Research in Architectural Engineering Series, Volume 9

THE FUTURE ENVELOPE 2

ARCHITECTURE - CLIMATE - SKIN

edited by Ulrich Knaack and Tillmann Klein

THE FUTURE ENVELOPE 2

Architecture - Climate - Skin

edited by

Ulrich Knaack & Tillmann Klein

Research in Architectural Engineering Series
Volume 9
ISSN 1873-6033

Previously published in this series:

Volume 8. U. Knaack, T. Klein (Eds.)
The Future Envelope 1 - A Multidisciplinary Approach

Volume 7. M. Eekhout, F. Verheijen and R. Visser (Eds.)
Cardboard in Architecture

Volume 6. M. Veltkamp
Free Form Structural Design – Schemes, Systems & Prototypes of Structures for Irregular Shaped Buildings

Volume 5. L. Bragança, C. Wetzel, V. Buhagiar and L.G.W. Verhoef (Eds.)
COST C16 Improving the Quality of Existing Urban Building Envelopes – Façades and Roof

Volume 4. R. di Giulio, Z. Bozinovski and L.G.W. Verhoef (Eds.)
COST C16 Improving the Quality of Existing Urban Building Envelopes – Structures

Volume 3. E. Melgaard, G. Hadjimichael, M. Almeida and L.G.W. Verhoef (Eds.)
COST C16 Improving the Quality of Existing Urban Building Envelopes – Needs

Volume 2. M.T. Andeweg, S. Brunoro and L.G.W. Verhoef (Eds.)
COST C16 Improving the Quality of Existing Urban Building Envelopes – State of the Art

Volume 1. M. Crisinel, M. Eekhout, M. Haldimann and R. Visser (Eds.)
EU COST C13 Glass and Interactive Building Envelopes – Final Report

THE FUTURE ENVELOPE 2

Architecture - Climate - Skin

edited by

Ulrich Knaack & Tillmann Klein

ISBN 978-1-60750-026-1

Published and distributed by IOS Press under the imprint Delft University Press

Publisher IOS Press BV
Nieuwe Hemweg 6b
1013 BG Amsterdam
The Netherlands

tel: +31-20-688 3355

fax: +31-20-687 0019

email: info@iospress.nl

website: www.iospress.nl
www.dupress.nl

Editors
Ulrich Knaack uk@pduk.de
Tillmann Klein t.klein@tudelft.nl

Reviewing committee
Prof. Dr. Uta Pottgießer, Ostwestfalen-Lippe University of Applied Sciences
Prof. Dr. Mick Eekhout, Delft Technical University
Prof. em. Dr. Klaus Daniels, Swiss Federal Institute of Technology Zurich

Layout & bookcover design
Usch Engelmann

Photography cover and content
Copyright by the respective authors unless indicated otherwise.

This publication is based on the contributions to the *The Future Envelope*, a Symposium held on 5 June 2008 in Delft. This symposium was organized by the Faculty of Architecture, Delft University of Technology (Chair Design of Construction) in cooperation with VMRG (Vereniging Metalen Ramen en Gevelbranche) and FAECF (Federation of European Window and Curtain Walling Manufacturers Associations).

PRINTED IN THE NETHERLANDS

PREFACE

If there is one thing we can learn from the latest news about climate change and global warming, it is that building should no longer be built without a climate concept and an optimization of its use of energy. Façades play an important role in achieving these goals. The future façade will be more adaptable to the changing environmental conditions and it will encompass building service installations to make this possible. The façade is becoming a complex product, highly interacting as an integral part of the building, reacting on the environmental conditions and user needs.

Important steps have been taken, but we have to admit that we are far from building in an optimal manner in as far as relates to our climate. Climate-orientation is a necessity and we have to investigate how this can be done.

A new generation of tools is available today: computer hardware and software to calculate and simulate the complex relations of construction and building physics and devices that make the integrated design communication possible. But the practice has shown that being able to design something does not yet mean that it can be built. Climate orientation will have a big impact on the building industry. Will it adapt to follow the arising market needs or is it taking the opportunity to lead the trend and use it to its best benefit?

Can we continue designing buildings on a project by project basis, or will the growing complexity result in a way of building which is strongly related to a product driven architecture? In addition, it is important to look at the architectural impact of this development. What will the future climate-oriented façade look like and can it be a tool for architectural expression?

The topic is related to all aspects of building. It will effect the design as well as the building process and the construction itself. Specialists from the fields of architecture, engineering and research were asked to share their practical experience and their visions for the future of the climate-oriented building envelope.

Ulrich Knaack

Design of Construction
Faculty of Architecture, Delft University of Technology

CONTENTS

Prof. Dr. Ir. Jos Lichtenberg from Eindhoven Technical University underlines the role of Product Development for climate oriented architecture. Enlarged façade functionalities will lead to a more product oriented approach and to new building processes. He explains how the rules of the market will influence our approach to the future façade.

The Future Envelope 2 – Architecture-Climate-Skin. U. Knaack and T. Klein (Eds.). IOS Press, 2009.

MARKET MOVEMENTS AND NEW FAÇADE CONCEPTS

Jos Lichtenberg

TU Eindhoven /
Product Development

Product development is a kind of reflection of, on one hand, the technology progress and on the other the evolution of market needs.

The role of the product designer is not only to follow developments in both worlds and to meet the needs of the market, but also to inspire the market and to take the opportunity to take a look ahead. In this context a task of the designer is also to develop a vision about the future. Not in order to change the world at once rather than to challenge the market, to test the viability or even to set trends. For the industry this is a way to communicate with the market and to have an instrument to develop a company policy as a basis for product development. In for example the automotive this is already a proven strategy for bringing new developments to the market.

It is like playing golf. It is the purpose of the game to get the ball into the hole. A precondition for achieving this goal is knowing where the hole is and being informed about possible obstacles in getting there. Nobody expects a hole in one, but with the knowledge of the direction and the possible threats one is at least able to hit the ball into the right direction.

The first products do not necessarily have to be a visionary design. On the contrary, they will probably have more business success by staying close to the today's market needs. A step by step approach is from a business point of view to prefer. But, by having a vision on the long run one will be able to direct these steps in the frame of the future vision and developments will eventually more consistent and efficient. In between also the steps as such need to be successful. This paper contributes in mapping some major developments and trends concerning façades.

Primary function

A sound vision for future façades will primarily be based on the expected requirements. Of course these requirements are from a rational perspective the result of outdoor and indoor developments as well as the growing need for high standard indoor comfort. The primary function of a façade is to separate an inside environment from an external one.

Climate change will evolve gently, but the weather can change rapidly, even on an hourly basis. Inside buildings there is a fast growing consciousness about the value of indoor climate control. Not only the outside climate but also the indoor use is predominantly dynamic, for example by changing tenants or functions (5-10 years) but also on a daily or even hourly basis by changing presence of people in rooms or the use of heat generating devices. Façades do therefore have to anticipate on changes, they have to be interactive with the indoor and outdoor environment. Not only for climate conditions and comfort but also in order to provide a.o. for fire resistance and noise control.

Façades being part of services

Façades already are and will even be more part of the integral building services. For example a modern approach for ventilation is not to get the air from outside through an extended system of ducts led through the building but to get the fresh air directly from outside and to treat or preheat it with devices that are part of the façade system and centrally controlled. Actually also the second skin façade and even better the climate window are by controlled airflow examples of integrated service functions.

Some developments do focus on bringing daylight into dark zones of the building. In fig 1 a scheme is showed with reflecting foils, bringing daylight in underground floors. This system has been already tested in a day light simulator and appears to be a promising concept. [Westerlaak, 2007] and [Woertman, 2008]

In some projects the façade function is extended with collecting energy by integrated solar panels, photo voltaic cells or even wind turbines. Fig. 2 shows an example where wind energy according to the warpage principle is used in high rise architecture. The system turns out to be not feasible on an energy return basis. But taking emotional value (architecture) into account it is very well possible to realize applications as shown. [Braun, 2006]

Innovation in façades will therefore not only be based on the primary function for envelopes that is separating indoor and outdoor climate.

