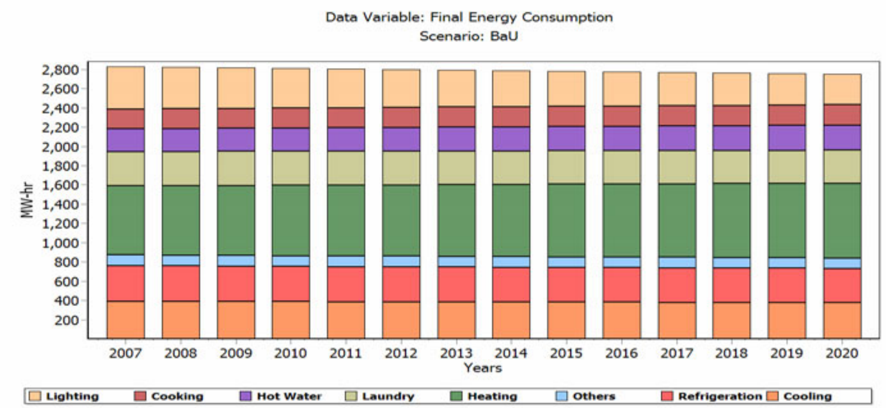

Fig. 3. Total final energy consumption by service in five star hotels

3.2.2 Policy Scenario

The results from the policy scenario are displayed in the figure 4. The assumptions considered in this scenario are the increased use of efficient lighting, aiming at a decrease of approximately 30% by 2020, as the Ministry of Development includes in the National Action Plan for Energy Efficiency (2008), for the buildings of the commercial sector. Furthermore, the use of electrical equipment is expected to replace old and inefficient ones, in services such as laundry services, cooking, refrigeration and air-conditioning. Furthermore, improvement of thermal insulation in buildings could reduce the energy consumption by almost 5% in annual basis per building, since heating losses are prevented.

It is observed that the policy measurements for lighting services could be effective in five star hotels. By the year 2020 and the implementation of the policy measurements for lighting, it is possible for a reduction of almost 270 MWh in electricity consumption for lighting.

The policy scenario could contribute in an approximate reduction in energy consumption in cooking facilities of 150MWh by 2020. This could be achieved with the use of more efficient electrical equipment in the kitchen, with control and information to the staff to use rationally the equipment such as switching them on only when needed.

Refrigeration in hotels is responsible for high electricity use. It includes the refrigeration equipment in the rooms, as mini bars, in the kitchen and in the restaurant and bars of the hotels. Efficient equipment could reduce electricity by almost 90MWh by 2020.

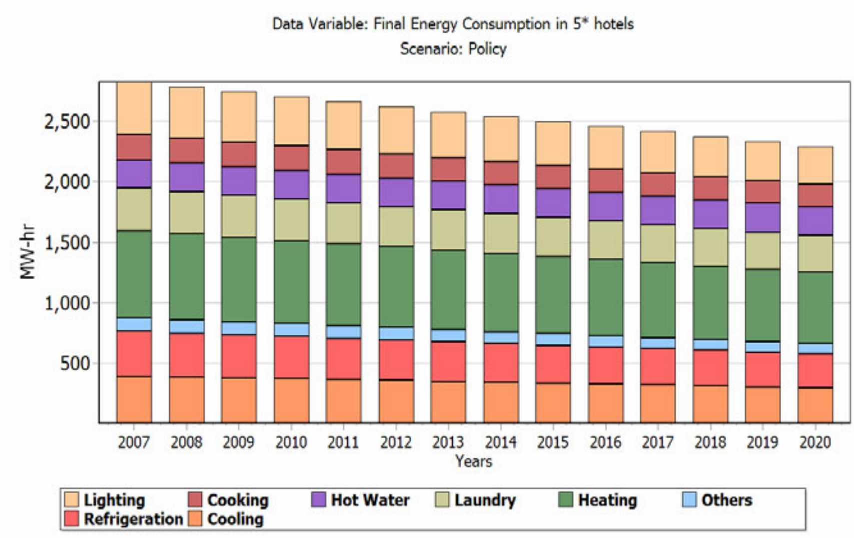

Fig. 4. Final energy consumption in the policy scenario in 5 star hotels

As figure 4 displays, the heating services in five star hotels have the highest share with 700MWh for the year 2007. Due to this large energy consumption, the policy framework suggests the installation of solar thermal panels, which decrease energy consumption by 10%per year. Additional measures such as thermal insulation to the buildings, information to the customers on how to control the energy consumption and energy management systems could contribute by almost 140MWh reduction by 2020.

The use of electrical efficient air-conditions, could also decrease significantly with the use replacement of existing with efficient equipment. A combination of rational use of equipment, thermal insulation of the building and energy management systems, along with the use of efficient equipment could reduce electricity consumption by approximately 100MWh by 2020.

Energy consumption in hot water facilities is expected to increase by 2020 around 3% per year. The policy scenario shows that there would be an increase as well despite the proposed measures mentioned earlier, by almost 4MWh by 2020. The success of the framework is not only when energy consumption is decreased but also when the growth is low. The policy framework requires the compulsory use of thermal solar panels for hot water. Assuming a 10% increase in use of solar thermal panels per year by 2020.

For laundry services, the policy framework could reduce the electricity consumption by almost 50MWh by 2020. The combination of the measurements included in Table 2 affect significantly the total electricity consumption.

Other services included are the gym and spa facilities. The final energy consumption in these services comes mainly from the hours that the equipment are staying switched on without been used. The replacement of the existing equipment with electrical efficient ones would reduce consumption by only 4MWh by 2020. This is because there are no available types of efficient equipment to replace the existing.

4 Hoteliers' Attitudes on Environmental Initiatives

At this point, it is essential to note that there is an indicative significance between chain hotels and individual establishments. The first have developed their own company policies and thus it is likely to be relevant with other hotels that belong in the same chain. It is therefore reasonable to consider that hotels of the same chain may have similar environmental initiatives. An attitude that has been already expressed in other projects (Bohdanowicz, 2005).

Interest on the environment

Hoteliers who participated in the survey were asked if the environmental issues play an important role for the hotels operations and consequently the development of tourism. Almost seven out of ten respondents expressed that these issues are important for tourism. However, they believe that the environment is mainly affected from hotel units that are based in natural and sensitive environment, such as islands or mountainous areas. In specific comments such as 'Our facility is in the city centre of Athens, the environment is nit affected mainly from us, but from hotels that are actually in the natural environment'. With that attitude, it is revealed their ignorance about the carbon footprint that occurs from the energy consumption from their facilities.

Furthermore, it is interesting to mention, that despite the perception that green action in hotels plays an important role in defining customers choice, this survey displays that Greek hoteliers do not believe environmental action as significant marketing factor to attract more customers.

Following to that, the participants were asked how important they would find the assistance from specialised people or governmental authorised personnel in order to reduce the carbon footprint of their facilities. All of them believe that professional assistance would be very useful and very effective for their energy operations. 'It would be a way to improve things and also to learn about new technologies and actions that would reduce the effect to the environment', some of them they declared. However, the most important factor in order to apply new eco-friendly technologies and actions, they need to know about energy costs and energy savings that could occur from these installations. For that purpose an economic assessment is presented later on in this section.

A total opinion expressed from all the respondents is that even though they have interest in preventing from affecting the environment in any way, still no one, authorised or governmental representative has ever approached them to inform them about requirements in order to be more environmental friendly. Moreover, they declared that, it is essential to know about policy framework or examples from other countries that already have applied similar initiatives. 'The government needs to inform the hotel owners about this issue, either in each individual hotel or through the National Organisation of Tourism' some of them stated; also 'they need to establish some legislative requirements for hotels and tourism sector in general; with that way owners, managers and customers would know what is the problem and what needs to change'.

Information on policy and green actions

The participants' response on how aware they are on the energy and environmental policy demonstrated the lack of knowledge on activities that would improve their facilities environmental performance. They declared that the small alterations take place in their hotels, such as replacement of efficient lighting, and use of electrical efficient air-conditions, are information that anyone could have. There is need to offer further information on these issues. They also stated, that even if we do not know we would require someone expert to inform us. *'After all, hotels support the second most important activity of the Greek economy, therefore we need more attention'*, one hotel manager declared from a four-star hotel in Crete. Furthermore, they declared that they would like to be able to inform their employees about more rational use in the hotels; *'This would save us money'*, most of them stated. At this point it is essential to note that this option on information and a possible training of their employees was an option considered only from three out of ten respondents. Under the same frame about information and policy action, Greek hoteliers declared that the government should develop a specific framework that would include specific measures for hotels. *'A hotel is a complex building; multiple services are offered using multiple types of fuels and equipment'*. This statement displays that hotel owners and managers prefer a specific legislative framework that would indicate specific actions to be taken in the hotel industry. Six out of ten hoteliers responded that they would follow a specific legislative framework if it would demonstrate clear action to be taken. In addition, they stated that it is essential to be informed about available technologies they could install.

As a final comment of the hoteliers' opinions, are the only factors that define the implementation of new technologies in their facilities. They are mainly concerned about the total cost of the investments, and the possibility of financial subsidies offered from the government. This obvious statement, with information and knowledge in the proposed technologies are the main factors influencing the hotel owners' views on changes to their facilities.

5 Conclusions

To conclude, this analysis demonstrates that even if there is a quite effective legislative framework, the hoteliers need more than that in order to apply it in their facilities. Even if they have increased environmental awareness and they would like to change the way their facilities are operating, still they find necessary to have the appropriate level of information. The efficient lighting and equipment is the most common and the easiest for them to apply. Still many potential technologies and alterations could benefit their facilities. In addition, they consider as appropriate to provide training to their employees in order to promote the rational use of energy. It is essential to note also, that the Greek legislative framework, even if it is quite general, without specified measures for buildings of different sectors, could reduce the energy consumption. However, it is focusing mainly only the electricity consumption, without giving a clear framework about types o f renewable energy technologies that could be applied in buildings with multiple services as hotels. There is need for information to the hoteliers. If they know what exists in the market and they have the appropriate explanation on these issues, they would follow the policy framework, as it would be beneficial for them. Therefore, it is necessary for the Government, to not only publish a policy framework and request from people to apply it, but also to inform them about its potential. Hoteliers had a positive reaction when they had the appropriate information on the existing technologies that could use in their facilities, since they would have reduction in energy consumption, in energy costs and in environmental effects. Hence, it is more important to convince people than posing to them a policy which is unknown to them.

Annex Tables

Table 1. Measurements and hypotheses used in BaU scenario

Measurements to be implemented by 2020 in hotels	Business as Usual Scenario
Efficient Lighting	-28% electricity reduction in electricity use
Efficient electrical equipment	-5% electricity reduction in electricity use
Natural Gas Penetration	+20% increase of natural gas use
Hypotheses	
Use of electricity	+1.5% growth of source use
Use of oil	+3.5% growth of fuel use
Hot water and heating services use	+3% growth in fuel used for these services

Source: Ministry of Development, 2007

Table 2. Measurements and hypotheses for Policy scenario

Measurements to be implemented by 2020 in hotels	Policy Scenario
Efficient lighting	-12 to 28% reduction of electricity consumption
Electrical efficient equipment in cooking, laundry facilities, refrigeration and A/C	-15 to -20% reduction of electricity consumption by 2020
Solar thermal panels for buildings over 1000m2	10% decrease of energy consumption for heating and hot water
Thermal insulation	-5% reduction in energy consumption in heating
	-5% reduction in electricity consumption
Renewable energy technologies installation	-20 to – 30% reduction in total energy consumption
Information for rational use of energy in the building	-2% reduction of electricity consumption
Energy Management Systems	-5% reduction of electricity consumption
Natural Gas Penetration	+30% increase
Hypotheses	
Use of electricity	+1.5% growth of source use
Use of oil	+2.5% growth of fuel use
Hot water and heating services use	+3% growth in fuel used for these services

Source: Ministry of Development, 2007

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The EcoSense Project: An Intelligent Energy Management System with a Wireless Sensor and Actor Network

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Abstract. Wireless sensor networks provide a new way of working for applications such as indoor monitoring, security or robotics. The Ecosense project aims to monitor all devices consuming energy in an intelligent building. We are developing this project in steps. Firstly, we have deployed a network equipped only with sensors (for temperature, humidity, luminosity, and electrical consumption, as well as presence detectors). Secondly, we will add an upper layer of manager agents (actors) to communicate and negotiate services. Afterwards, we will obtain conclusions about the sensed data and we will then extend a full wireless sensor network to cover the whole building. The network prototype will also be used to test power-and-time efficient protocols developed by us.

1 Introduction

Sensor networks have been identified as one of the most promising technologies for the future, mainly due to the wide range of real-world applications that have already been identified for this technology. WSNs have the ability to sample, coordinate and actuate at time scales and network dimensions not previously possible [1]. This ability should enable the deployment of a wide array of interesting applications. Our research group at the Albacete Research Institute of Informatics [2] is actively involved in the study and deployment of this technology for indoor and outdoor monitoring.

The Ecosense project has been motivated by the aim of effectively designing and deploying WSNs for monitoring environmental indoor conditions, such as the temperature and humidity in an office space. Also, our project includes the design and the implementation of a control system in a building with a wireless sensor network to monitor the situation of all devices that are consuming energy.

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To start with, the network is working only with sensors, and then, in a second phase, the system will be equipped with actors to permit the disconnection of devices and the sending of advice about controlling consumption. These actors may be agents with capabilities including goal management and task execution.

Thus, the objective of the project is to set up a control system in the Albacete Research Institute of Informatics with a wireless sensor network to manage their energy consumption and to help with the decisions about energetic reduction. Sensors may also be used by an upper layer of manager agents. These agents are able to communicate and negotiate services to achieve the required functionality [3]. In this paper we describe the sensor network deployed and, after a data gathering phase, we will install the agents to control the sensors.

Collaborating with us is the AGECAM, the regional Energy Agency of Castilla-La Mancha [4].

2 The Ecosense Project Hardware Description

We are deploying a smart wireless sensor network in the Institute building, to monitor it and optimize its energy resources.

The project is divided into several phases: 1. Deployment of a small wireless sensor network in a room of the building and analysis of the results; 2. Addition of actors to this wireless sensor network in order to improve energy saving and 3. Extensions of the wireless sensor network, to cover the whole building.
In terms of building energy saving there are several factors that have to be considered and studied carefully: temperature outdoors and indoors, luminosity, electrical consumption and presence detectors (passive infrared detectors, door and window opening sensors). Another variable considered in this project is the humidity, as it has been demonstrated that a good level of humidity in working areas is healthy for the workers.

The main variable in energy control is the temperature, as we have to establish a comfortable temperature for work, and the energy consumed by the air conditioning in cooling the room, or by the heaters, depends to a great extent on this factor. To measure this variable it is not enough to collect data only at one point in the room, we have to deploy several temperature sensors in the room and calculate the average temperature. To optimize energy consumption as much as possible it is very useful to also install a sensor measure the outdoor temperature. In this case we can compare both temperatures. If, for example, outside is colder than inside and we want to cool the room, instead of turning on the air conditioning it is preferable to open the window, reducing in this way the energy consumed by these devices.

The device chosen for this task is the embedded system MTM-CM5000-MSP made by Maxfor Technology INC (see fig.1) [5].

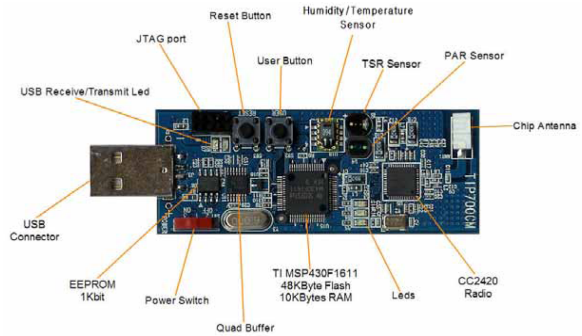

Fig. 1. Maxfor sensor node

Some advantages of this node are the IEEE 802.15.4 compliant wireless sensor network platform, the fact that it also supports TinyOS, has temperature, light and humidity sensors embedded in the main board, and has an expansion connector that allows other sensors and devices to be plugged into it. The sensor network distribution is shown in fig.2

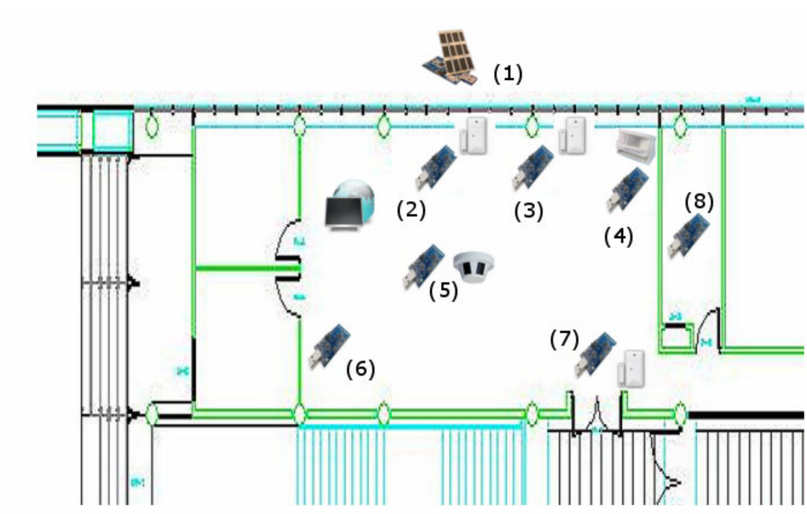

Fig. 2. Sensor network distribution

The outdoor sensor node, (1) in fig.2, is used to measure temperature, humidity and luminosity outside the building. The platform assigned to this task is the same as for indoors (MTM-CM5000-MSP), together with a new solar supply prototype that avoids the use of batteries. This is the device called ATON-II, a prototype developed by us in our laboratory [6]. ATON-II is tied to the MTM-CM5000-MSP through its expansion connector and it manages in a smart way the photovoltaic energy adapting the voltage level, filtering noise to avoid node malfunction, and storing the remaining energy in an accumulator in order to be used when the ambient light is not enough to supply ATON-II (see fig.3).