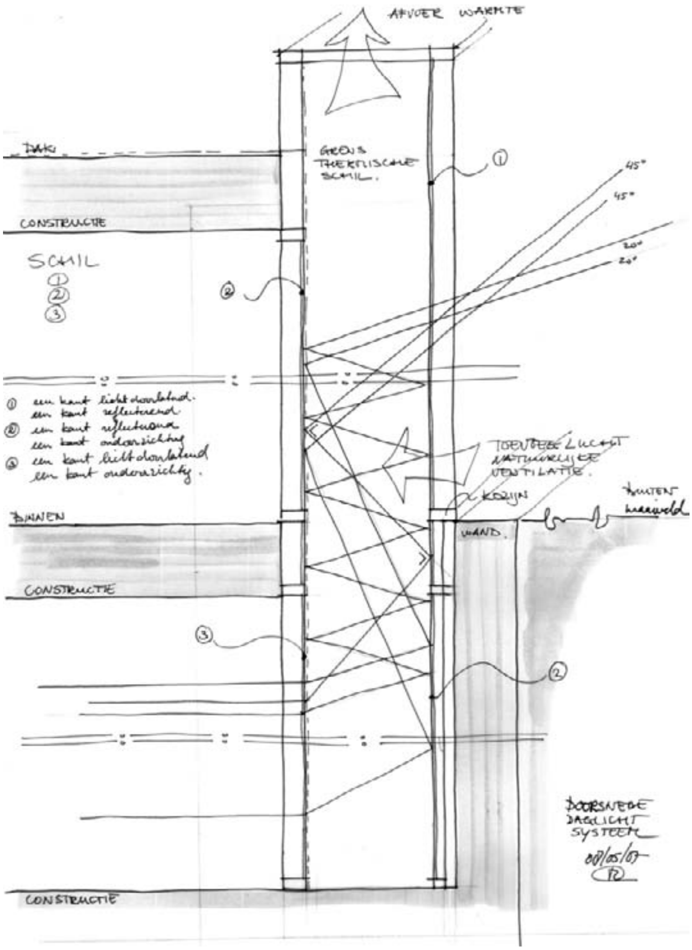


Fig 1: Scheme for getting daylight into underground indoor areas (Product design: Marc Westerlaak, supervised by, among others light expert Dr. Ir. Martine Knoop). Research was carried out on a solution with a type of shaft surrounding a building with a circular ground plan. Based on a model several types of reflecting foils for the interior of the shaft were tested in the daylight simulator in the BPS Laboratory at the TU/e. One of the characteristics of the foil is that it does not necessarily function as a mirror. Light is spread to some extent in order to achieve diffused lighting in the underground areas. Variations using different foils for different zones is subject for future research.

Fig 2: Wind energy applied in a high rise building (concept Bouke Braun under supervision of, among others wind expert Dr. Ir. Sander Mertens). The design is part of a research on the feasibility of wind energy in high rise buildings. The research was carried out on basis of a location in Rotterdam (in the coastal area of the Netherlands). The warpage concept with a rotating ring is designed such that the turbines are always oriented directly into the wind. Due to the shape of the building the wind velocity in the necking-areas in is considerably higher.

Communication

Apart from being part of the building services, façades also have the ability to communicate. They basically already express in many cases what is happening inside and represent the owner or tenant of the building.

Fig 3: Temporary façade [Vertical Vision, www.verticalvision.com]

The expression is however very often related to a certain period. After some time the value of the building can easily decrease by changing common consents. For that reason even fashion can easily become part of façade technology. In the frame of this phenomenon skins based on fabrics are already being applied in building projects (fig. 3).

In some cases façades can even communicate literally in showing messages or commercials to the outside world. Especially a commercial function requires the possibility of a rapid change. The extra investments are to be returned by the benefits from the

Fig 4: Times Square, the property value is in the façade

commercials. At New York's Times Square or London's Piccadilly Circus the buildings are hired out by façade surface instead of floor surface (fig 4).

The dynamics of façades is apparently not restricted to the rational and functional performance but also to the emotional and communicational values.

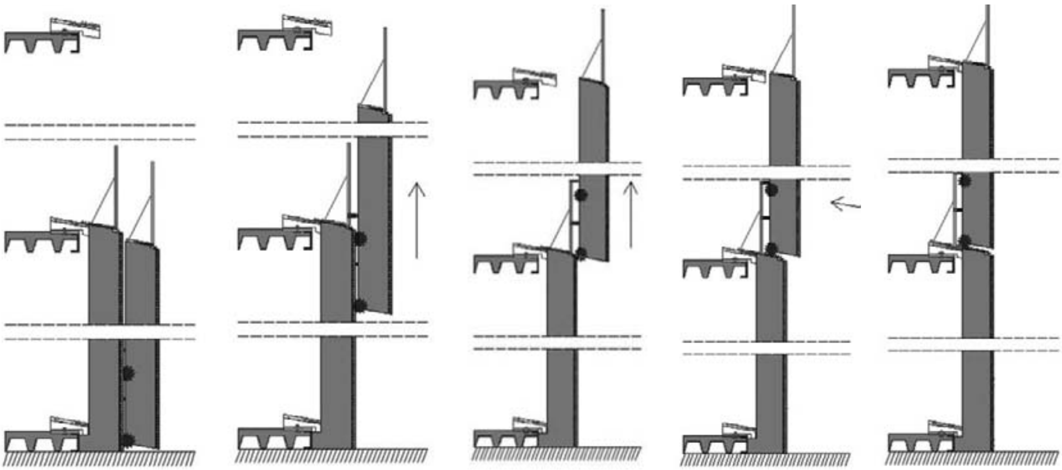


Fig 5: The scheme presents a design for a self mounting façade [Concept design: Pascal Schrijver]. The concept is based on using a vertical conductor for electromotive climbing elements. The elements are also individually demountable in order to carry out maintenance.

Process driven development

Apart from rational and emotional values of the façade in the operational phase, changes in façade technology are also strongly influenced by process conditions. At present we already have to deal with substantially less skilled labour on building sites but the trend is that this situation will be even worse in the future. Automation and robotics might therefore become to an already longer expected development (fig. 5). [Lichtenberg et al., 2006]

More frequently buildings have to be constructed in the inner city with limited space and time. Especially in this kind of circumstances one will be challenged to achieve an efficient process including logistics.

In the frame of changing processes also the maintenance during the operational phase and the life cycle approach including the dismantling of the façade or the building at the end of the life cycle are more and more decisive aspects in façade product development.

New building approach

Another influence on future developments is to be expected from the building process as a whole. Apart from requirements strictly related to façades there are also changing process constraints on a conceptual building level. In the frame of the Slimbouwen[1] program this is already elaborated. [Lichtenberg, 2005 and 2006] Slimbouwen is a reaction on building tradition that is to be characterized as a result from stacked innovation (innovation by addition). Especially the gradual addition of services during the 20th century has caused a complex building process with avoidable loss, inefficiency and an overkill of both material and labour. The buildings are too heavy and too voluminous with bulky building structures. Flexibility is rare in buildings. Functional changes after some decades immediately show the conflict of the need for adaptation and the inflexibility of the building especially concerning services (fig. 6). Also nowadays scenarios for change are not common practice and buildings are hardly prepared for future functional adaptations.

[1] Slim in Dutch has a double meaning. It stands for intelligent, smart but also has the English meaning (compact, lean). Bouwen means to build.

Fig 6: The undesirable compromise of adapting inflexible buildings

Inflexible buildings harm the environment substantially by a.o. dissipation of energy and CO_2 emission. In fact the construction industry at present turns out to be a leading polluter. In the Netherlands the construction industry represents "only" 5,1% of the GNP but at the same time it generates about 25% of all material transport (source Logistiek Nederland), 35% of the total waste (source Dubocentrum) and even 43% of the national energy consumption (source CBS).

In western countries these figures might differ slightly per country, but in general they show the same trend everywhere.

Future buildings will be established according to innovative processes that will facilitate the efficiency and the control of costs of the building as a whole. Flexibility or adaptability will be more important since this strongly supports the appreciation and increase in value of the property as well as the return on investment. Sustainability in general will be a leading aspect in designing and constructing buildings. After the presentation in 2006 of Al Gore's documentary "An inconvenient truth" a new basis for sustainability seems to be created in a way that not only professionals are involved but also the society as a whole. The new age of communicating this message is illustrated by the Cradle to Cradle concept (waste equals food) of McDonnough and Braungart [Braungart et al., 2002] and the fast rise of sustainability assessment systems like Leed, Breeam and Greencalc. It is not to exclude that these phenomena as such are only temporary, but the attention for sustainability as a conception seems to be sustainable in itself.

As a result of this awareness it is to be expected that buildings including façades will have to be lighter (less materials), more compact (slim) in transportation but also on site, since a slimmer structure will provide for more valuable space. If for example a façade will be reduced from a thickness of 300 mm to 150 mm, this will generate about 6% extra internal floor space while maintaining the outside sizes and therefore positively influence the gross/net ratio.

In order to achieve an industrial process it is important to separate the services from the structural parts. In the traditional process the services are highly interwoven with the building parts. In Slimbouwen separating (disintegrating) the services is a crucial principle. The separation of services will facilitate both the efficiency of the building process and the flexibility during the operational

Fig 7: La Fenetre, The Hague
[Design Rudy Uytenhaak]

phase. By decoupling the services from the building parts it will be possible to divide the process into four main steps. The structure, envelope, services and finishing. Each step can be represented by a subcontractor. Together they are not only constructing the building on site but also are involved in the preparation phase by having input of know how in the design process. In the process the subcontractors are able to work quite independently from the other subcontractors and therefore they are able to be fully responsible for their contribution.

In the Netherlands right now already about 40 building projects are carried out according to the Slimbouwen outlines. (fig. 7 and 8)

Fig. 8: Kraanspoor, Amsterdam [Design: Trude Hooykaas]

The façade will be part of the envelope and it is evident that the façade supplier will be one of the subcontractors in the Slimbouwen process. Therefore he will be in a more prominent and powerful role in the building process. Apart from the full responsibility for the supplier which is by the way not per definition to be considered as a burden, this new position also offers a lot of new opportunities. For example the possibility of not only supply for a façade but also to maintain the system offers a new role for the façade industry.

On basis of the Slimbouwen process the challenge for product development is to create façade systems that contains already all the necessary services for operating the system (solar screens, intruder alarm system) or to facilitate the utility (sockets, air inlets) and that can be easily connected to the nearby infrastructure that is installed into for example the floor system or a zone in parallel to the façade. In some respect the façade element can even be considered as a device entity (integration strategy). Another design strategy is to avoid the integration of services but to create openings, hollow cores, etc. in order to be able to install services on site together with

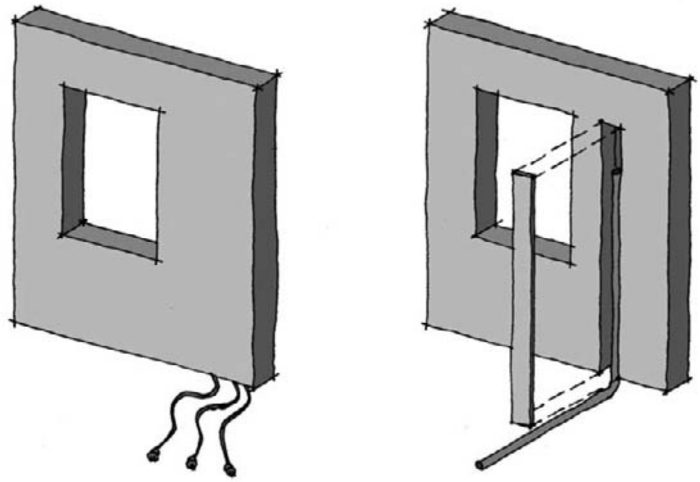


Fig. 9: integrated and disintegrated services in façades

installing the main infrastructure in the floor system (disintegration strategy). See fig. 9.

The separation is desirable during the building process on site in order to be able to create a building planning in which the four subcontractors will work on a sequential basis. After finishing the sub contract the work can be inspected and approved on basis of specifications agreed upon and after that the site is ready to receive the next subcontractor.

In the preparation phase, especially during the design process, it is desirable that the subcontractors are closely cooperating together with the architect and that they will contribute with know-how. Where the building process is of a sequential nature (disintegration), the design process will have to be a parallel process (integration).

Especially for façades this is easily to illustrate, since there is a great deal of interaction between the façade design (glass surface, blinds, shutters, overhang) and the need for climate control by air or activation of building parts (hoses integrated in parts).

In this process the façade supplier will be able to take full responsibility for his contribution and if the specification is not made on a material level but on functional requirements a lot of room is left for creative solutions.

Conclusion

Change is to come, but will be evolutionary rather than revolutionary. By a better understanding of market needs and future possibilities product designers and influencing parties like among others architects, contractors and industry will feel more secure to take major leaps and to speed up developments. This article aims to point out some trends and new developments and by that to contribute to develop a vision and innovation.

References

Braun, B.C. (2007) Hoogbouw en windenergie: The Wind Amplified Rotor Building, graduation thesis, Eindhoven University of Technology (only available in library Dep. Architecture building and Planning).

Braungart, M. and W. McDonnough (2002) Cradle to Cradle: Remaking the way we make things, North Point Press, New York

Lichtenberg, J.J.N., Gassel, F.J.M. & Schrijver, P. (2006) Assembling Wall Panels with Robotic Technologies In: Proceedings 23rd International Symposium on Automation and Robotics in Construction – ISARC 2006, 3-5 october 2006, Tokyo, Japan, pp. 728-181

Lichtenberg, J.J.N. (2005) Slimbouwen®, Aeneas, Boxtel, ISBN 90-75365-74-8

Lichtenberg, J.J.N. (2006) Slimbouwen, a strategy for efficient and sustainable building innovation, paper International Symposium “Construction in the 21st Century – Local and Global Challenge”, ARTEC, Rome October 2006

Westerlaak, M. van (2008) Contact, Een informatiecentrum voor de bouw, om het contact tussen de bouwwereld en de samenleving te versterken, graduation thesis, Eindhoven University of Technology (only available in library Dep. Architecture building and Planning).

Woertman, S (2008) Licht op de zaak, De Architect, SDU

Nico Kremers, Director of VMRG – Vereniging Metalen Ramen en Grevelbranche (Dutch association for façade manufacturers) and head of the company Kremers Aluminium underlines the potential for innovation and concentrates on strategies for the future development of the industry through growth and integration.

The Future Envelope 2 – Architecture-Climate-Skin. U. Knaack and T. Klein (Eds.). IOS Press, 2009.

THE FAÇADE SECTOR

Nico Kremers

VMRG / Façade Industry

1. Company and sector

The VMRG is an organisation of entrepreneurs in the façade industry of which I am fortunate enough to be the chairman. I mention this because it is a unique position.

Not because of the status, but due to the fact that, as an entrepreneur, you are continually focused on the day-to-day running of your company, while as the chairman of a business organisation, you are able to see things more comprehensively.

Not only are you working within the façade construction industry, but you are capable of directly connecting issues at sector and social level to your company as well.

Both positions allow me to tell you something about the façade construction industry, about the things that keep us busy as well as outlining several future developments for you. I will also give you an overview of what the VMRG would like to call the Gevelsector®.

2. The entrepreneur

Firstly, we have the role of the entrepreneur, who is often regarded in terms of the product or the production process. While this is, of course, correct, more important aspects are his innovating, organisational and financial risk-bearing capabilities.

The entrepreneur not only manufactures in order to make products but he also makes such production possible and creates value as a result – value for the customer, the employees and every other party concerned.

The entrepreneur is someone who shoulders complete responsibility and dedicates everything that drives him to the success of the business. He is the factor that converts possibilities into reality and accomplishes future goals.

Moreover, entrepreneurship is also an attitude, a combination of knowledge and skill, intuition and, particularly, internal motivation. And this motivation brings me to a number of issues that I would like to present to you today that will be of importance to everyone in the façade industry in the years to come.

3. Developments: 'the elimination of artificial borders'

Put simply: we are going to drop the construction part in the façade construction industry, because it has been the focus of everyone's attention for too long and has diverted attention from issues that are equally as important and certainly as numerous. The process we use to work with façades is much more extensive than the several months that we are actually involved in the construction process.

Of course, the design is realised in the execution process, and the construction costs and associated risks demand our total attention. We have to realise that designing, engineering and developing a façade are actually activities that create value. It is therefore necessary that we create a cooperation with architects and designers in a precompetitive situation.

I would like to see designing and engineering occupy a more important position. And not only that, I want to see it purely from the perspective of the industrial manufacturing of façades and façade elements. But a process of change will lead to the situation that our production orientated firms will become market en innovation driven open organizations. Those modern firms are able to cooperate with designers and architects.

The objective that will be achieved as a result has a number of advantages:

1. Involving the façade industry in the design of the building and its façade will lead to a better end product. We can optimally tune our technology to the desires of the designers and, therefore, the client. Mundane concessions purely from the point of view of price reductions will become a thing of the past.
2. Optimum industrial construction will also lead to a more manageable process, as a result of which quality will also become more manageable and construction times will be reduced.
3. Exchanging ideas also provides value in the long term because the sustainable behaviour of the façade products and the guarantee is grounded in the approach of the façade supplier and is, therefore, simply one element in the decision-making process.

The compulsory price competition in the market and the struggle to land the most competitive price through economising leaves deep scars, not only during the production and construction processes but also on the end product. And this is something we have to put an end to!

The purposely made barriers between all partners in the process must be removed. In doing so, we will create room for one another and optimise our ability to collaborate. And this is a necessity given the fantastic opportunities that lie before us. Normal business practice dictates that we aren't going to ask that this happen, we're just going to do it!

We see a market in which we can create greater value for our clients. And I'm not talking about the façades themselves but what we can achieve through them. Because the elimination of the borders between the different disciplines will provide yet more creative possibilities. These possibilities will lead to value in terms of the environment and energy conservation and will eventually result in increased value for the users and owners of the buildings for which the façades are being manufactured.

I am, therefore, pleading that the partitions be eliminated, even those within our own sector! Limiting ourselves to traditional areas of work will be our undoing. Our objective has to be: complete integration of all disciplines that are involved in the façade construction industry.

If we can successfully apply this capacity and creativity to an industrial process, this will result in BOTH an efficient production process AND a substantial positive effect on the end product – both the façade and the building!

And this is exactly what our architects and clients would like to see.

4. The Gevelsector®

The Gevelsector® has ambitions and is faced with challenges. In the context of the future envelope, I also propose to outline a future façade sector. In this respect, I am conscious of the fact that the future of this sector is perhaps a somewhat abstract concept, but that the roots of this future are planted in the here and now. Entrepreneurs are taking decisions and making investments today with a view to tomorrow. However, in order to understand the results of those decisions and investments, a picture of that future is a necessity. We are used to working with goals and to controlling the processes necessary for the realisation of those goals.