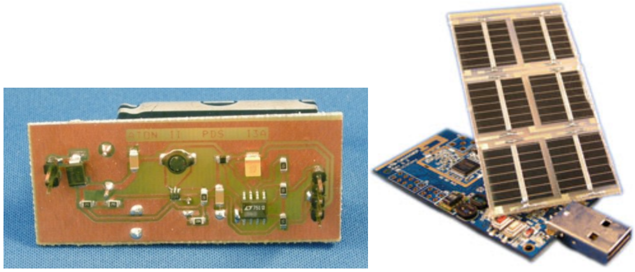

Fig. 3. The ATON II prototype

ATON-II uses a small 7x4cm solar panel and a 50F high-density capacitor as an energy storage device. When the capacitor is fully charged, ATON-II can supply the MTM-CM5000-MSP without light for up to four days.

In order to know if the windows are opened or closed there are some sensors that can control this event. These are the sensors labeled as (2) and (3) in fig.2. The device used is a magnetic switch plugged into the Maxfor node through its expansion connector; this switch can interrupt the node, detect the window event and send this event to the main server. To collect more data about temperature, humidity and luminosity at different points in the room, these Maxfor nodes also get data about these variables. In addition, some sensor nodes are responsible for detecting people. These sensors are labeled (4) and (7) in fig.2. Node (4) uses a motion detector based on passive infrared (PIR), and this device is plugged into the Maxfor node and interrupts it, triggering the sending of data to the server of the motion detect event. The sensor labeled (7) in fig.2 can also monitor people´s actions. This control is carried out through the open/close door event. For this task we use the same magnetic switch plugged into the Maxfor node as nodes (2) and (3).

It is very important to know if there are people in the room, otherwise the air conditioning or the heaters are using energy that could be saved. Besides energy control in the building, we install some sensors in order to create a safe place of work and control it in terms of security. Along these lines there is one sensor used as a smoke detector. This is the sensor node labeled (5) in fig.2. The device that detects the event of fire or smoke is a commercial one adapted to plug into the sensor node. Like the other sensors, this device is tied through the expansion connector of the node and when it detects the event, the node sends this data to the main server and produces an acoustic signal as an alarm.

Finally, in order to measure and monitor the energy consumed, instantaneously, and to perform data collection with energy trends over time, we have to insert a new sensor device. This sensor is placed in the room of the electrical cabinets; in fig.2 this sensor is labeled (8).

We have developed a device that can measure this variable without the need to disturb the electrical installation. The principle on which the device is based is the magnetic field generated by the wires of the installation. Through the magnetic field and a specific transducer we can obtain a voltage depending on the current through one wire. This device consists of a ferrite core surrounding the specific wire with a magnetic transducer inside it. The connection is shown in fig. 4.

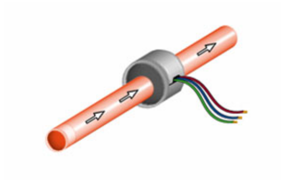

Fig. 4. Connection of the magnetic field sensor

The output from the device has to be managed to adapt the levels of voltage. We have implemented this intermediate stage in order to plug it into the Maxfor sensor node.

The nodes making up the Ecosense project, gathering and storing data, are also used as a special platform to create a testbed. This testbed is very important in our laboratory because there are many activities related with the development of energy-efficient protocols. Our power-efficient work methodology integrates different energy-aware network protocols through the principles of cross-layer protocol engineering. We focus on the medium access control and network layers, as the radio device is the most power -consuming device. We have developed an optimal architecture for sensor networks [7] and we need to test the different protocols that operate in this architecture.

3 Our Sensor Testbed

Sensor Network testbeds provide a platform network that can be used for real-time analysis and evaluation of a sensor network application. Experimental evaluation through testbeds is a fundamental step in most of the research projects in sensor networks in the main universities of the world. Moreover, testbeds together with a simulation and the later deployment of the hardware and software evaluating a real platform will help us to obtain reliable and innovative sensor network prototypes.

Some related projects in this field are the testbeds developed in the following universities:

- University of Harvard. Motelab [8] is a wireless sensor network testbed deployed in the Maxwell Dworkin laboratories. This testbed is composed of MicaZ sensor nodes plugged by Ethernet through UTP cable to a central server. This testbed has a web interface to interact with the system and a database system (MySQL server).
- Ohio State University. Kansei [9] is a testbed divided into three subsystems: static array, portable array and mobile array. The static array consists of 210 sensor nodes deployed in a square platform separated by 75 cm.

- As sensor nodes, the Extreme Escala Motes (XSMs) are used.
- University of Harvard BBN Technologies. Citysense [10] is a testbed composed of more than 100 wireless sensors deployed around the city on streetlight posts, and private and public buildings. Each node is composed of a computer with a WIFI interface. The sensors monitor environmental variables and atmospheric pollution. As a result, this is an example of how a testbed can be deployed that covers a whole city and which is not focused on a laboratory or research center.

In the last few years, in our laboratory we have tested the sensor network protocols through simulators and emulators. After testing we implement these applications and protocols in real sensor networks such as IntellBuilding [11] and WiseVine[12]. In these real sensor networks we have the problem of the power supply, and we lose data packets and so we cannot make a reliable study of our protocols because the final results are affected.

As a result theI3ASensorBed was born. We needed a real cabled sensor node platform in order to test our applications and protocols easily, without the problem of power supply.

The architecture of our system is organized in a tree. This tree form has three levels; each level is interconnected via different technologies. On the one side, there are the sensor nodes MTM-CM5000-MSP (they are the final devices or the leaf) tied through USB cables to special nodes called *super nodes*. Finally, as root of the tree there is a central server to which the super nodes are connected through an Ethernet network.

The use of these super nodes is due to USB standard restrictions. If we use only USB connections, the maximum number of nodes will be 127 and with a distance of 30m between nodes. For this reason we need a change between the USB environment to the Ethernet one with UTP cable and RJ45 connections because these kinds of networks are cheap and accessible.

There are some devices on the market that can connect USB massive storage devices through an Ethernet network, but our sensor nodes, although they have USB connectors, are not like storage devices and we need to modify some factors in the firmware. For this reason we have to find a new solution. As a consequence, we use a specific device by Linksys, the *Network Storage Link* for USB2.0 (NSLU2). This device has firmware based on the Linux O.S. and consequently the source code is released by Linksys. It has permitted us to modify the firmware and install a full version of Linux for embedded devices (Debian version). Thus, we have a full computer with Ethernet connections and USB ports for a small cost (less than 100€).

NSLU2 has an Ethernet port and two USB ports, shown in fig.5, right. This device uses an Intel IXP420 processor of the XScale family, and runs at 133Mhz. It has 32 MB of SDRAM and 8 MB of flash memory.

Fig. 5. (left) Linksys Network Storage Link for USB2.0, NSLU2, (right) Partial view of room

In the environment of each layer of the tree architecture there can exist other intermediate devices, so between the node layer and the super node layer USB hubs can be deployed in order to connect more USB nodes into the same super node. Furthermore, between the super node *l*ayer and the server there exists an Ethernet switch in order to connect several super nodes to the central server. Fig 6 shows the complete tree architecture of the I3ASensorBed.

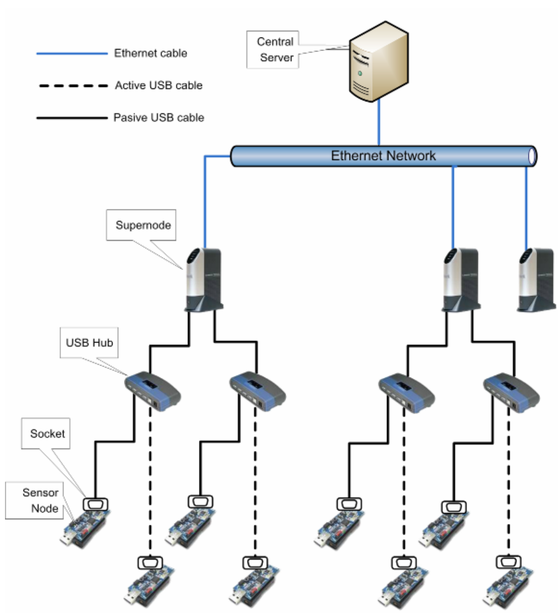

Fig. 6. Tree architecture of the I3ASensorBed

The device used as USB hub is the USB2HUB4 by Linksys. It is very useful in our application because we can turn on or turn off the sensor nodes in order to test the network application in a better way.

Lastly, we have the central server. This element will control all the system, interacting directly with the super nodes through the Ethernet connection of the test-bed. This machine offers the necessary network services for the correct working of the super nodes in the testbed: DHCP, DNS, NTP and NFS.

The server will offer a database to store the testbed information. The data-base motor is based on PostgreSQL because it is a robust, stable and free code.

Another function of the server is to send scripts through the `ssh` connection to the super nodes in order to interact with the sensor nodes. The interaction with the user is by means of a web interface; so this machine will be a web server too (see figure 7). Through the web interface the final user can program, reset, turn on or turn off and activate the *serial forwarder* in a specific node or a group of nodes chosen by the user. In order to implement this interface we use a work environment based on Python and Python Twisted Tools.

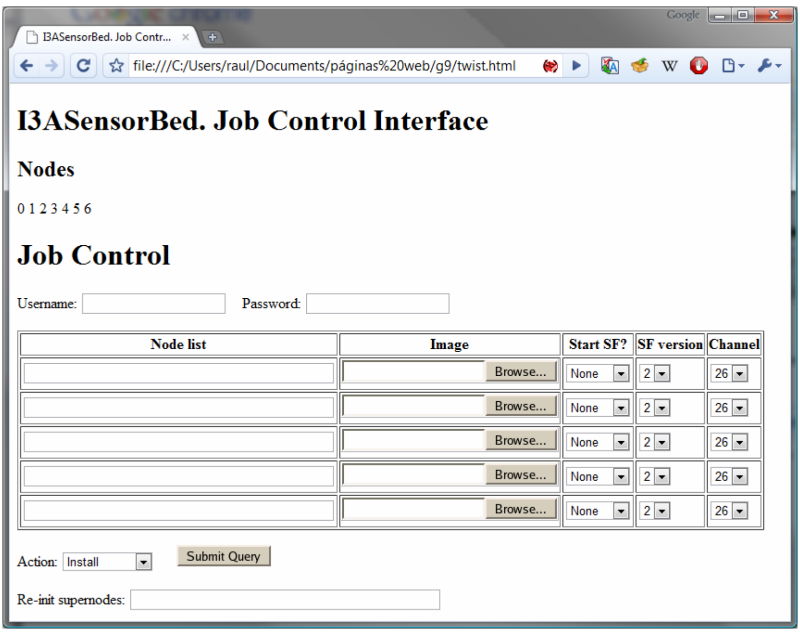

Fig. 7. I3ASensorBed web interface

4 Conclusions and Future work

We have set up a cabled and controlled network in an indoor environment. This network will help us to monitor all important parameters for making an energy study. We wish to obtain categorical conclusions about energy efficiency in our building, and after this, to take actions to improve the consumption and working environment. However, this network is not a simple and experimental macroscope of our building, but this network will also be used as a testbed to evaluate the protocols designed by our group. We hope that this experience will be a good opportunity to improve the energy consumption in buildings, turning these into sustainable environments. After the preliminary data, we can extend and clone this network prototype to other rooms of the Institute and to other buildings on the campus.

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The Use of Intelligent Systems for Monitoring Energy Use and Occupancy in Existing Homes

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Abstract. In the UK the existing domestic building stock accounts for 30 % of the total carbon dioxide emissions [Domestic energy fact file, BRE, 2008]. The UK Government has set ambitious targets for reducing UK carbon dioxide emissions by 80% by 2050. These targets will require significant changes to the existing buildings. To understand and quantify the benefits of refurbishment solutions, it is vital to monitor exemplar buildings and to bring them to an energy efficiency standard with lower associated carbon emissions, by finding the most efficient way to refurbish them. A 1930's replica three bed semi-detached house analyzed in this study is located in the University of Nottingham campus and is fully monitored, including monitoring of the occupants patterns, environmental monitoring, electricity use and energy associated with space and hot water heating. This paper analyses techniques used for tracking computing technologies in everyday domestic settings. A Real Time Occupancy Monitoring System using ultra wideband (UW) radio frequency (RF) is used in this study to track person's location within the research house. The results presented in this paper shows that energy consumption profiles are related to the occupants and their profiles. The data also depends on the outside weather conditions and occupants' behaviour. The study shows that it is not enough just to improve building performance in order to improve energy efficiency; it is also important to understand and influence occupant behaviour, due to the fact that in domestic buildings the occupants exert complete control of the appliances, lights, heating, and ventilation. The results of this study suggest that general behavioural trends and patterns can be extracted from long-term collected data. This systematic study could benefit the existing housing stock in the UK by applying the same methods used in the research house.

Keywords: Energy Efficient Dwellings, Post-occupancy Evaluation (POE), Occupants Behaviour; Building Performance.

1 Introduction

The threat of climate change due to the increase in greenhouse gas emissions has led to a worldwide concern. According to the 'Fourth Assessment Report' of the Intergovernmental Panel on Climate Change (IPPC), the primary causes in climate

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change are due to human activities. Many studies state that the energy usage depends on the occupant behaviour, but very little research shows clearly how the consumption and occupant behaviour are related each other. There is an urgent need to implement methods in order to determine the occupants' interaction behaviour with available domestic technology, such as heating system, electrical equipment, lights and to come with solutions in order to reduce the energy use in the existing homes.

The objective of this study is to investigate and develop a novel POE methodology and software that integrates energy use, environment data and occupancy in one package. The necessity of such software is to analyze and reduce excessive energy consumption and high energy cost due to occupants energy usage behaviour. Besides implementation of various technologies in improving buildings, there is also a need to determine the occupants' behaviour and the energy consumption depending upon the number of occupants. The data will enable us to determine the carbon footprints of individuals within the house by linking their whereabouts to the household energy consumed, during different stages of house being refurbished.

2 Systems for People Tracking and Activity Recognition

Tracking people, their activity and location, as well as objects within buildings is a process applied by many researchers in various fields, such as pervasive computing, multimedia processing, and computer vision. Many studies suggested that using occupancy sensors good measured data performance and savings of 25%-75% in variety of spaces can be obtained [3]. A variety of methods for existing tracking technology in the ubiquitous computing area have been developed, including wristbands, radio frequencies, Wi-Fi technology, GSM technology, and GPS.

The system based power line network [2] uses switches and motion sensors (detectors) to track indoor human activities. The system provides reliable data and easy to be processed, but it cannot provide detailed information, because a motion sensor can say if there is or not a person present in monitored area. It can't provide any data about the exact location of the person. Koile et al. [6] proposed a computer vision system to monitor the person location and the moving trajectory.
Aggarwal et al. [1] has reviewed 2D and 3D methods for human motion tracking and human activity recognition.

Many systems using sensing technologies such as Radio Frequency Identification (RFID) are available on the market, being very efficient and reliable in collecting data. An RFID system is an automatic system that uses radio waves to capture information from tags. RFID system is used in various fields (health, pharma, manufacturing, defense, energy, aviation) for real-time localisation/positioning and identification of objects and components, providing accurate location information. One of the first users of RFID for researching occupancy patterns in domestic buildings was the research done by Gillott et al. [4]. Over the time, researchers have tried to improve the accuracy and precision, improving the sensing hardware by minimizing the size.

3 The Case Study Considered – The E.ON 2016 Research House

A semi-detached house (Figure 1) was built in the University of Nottingham' campus to 1930s building standard, being representative of several homes which still exists in UK. This project will provide scientific data to verify current retrofit technologies to upgrade existing homes, by developing innovative solutions for improving energy performance and assess cost effective measures for reducing carbon emissions from age's buildings and potentially applied to similar properties across the UK.