The Gevelsector® is full of dynamism and creativity and will have the following characteristics in the new situation:

1. The companies take a multidisciplinary approach to work. The borders between process specialisation within the companies have blurred, resulting in optimal collaboration between companies. Therefore, in the Gevelsector®, electronics, entrance technology, climate, environment and façade technologies, etc., go hand in hand. The current requirements for the façade industry mean that the usual approach concerning water- and air tightness is not sufficient anymore. The modern concepts are systems, not rigid skin constructions. Those systems need electronic devices such as sensors and regulating devices to create a safe and convenient climate. The reason that our industry is confronted at this moment with these requirements is a combination of a specific new demand (from climate installation to the climate itself) and the availability of modern components in our façades. This is a momentum now, because of the big differences we see in other technological areas and in the traditional construction sector.
2. The Gevelsector® is a sector in which the most diverse materials are processed. The artificial arrangement and division of interests between the different materialisation has become blurred or has completely disappeared. I think, and I am very sure about this, that the façade industry has the duty to increase its value as a modern sophisticated building part. And these components actually form a dynamic system that regulates the climate situation (comfort) inside and environmental aspects outside. The façade will in my opinion be the most complex building component in the nearby future.
3. The Gevelsector® is responsible for the entire process that is necessary for the realisation of the façade. The process, therefore, extends from the formation of ideas and designing to the performance of the façade. Even recycling will be one of the Gevelsector® competencies. You may see this in line with the outdated and traditional organization of the building process. When we add up the value of façade industry and installation industry we read the amount of about 60% of the whole value of the building. Then it is logic that the overall coordination and organization of the building process will be in the hands of the façade/installation industry! A new an intelligent partner in construction.
4. The Gevelsector® is a sector that takes its social responsibilities seriously, including problems in the areas of security, energy, productivity, etc.
5. The Gevelsector® is internationally oriented. Borders have also disappeared here and the work is supported by international

experience, standards and legislation. We have to solve problems coming from a traditional approach and specific national legislation. But we have benefits as well: increasing and varied markets with many different clients and partners in business.

6. The Gevelsector® is a breeding ground for new technologies and innovations. The knowledge and skill of the most diverse types of companies, both large, international companies and small, local ones, are being continually updated. Research and development and tests are implemented as a matter of course for the purpose of the development of the sector and its products.

In this respect, I feel I have the full support of the experts who are working in our field.

Look at Slimbouwen®, Jos Lichtenberg's vision that has handed us the opportunity to reorient ourselves and create an optimum chain of construction partners through the creation of an entirely different arrangement of products, constituent products and production processes.

I also feel the full support of the Faculty of Architecture of the TU Delft, where Ulrich Knaack is the professor of Building Construction, which enthusiastically and energetically ensures that our industry receives a more mature character.

In short, get rid of all those borders and limitations today and give each other room in which to work, create new relationships and lay the foundations for new collective success within the façade industry. Façade suppliers are entrepreneurs with an excellent business in which we can all feel at home and do our own thing!

Prof. Ir. Rob Nijsse is a structural engineer and a pioneer in the field of load-bearing glass structures. His paper shows the latest developments in glass and plastics, and the role of these materials as transparent building materials for architecture.

The Future Envelope 2 – Architecture-Climate-Skin. U. Knaack and T. Klein (Eds.). IOS Press, 2009.

CORRUGATED GLASS AS IMPROVEMENT TO THE STRUCTURAL RESISTANCE OF GLASS

Rob Nijsse

TU Delft / ABT Structural Design

Abstract

By deforming or moulding a flat panel into a corrugated panel a great improvement in strength and stiffness is achieved. This strategy is applied to the design of façades in order to achieve smaller thicknesses of structural glass elements and thereby create surprisingly shaped façade surfaces and lower building costs. A study in possible shapes is made in relation to the joints and the connecting details not only from a structural point of view but also from architectural engineering issues such as water-proofing, insulating, assembling and cleaning.

Two realised projects are discussed, The Casa da Musica in Porto (P) and the Museum aan de Stroom in Antwerp (B).

1. General

In most façades flat glass panels are used to fill in the transparent part of the façades. This implies that all horizontal forces on the façades, e. g. the wind, have to be taken up by bending of the flat panel. Bending is not a material friendly way of transporting forces over an element. For larger spans, high thicknesses are required and therefore the building costs rise as well and if the normally available thicknesses (up to 19 mm) are exceeded, it is not possible at all. One manufacturing "trick" to overcome this problem is to corrugate the flat panel; corrugated steel plates are a good example of this. By corrugating or folding the flat plate a three dimensional action is possible and the lever of the pressure and tension areas in the material is enlarged significantly compared to the thickness of the plate itself.

For glass, the question is how we can achieve this corrugated shape. One possibility is by cold deforming in a dictated shape but the elasticity of the glass makes it necessary to constantly push/clamp the glass panel in its required shape. And the stresses evoked by cold forming remain in the glass and have to be added to the stresses caused by the wind action. Therefore warm deforming is preferable. With this method a flat glass panel is heated to 600°C in a furnace. At 600°C the material glass becomes more or less plastic and can be shaped in any desired form. Due to the plasticity stresses are not called up in the material although some restrictions have to be made, see later in this text. For warm bending two methods are possible, the first is to use gravity and let a heated glass panel flow over a mould, the second is to push the heated glass panel actively upward (or downward) against a mould. We will describe the forming process of corrugated glass with the gravity method. At a temperature of 600°C the heated panel is laid over a mould that is shaped in the desired form. Due to the plasticity the heated glass flows across the mould. This is a critical point in the process since the heated glass panel has a tendency to take one bending location, mostly the top part of the mould, where the cross section of the panel diminish and the parts to the left and the right flow down on the mould with constant thickness. Once the glass panel has completely taken the shape of the mould the heating can be turned of and the temperature may drop slowly; this is essential since tempering has to be avoided. Once room temperature is reached the, now corrugated, glass panel can be taken out of the furnace. Although as mentioned before, it should be expected that the plastic deformation does not create residual stresses; study and experiments by the university RWTH Aachen have shown that up to 30 N/mm^2 (maximum, extra) stress has to be calculated due to the moulding process for the gravity variant. Another negative characteristic of the gravity based production process is the fact that the thickness of the material may vary/ diminish due to the sagging of the panel over the mould. Especially in places where higher curvatures are required this may lead to lower thicknesses at the top of the curvature and, hence, a weaker spot in the panel. In the other manufacturing form of corrugated glass, the pressing of a heated, flat panel in a mould this variation in thickness will happen far less frequently since the material has no choice but to follow the dictated shape.

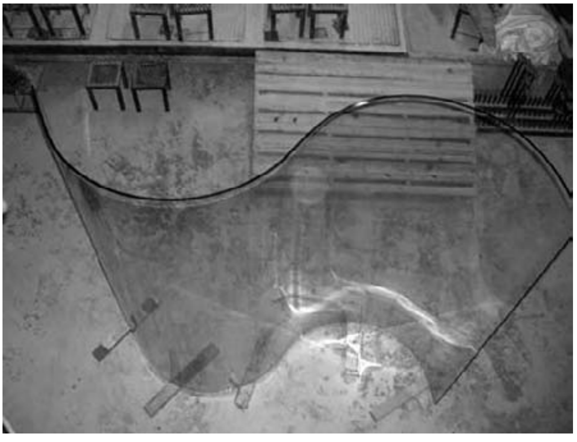


Fig. 1. A corrugated glass panel directly after production in the workshop.

Another serious critical point of the production of corrugated glass is the exactness in which the panel's dimensions can be made. Preferably we would like all elements to have the same width, the same length and the same curvatures. Since it is a production process producing the elements one by one, exact uniformity is an illusion. In ref. [1], Thomas E. Noe provides helpful guidelines for this issue and it is also our experience from the Porto and the Antwerp projects that tolerances of +/- 2 mm are possible. A lot of the smaller companies that produce - as they call it - bent glass make use of the gravity method and, if this is done with knowledge of the material glass and its behaviour, quality is not a problem. However, thorough examination of the delivered products is required. Larger companies such as Tambest, Pirkkala (FIN), Sunglass, Villafranca (IT) and Cricursa (SP) use the second method, pushing the glass in a shape/ mould which provides better quality in both uniform thickness and uniform dimensions of the various elements produced in a series. Regarding the shape of the corrugated glass panel, the designers can choose what an element should look like. This is an architectural or visual issue but it may have large implications on the structural behaviour and the building costs. It also relates to the number/length of silicone joints that have to be made. In the respective projects Casa da Musica-Porto and Museum-Antwerp, this aspect is dealt with specifically; but in general it is recommended to use symmetric elements. This is not required by the manufacturing process although there are other restrictions related to the shape. But they can be resolved by following a simple rule that states: if you can fold the desired corrugated shape out of piece of paper, the glass industry can make it.

The requirement mentioned here is due to structural restrictions. It does not rule out asymmetric cross-sections but one has to be aware that asymmetric profiles means extra stresses on the material glass, mounting up to 25%!

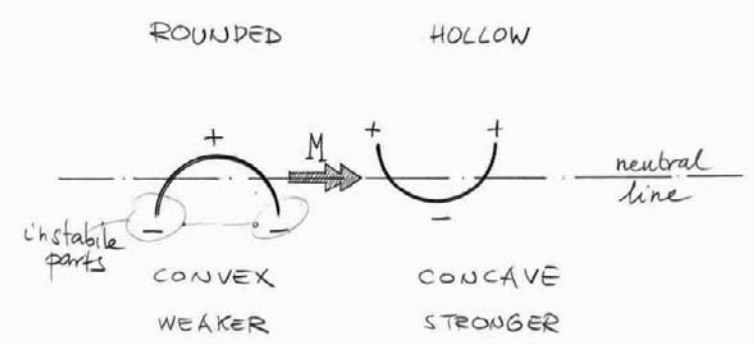


Fig. 2. The structural effect of being concave or convex for a corrugated surface.

The reason for this is that there is different behaviour in stiffness when a concave element (hollow shape) or a convex element (rounded shape) is loaded. The convex shape is weaker and deforms easier. Therefore, if we look at the shape of the corrugated glass panel in fig. 1 we notice that this asymmetric shape has a convex and a concave half.

The convex part will move more under loading and will flatten out in the middle. The concave part will stay more in the shape and the overall shape of the total profile will rotate in the direction of the convex part.

However; at the supports, the corrugated glass panel is forced into the steel profile that creates the support by clamping the glass (with an elastic intermediate). There, the deformed, rotated shape is forced into the original radius, resulting in extra stress on the glass locally at the supports, which may be as high as 25% or more. And the vertical joint along the side of the corrugated glass panes will behave accordingly; during loading the joint will be broader in the centre of the span and smaller at the supports. This will cause tensile stresses in the silicone joint resulting in tearing and leaking of the joint.

Casa da Musica in Porto (P)

Fig. 3. The white concrete shape of the Casa da Musica during construction. Notice the large window in front.

In 1997, the Office for Metropolitan Architecture (OMA) headed by the Dutch architect Rem Koolhaas won a competition for the Cultural Centre of Porto in Portugal. They had designed a rather unusual shaped box of white concrete that contained the various required cultural activitie, such as a large auditorium, various foyers, children's cultural learning grounds, a small auditorium, a restaurant, a bar and parking garage with all the technical rooms belonging to these activities. The story goes that the shape of the building originates from a previous design for a Dutch villa that was reused and adapted; but this is apocryphal. In the white concrete box, large, very large openings were made to let the daylight enter the building and to present the visitors of the building with an amazing view of the town of Porto, located on the slopes of the river Douro.

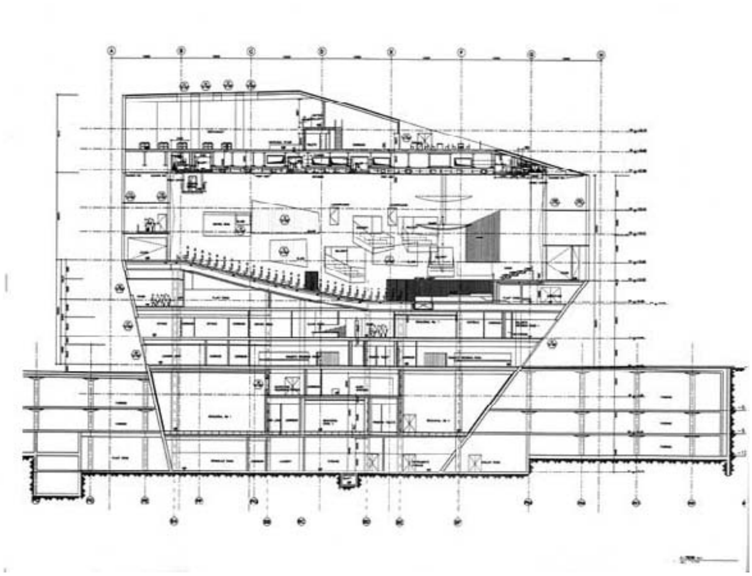


Fig. 4. Cross section of the Casa da Musica. The large windows are directly adjacent to the big Auditorium.

ABT/ Rob Nijsse was asked to make a proposal for the façade with the large windows, the biggest one measuring 25 by 12 meter, using as much glass as possible and, preferably, no steel. We tried all kind of slender cable structures but these remained unacceptable for the architect. Quote: "I don't want all that steel spaghetti around the glass". As we tried to figure our way out of this "mission impossible" I happened upon a publication of the Spanish firm Cricursa that made a large corrugated panel wall for the interior of a shop. Putting one and one together I made a proposal for a large window made out of large corrugated glass panels stacked on top of each other. Due to then valid production restrictions we could make 4.5 meter high corrugated glass panels, so the total height of 12 meter was divided in three parts which fortunately fitted in with the position of the floors of the foyer/ circulation space that in some locations passed through the voids. The architects immediately embraced the proposal. As I later learned, he found the contrast between the flat, smooth surface of the white concrete and the corrugated, shining, brilliant surface of the glass façade especially appealing. It was considered a texture gimmick in the appearance of the building that reminisces fashion tricks by combining different materials. The structural effect of a corrugated panel is clear; it can take up much more wind load then a flat one of the same thickness. Therefore no steel supports in the shape of cables, columns and beams are necessary for the glass. On an overall level, support for the components of the façade is needed. We combined these with the planes of the floors that crossed the voids behind the façade.

Here, horizontal steel trusses were placed, made as slender as possible; thus using double diagonals in order for each to absorb one direction of tensile stress. In places were there is no floor these diagonals simply hang in the air.

Fig. 5. In between the two corrugated glass walls a bar was installed,made of glass, of course. Above hang the trusses that take up the wind load on the façade.

The architect wanted to have daylight in the large auditorium, a feature rarely seen in theatres. So we had to make two walls of corrugated glass, one wall on the outside, to take up the wind load and to provide water tightness and insulation and one wall on the inside dividing the theatre from the foyer/circulation area. It might be suspected that sound quality inside the theatre was affected by the presence of glass, a hard reflecting material. Study of the acoustical adviser showed that due to the corrugated surface a very effective dispersion of the sound was obtained and the effect of a double glass wall let to more than enough sound insulation from the inside to the outside and vice versa.

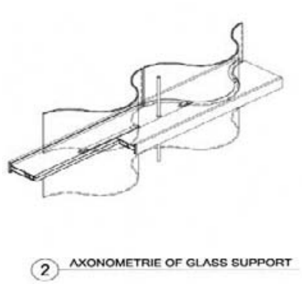


Fig. 6. The support beam and detail for the corrugated glass panel.

The weight of the corrugated glass walls is carried by steel beams that are hung from the concrete wall on top of the opening in the concrete shape of the building. In total six, more or less large, openings in the white concrete box were filled with this concept of corrugated glass walls. In addition, eight walls/openings inside were filled with a single line of corrugated glass wall, making corrugated glass a feature item for the architecture of the Casa da Musica in Porto.

These steel beams are part of the horizontal steel trusses and have facilities for both mounting and adjusting the tolerances of the corrugated glass panels. Waterproofing and thermal separation between outside and inside is also taken care of.

Fig. 7. The façade of the Casa da Musica; corrugated glass and white concrete: an unexpected match.

Museum aan de Stroom (MAS) in Antwerp (B)

A strong desire to improve both the situation of the various museums in Antwerp, no longer suitable for the 21st century, and to improve the quality/atmosphere of the old disused harbour quarter directly situated near the historic City centre of Antwerp, led to plans to develop a new large museum on an island, the Hanzestedenplaats in the Napoleonsdok. A museum meant to house all the museums in Antwerp, encompassing subjects as divers as historic, folkloric and modern art.

In 2000, an architectural competition was tendered for 5 selected architects. The competition for the 12.000 m^2 floor space building was won by Neutelings Riedijk Architecten with ABT as structural advisor. The design of Willem Jan Neutelings was simple but beautiful. By housing each category of the museums in a concrete flat box, security, fire proofing and optimal climate control was possible. By placing the total of eight boxes of the museums on top of each other and placing an entrance layer on ground floor and a restaurant on top, a 60 meter high building was created. The stroke

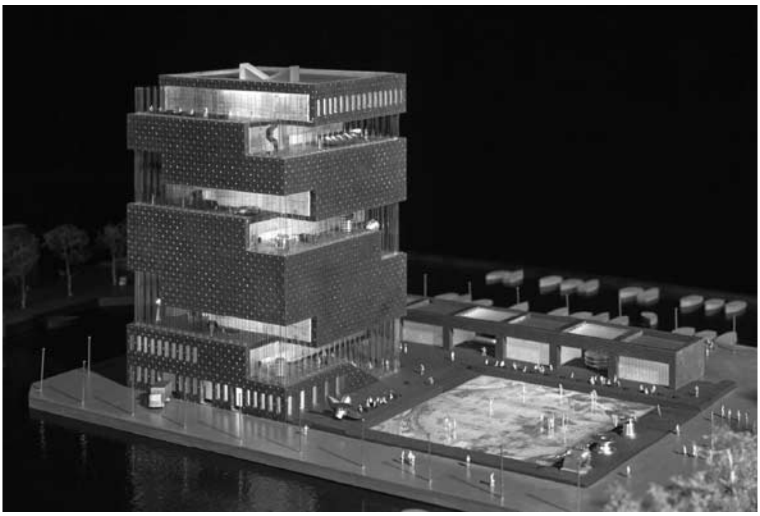


Fig. 8. The building of the Museum aan de Stroom (MAS) on the “Eilandje” in the old harbour of Antwerp.

of genius on the part of the architect was that by twisting each layer of this stack of boxes by 90 degrees, a spiral walkway was created connecting the various museums boxes. Another result of this twisting is that the while climbing the stairs visitors have beautiful views over the city of Antwerp, from changing positions.