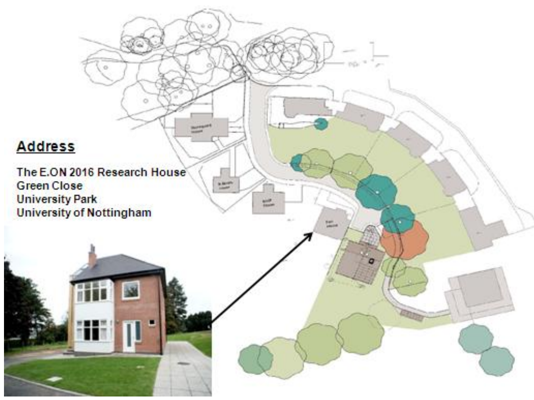

Fig. 1. The E.ON 2016 Research House on the University Site Campus

The house is occupied by a family (mother, father and a daughter). Comprehensive equipment is used for measuring electricity, water and gas consumption, environmental measuring and occupants' patterns, to assess the performance of a typical 1930s house and the upgrades to different levels of sustainability [5]. A range of sensors, such as temperature, black bulb temperature, air quality, humidity were placed across the house in different locations: walls, floors and ceilings.

The loft space is a research laboratory with access provided through the 'service zone' to the party wall side of the house (where data are collected), simulating the environmental performance of an adjacent property, keeping the party wall warm. All the measurements from the BSM system are recorded in the central control panel and are accessed through a 963 Supervisor software v.2 (provided by Horizons Control) on a pc located in the loft space. The data logging equipment is a graphical real-time user interface for the building control system, providing acceptable accuracy, but a limited storage capacity, being able to host on a page a maximum of 100 sensors [10]. The quantitative data are logged continuously and periodically collected in .*txt files and will be used as a benchmark for the energy performances for UK houses. The data can be seen also on the internet through a wireless ZigBee, an area network technology based on IEEE 802.15.4 - 2006 standard, with a transmission range of 100+ meters, which consume very little power [12].

4 Real-Time Occupancy Monitoring System Used

Technology used in this work includes an ultra wideband radio (UWB) radio frequency (RF) location system (supplied by UBISENSE) to track and monitor the occupants and space use [11]. It is the first time that this version has been used for an application in a domestic property. With a high positional accuracy and reliability, the system is used to track patterns of space usage in the house for real time and location, by determining their ‘real-time’ occupancy patterns. A number of sensors were placed strategically around the house and pointed towards the floor so that to be able to detect a robust localization of the worn tag by the person within a relatively high accuracy (Figure 2).

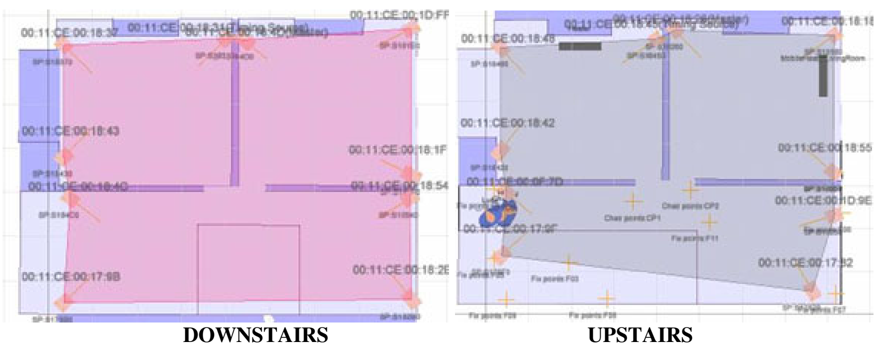

Fig. 2. Schematic Map of Sensors Location in the E.ON 2016 Research House

Each sensor network cable has been connected to an ethernet switch. For the occupants, the devices used are active Ultra-High Frequency (UHF) Radio Frequency Identification (RFID) tags.

Following steps of the process were done: install mounting brackets for sensors and cabling, mount sensors, connect network data cables and timing cables to the sensors, connect power supplies, calibrate and test the occupancy sensors in the test house. Then upload the plan of the house and locate the sensors on it. The tag details were introduced in the system and the settings done.

Once that was done, the zones and sub-zones were defined and the necessary monitoring settings by creating roles and associate shapes to them, so that a detailed map of occupants’ actions can be determined. Figure 3 shows the sub-zones created in the Living Room Zone. For each zone in the house were created sub-zones, so that to determine a detail map of occupants’ pattern.

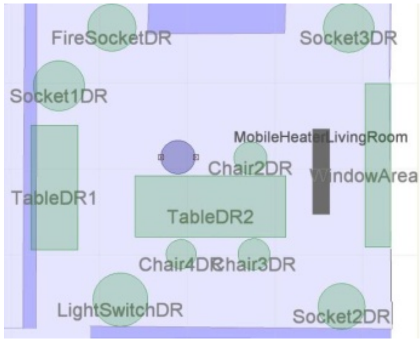

Fig. 3. Sub-Zones defined in the Living Room Zone

Using Microsoft Visual Studio 2005, a C# application in the host computer was created to place all the tags in a list view, to obtain the location data for any particular tag (person location and person description) and to monitor the spatial relationship. The GUI aspect of the form was design using labels and buttons.

A monitor Schema was created in order to query current relationships between objects. Another schema was created to query the names of the tags (persons) and the role relationships for this particular situation.

When a person or object with an assigned tag moves in the close proximity of the sensors, the ID of the tag is detected by the sensors and the tag reader send the data in the system, where it is translated and combined with a set of pre-stored data parameters. There, based on the user' request, the system detects information about the tag ID and person identity. The information about occupants' location actions of the occupants are logged by the reader program to a .*csv file (a comma separated file).

5 A Post Occupancy Evaluation Tool - Data Processing and Evaluation

A key aspect in our study is the data process. The *csv files with the occupants data obtained with the Ubisense system and the .*txt files with the quantitative indoor measurements are transported and sorted in a database, created using Microsoft Access 2007, capable to store information about environmental parameters, energy consumption and occupancy (IN/OUT status from a particular space and (X,Y) location). Computer interface software has been developed, capable to store methods to retrieve information and access the data from the database by processing it further. The program code written in Microsoft Visual Basic 6.0 was made up of a number of event procedures, so that it can perform an action or a series of actions. The GUI-aspect of the form, including check boxes and buttons was designed, so that it can perform actions by accessing the database easily. A schematic diagram of the entire POE process that integrates energy use, environment data and occupancy is shown in Figure 4.

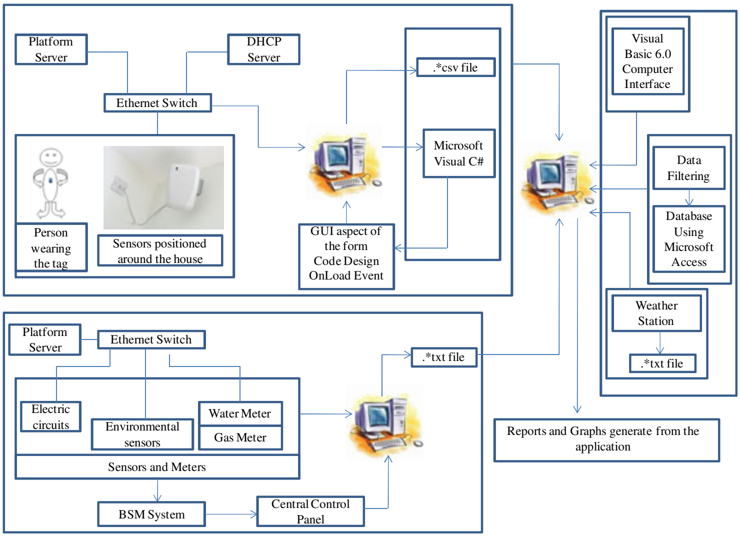

Fig. 4. A Schematic Diagram of the POE Process

The computer interface software developed will enable the researchers to analyze the data efficiently and in a short period time and large data sets can easily be accessed. The input data were categorized in: parameters (sensors), persons (occupants), cells (zones considered in the house). The interface software can provide breakdown domestic energy consumption and environmental, occupancy profiles and the relations between them for any specific period. This is an essential part in the POE study, because it provides accurate data that will enable us to determine the carbon footprints of individuals within the house by linking their whereabouts to the household energy consumed, during different stages of house being refurbished. Detailed occupancy data is often the one unknown variable even in the most comprehensive POE studies.

In order to provide detail information, it is necessary to take into account the following factors: number of occupants and daily presence time, if they are active or asleep, duration of lighting in each room, real indoor temperature, type and use of appliances. Identification of zones within the house is important to know where each person is located. From the information collected, it can be determined where the energy is consumed in excess.

The patterns of time spent in particular spaces depend by the number of person present in the house. Figure 5 shows the number of active occupants over 24 hours. These patterns could vary over the course of each day.

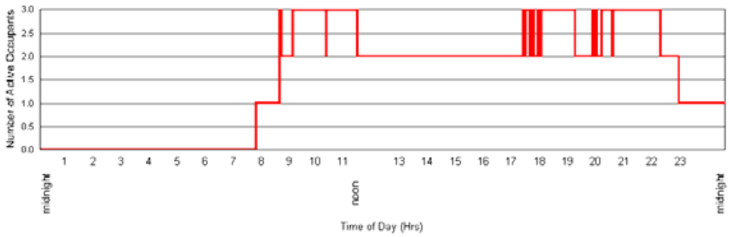

Fig. 5. Number of Active Occupants during 24 hours

In order to see how much these patterns vary, the occupants are monitored in each season during the year. From real data can be calculated the occupant density. It is vital to know the occupancy pattern in order to determine how the space is used, where the energy is waste and how it can be reduced. Figure 6 shows the patterns of space usage of an occupant (father) during 24 hours.

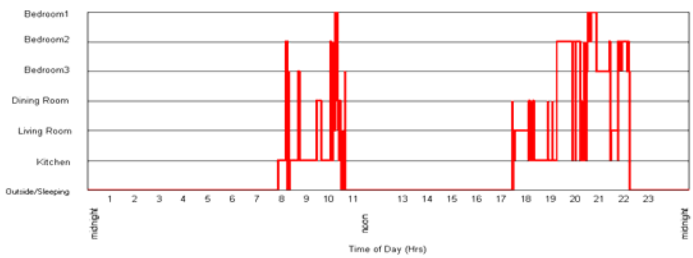

Fig. 6. Patterns of Space Usage of an Occupant during 24 hours

The amount of gas usage is related to the outside temperature and occupants presence in the dwelling (Figure 7). Once the outside temperature is low, the gas consumption increase so that the temperature inside stay almost constant during

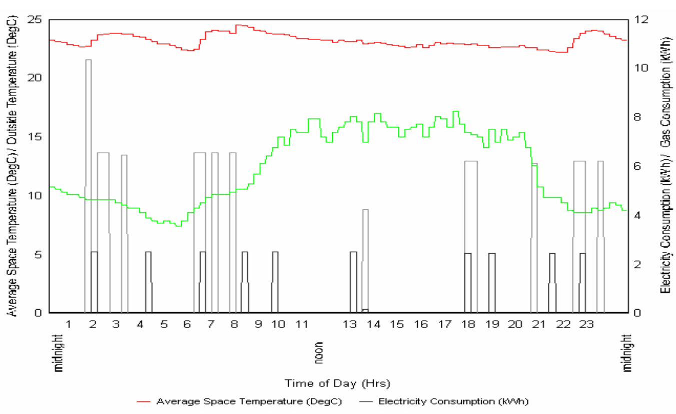

Fig. 7. Environmental Conditions vs. Energy Consumption Schedule during 24 hours

the 24 hours. When the inside temperature drops, the central heating system is used and an increase in temperature was observed. Therefore, as expected colder temperatures lead to higher energy use.

Relations between electricity consumptions and occupants' patterns were determined (Figure 8), by supporting the previous studies which states that the electricity demand is affected by occupants' behaviour [7, 8, 9].

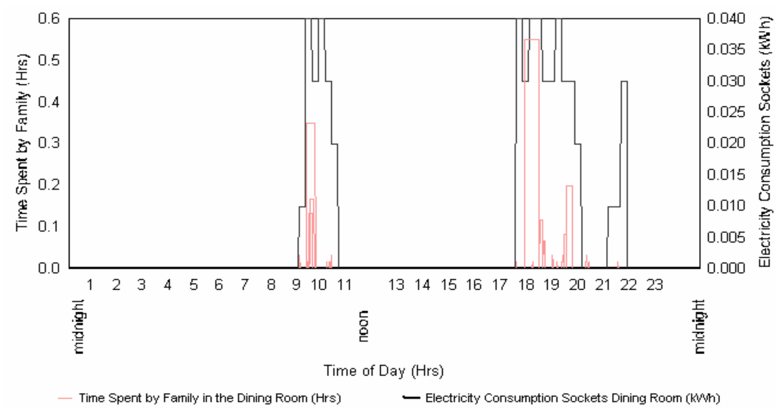

Fig. 8. Occupants' Pattern vs. Electricity Schedule in Dining Room Zone

The interface software can generate also graphs for any period of time chosen. Figure 9 shows the occupants' pattern and temperature for a week. Indoor temperatures for the period selected varies fairly constant. It was observed that behavioral actions affect the electricity and gas consumption in the house.

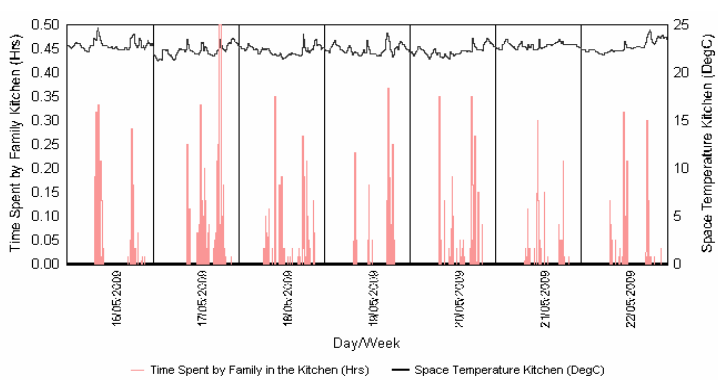

Fig. 9. Occupants' Pattern vs. Temperature

The computer interface software is capable of generating a series of graphs, for any interval of time with various combinations for selected parameters: pie charts showing percentage of electricity and gas consumption and occupancy per zone, bar charts by comparing the time spent for certain periods of time (work days and rest days), bar charts showing the consumption for different periods of time during a day and occupancy mapping for time and location density.

Occupant patterns are valuable in making a decision regarding thermal comfort in the house before and after each phase of refurbishment. These data can provide information, such as occupant density and can help in finding solutions of reducing electricity and gas consumption.

6 Discussion and Conclusions

The results indicated that the interface software developed is very computationally efficient, being able to generate a series of information in various forms. It is only necessary to choose the desired parameters, persons and type of graph. Large quantities of data can be stored in the database and accessed through the interface software developed.

It has been proven that the system supplied by Ubisense is able to locate and track occupant location with a high degree of accuracy. Our results indicated that it is possible to build a tool, able to combine the person location data with environmental and energy consumption data. Using this certain method great information can be obtained and rich conclusions can be drawn. Being a complex study with an enormous data, there is necessary to have a tool able to respond to the changes. In general a Post Occupancy evaluation study can have a key role in minimizing energy consumption and helping to bring the existing homes to zero carbon targets. Previous work has shown that there is a relation between occupants' behaviour and energy consumed in a household. This fact become over the time increasingly important as it can answer to the question rose by many researchers Can a zero carbon home really be "zero carbon" if it has energy wasteful occupants? It is therefore essential to determine in detail the occupants' patterns and their respond and behaviour.

Further investigation into the data is necessary to highlight with precision trends for same periods of time, but in different stages of refurbishment. The method constructed for this house, can be extended to multiple houses. The real-time data accumulated over the time can be used to develop a tool able to predict possible savings in different types of houses with different number of occupants and in various type of climate.

The POE work goal was to explore integration of indoor climate, perception and behaviour of occupants and energy performance in one system, allowing results obtained to be combined. Patterns of occupants in a building is of high importance in simulating the behaviour of occupants within a building and their effects on the buildings' demands for resources such as electricity, gas or water, as well as the production of waste.

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Assessing the Energy Performance of Office Buildings

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Abstract. The production and use of energy are the cause for the 94% of CO_2 emissions, with an important share, at least 45%, corresponding at the building sector. Buildings are accounting for the 40% of energy consumption in Europe, while the increase of demand of electric energy is forecasted to reach up to 42% at 2020. Greek buildings absorb roughly the 1/3 of consumed energy and emit the 45% of CO_2. Particularly, the tertiary sector represents roughly the 25% of total number of Greek buildings. The category of offices/commercial buildings constitutes the higher percentage between the main categories of tertiary sector and it represents the 2.74% of total building reserve, that corresponds at a total energy consumption equal to 339 kWh/m^2.

In this paper, the energy behaviour of public buildings is studied. The energy situation of public office buildings in the prefecture of Florina, in North Greece is investigated. The paper demonstrates the energy assessment of office buildings and it formulates proposals for the improvement of their energy efficiency. The evaluation of the existing energy situation and the proposed energy interventions was performed with the EPA-NR software,

The parameters that were taken into account were the constructional data of the buildings, the data on the operation of the buildings, energy consumption and the exterior climatic local conditions.

1 Introduction

The production and use of energy are the cause for the 94% of CO_2 emissions, with an important share, at least 45%, corresponding in the building sector. Buildings are accounting for the 40% of energy consumption in Europe, while the increase of demand of electric energy is forecasted to reach up to 42% at 2020 [1].