Although the structure of the MAS itself is interesting the glass façades filling in the space between the various museum boxes are the subject of this paper. As one can see in fig. 8 the height of this façade in the corner areas is two times the story height of one museum box (5,5 meter), resulting in an 11 meter high glass façade. Of course, for the architect glass was the only material of choice. From the experiences with the Casa da Musica project, which at that time was in the design phase, we were able to propose corrugated glass for this project as well. The special challenge of the MAS project was that a façade of 11 meter had to be realised in one piece. Corrugated glass elements of 11 meter long are an illusion; they can not be made in the furnaces and the glass industry has a 6 meter length limitation due to production and transport restrictions. The Italian glass provider Sunglass was able to produce the desired shape of corrugated glass in the length of 5,5 meter. So we divided the 11 meters in two parts of 5,5 meter. This implied a "support" halfway that, of course, had to be as slender as possible not to destroy the desired overall transparency (and view) of the façade. This issue was easily solved by connecting the two corners of the adjacent concrete blocks with a steel tube as intermediate support (see fig. 8). This tube is only meant to carry the wind load and serve as a horizontal support for the façade; the own weight is carried by simply stacking the corrugated glass panels on top of each other. So for wind load the corrugated glass panels structurally behave as a plate on two lines of support, spanning 5,5 meter. The fact that the glass panels are merely standing on each other led to some discussion.

One: are the stresses induced by this stacking acceptable? Two: if a lower panel breaks, for whatever reason, will the top one not come down? And three (as important): can the broken panel be replaced? Question one - stress level: depending on the spread made by the elastic layer between the two stacked corrugated glass panels the level of normal stresses (compression) varies from 2 (concentrated points of support) to 0,2 N/mm^2 (uniform support), very acceptable values certainly for compression, one of the strong features of the material glass. Second question - breakage lower panel: if one simply lets the panels stand on top of each other, this is a problem. And in combination with question 3 - replacement: this is a critical aspect. Therefore it was decided to add a horizontal steel beam that was strong enough to carry the weight of the top panel, if the lower panel collapses, but slender enough to be incorporated within the connecting detail, see fig. 9.

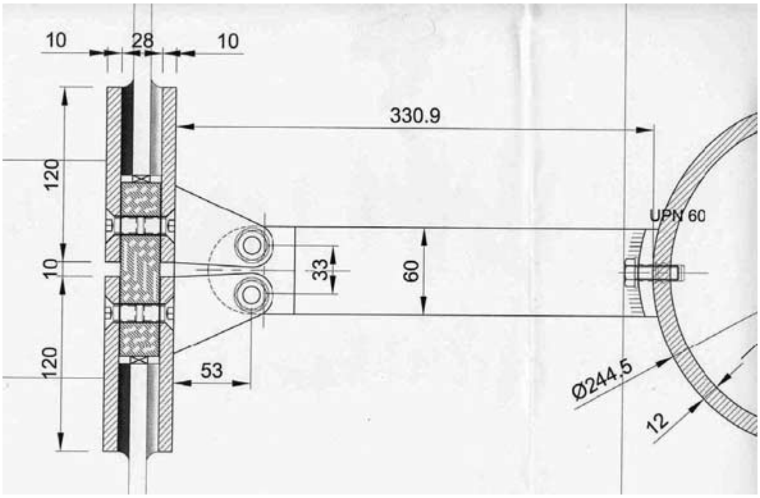


Fig. 9. The horizontal, intermediate connecting detail of the 11 meter high corrugated glass façade of the MAS.

As one can also see in Fig 9, steel plates follow the shape of the corrugated glass in order to create a good detail, easy to maintain and assemble. The making of the corrugated steel profiles proved to be difficult in practice since steel always has an uncontrollable tendency to spring back after deforming and the effect of temperature change was also apparent. These problems were solved by extra attention and control during manufacturing and by making the steel elements not too long; more vertical joints were added. The waterproofing is guaranteed by silicone joints at both the inside and the outside. The connecting detail at the underside and the upper side was worked out in the same principle. We have to realise that insulation demand for this façade were minimal. The circulation zone for the visitors of the MAS is considered a "half-climate", the most serious demand was no condensation on the façade or the floor.

Although the details look very simple and straightforward, it took a lot of time to develop them, working together with the technical advisor of the architect Bureau Bouwtechniek- Antwerp (B) and the glass supplier Atelier de Verre- Luik (B). We also learned a lot from making a mock-up scale 1 to 1 on site.

With glass structures that have the image of "not being there", beauty certainly lies in the detail; thus it is important to perfect them. And we must not forget maintenance and cleaning.

Up to now we have been talking about "a" corrugated glass panel. But how do you choose the form and level of corrugation? Two different visions have to come together; the structural engineer who wants to have a usable "wave height" and the architect who

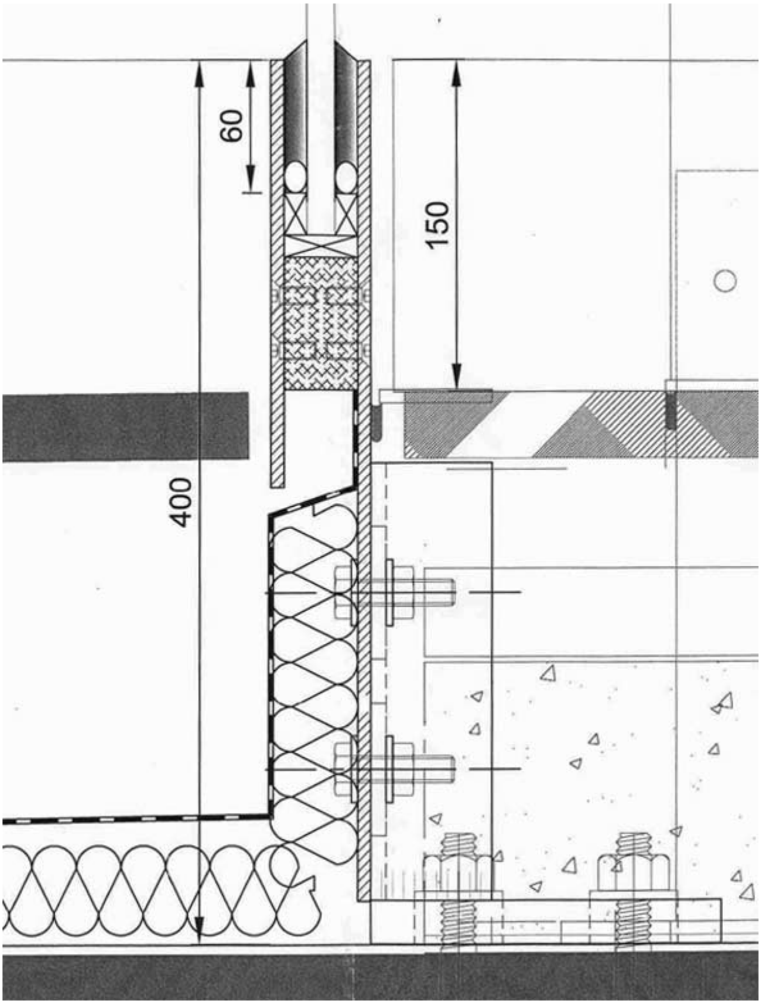


Fig 10. The connecting detail to the floor below the corrugated glass façade of the MAS.

wants to have an undisturbed view on the surrounding - i. e. a panel as flat as possible. During this discussion we made some calculations that showed that from a ratio of 1 to 20 of wave height to span, the structural effect of corrugation was evident. So this was our guideline, but the architect reacted by doubling this value with the argument that the distortional effect is less from a distance and that people could stand "in" a wave of glass close to façade. The distortion close to the glass is also minimal. All this implied that our "wave height" now was 2 x 300 = 600 mm. The elements were chosen to have the shape of a lying S, with a width of 1800 mm. We calculated a required glass thickness of 12 mm float glass. The presence of visitors close to the façade let to the demand that the glass should be laminated in order to avoid falling through in case of an accident. We calculated that 2 times 8 mm float glass should do the job.

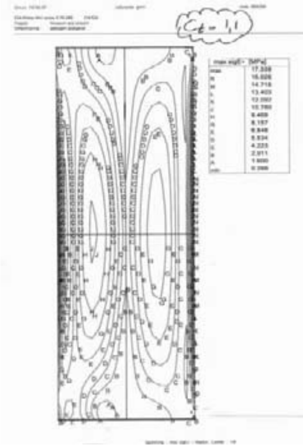


Fig. 11. Stress distribution for a single corrugated glass panel. Note the different behaviour between the left and the right side at the support. The negative effect of asymmetry was prevented by carefully avoiding clamping in the support-details

Fortunately the Sunglass firm was capable of making two corrugated panels as fitting as possible so that a laminated panel could be provided. However the scale of the façade made out of corrugated glass panels, and the fact that in a public building a lot of people would be close to it, let to the demand of the client, the town of Antwerp, that loading tests on live size corrugated panels should be conducted. This was done in a statistical series in the hall of the manufacturer of the corrugated glass panels; Sunglass in Villafranca (near Padova). During these tests loads of up to 300 kg/m^2 were imposed on the glass panels of 5,5 meter span, equaling the maximum wind load with a safety factor 1,5.

The test loads proofed that a load of 300 kg/m^2 could be carried easily, no breakage and only minimal deflection, maximum value 3mm in the centre of the span, NB only at the rounded, convex side!

We also did a test on a laminated corrugated glass panel; 2 times 8mm float glass, specifically to see what the effect of prolonged loads would be. But, probably due to the fact that a corrugated panel does not show so much shear stress in the intermediate resin layer (that glues them together) compared to a flat panel; after 5 hours of a continuous load of 300 kg/m^2 no effect of on-going deformation (creep) was visible.

Fig. 12. Test load of the corrugated glass elements

The future of corrugated glass panels

Now that two, different structures have been worked out for large façades, one could ponder over other applications for corrugated glass panels. The first thing that comes to mind is to use them horizontally, as a roof or a floor. The structural properties that helped us create the façades in response to the wind load will naturally help us in a similar way for dead load and live load on a floor/ roof. A restriction that can represent a problem is the fact that currently no elements larger then 6 meters can be produced. This means that a structural connection has to be made between two, or more, elements. This can be done by gluing an overlap between elements. However, objections exist against extensive gluing, some of which more or less emotional, but there are questions in terms of durability and lifetime quality. Perhaps the still experimental welding of glass is a future option. One could also think about mechanical connections with bolts. We identified a way to connect two corrugated glass elements standing on top of each other for the MAS-project. This method of joining two glass elements by steel bars and bolts has been worked out previously by ABT, see fig. 13. For the MAS project we found this structural tactic a little too much; thus the steel tube was used.

Fig. 13. connection by steel bars and bolts

Another possible application for corrugated glass elements could be as load carrying walls. Due to the corrugation, the buckling behaviour is good, very good. Therefore these panels can take up a large regular load, meaning they can be used as walls that carry a roof, or even a floor.

Fig. 14 Load carrying walls (here they are flat)- a possible future application for corrugated glass?

References

[1] Noe, Thomas E., Tempered Bent Glass Quality, proceedings of the 9th International Conference on Architectural and Automotive Glass (Glass Processing Days), Tampere, Finland, 2005.

[2] Knaack, Ulrich, Konstruktiver Glasbau, Verlag Rudolf Müller, Köln, Deutschland, 1998.

[3] Nijsse, Rob, Structural Glas, Birkhäuser, Basel, Switzerland, 2003.

[4] Willem Jan Neutelings et al, At Work!, Uitgeverij 010, Rotterdam, the Netherlands, 2004.

[5] El Croquis 131/132, OMA Rem Koolhaas, Croquis editorial, Madrid, Spain, 2006.

Dr. ir. Arjan van Timmeren is part of the Research Group Climate Integrated Design at the Faculty of Architecture, TU Delft. He describes numerous projects with a focus on climate design and its possible application in the façade technology. The result is the image of a building envelope with its functionality reaching beyond its traditional function as a climate separating element.

The Future Envelope 2 – Architecture-Climate-Skin. U. Knaack and T. Klein (Eds.). IOS Press, 2009.

CLIMATE INTEGRATED DESIGN (CLIMATE ID) OF BUILDING SKINS

Arjan van Timmeren

TU Delft / Climate Design
"Skins" subresearch group

Buildings are like organisms, sucking in resources and emitting wastes. The larger and more complex they become, the greater the necessity of infrastructures and the greater their dependence on surrounding areas, and last but not least, the greater their vulnerability to change around them. With recent and coming perturbations of the weather as well as constantly increasing demand of energy, water and materials, this aspect of vulnerability and dependence is becoming essential for sustainability, as the world may be entering a period of scarcity. Therefore, a renewed look on the building metabolism is necessary. Within this metabolism several components are essential. As for sustainability and especially the potential for climate integrated design, the building envelope, or better: the building skin is the most essential component.

Critical to the implementation of a changed approach to the building skin in close coherence with integrated resource management in the urban living environment, are reciprocity between skin and surrounding influences respectively indoor comfort and behaviour related influences and climate change influences. Besides of that inclusion of low energy solutions together with strong feedback systems between the different physical scales, and introduction of regenerative systems will be directive.

The previous stated key aspects concern the main issues within this paper, which represents an essential part of the research program of the TU Delft 'Climate Design' group, DISC (Design and Integration of Sustainability and Comfort), sub-research theme "Skins". The objective of the Skins sub-research programme is to define, explore, design and assess concepts of bioclimatic and environmentally responsive and adaptive building skins and related elements such as building mass. All parts of the building envelope that separate the inner climate from the outdoor climate are taken into account, while various indoor climate conditions are considered as well. Within this sub-research, the used pluricentric method of interaction combined with the concept of "open design" offers good perspectives, and is particularly suitable because of the current "specialists' society" and the many parallel dynamic processes playing a part: it is an interactive learning process, in which participants can only develop and tune (adjust) their goals during the process. The emphasis is on directing the transformation processes and developing alternative responses while the process itself is going on. The orientation may take place by means of values, after which detailing can be done at the level of standards. After that, this detailing is discussed in an interdisciplinary context, which will lead to adjustments that may have consequences for all disciplines. In this approach, synergy (interweaving of goals) and arrangement (collaboration and conflict management through temporary collaborative groups) are considered as goals. It is essential to recognize the complicated character of the desired development; this may prevent conflicts and may enhance the efficiency of the process as a whole.

Definition and delimination of climate design related criteria

The building skin is a major building component: external forces meet internal ideals at this point. The building and its site are a landscape of possibilities, with the skin (or skins) as the mediator between in-ness and out-ness. It concerns itself with climate (or perception of climate) as a major contextual generator, and with benign environments using minimal energy and materials as its target.

When speaking of climate adaptive skins, most people will understand the general idea behind it: a building skin that changes its characteristics under influence of the climate. A possible interpretation problem rises with the exact definition of adaptive: different people with differing backgrounds and perspectives have a different view of the term 'adaptive'. In general adaptive is referred to as "to become adjusted to new conditions".

While adaptive means the ability to adjust and adapt to changing circumstances by itself, adjustable, similar to adaptable, means the ability to adjust by external interference, such as human hand. Shutters for example will therefore not be classified as adaptive, but as adjustable. Within this context responsive building elements, among which (parts of) façades are investigated as well. Responsive in this is addressed to as 'responding readily and positively' while respond in this context means 'doing something as a reaction'. Climate-responsive building elements are building construction elements in which building service functions (e.g. heating, ventilation, lighting) are integrated and which assist in providing a comfortable and healthy environment at low-energy use.

With respect to façades, the difference between adaptive and responsive is that responsive does not actually mean the adjustment of specific characteristics to the environment, but merely responding to a change in climate by, for example, lowering blinds or opening windows. The result could be interpreted as a change in characteristics, but technically nothing has changed in the façade itself besides the orientation of certain building elements by a mechanical action.

Before the research and design for a new building skin concept starts, it is vital to realise what exactly the requirements for the building skin are. The term building 'skin' to some extent already explains what the research is about. A skin separates the inside from the outside, protecting its contents, which automatically implies that on the one hand there is a need for protection, meaning that inside the skin conditions are preferable above the outside conditions, i.e. inside is, or should be at least, more comfortable. On the other hand it implies interaction and a mediator of reciprocal relationships of inside and outside conditions.

Originally a building façade should perform all the tasks for which we seek shelter behind it. Today however, no longer the building façade simply has to act as a shelter against rain, wind and cold only, but more and more it is expected to act as a skin the same way as a human skin acts: as a vital part of our body, responsible for keeping the temperature of the body itself within comfortable limits, but also harvesting water, electricity, clean air and treating or emitting waste sustainably. Depending on the location, nature of the building, architect and client, additional requirements such as solar control or acoustic damping can become part of a façade. To provide optimal comfort to the user, it is not possible to cater for every physical aspect: requirements for acoustic quality are different from those for avoiding PM10 emissions to enter the building, bounding and/or emission of harmful CO2 and ozone produced in the building or for thermal insulation, which in turn is different from the requirements for visibility or natural light admittance. However, there are some basic functions of a building skin that every façade needs to encompass: waterproofing; shelter from wind (not to be confused with ventilation); thermal insulation; and structural soundness. For determining or testing the possible solutions with respect to these basic needs as to the sustainability of the building skins, it is of importance to determine more precise the preconditions or assessment criteria for arranging and preserving systems. This paper distinguishes three directions of approach: environmental conditions, spatial conditions and social (user-related) conditions or criteria for climate integrated design solutions.