Greek buildings account for about the 1/3 of consumed energy and emit the 45% of CO_2 [2]. Particularly, the tertiary sector represents approximately the 25% of the total number of Greek buildings. The category of offices/commercial buildings constitutes the higher percentage between the main categories of tertiary sector and it represents the 2.74% of total building reserve that corresponds at total energy consumption equal to 339 kWh/m^2 [3].

According to a study on the energy behavior of public office buildings in the Prefecture of Florina [4], the average total specific energy consumption of public

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buildings of the Prefecture of Florina amounts in 164.56 kWh/m^2, with an average thermal energy equal to 139.08 kWh/m^2 and average electric energy equal to 25.47 $kWh/m^{2.}$ This means that the thermal energy constitutes the 84% and the electric only the 15% of the total energy consumed in this building category.

2 Assessment of the Energy Performance of Buildings and Energy Interventions

The aim of this work was the assessment of the existing condition of office buildings in the public sector in this region and investigation of possible energy interventions in order to improve their energy performance and indoor thermal conditions. Simulations were performed for representative public offices in the area with the use of the software 'EPA-NR'

2.1 Investigated Public Buildings in Florina

The region that was selected for the study is the prefecture of Florina, in north Greece. It is among the coldest regions of Greece and according to the existing Thermal Insulation Regulation belongs to the C' climatic region, where the buildings have very small cooling needs and very high needs for heating (according to the draft Law 'Energy Regulation for Buildings', the coldest areas of Greece, like the prefecture of Florina, will belong to the D' climatic zones). The dominant characteristics of the climate of the studied region are the cold winters with particularly low temperatures, snowfalls and frequent rainfalls. On the contrary, the summer period is characterized by high temperatures during the day, where they are progressively decreased while the night falls.

According to the climatic data of the National Meteorological Service, the annual average temperature is 11.1 ^{o}C, with average minimum temperature equal to 0.8 ^{o}C and average maximum temperature 21.0 ^{o}C. The rain height is in high levels and ranges from 33.9 mm in August to 71.,3 mm in October. The annual average height of rainfalls is 643.4 mm. The air relative humidity is also high, ranging from 66.1% in July to 92.1% in December, with an annual average of 76.9%. The winds are usually cold with northern direction. The annual average speed of winds is 0.6 m/s.

Three office buildings that accommodate public services were selected and simulated with the software "EPA-NR" An effort was made to select neoclassic buildings, for which data on their energy performance were available and they were presenting a potential for energy upgrade. The selected buildings were constructed between 1880 and 1910. Buildings 1 and 3 accommodate only offices; while in building 2 courses of education of adults also take place. Consequently, the buildings 1 and 3 operate from 7:30 a.m. to 15:00 p.m., while the building 2 operates from 7:30 a.m. to 22:00 p.m. All the buildings are located on the main road of the city, in distance of two building squares. They have north orientation and their main facade faces the main street that is characterized by dense layout. Their south side faces the river Sakolebas, which crosses the city of Florina.

In all buildings some repairs were made years ago, mainly on the building fabric, like change of windows, and strengthening of their support capacity. Regarding the electromechanical installations, replacement of the boiler was the usual intervention.

The building 1 has wooden exterior window frames and shutters and the floor is made of marble. The total area of the building is 1,383.87 m^2, with the surface of basement equal to 460.11 m^2, the ground floor equal to 461.88 m^2 and the first floor 461.88 m^2. The total heated area is 1,383.87 m^2, including the surface of the basement. Respectively, the total volume of the building is 5,721.13 m^3, with the basement equal to 1,610.39 m^3 and a typical floor 2,055.37 m^3.

The building 2 has, also, wooden exterior window frames and shutters and the floor is covered by marble in the corridors and the staircase, while the floor in the rooms is wooden. The total area of building is 676.8 m^2, with area of formal floor equal to 169.2 m^2. The total surface of heated area is 507.6 m^2. The total volume of the building is 2,030.,4 m^3, with volume of a typical floor equal to 507.6 m^3.

Finally, the building 3 has wooden exterior frames and the floor is covered by marble. The total area of the building is 646.49 m^2, with the area of basement equal to 218.82 m^2, of the ground floor equal to 212.58 m^2 and the first floor 215.09 m^2. The total surface of heated area is 646.49 m^2, including the surface of basement. Respectively, the total volume of the building is 2,089.47 m^3, with the volume of basement 645.52 m^3, ground floor 669.63 m^3 and first floor 774.32 m^3.

2.2 Proposed Energy Interventions

The energy evaluation of buildings was achieved with use of the software EPA-NR [5, 6]. The “EPA-NR” is a methodology and computational software, which was developed in the frame of the programme “Intelligent Energy Europe” of the 17th D.G. of the European Committee, for the evaluation of the energy efficiency in existing buildings of the tertiary sector. It includes calculating tools for estimation of the energy consumption and savings for heating and cooling of the building, heating of domestic water and artificial lighting of the building.

In all office buildings that were studied in the prefecture of Florina the energy needs should be decreased in order to improve their energy behavior. Aiming at energy savings, various energy interventions were proposed for the energy upgrade of these buildings.

In particular, interventions to be applied at the shell of each building were investigated. The building’s shell constitutes by the exterior walls, the floor, the roof, the frames of openings and the glass panes, all of them influencing the thermal behavior of the shell. Thus, the interventions concern the insulation of these elements and the airtightness of their openings.

Thus the interventions that were investigated in each building are the following ones:

- Replacement of the single glazed windows with double glass panes with distance 4cm<d<7cm.
- Insulation of stonewall. Two thicknesses of thermal insulation were tried: d=0.05 m and d=0.08 m.
- Insulation in the roof, with insulation thickness d=0.06m.
- Insulation in the floor, with insulation thickness d=0.05m.
- Combination of insulation of stonewall, roof and floor
- Combination of insulation of stonewall, roof, floor and windows.

The results of all simulations are summarized in the following tables, 1 to 3.

Table 1. Energy interventions of building 1

	Windows replacement	**Insulation in the stonewall (5 mm)**	**Insulation in the stonewall (8 mm)**	**Insulation in the roof**	**Insulation in the floor**	**Insulation of stonewall-roof-floor**	**Insulation of stonewall-roof-floor-windows**
Energy demand, kWh/m^2							
Heating	312.27	298.3	289.96	351.25	218.36	153.81	146.39
Consumption of energy, kWh/m^2							
Heating	510.86	486.98	473.34	573.5	359.86	254.06	242
Lighting	14.24	14.24	14.24	14.24	14.24	14.24	14.24
Auxiliary electric energy	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Total	525.79	501.92	488.27	588.43	374.79	268.99	256.93
Financial and technical study							
Energy cost, (€)	78,276.95	74,724.70	72,694.12	87,596.34	55,811.17	40,071.02	38,277.41
Cost of investment, (€)	27,570.90	29,642.80	29,642.80	18,475.20	55,354.80	103,472.80	131,043.70
Payback period (years)	2.83	2.23	1.93	44.05	1.72	2.16	2.63

Table 2. Energy interventions of building 2

	Windows replacement	**Insulation in the stonewall (5 mm)**	**Insulation in the stonewall (8 mm)**	**Insulation in the roof**	**Insulation in the floor**	**Insulation of stonewall-roof-floor**	**Insulation of stonewall-roof-floor-windows**
Energy demand, kWh/m^2							
Heating	283.05	217.63	206.24	313.44	220.21	114.79	101.38
Consumption of energy							
Heating	397.43	306.24	290.39	439.29	310.21	162.93	144.18
Lighting	21.78	21.78	21.78	21.78	21.78	21.78	21.78
Auxiliary electric energy	1.55	1.55	1.55	1.55	1.55	1.55	1.55
Total	420.75	329.57	313.71	462.61	333.54	186.26	167.51
Financial and technical study							
Energy cost (€)	22,990.47	18,014.29	17,149.19	25,274.63	18,230.96	10,193.73	9,170.53
Cost of investment (€)	22,908.30	16,057.20	16,057.20	6,768	23,928	46,753.20	69,661.50
Period of settlement (years)	8.97	2.13	1.91	25.09	3.27	3.05	4.25

Table 3. Energy interventions of building 3

	Windows replacement	**Insulation in the stonewall (5 mm)**	**Insulation in the stonewall (8 mm)**	**Insulation in the roof**	**Insulation in the floor**	**Insulation of stonewall-roof-floor**	**Insulation of stonework-roof-floor-windows**
Energy demand, kWh/m²							
Heating	283.56	259.06	252.99	307.72	176.25	118.31	111.35
Consumption of energy							
Heating	494.5	450.54	439.88	535.84	310.36	208.49	196.36
Lighting	21.33	21.33	21.33	21.33	21.33	21.33	21.33
Auxiliary electric energy	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Total	516.53	472.57	461.91	557.87	332.39	230.52	218.40
Financial and technical study							
Energy cost (€)	35,935.54	32,880.55	32,139.29	38,809.11	23,137.41	16,057.61	15,214.71
Cost of investment (€)	12,424.10	13,110.40	13,110.40	8,603.20	25,859.60	47,573.20	59,997.30
Period of settlement (years)	4.03	2.14	1.91	41.15	1.63	2.07	2.52

3 Conclusions

The results of simulations of each building, for the various energy interventions are discussed below.

For the building 1, after the analysis and the annotation of all likely interventions, it results that the recommended modification is the combination of insulation of stonewalls, roof, floor and windows, that is the insulation of the whole shell of the building. Even though it results to higher initial investment cost compared to the other interventions that are related to the heating period of the building, nevertheless it presents the lower requirements and consumption of energy. Also, with regard to the cost, it presents the smaller energy cost and the payback period varies between 2 to3 years, which is considered as a very reasonable investment.

For the building 2, it is also concluded, with regard to the heating period, that the recommended modification is also the combination of insulation of stonewall, roof, floor and windows. It is the scenario, where the biggest reduction to both the requirement and consumption of energy and the energy cost and the investment cost is achieved. Moreover, the payback period varies in the same range with the other scenarios.

Similarly, for the building 3, it results that the combination of the different scenarios constitutes the recommended intervention, with the more satisfactory results.

According to the Greek law 3661 'Measures for the reduction of the energy consumption of buildings', minimum energy requirements that concern the improvement of the total energy performance of buildings are established. The thermal performance of the structure shell is important for the heating period. Particularly in cold regions with heavy winters, like the region of study, becomes imperative the need of proper thermal insulation and airtightness of building's shell.

In conclusion, it is figured that the thermal insulation of the shell of the building decreases the energy requirements and is considered necessary for the thermal comfort for the occupants. At the same time, savings of energy and reduction of cost are achieved.

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Optimisation of Integrated Low-Carbon Energy Strategies: A Case Study for 'Zero Carbon' Social Housing in the UK

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Abstract. This paper details the modelling and prediction of the solar energy supply available for hot water and space heating in a domestic house designed to 'zero carbon' standards in the UK Midlands. The design strategy for the dwelling includes a highly insulated timber frame fabric with a south-facing full-height sunspace and 'low-U' glazing to optimise natural lighting and solar energy gain over the year. A solar thermal system installation is intended to further reduce fossil energy consumption. In conjunction with post-occupancy evaluation, a computational whole-building model with sub-systems has been configured to represent and evaluate in detail the integrated system energy performance including domestic hot water and space heating requirements.

1 Introduction

With more than one quarter of CO_2 emissions arising from domestic energy use, a clear opportunity exists for the UK to greatly reduce its carbon footprint via the implementation of effective sustainable and renewable energy solutions. As it is often not feasible for renewable sources to completely supply the energy required for domestic use, the optimal integration of fossil and renewable energy sources is therefore required. One such solution for reducing fossil energy use and satisfying domestic comfort and hot water demands is by integrating a hybrid fossil fuel solar hot water/space heating system within a new build or retrofit dwelling context. In order to help optimise the system design, accurate site-specific simulation of the whole building energy demands and optimal supply through efficient design and control of the integrated energy sources is required. With these drivers in mind, this work has two key objectives; firstly to utilise advanced transient mathematical models that can be configured to represent a proposed or existing domestic building system (including energy supply and consumption) and secondly to apply these models in simulations designed to achieve a detailed system understanding and ultimately to support optimised system and configuration carbon emission reduction during occupancy.

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This paper details the prediction of the solar energy supply available for hot water and space heating in a domestic house designed to 'zero carbon' standards in the U.K. Midlands region. The design strategy for the dwelling includes a highly insulated timber frame fabric with a south-facing full-height sunspace and 'low-U' glazing to optimise natural lighting and solar energy gain over the year. A solar thermal system and PV installation are intended to further reduce fossil energy consumption. In conjunction with post-occupancy evaluation, a computational whole-building model with subsystems has been configured to represent and evaluate in detail the integrated system energy performance including domestic hot water and space heating requirements.

Due to the complex nature of the temporal response of the system to both environmental and occupant-related parameters, it is necessary to analyse whole-system performance using a detailed & validated transient method. The methodology used in this paper includes modelling and simulation of the system using the TRNSYS [1] dynamic computing environment.

In the specific case of using solar-derived energy for hot water and space heating requirements, the problem of mismatch between the energy demand and the energy supply is usually addressed through the integration of hot water storage and an auxiliary heat source. In addition to the consideration of solar collector selection and sizing, along with that of the storage tank and auxiliary heater, optimised system control (including that of the auxiliary heat device duty cycle) offers potential energy and carbon savings. It is the evaluation of both optimised control strategies together with system design and configuration factors that are the foci of this work, explored via simulation of the whole building model. In terms of system configuration for this building-specific case, the work evaluates the simulation results of monthly solar fraction and system efficiency in conjunction with solar collector area and the water storage dimensions. The effect of the immersed auxiliary electrical heater geometry within the storage tank is also analysed.

2 System Description

2.1 Building Modelling

The real building modelled in this study is located in Northampton, UK (52°15'N 0°53'W) and is designed to 'zero carbon' standards which combines building integrated renewable energy systems with an appropriate building fabric design strategy. With six units in a terrace configuration, each dwelling consists of a sitting room and a kitchen located on the ground floor with three bedrooms to the first floor.

To the southern facade, a full height double glazed sunspace with retractable shade is attached to the building. This sunspace is designed to provide natural daylight and optimal solar gain in energy over the year. On very warm days, the inner doors can be closed and the sunspace acts as a ventilated buffer zone to shield the home from extreme temperatures. Overheating is mitigated via a roof overhang and solar shading in conjunction with secure sunspace ventilation. A view of the building can be seen in Fig 1.

Fig. 1. 'Zed' zero carbon dwellings

The 'zero carbon' design strategy includes high levels of insulation and optimised thermal mass aspects. The building frame is made from glulam timber, an engineered timber that has better strength characteristics than normal solid wood. The timber frame is in-filled with a secondary timber studwork, creating a 300mm void for rockwool insulation. The whole building is wrapped in a breather membrane, that keeps the building airtight, but allows moisture egress. This membrane is covered and protected by a lightweight rainscreen of lime render with timber weather boarding at high level. A partial brickwork outer skin is also utilised. By using precast concrete panels for the walls and ceilings and waxed slabs laid on the floor, significant thermal mass is incorporated in the building.

Based on information supplied by the designers, the summary of the building materials with their properties are listed in Table 1 [2].

During construction of the computer model used in the simulation, the six units 1-6 are designated as individual thermal zones, whilst the six rooms in unit 4 are designated as sub-zones. Thus, the average dwelling temperatures for unit 1, 2, 3, 5 and 6 and the individual room temperatures for unit 4 can be generated using the TRNSYS simulation program.

Table 1. Building materials properties:

North wall	Thickness (mm)	Density (kg/m^3)	Conductivity (kJ/hmK)	Heat Capacity (kJ/kg.K)	Resistance (hm^2K/kJ)
Lime render	22	1300	1.8	1	
OSB	12	650	0.468	1.88	
Air gap	25				0.038
Rockwool	300	25	0.126	1.4	
Plasterboard	12.5	950	0.576	0.84	
U_value	$0.129W/m^2K$				

East/west wall	Thickness (mm)	Density (kg/m^3)	Conductivity (kJ/hmK)	Heat Capacity (kJ/kg.K)	Resistance (hm^2K/kJ)
Brick	100	1700	3.024	0.8	
Air gap	25				0.038
Rockwool	300	25	0.126	1.4	
Plasterboard	12.5	950	0.576	0.84	
U_value	$0.128W/m^2K$				

Ground floor	Thickness (mm)	Density (kg/m^3)	Conductivity (kJ/hmK)	Heat Capacity (kJ/kg.K)	Resistance (hm^2K/kJ)
Charcon (Paviour)	45	2000	4.32	0.84	
Plywood	27	800	0.52	1.88	
Rockwool	280	25	0.126	1.4	
Plywood	18	800	0.52	1.88	
Air gap	240				0.047
Foundation	360	2400	7.56	0.8	
U_value	$0.127W/m^2K$				

Ceiling	Thickness (mm)	Density (kg/m^3)	Conductivity (kJ/hmK)	Heat Capacity (kJ/kg.K)	Resistance (hm^2K/kJ)
Rockwool	50	25	0.126	1.4	
Plywood	18	800	0.52	1.88	
Rockwool	250	25	0.126	1.4	
Cement wood	40	700	1.296	1.05	
U_value	$0.126W/m^2K$				

Roof	Thickness (mm)	Density (kg/m^3)	Conductivity (kJ/hmK)	Heat Capacity (kJ/kg.K)	Resistance (hm^2K/kJ)
Red cedar cladding	10	370	0.396	1.88	
Euroseam Roof	222	25	0.144	1.4	
Red cedar cladding	10	370	0.396	1.88	
U_value	$0.176W/m^2K$				

Intermediate (party) wall	Thickness (mm)	Density (kg/m^3)	Conductivity (kJ/hmK)	Heat Capacity (kJ/kg.K)	Resistance (hm^2K/kJ)
Gypsum	12	1200	0.756	1	
Rockwool	50	25	0.126	1.4	
Gypsum	12	1200	0.756	1	
U_value	$0.652W/m^2K$				

2.2 Solar Thermal Water System Modelling

An indirect forced circulation solar thermal water system with auxiliary electric heating is modelled in this study. The system consists of two heating sub-systems and two heating loads. The first heating sub-system includes a flat-plate solar hot water collector array of area $4.0m^2$, which absorbs and transports the solar heat exchange fluid to a coil heat exchanger immersed in the bottom of the water storage buffer tank. If required, the water in the buffer tank is subsequently heated by the second heating source, which is an in-tank auxiliary electrical heater when the solar-heated water does not reach the desired set temperature.

The auxiliary electrical heater is controlled by a thermostat in the top part of the tank in order to maintain the required set point. However, if sub-optimally controlled, under specific ambient conditions the auxiliary energy may increase the temperature of the water in the bottom of the tank to a level that reduces the system efficiency of the solar thermal technology – this can be seen in the later simulation results.

The heating loads include the domestic hot water supplied to the household and water utilised for space heating purposes. The DHW supplied to the household is derived from a heat exchanger immersed in the top portion of the water storage tank. Space heating is directly supplied from the water storage tank to the radiators during the heating season.

The main components of the system are described below and schematically shown in the Fig.2

1. South facing solar flat-plate water collector with area of $4m^2$ mounted on the roof with a tilted angle 24^o. Absorber plate emittance is 0.7. Absorptance of absorber plate is 0.8.

2. Fully stratified water storage tank (6 nodes) with total height 1.5m and volume $0.25m^3$. Overall tank heat loss coefficient is assumed to be 3 $kJ/hr.m^2.K$. Two heat exchangers are immersed in the water tank. One is located near the bottom of the tank and connected to the solar collector system; another one is located near the top of the tank and to supply hot water to the residents.

3. Auxiliary electric heater rated at 16200kJ/hr is immersed in the water tank to directly heat the water to the demanded set temperature if required. The electric heater and the thermostat are located near the top of the tank. The auxiliary electrical heater is controlled by a thermostat which will activate when the temperature of the water in the node containing the thermostat falls below 55^oC and continues to heat the water until it reaches the set point temperature of 60^oC.

4. Circulation pump controls flow between heat exchanger and the solar collector. When the temperature of the inlet of the heat exchanger is low or equal to the outlet temperature, the pump will be in the stop state.

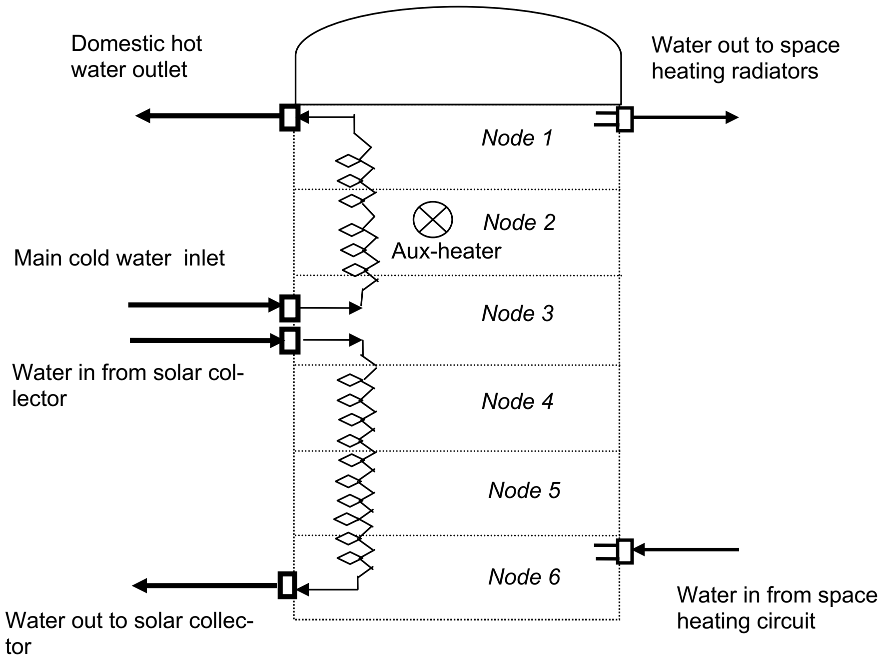

Fig. 2. Schematic of a solar water tank system

2.3 Hot Water Demand

For solar heating/hot water modelling, an estimate of domestic hot water consumption profile is required. Using data derived from BRE studies [3], an average consumption of hot water is taken as 4 litres per person per day for washing machines and 35 litres per person per day for baths and showers. An additional 10 litres of hot water is used for the cleaning of dishes at the sink and for hand and face washing. This gives a total average usage of 49 litres of hot water per person per day. For this study, the hot water consumption profile contains morning and evening peaks as shown in Fig. 3.

The cold water inlet temperature depends largely on the external ground temperature. Data from the Energy Saving Trust is used which indicates a mean value of 15°C for the cold water inlet temperature with a 95% confidence interval ± 0.5°C in the U.K [4]. The actual current hot water set-point temperature of 60°C is also used.

For simulation purpose, weather and meteorological data is taken from the Metronome data bank for London. For the purposes of this study, space heating is set to operate in two periods of the day, namely 5am to 10am and 4pm to 11pm. A space heating set point temperature of 22°C was utilised in the study.

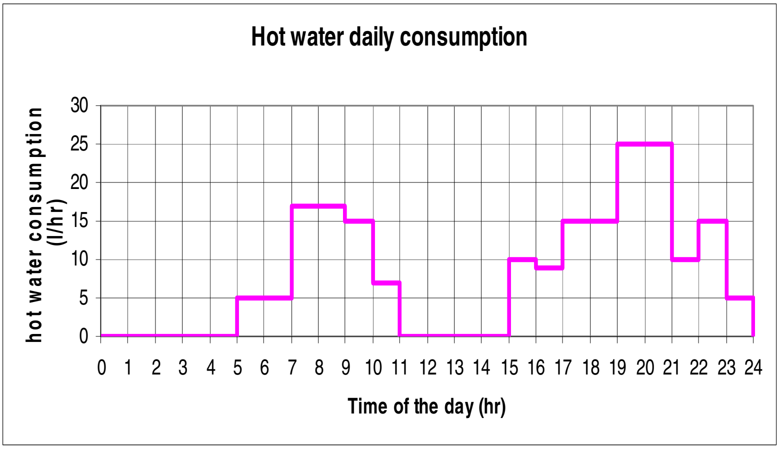

Fig. 3. The profile of the hot water consumption for a day and four persons

Based on the requirement of the heating loads, there are several scenarios for solar thermal system operation. When solar energy is available and DHW or space heating loads are not needed for the residents, the energy gain from the collector will be added to the storage tank. When solar energy is not available and a heating requirement is present, the stored energy in the tank will be used to supply the building needs, either hot water or space heating. If the stored energy in the storage has been depleted, auxiliary energy is used to supply the building needs.

3 Simulation Results

3.1 Building Performance

The first set of simulations is designed to analyse the baseline building thermal behaviour (i.e. without any energy supply from heating systems and additional heating gains. An air infiltration rate of 0.2 litres/hr was assumed. The simulated room temperatures are only dependent on the external ambient temperature, and the short wave and long wave solar gains to the building surfaces. The simulation results show that the average room temperature in winter season is around 10^{o}C ±5^{o}C and in summer season is 30^{o}C ±5^{o}C.

3.2 Solar Water System Performance

For the solar thermal system simulation, key aspects include the water temperature distribution and gradient in the storage tank and the DHW set-point temperature. From Fig. 4, the water temperature of the 'six nodes' within the storage tank for two days in March and June respectively can be seen. The water temperature at 'node1' and 'node2' is always around 60^{o}C since the water is heated by both the solar energy and the auxiliary heater. The water temperature at the remaining 'nodes' varies depending on the level of auxiliary heating and the available solar energy. 'TEX1out' expresses the DHW outlet temperature and is maintained at the 60°C set point. 'TSCout' expresses the outlet temperature of the solar collector and can reach 70°C ~80°C at noon on these sample days.

Based upon the building heating control function (assuming a heating season is from 1st of October to the end of April) [5], the heating energy can be transferred from the solar water /heating system to the building space, where the room temperature setting is assumed to be 22°C.

In Fig. 5, a comparison of the room temperature with and without active heating input in February is shown. The temperature of unit 3 which contains a solar heating system with electric auxiliary back-up heating can achieve 22°C or above when the heating system is operating. Unit 2 without the solar heating system is not able to achieve the set-point temperature via solely passive solar heating.

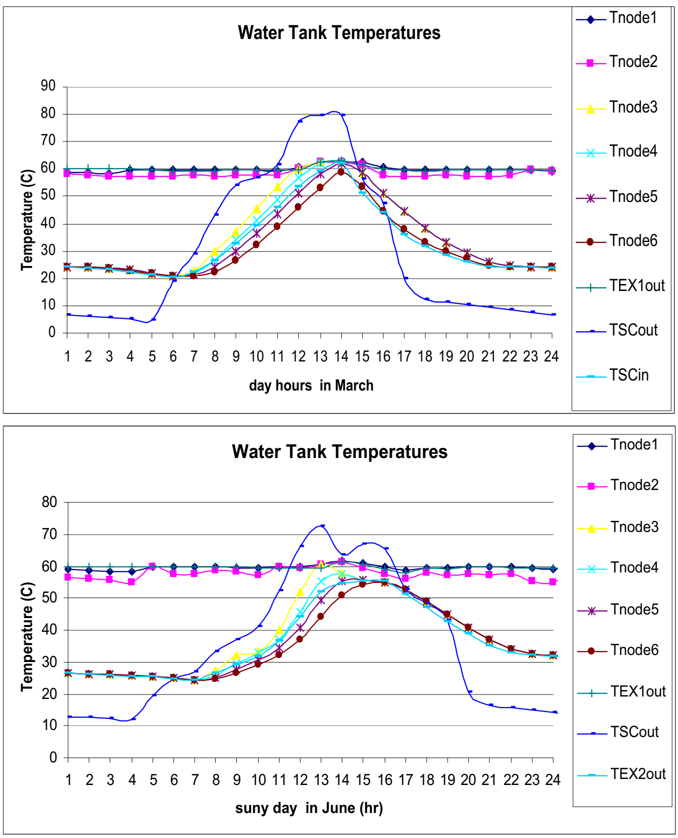

Fig. 4. Simulated water temperature in storage tank

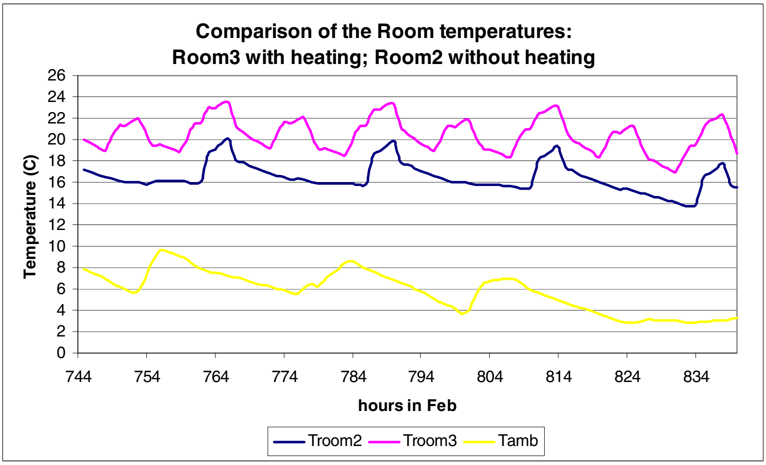

Fig. 5. Comparison of the unit temperature with and without solar heating

3.3 Energy Analysis

Based upon the thermal performance simulation of the solar water system, the monthly solar fraction of the system can be calculated by using the equation [6]:

$$f = (Q_{laod} - Q_{auxiliary}) / Q_{load}$$

Where Q_{load} is the total energy supplied by the system to support the DHW/space heating requirements and $Q_{auxiliary}$ is the total auxiliary energy supplied to the system to support the portion of the total load that is not supplied the solar energy. In Fig. 6, the calculated monthly solar fraction is shown. This can reach a maximum

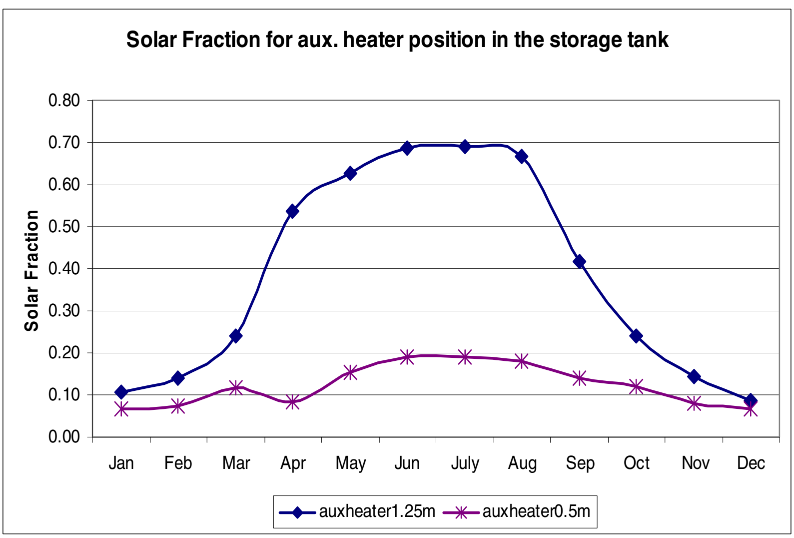

Fig. 6. Comparison of solar fractions with auxiliary heater positions

value of 0.7 when the auxiliary electric heater is positioned near the top of the storage tank. Also, in Fig. 6, the effect of the vertical position of the auxiliary electric heater in the storage tank on the available solar fraction is presented. A lower auxiliary heater position increases the solar collector inlet temperature and therefore its thermal power input via the tank solar heat exchanger coil. For the selected tank volume of 250 litres, the effect of increasing solar collector area on solar fraction available for both space heating and DHW consumption is also analysed via simulation. In Fig. 7, it can be seen that the monthly solar fraction of the system varies negligibly with increasing solar collector area.

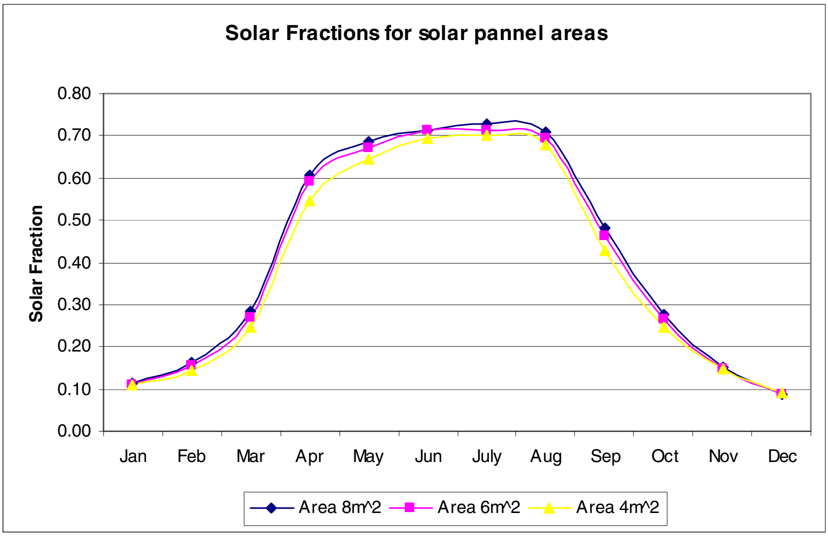

Fig. 7. Comparison of solar fractions with solar corrector areas

Another indicator of solar thermal heating system performances is the monthly or annual solar thermal system efficiency which is the ratio of the useful energy gain to the absorbed solar energy by the collector and is defined by [7]:

$$\eta = Q_u / (A_c I_T) = mC_p(T_{out} - T_{in}) / (A_c I_T)$$

The simulation results in Fig. 8 show the monthly solar system efficiencies when the auxiliary heater is placed near top and bottom of the storage tank. It can be seen that if the auxiliary heater is placed near the bottom of the storage tank, the seasonal system efficiency will be reduced by up to 22% compared with the auxiliary heater placed near the top position. It should be noted that the maximum indicated value of the monthly solar system efficiency of 0.35 is considerably lower than the indicated solar collector efficiency of 0.76. This is because the system efficiency depends in large part upon the collector inlet water temperature which in turn is affected by the temperature of the water in the lower portion of the storage tank. When calculating the solar collector efficiency for specific ambient conditions, the collector inlet water temperature may be assumed to be a significantly lower temperature (say 15°C) than exists in practice.

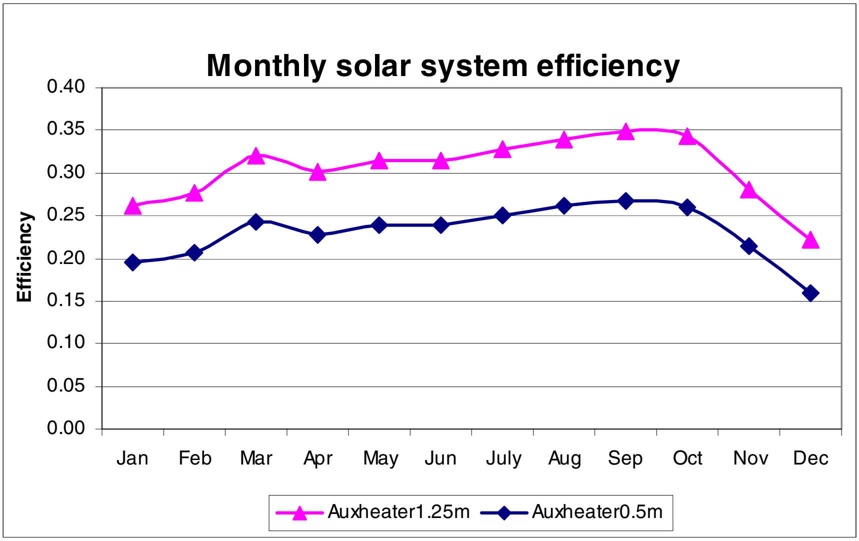

Fig. 8. Comparison of the monthly system efficiency with auxiliary heater positions

4 Conclusions

A detailed prediction for the thermal performance of a 'zero carbon' building has been studied using the TRNSYS computer simulation programme, and the heat energy requirement for domestic hot water and the space heating loads has been estimated.

In terms of system configuration for this building-specific case, the work explores variations in the monthly solar fraction and the system efficiency in conjunction with the auxiliary heater geometry and the solar collector areas. The results indicate that the auxiliary heater position within the water storage tank affects useful available solar energy and system efficiency. For example, for a change in auxiliary heater position from 1.25m to 0.5m vertically from the bottom of the tank, the available solar energy will be reduced by more than 50%. It can also be concluded that when the solar collector area is doubled in size, the monthly solar fraction of the system is increased negligibly due to the limited size of the water storage tank and the heat exchanger. In a particular case, the simulated solar system efficiency of 30% on average for an area of $4m^2$ solar corrector and a 1.5m high (250litre) storage tank is shown, while a simulated solar fraction of up to 70% is presented.

In this study, the modelling of the selected building and the solar water/space heating system has been completed and the thermal performance of the modelled system has been assisted by the computer simulation results. In the future work, the validation of the system model by real measurement will be necessary. Based on an accurate computer model, some additional work can be performed. For example, the implementation of an appropriate integrated building-specific control strategy together with a well designed and specified system configuration can offer significant potential energy and carbon savings. A primary result has shown that a solar/storage/ auxiliary heating system control matched to both occupants' demands and available electric tariffs can lead to increases in average solar subsystem efficiency of 19%. The authors will carry out more work on these issues in subsequent research.

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Characterisation of a Line-Axis Solar Thermal Collector for Building Façade Integration

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Abstract. The integration of concentrating solar thermal collectors into the structural envelope of buildings can significantly increase the cost effectiveness of solar thermal utilisation in the UK. The key, however, to their wide scale application is performance. Typically, most solar thermal collectors are mounted on inclined roof structures, thus presenting an optimal surface area for solar gain. Vertical building facades offer an alternative mounting surface and whilst they may have an overall lower level of incident solar radiation, the collector receives a more uniform annual distribution of solar radiation, reducing potential summer over heating problems. Furthermore, facade integration is beneficial to the building performance as the collector unit results in a higher U-value realising higher building heat retention.

In concentrating solar thermal collector systems, the absorbing surface area is reduced relative to that of the aperture, leading to a reduction in the overall heat loss from the system, hence improving thermal efficiency. To maximise collection in a vertically mounted concentrating solar thermal collector however, the concentrator profile should be optimised to benefit solar collection relative to the mounting inclination.

This paper presents the optical and experimental investigation of a low concentration line axis solar thermal collector employing symmetric and asymmetric CPC geometries. The potential for collected solar radiation when façade integrated has been investigated with the use of three-dimensional ray trace. Several prototype units were fabricated and experimentally evaluated. A series of fluid flow configurations (serpentine and parallel) using different flow velocities have been investigated and a range of slope angles (β) considered.

Results from this study have shown that this type of concentrating solar thermal collector has particular application for domestic hot water production and that the design can effectively operate in the vertical orientation and is suitable for building façade integration in Northern European locations.

R.J. Howlett, L.C. Jain, & S.H. Lee (Eds.): Sustainability in Energy and Buildings, SIST 7, pp. 277–287.
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1 Introduction

Solar thermal collection has the potential to significantly reduce the dependence of hot water production from fossil fuel sources. The typical energy demand of a family dwelling in Europe for water and space heating represents almost the 50% of the total energy consumed [1]. Given the particular issues, however, in balancing solar functionality with aesthetics. It is imperative that the integration of solar thermal collectors into the physical structure of the dwelling form is addressed. However, many Renewable energy systems in particular solar thermal collectors have already become a common feature device in many dwellings in Europe. Solar thermal collectors are normally positioned on flat terraces or sloped roofs making them very visually obvious and perhaps not very attractive. Integrated solar thermal collectors as building façades can protect building against external atmospheric conditions whilst, improving the building's thermal performance.

Most of the solar collectors in European countries have an optimal slope angle of between 35° and 55° to maximise solar collection. Having a 90° slope angle, the annual reduction solar energy collected is around 30%. However, according to Matuska and Sourek (2006) heat losses by natural convection in the gap between the absorber and the glazing are reduced in a verticaly positioned façade solar collector. Moreover, back and edge frame heat loss is reduced for the same position. Finally, extremely high temperatures due to stagnation during noon summer hours are reduced because of lower incidence angles thereby reducing energy collection, [2].

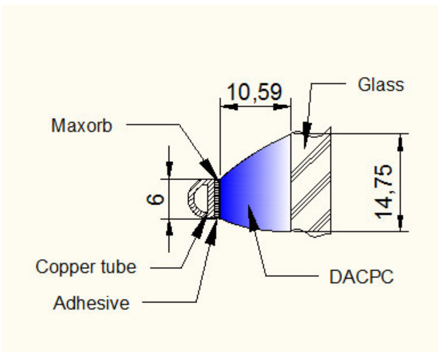
2 Description of a Novel Integrated Solar Water Heater

A low concentrating solar thermal collector using a dielectric asymmetric compound parabolic concentrator (DACPC) was designed, fabricated, modelled and evaluated using outdoor conditions. The prototype was exposed to a wide range of testing parameters such as flow arrangements and slope angles.

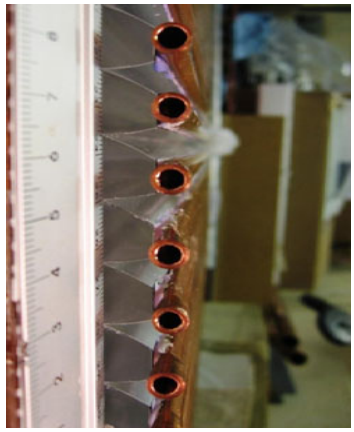
The concentrator material used for this experiment was fabricated and evaluated by Mallick and Eames (2006) where a range of façade collectors using photovoltaic cells were characterized. The concentrator material was fabricated using an injection moulding machine with a treated smoothed surface to achieve an optimum internal reflection into the material. Due to limitations in the moulding machine the material was cut in plates 24mm in length and 21mm wide. The DACPC had a concentrating ratio of 2.45 and the acceptance angle of the upper and lower parabolas of the truncated system was 0° and 37°, with a refractive index of about 1.49, [3]. The experimental optical efficiency of the dielectric acrylic was calculated to be 81% for a wide range of solar incident angles, [4].

For this work the DACPC consisted on four plates positioned in a 2 x 2 alignment giving a total aperture area of $0.2m^2$. In total, twenty-eight rows of asymmetric concentrators each focused on an imbedded 6mm wide receiver.

The absorbing surface of the receiver was covered with a solar selective adhesive (Maxorb) optimizing the thermal energy collection/absorption and transference by conduction (thermal conductivity of 1.6W/mK). Copper tubes of 6mm OD (outside diameter) and 1mm wall thickness were shaped by pressing to achieve a planar surface one side along its length, and a semi-circumference depth of 3mm. A thin layer of a thermal conductive adhesive (Output 315) was used to enhance thermal conductivity (was 0.815W/mK at 30°C) and its thickness was about 1mm. A cover glass 600mm, 490mm and 6mm thick was placed on the aperture face of the collector reducing thermal losses by suppressing convection. A section view of the collector arrangement and the actual section image are shown in Figure 1.



(a)



(b)

Fig. 1. (a) Side section view of the row of the DACPC solar collector, and (b) image of the DACPC and the copper tubes located on the absorber surface

The collector was designed to be tested using two different flow arrangements, serpentine and parallel. In the case of serpentine arrangement, each of the twenty-eight absorber copper tubes were connected to flexible silicon tubes of 8mm OD and 5mm ID and arranged to form the flow configuration.

The complete system was mounted in a wooden casing complete with open aperture and holes for water inlet and outlet tubes. The absorbing tubes were insulated using Superwool 607-MAX 25mm thick and with a thermal conductivity of 0.07W/mK. The collector was supported by a double-axis motion table thus tilt angles could be modified. The whole system was put on a wheeled table along with space for the instrumentation and monitoring devices.

3 Experimental Procedure

All the tests took place at the outdoor's experimental facility of Heriot Watt University in Riccarton, Edinburgh (Latitude 55.9255, Longitude -3.2882). The DACPC collector was mounted facing due South and testing was conducted between 12:00 and 16:00 during the months of July and August.

Monitoring and data logging was conducted using a range of instrumentation and sensory devices. Thirteen T-type thermocouples were employed to measure surface, air and water temperatures of the system. Nine were located on the copper tube surface as shown in Figure 2. Two thermocouples monitored the water temperature of the inlet and outlet water flows and two more measured ambient temperature.

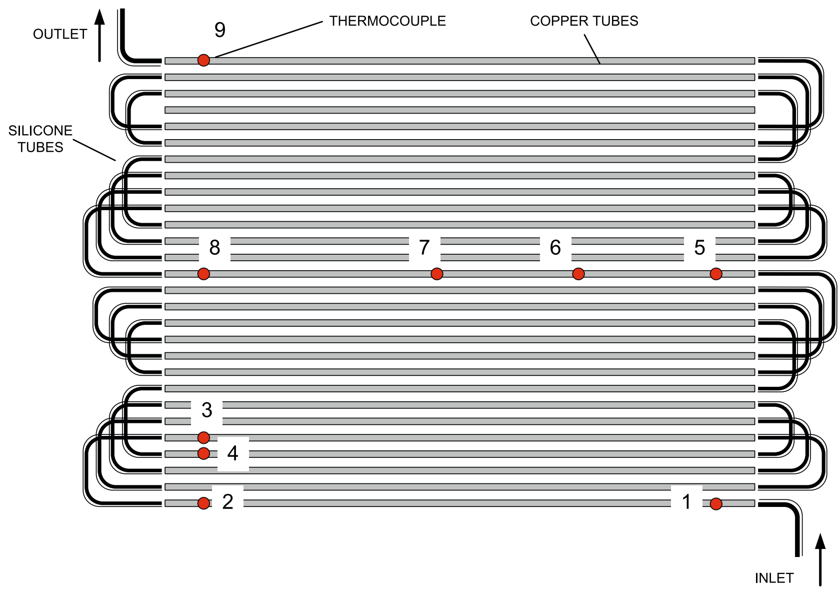


Fig. 2. Location of the thermocouples on the copper tubes surface

The data from the thermocouples was collected by a Multimeter (Keithley-2700) which was connected to a computer in order to visualize and save data. A pyranometer (Delta-T SPN1) was used to collect levels of the incident radiation on the aperture area of the collector. A schematic diagram of the experimental setup is shown in Figure 3.

Water was pumped from a water storage tank using a peristaltic pump (Marlon Watson 505S) to the collector inlet. After passing through the collector absorbing tubes it passed back to the water storage tank through a flexible hose. The peristaltic pump has a wide range of flow rates (80 to 220ml/min of water) and low pressure operating duty.

A range of test variables were evaluated, including slope angle (β), fluid type, flow arrangement and flow rate. The DACPC was set at slope angles of 45° and 60° with air and water as working fluid. Serpentine and parallel arrangements were also tested.

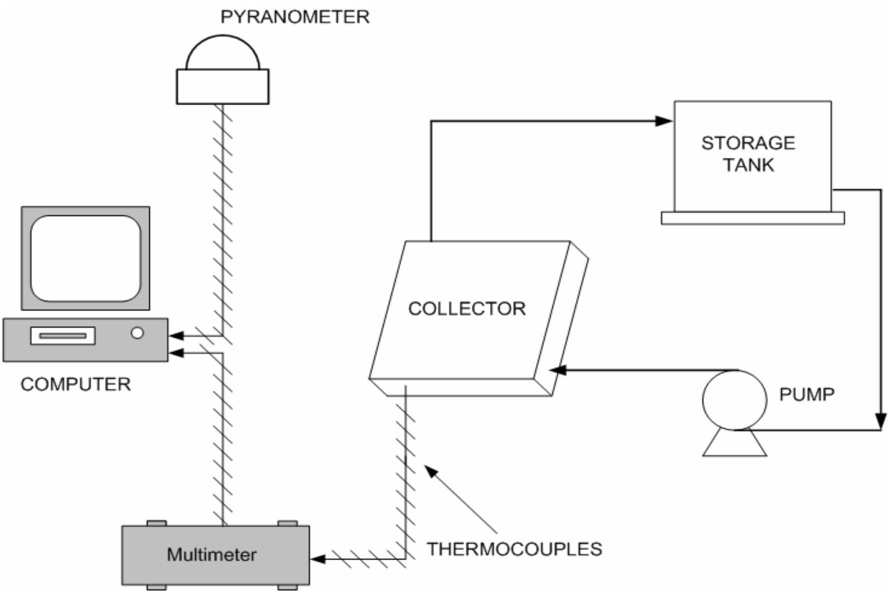


Fig. 3. Schematic diagram of the experimental setup

4 Ray Tracing

The most important limitation of any outdoor experimental procedure for solar collectors is the instability of weather and loads. However, simulation software can show the variability of the collector performance under any solar radiation, temperature or other parameters.

This work was supported by simulation using ray-tracing techniques, the optical parameters of the DACPC and solar radiation data from two test days was selected (14th of August and 21st of December), and modelled using the ray-tracing software. Figure 4 details the solar radiation and collector temperature for the 14th August.

The performance of the DACPC collector was simulated at three different slope angles (β), 30°, 60° and 90°. The maximum solar altitude angle for the 14th of August was calculated 48°. Therefore, the incidence angles for 30°, 60° and 90° slope angles is 12°, 18° and 48° respectively. However, the DACPC was designed to optimize the refracted solar beam that the receiver absorbs at vertical positions. At a slope angle 30° the collection efficiency was lower than the other two cases as shown in Figure 5.

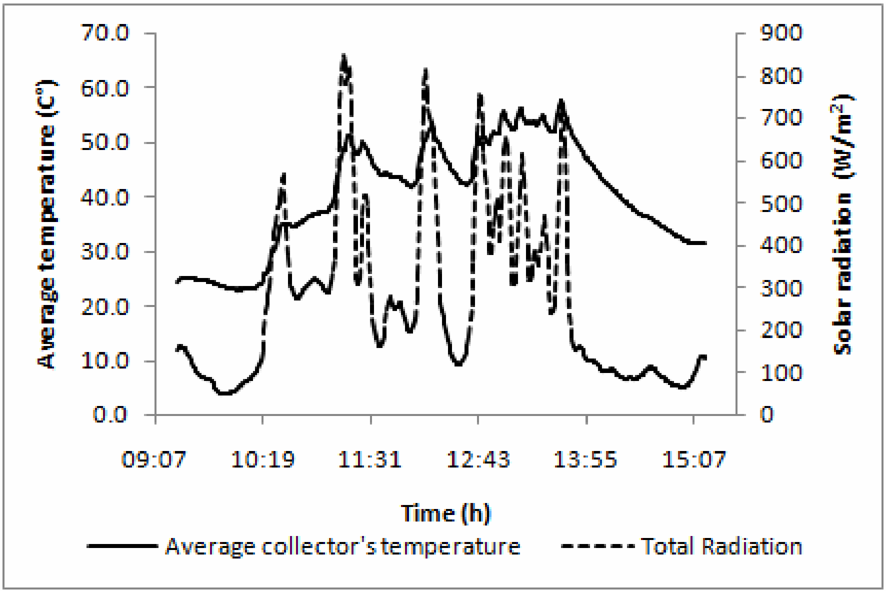


Fig. 4. Solar radiation and DACPC collector's temperature during outdoor testing on the 14th of August

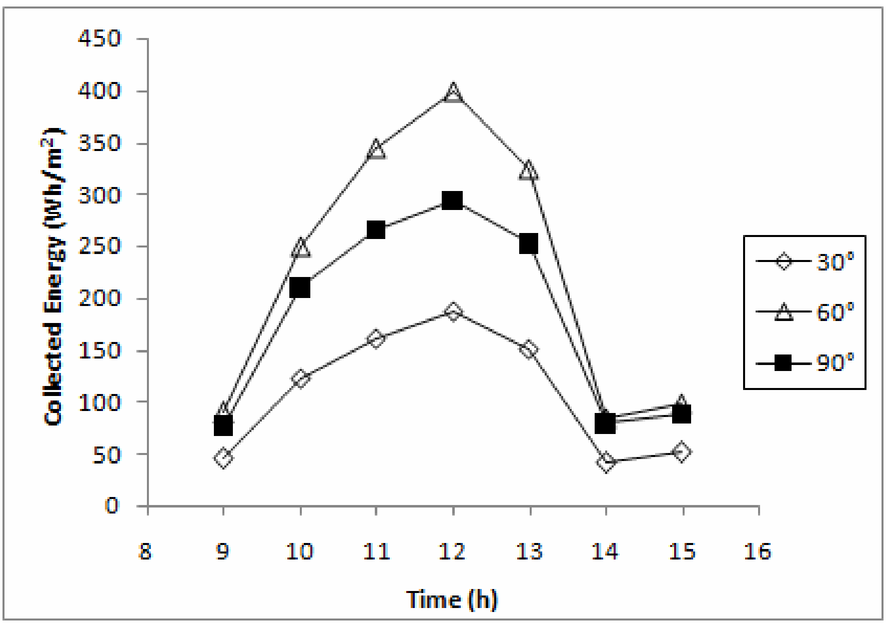


Fig. 5. Total solar radiation collected by the DACPC at three different tilt angles on the 14th of August

In Figure 6, diagrams of the simulation of thermal energy absorbed by the DACPC collector for both beam and diffuse radiation are presented. Tilt angles of 60° and 90° had significant variation with regards to optical efficiency. Energy collected through diffuse radiation is relatively stable whilst energy collected from the direct component at 90° has a drop of about 35% compared to 60° for this specific date.

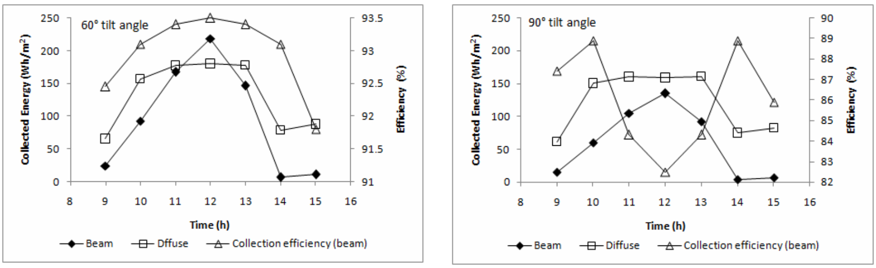


Fig. 6. Variation of optical efficiency and solar radiation collected by the DACPC at different tilt angles during 14th of August

Matuska and Sourek (2006), concluded in their study that vertical position (90°) of solar collectors during peak summer season can avoid extremely high collector stagnation. This happens due to the fact that solar collectors with a high solar fraction mounted on roofs achieve high temperatures whilst the daily hot water demand is even throughout the year. A façade solar collector positioned vertically is not collecting the peak amounts of energy that could expose the system to high temperatures. Therefore, a stable energy collection is achieved without pressure and temperature limits being exceeded.

The collector positioned at 90° can also give higher energy collection during seasons with low solar altitude angles. This case is presented in Figure 7, where data from the 21st of December was used to simulate the DACPC collector's performance at 90° slope angle.

A theoretical collection efficiency of about 93.5% from direct beam is achieved and the amount of solar energy collected is almost 450Wh/m2. For diffuse beam radiation all the cases of simulation indicated a stable theoretical optical efficiency of 54.5% during daylight hours.

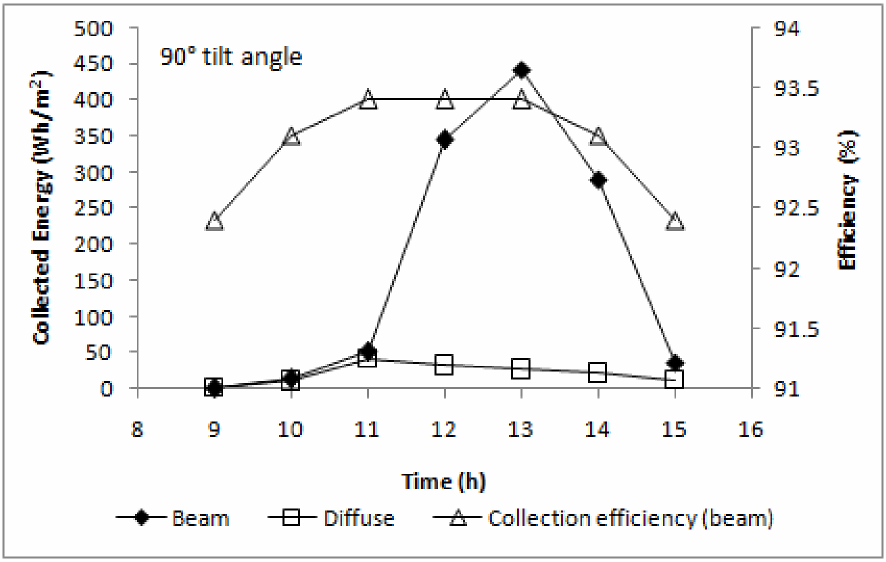


Fig. 7. Solar radiation energy collected by the DACPC collector and efficiency positioned at 90° slope angle for the 21st of December

5 Experimental Results

The experimental performance of the DACPC solar collector was evaluated and the results presented in the form collection efficiency and temperature profile. The amount of thermal energy collected (Q_{out}) by the collector was expressed by Eq. (1).

$$Q_{out} = m_{water} \text{ x } Cp,_{water} \text{ x } \Delta T_m \tag{1}$$

The collection efficiency (η) was calculated using Eq. (2), where A_{ap} the aperture area of the collector and G_{ave} the average of incident solar radiation during certain period of time.

$$\eta = Q_{out} / A_{ap} \text{ x } G_{ave} \tag{2}$$

The period of time used to calculate the variables of efficiency and Input/Output energy balance was 10 minutes. This step was chosen instead of 1 hour due to the fact that the collector was tested outdoors and the conditions were highly variable. Solar total radiation, ambient and inlet/outlet temperature data from every 10 minutes were averaged and used to calculate the performance of the prototype.

The average collection efficiency of the DACPC overall the tests using water as the working fluid was almost 65%. Figure 8, shows the input/output of the collector during the testing period, indicating the average collection efficiency. However, the collector performance could be higher if heat losses were reduced by simple modifications. The casing of the prototype was fabricated with simple materials such as glass and wood. Heat loss by convection from the face of the collector was a problem and significant heat loss was detected from the cover glass. That was due to the fact that thermal energy absorbed by the selective surface was transmitted by conduction to the DACPC material and thus back to ambient. The overall thermal coefficient calculated was 5,56W/m2K°.

The collector was tested at two slope angles (β), 45° and 60°. They were chosen as the solar altitude angle (α_s) during the test was approximately 48°, thus the angle of incidence varied between 3° and 12°. The average collection efficiency was 61.8% for 45° and 62.4% for 60° slope angle under average incident solar radiation (I_{ave}) of 675W/m^2 and 426W/m^2, respectively.

Parallel and serpentine arrangements were tested using different tube connections. In the case of the serpentine, the incoming water was conducted linearly through 13m length of copper and silicon tubes. The water in parallel arrangement passed through a manifold and then through twenty-eight small absorbing copper tubes, before flowing back into the outlet manifold. The collector's average collection efficiency using the parallel arrangement was 43.7% for I_{ave} of 673W/m^2. Collection efficiency for the serpentine was calculated 50.1% under 745W/m^2 for 180ml/min flow rate.

A wide range of flow rates were possible using the flow control of the peristaltic pump. The set flow rates were 80ml/min and 220ml/min and a ΔT_{ave} between the inlet and outlet was almost 11°C with I_{ave} of 525W/m^2 for 80ml/min and only 6.2°C under 639W/m^2 for 220ml/min.

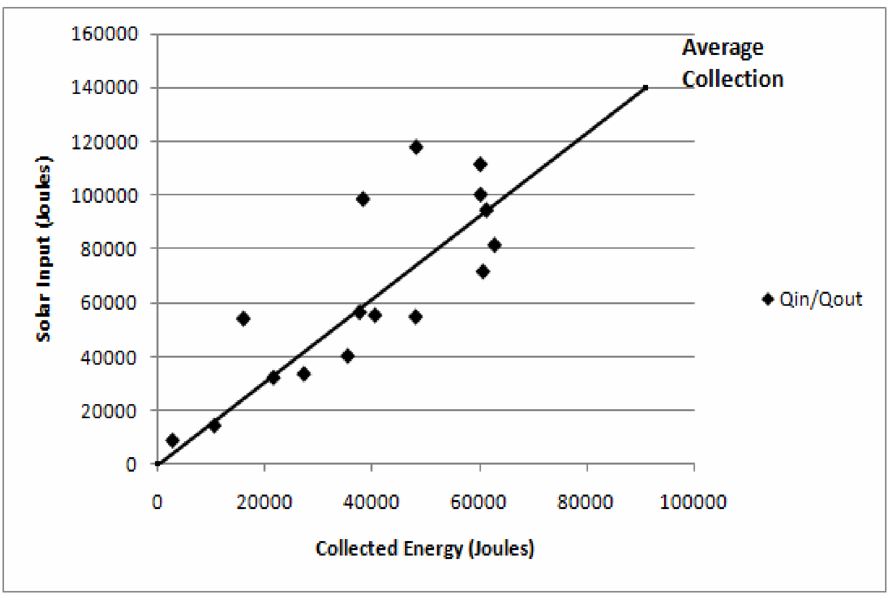


Fig. 8. Input/Output performance of the LCSWH during summer months using water as a transfer fluid

The maximum temperature achieved by the collector during stagnation was 80.2°C with an average solar radiation of 760 W/m^2 during the 80 minute test period. During a lower average incident radiation level (110W/m^2) the temperature of the water in the collector was 30.3°C with an average ambient temperature of 19.2°C.

6 Conclusions

Using simulation and experimental evaluation the DACPC collector performance was determined. The ray-tracing software using solar data from the 14th of August, produced the optical efficiency at three tilted angles (30°, 60° and 90°) detailing the theoretical performance of the system. At β=30° the average optical efficiency of direct beam was 44.3% having a total energy collected of 0.758kWh/m^2 from 9:22 to 15:15. For sloped angles of 60° and 90° the average optical efficiencies for direct beam were 93% and 86%, respectively. The total collected energy was 1.591kWh/m^2 for β=60° and 1.266kWh/m^2 for β=90°. However, simulation of the system for the 21st of December showed a 93% optical efficiency of direct beam and a total energy collection of 1.322kWh/m^2. Optical efficiency of diffuse beam was 54.5% for all cases.

Outdoor experimental characterization of the DACPC collector during July and August showed that the average collection efficiency is 65%. Slope angles of 45° and 60° had collection efficiencies of 61.8% and 62.4% under 675W/m^2 and 426W/m^2, respectively. The serpentine arrangement had a collection efficiency of 50.1%, which was 7% greater than the parallel arrangement at the same solar conditions. The maximum temperature achieved by the DACPC collector was 80.2°C under stagnation with an average solar radiation of 760W/m^2. Under 110W/m^2 for a period of time of about 50 minutes the maximum temperature reached was 30.3°C.

Roof mounted solar collectors have a significant visual impact for most dwellings. South facing building façades can provide enough surface area to collect enough solar thermal energy for domestic hot water production in the UK. The studied system could be an important response to any aesthetical limitations of roof mounted collectors.

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Nomenclature

m_{water}	mass of water [kg]
$Cp,_{water}$	specific heat capacity of the water [kJ/kgK]
T_m	Main temperature, temperature difference between water inlet and outlet divided by two [°K]
T_{amb}	ambient temperature [°K]
T_{max}	Maximum temperature [°C]
I_{ave}	Average of total incident solar radiation [W/m^2]

Greek symbols

β	Slope angle of collector [°]
α_s	Solar altitude angle [°]
ΔT_m	temperature difference between water's mean temperature of inlet/outlet and ambient temperature [°K]
ΔT_{ave}	average temperature difference between inlet and outlet of working fluid [°K]

Proposed Model for Design of Photovoltaic Mounted Steep Roof Systems and Case Study: Istanbul, Turkey

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Abstract. Photovoltaic (PV) can supply all or a significant part of the electricity consumption of a corresponding building without depletion of finite fossil fuel resources. They can be mounted on buildings' roofs or facades. Energy production in buildings by renewable energy sources has recently gained importance and has been referred in laws and regulations regarding energy efficiency policies. Although Turkey has one of the most solar electricity generation potential in Europe, there are only few PV applications in buildings. These examples include mostly PV systems mounted only on low-slope roofs as alternative constructional designs are still unknown in Turkey. Moreover, there is not a guide, regulation or standard regarding the construction of PV roof systems. In order to assists architects, constructers and roof covering material producers to develop correct design alternatives, a model has been developed for the constructional design of PV roof systems. The aim of this paper is to present the model proposed for the design of PV mounted steep roof systems and based on the model, a case study in which a PV mounted steep roof system is designed for Istanbul, Turkey.

1 Introduction

Energy consumption in buildings constitutes a significant part of total primary energy requirements in Turkey. In 2006, the second most used energy source in buildings was electricity with 25%, followed by natural gas [1]. Within the energy sectors, the most responsible sector from green house gas emissions is also electricity: 70% of electricity production is supplied by thermal energy and 85% of this energy is produced from fossil fuels [2]. In order to decrease green house gases emitted from buildings and to supply all or a part of the electricity consumption of buildings in their structure, renewable energy production in buildings was recently considered important in Turkey.

In terms of energy efficiency policies, producing energy in buildings recently became a significant issue. First Turkish energy efficiency policy for buildings,

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which has been represented by “TS 825 - Conservation Rules of Heat Effects for Buildings” standard has been activated in 1970 and it was related to energy conservation. This standard has been revised to increase the U values of the building envelope in the following years. Additionally, regarding energy conservation, “Thermal Insulation in Buildings” regulation has been activated in 2000. The law regarding “Using Renewable Energy Sources for Electricity Generation” has been activated at 2005. The first feed in-tariff to renewable energy production which is 5, 5 euro cents/kWh has been imposed by this law. Nowadays this feed in-tariff is being discussed to increase by Turkish Ministry of Energy and Natural Resources. As an energy efficiency issue; producing energy by renewable sources was first mentioned in 2007 within “Energy Efficiency Law”; energy production in buildings by renewable sources was mentioned in 2008 in “Energy Performance Regulation for Buildings”. Eventually Turkey has signed Kyoto Protocol in 2009 and decreasing green house gas emissions has become a current issue. As a result of these progresses in energy policies, producing energy in buildings by renewable energy sources gained importance in Turkey in recent years.

As a renewable energy technology, photovoltaic (PV) can cover all or a part of buildings’ energy consumption without depletion of finite fossil fuel resources and emission of greenhouse gases. These applications in buildings do not require any extra land area and infrastructure installations for electric generation. Besides electricity losses during the transmission and distribution are reduced due to the short distance between the generator and electricity consumer. Roofs are frequently the most suitable surfaces for PV applications in buildings due to their solar access potential. The first PV integrated PV roof system was built in Saarbrücken-Germany at 1985 [3]. In 1996, the first city district, which consists of six PV integrated roofs was constructed in Nieuw Sloten, Netherlands [4]. In 1999, the worlds’ largest urban PV project, Nieuwland was constructed again in Netherlands. The project consists of over 500 houses and several other buildings with PV modules integrated in their roofs [5]. Following these initial steps, many PV roof systems were constructed especially in Europe, Japan and USA with support funds of governments and various communities.

Although Turkey has one of the most solar electricity generation potential in Europe (above 1200 kWh/kW per year) [6], there are only a few PV applications in buildings as given in Table 1. Observation of Table 1 reveals that PV mounted on low-slope roof system is the commonly applied system among other systems. PV attachments on existing buildings are very important in Turkey, since the biggest part of the building stock consists of existing buildings. In 2007, Diyarbakır solar house was built, and it included a PV attached tiled steep roof. This house represents the only PV mounted steep roof example in Turkey. PV attachment on steep roof systems is not a common application in Turkey. As different fixing systems suitable for different roof coverings are not known.

Unfortunately, there are only few built PV roof examples in Turkey due to poor financial supports at the governmental or municipality level. In recent future, it is expected that PV applications will be more affordable, hence more common due to the progresses on policies about renewable energy production. In this case, lack of experience at PV applications may result in improper designs and incorrect detailing of PV roof systems. As for retrofit applications, especially different alternatives for steep roof attachments are not applied and known in Turkey. In order to overcome the above given issue, a model has been developed for the design of PV roof systems, which enables architects to select and develop correct design alternatives for PV roof systems. The model comprises design processes, stages and step; for each step some inputs are given to direct the designer to the appropriate detailing. This paper presents only the sub model proposed for the design of PV mounted steep roof systems and based on the model, a case study in which PV mounted steep roof system alternatives are designed for Istanbul, Turkey.

Table 1. PV systems installed on buildings in Turkey

Location	Construction Date	Capacity	Degree of Integration	PV application type
Mugla University, Main Library, Mugla	2001	10 kWp	Retrofit	On low slope roof
Mugla University, Student cafeteria, Mugla	2003	35000 kWh	Retrofit	On steep roof
Ege University, Solar Energy Institute, Izmir	2005	11,1 kWp	Retrofit	On low slope roof
A Shooping Store (Kipa), Marmaris	2007	30 MWh	Retrofit	On low slope roof
Diyarbakır Solar House, Diyarbakır	2007	3,88 kW	New building	On steep roof
A Factory (Toyota), Sakarya	2008	30 MWh	Retrofit	On low slope roof
Mugla University, Rectorate building, Mugla	2008	49000 kWh	Retrofit	On facade
H. Avni Incekara High school, Dormitory, Nevsehir	2009	13,5 kW	New building	On steep roof and low slope roof

2 Proposed Model

2.1 Architectural Design Process of PV Roof Systems

Proposed model developed for the design of PV roof systems consists of two main processes, one of which is PV roof system architectural design process followed by PV roof system constructional design process. Figure 1 illustrates the model of architectural design process of PV roof system. At the given process, initial stage is PV array design and second stage is PV roof system type determination.

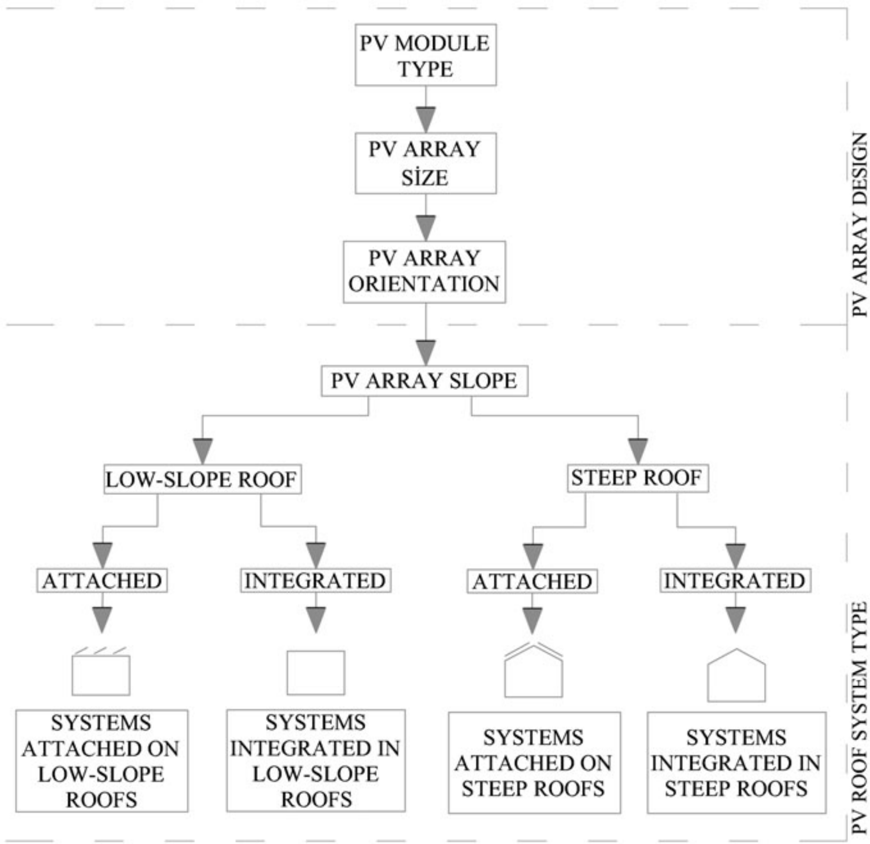

Fig. 1. Architectural design process

PV array design consists of four steps: PV module type, array size, array orientation and array slope determinations. Module type can be determined according to power output of the module, required visual impact, module size, and module substrate materials. The power outputs of modules are measured in watts. Power output changes due to PV cell type, number of cells per module, and module size. For instance, a 170W PV module can consist of 72 monocrystalline cells in dimension of 1.575 x 826 x 46 mm (130m^2). PV cells deliver different efficiency rates: Monocrystalline cell delivers 14-17 %, polycrystalline cell 13-15 %, and amorphous silicon cell 5-10 % efficiency. Cell efficiency means the ratio of electric power produced by a cell at any instant to the power of the sunlight striking the cell. According to back and front substrate materials, there are glass-glass, glass-film, film-metal, and film-film modules; in addition they can be framed or frameless modules. In the second step, PV array size is determined according to power output of the selected module, possible installation area, total energy demand and budget. Maximum power output of an array is calculated in kWp (peak) for typical rating conditions. For instance, a 10 kWp array capacity can be achieved with 75 pieces of 150 W PV modules. Subsequently, PV array orientation is determined. Typically, the most favourable orientation is south in the northern hemisphere and north in the southern hemisphere. For instance, for a new building, the PV roof should be oriented to south direction in Turkey to access maximum energy yield. Last step of PV array design stage is the determination of PV array slope; this also affects the energy efficiency performance of the PV system. When the PV surface is perpendicular to sun's rays, they receive the maximum solar radiation. Based on this knowledge, an optimum tilt angle (slope of the PV system) is defined to generate maximum electricity for whole year or for a specific period of the year (e.g. summer). This decision is dependent on the use period of the building. For instance, a PV system in Turkey which is planned to be used for whole year should be tilted from horizontal plane to 26-30º to take advantage of maximum energy generation. PV simulation programs, which utilize meteorological data based on monthly or hourly measured irradiance, can be used for the calculation of the optimum tilt angle. Some of the commonly used PV simulation programmes are PV-DesignPro (Mauisolar Software), PV SOL (Valentin EnergieSoftware), PV F-chart (F-Chart Software), and PVSYST software for photovoltaic systems (University of Geneva). Additionally, PV modules can be mounted on a movable or sun tracking systems in order to gain a higher yield. Tracking systems are generally used in sun shading systems and systems mounted on low-slope roofs.

Following stage is PV roof system type determination. PV roof system type is determined in two steps: roof slope determination and decision about whether system will be integrated or mounted. The slope of the roof system is determined according to climatic conditions, surrounding buildings' roof slopes, roof coverings, local construction methods, regulations and particularly PV array slope. The roof system may be determined as a low-slope or a steep roof system. For example, if the decision making process results in a low-slope roof; i.e. the roof system would be built at a location where the rain intensity indicates dry conditions, and the defined PV array slope remains higher than the defined slope of the roof; then the PV array can be mounted at the determined slope separately on top of roof covering of the low-slope roof. On the other hand, if the decision making process results in a steep roof system, the slope can be arranged at the same slope of the PV array and then, the PV array can be mounted separately on top of pre-constructed roof covering or be integrated in the roof system as a roof covering, Figure 1. Ultimately four types of PV roof system are determined: PV systems mounted on low-slope roofs, PV systems integrated in low-slope roof, PV systems mounted on steep roof and PV systems integrated in steep roof. In the following sections, the sub model for the constructional design of PV mounted steep roof systems is explained.

2.2 Constructional Design Process of PV Mounted Steep Roof Systems

Proposed model for constructional design of PV mounted steep roof systems is given in Figure 2. The design process comprises three decision stages: Roof fixing type, settlements of support rails, and module fixing type. First stage is roof fixing type determination. This decision depends on the type of the roof covering used under the PV system. For tile covered roofs, roof hooks or special fixing tiles can be used as roof fixing. Roof hooks, which are metal profiles are screwed to the roof substructure (roof battens, etc.). Their shape enables connection between roof structure and support rails; bottom part passes below the roof tiles for roof fixings and upper part remains above the roof covering for supporting the rail fixings. As for applications with special fixing tiles, the tile, which is fixed like conventional roof tiles, contains metal supports as rail fixings. The difference between these roof fixings is that hooks transfer loads directly to roof structural system, fixing tiles transfer loads to the roof covering (tiles). For trapezoidal metal sheet or sandwich panel covered roofs, there are two alternatives as roof fixing: trapezoidal fixing profiles and hanger bolts. Fixing profiles, which are specially produced to fit with trapezoidal sheets are screwed -and sometimes glued- on top points of the sheets. Appropriate screw fastenings must be chosen according to the substructure material: wood, concrete or steel screws. Hanger bolts are not only suitable for fastenings on trapezoidal metal sheet and sandwich panel covered roofs, but also for fibre cement corrugated sheet covered roofs. To ensure that the roof remains leak proof, installation should be done at the highest point of the roofing with EPDM seal underneath. With hanger bolt fastening, the connection to the supporting rail can be made using a Z-hook, a flange, or a flange with lateral adjustment. Sealing must be achieved properly in these roof fixings of trapezoidal sheet covered roofs, since the roof covering is drilled for these applications. In standing seam metal roof systems, seam clamps are used as roof fixings. Like fixing tiles in tiled roofs, they are fastened to roof covering and hence transfer loads to roof covering.

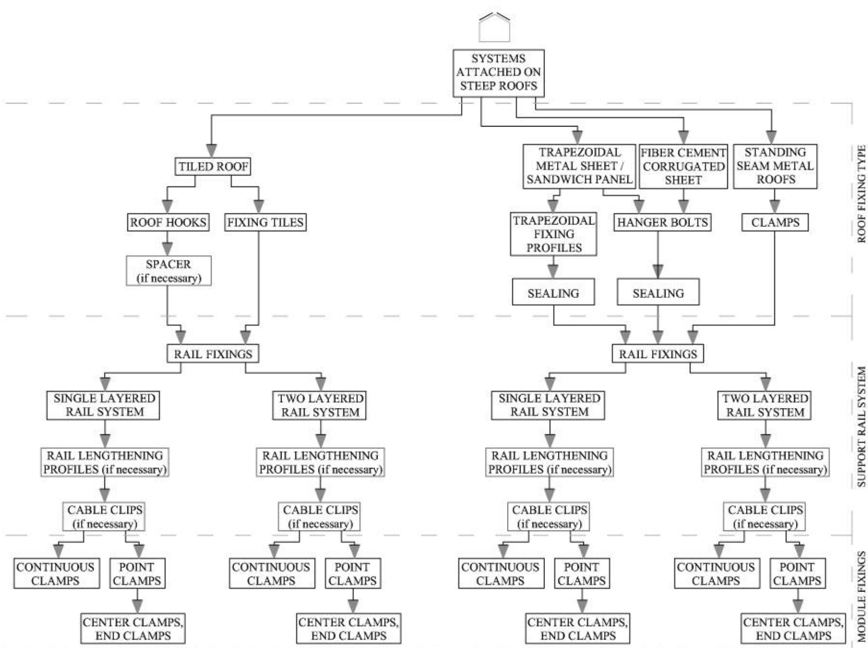

Fig. 2. Constructional Design Process of PV mounted steep roof systems

After the roof fixing type decision, settlements of support rails are arranged. There are two alternatives for support rails settlements: single layered and double layered. In single layered settlements, only vertical or horizontal supporting rails are used. In double layered settlements, vertical and horizontal rails are used together. Double layered settlements provide more flexibility regardless of the supporting structure; the only drawback is the increased material consumption. Different supporting rails are available, depending on the offset of the substructure elements, the loading forces (snow, wind), and the type of installation. If lengthening is needed, rails are connected together with connection plates below rails or insertion connectors inside the rail channels. Horizontal and vertical supporting rails are connected together with clamps. Cable clips or channels in rail profiles are used for cable attachments to the support rails.

The last stage for PV mounted steep roof system design is the determination of module fixings. The modules are fastened using clamps. The alternatives are point clamps and continuous clamps. Applications with point clamps require modules to be aligned and fixed one by one, thus they need more labour; only in a case of maintenance, modules can be disassembled individually by each other. In applications with continuous clamps, the joints between modules are closed; hence ventilation under the PV modules is poorer than applications with point clamps.

3 A Case Study of the Model: A PV Mounted Steep Roof System for Istanbul, Turkey

A PV roof is designed for retrofitting an old building in Istanbul, Turkey. The building is located in a suburban area of Istanbul, and is used as a residence. Existing roof is a steep roof due to building typology, snowy and rainy climatic conditions of the location and surrounding buildings' forms. The roof structural system is a built-up timber roof. During the retrofit process, 5-cm thick expanded polystyrene thermal insulation material is used between timber rafters to provide the required thermal resistance value. A modified bituminous waterproofing membrane with a thickness of 4-mm is used on the rigid thermal insulation material and rafters to prevent rainwater entry. Another modified bituminous waterproofing membrane with a thickness of 4-mm beneath the rafters is located as vapour barrier to prevent the occurrence of condensation on the rear side of the waterproofing membrane. Existing roof covering is clay based tiles. Architectural design of PV roof system initiated with PV array design stage. A 170W monocrystalline glass-film framed module was selected according to its power output (170W), cell type efficiency (13-15%), module sizes (1.575 x 826 x 46mm) and substrate materials (glass, film). PV array size was determined as 5 module according to energy demand, possible construction area (650m^2) and budget. PV array orientation was determined as south to generate maximum energy. Optimum tilt angle in Istanbul for whole year was calculated by PVSYST simulation program as 26°-30°; the PV array slope was decided to be same with roof slope. The roof was a steep roof with a slope of 24°. Finally PV array was determined to be mounted on this steep roof, in order not to disassemble the existing roof covering.

At the constructional design process, the roof fixing type was determined. The roof hooks were preferred to fix the system directly to the roof structure and not to the roof covering. Next stage was to determine the support rail system arrangements. Single layered rail system was selected for less rail consumption. Module fixings stage was finalized with the selection of point clamps to ensure ease of disassembly of modules in the case of maintenance. Final design of the roof system is given in Figure 3.

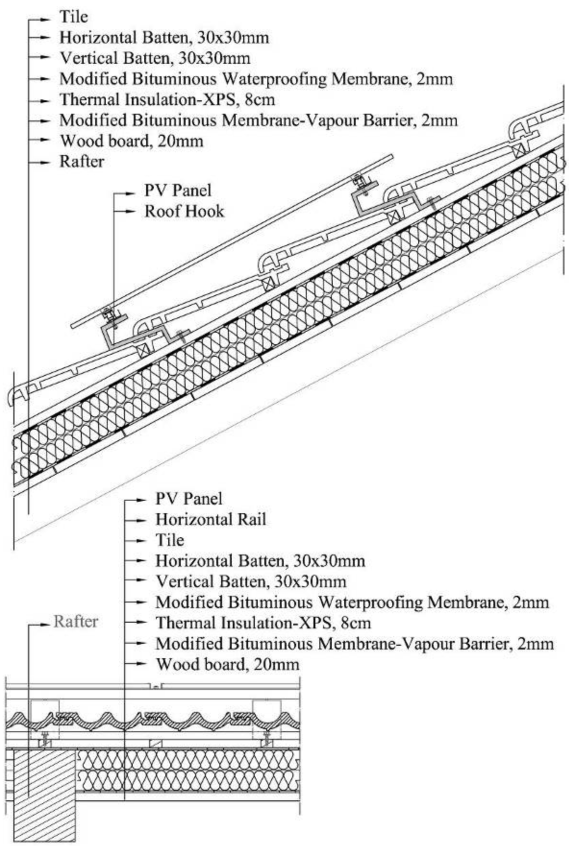

Fig. 3. PV mounted steep roof system with tile as roof covering

4 Conclusions

Energy production from renewable sources is important for Turkey for not only in terms of environmental aspects but also to lessen dependence on importing electricity. Turkey imports more than half of her energy requirement from abroad and energy consumption per head increases dramatically as the standard of living improves [7]. Therefore buildings' envelopes should also be utilized as energy generators; the possibilities of using solar energy in buildings must be analyzed. Primarily public facilities' buildings' and mass housing buildings' envelopes should be considered as an electricity generator due to their large envelope surfaces.

PV systems are being able to be integrated in projects at the beginning of the design process; hereby building envelopes can be designed suitable for electricity generation; optimum orientation and slope can be considered. On the other hand PV attachment systems should be especially considered since existing buildings constitute the biggest part of the Turkish building stock. When PV will become a building material in Turkey, the architects will be able to design suitable PV roof systems for their projects. Therefore in this paper, a design model was proposed for PV mounted steep roof systems, and the model was applied for Istanbul, Turkey as a case study. The proposed model is expected to be a guide for the architects and constructors to assist in the constructional design of suitable PV mounted steep roof system alternatives. Additionally design inputs about material consumption, visual impacts, ease of installations, speed of installations, ventilation rates helps to evaluate and improve the design. This design model was formed by analyzes of current PV roof systems in world wide. Hence new systems can be produced by following up the model and design inputs. The model can be also revised due to improvements about PV technology.

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Abbreviations

TS: Turkish Standards
U value: Overall heat transfer coefficient
PV: photovoltaic
UCTEA: Union of Chambers of Turkish Engineers and Architects

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