Environment-related criteria

The main environment-related criteria concern:

1. A maximum of health guarantees, hygiene and safety (free from threats); It mainly concerns health and hygiene related aspects. Safety may be divided into social safety and physical safety (Voordt & Wegen, 1990). Physical safety concerns the complex of being as free as possible from the risk of possible injuries and/or end of one's life, as a result of natural or human danger (adapted from Suddle & Waarts, 2003). Social safety implies the perception of safety, and is also called perceived safety (Dorst, 2005). Feelings of unsafety depend on personal characteristics and the environment (Hoek, 1994). The environment implies both the social and the physical environment. Safety may also imply no nuisance caused by other users. Because of the large differences between users, for one person nuisance (a problem) occurs sooner than for another person. This argues in favour of location and user-specific solutions (from source to service).
2. Security of utilities & supply and consistency; This aspect holds both for the shared scale of supplying flows (materials, clean air, warmth/cold, electricity) and the returning flows (waste, better to be addressed at as 'nutrients'), and for the individual scale in the sense of being free from maintenance and disturbances. Each system within a building skin has its own limit as regards the time that a utility is allowed not to perform.
3. A minimum or an optimum of added raw materials; The use of materials in number and size, and the environmental load of these materials is what it is all about. It is a matter of minimum use of, for example, the high-quality raw material for low-quality purposes. A low as possible use of chemicals (i.e., non-natural materials) and quality control also falls under this criterion. All this from cradle to cradle. Particularly decisive aspects are the scale of application (distance and quantities) and the over-dimensioning, necessary or not.
4. A minimum of pollution of soil, air, ground area and surface water; This criterion concerns the influence of the technical component in our environmental system on the other three sets of components of our environmental system: the physical components, the biotic components and the a-biotic components. This implies no or a minimum use of problematic materials (seen from an environmental-technical viewpoint) ("source") and no or a minimum emission as a result of leakage and losses ("drain"). Moreover, a substantial change/deterioration of the biodiversity must not occur.
5. Closing cycles as much as possible; This aims at the reduction of raw materials by the maximum reuse of flows or subflows of materials and energy components, or the generated electricity

and heat. As to electricity, heat and waste (or their reuse), a correct type of cascading based on energy, a refining according to quality is the solution. For the various flows, this implies that they must be kept as pure as possible. The various qualities or subfractions resulting from this can be processed later according to the principles of cascading, from higher to lower use quality, and perhaps be reduced.

6. A minimum of energy use or a maximum of renewable energy generation; This aspect may be translated to a maximum of exergetic return for the energy flow: finding applications as close to the quality of the energy carrier. For energy saving, people almost immediately think of enhancement of efficiency on the side of supply by using better conversion technology, leading to fewer energy losses. From the angle of future value, demand reducing measures are to be preferred to efficient conversion technology.
7. Resilience to incorrect use or even sabotage; It is crucial for the current building skin and integrated systems to have the resilience to absorb breakdown or change in quantity or quality of influences or flows. Thus, this 'ability to correct' is related to the ability of regeneration and reflexivity, or the ability to deal with change adaptively. Breakdown or damage may be the result of incorrect use, whether deliberate or not, or sabotage. From a sheer technical point of view, both aspects imply the same for a system, viz., to be insensitive to undesired processes other than for which it was designed. They do demand a different approach, though. Incorrect use will always occur, with any product or process. One of the measures to reduce this to a minimum is to involve users (hence make them understand) in the product, in this case the building skin, and its processes. This at least suggests a certain need to show users, have them see/feel/smell. To involve users more closely, however, is one of the least wanted aspects where deliberate incorrect use or sabotage is concerned. In this situation, on the contrary, there is the wish for a certain controlled distance.
8. Future value (flexibility, uniformity); The future value of a building skin and integrated systems is determined by flexible anticipation of future developments, or, in other words, how decisive present choices are for choices in the future. Technological enhancements are a "driving force" behind obsolescence. Any system should have some capacity to anticipate the dynamics of changes in the period of use (also described as ability for development), e.g., being able to absorb fluctuations with different time cycles. A distinction can be made between procedural flexibility and content-related or programmed flexibility. Contential flexibility can be divided into various programmes (e.g., technical subsystem, spatial zoning, etc.).

Spatial criteria

Spatial conditions with respect to the built environment are often linked to Vitruvius' "Utilitas, Firmitas, Venustas". Most people are inclined to call suitability for building open to objectivity, usability less so and beauty actually not. Within the presented research program the following general defined spatial criteria for new and/or alternative concepts of building skins with a focus on climate integrated-design are distinguished:

1. Optimizing structural layout in relation to climate design related integrated components (viz. ventilation, lighting and thermal, resp. acoustical comfort); Building skins should be optimized with respect to use of space, energy and materials. The latter two have already been worked out as an environmental-technical criterion. Spatial consequences depend on the scale of application (in m^2 and m^3), the way of responding to changes and possible clustering of systems and components. Using the human skin as an analogy for the building skin, the main requirements for climate integrated design of skins with possible spatial components will include:
   - Thermal and acoustical comfort. The ability to provide a comfortable indoor climate through adjustment of the façade characteristics. Similar to the human skin, this means that in case of overheating the façade will provide means to shed excess heat (analogy: sweating), while in case of cold, the façade will increase thermal insulation (analogy: goose bumps). Similar to the human skin, noise, or acoustic properties play a role. The need for soundproofing though is very site specific.
   - Ventilation. When the human skin is covered with an impermeable material it will suffocate. However, it is not responsible for the body's main supply of oxygen: similarly, the building's climate installations function as the lungs, the façade should be used to fine-tune the local microclimate.
   - Lighting. Outdoor lighting conditions, especially direct sunlight, have great influence not only on the indoor lighting level, but also on the indoor thermal climate. When the human skin is touched by sunlight, it automatically darkens to protect itself and its underlying tissue from harmful radiation. Although this is quite a slow process and not reversible within a short period of time, the general idea needs to be applicable to the building skin as well: with high light/radiation intensity, the façade should adjust in such way that the indoor climate stays comfortable. How this is achieved is to be seen, and the process should be easily reversible to be able to respond to changing lighting conditions.
2. Minimizing or optimizing use of materials; The exhaustibility

of certain elementary materials is an environmental problem. Everything that is built or planned should always be easy to modify or changes should be easy to be incorporated in the programme with minimum material adjustment. Themes such as "dematerialization" and IFD and disassembling for the purpose of reuse ('cradle to cradle') are becoming more important.

3. Adaptability and extendibility; Increasingly better techniques and continuously changing circumstances have caused the adaptability (i.e., flexibility) and the physical housing of the systems and flows to become an important factor. In addition to flexibility, this is also translated into diversity, or the quality influencing the possible types of human use. We must be able to meet not only growth, but also contraction, through enhanced technique and enhanced design of technical building services. This is the case since the life span of the system may differ from that of the building as a whole and/or from that of the related technical infrastructure or building skin components. A clear scale optimum can be linked to the notion of flexible.
4. Screening off against incorrect use, sabotage and vandalism; This criterion does not immediately have to be translated to the building skin or integrated systems being completely fenced off from the public space. Sabotage can only be prevented through far-reaching measures. It is better to particularly pay much attention to the detection rate (visibility) and any possible quick disconnection of part of the system (in case of large or relatively large systems) or the complete system (in case of smaller systems).
5. Compactness, and optimizing use of (surface) area; For systems that are dependent on sunlight (energy generation, water purification), or are sensitive to possible losses (radiation) this may be of more importance still. It is not just physical space needed that counts, but also the physical space which is not immediately required, including legal areas and nuisance zones, and space needed for access to systems, maximum load and any obstructions.
6. Fitting into the living environment; At the level of a building, specific preconditions must be met in order to facilitate integration of new technology. Aspects including noise nuisance, visual nuisance, stench, any results of dynamic processes (vibrations), health and safety must also be taken into account. In addition, technical units sometimes depend on specific environment factors, such as daylight and/or a specific temperature. A design specification always comprises a demarcation according to scale. A stratification in the design decisions comes into being, through which decisions at a higher scale level hold as a framework for designs at a lower scale level. In reality, the scale levels have "sliding" boundaries.

7. Accessibility of parties involved; Also referred to as "permeability". For control and management as well as for information and education, the various systems must be accessible for stake holders. This contributes to the awareness process of occupants/users regarding their acting and any consequences of this. Often, the accessibility does not confine itself to persons. It may also concern the necessity of devices to be able to come near (for repairs, supply and removal of parts or subflow volumes). Permeability may "conflict" with the desired screening off against incorrect use. A careful design of the accessibility may take advantage of this.
8. Aesthetic quality; This aspect as part of spatial quality appears to be hard to define objectively. Nevertheless, it may be considered one of the criteria for lasting success of sustainability of a designed building and as far as visible for the systems (Kennedy & Kennedy, 1997). There is a fundamental difference between autonomous systems which do their job as anonymously and invisibly as possible, and so-called integral systems which are visible and obvious parts of the daily living environment. For positive reasons, we must find positive incentives for the installation of an alternative solution (Winblad, 1998). The necessity of diversity – also hard to judge objectively – is an aspect which, for aesthetic quality, is connected with creating optimum possibilities for the identity and/or expression.

User related criteria

It is important to map out the stake holders and their interests. Moreover, a successful implementation of new systems also depends on the users' acceptance. Acceptance (adoption), early participation and the correct knowledge, or the attempt to reduce the lack of knowledge of users, is of decisive importance for commitment to the issue. Therefore the users' interests are put first, when alternatives or solutions are offered. Therefore, the social criteria for the successful implementation and use of alternative systems or techniques have been drawn up from a user perspective. They are:

1. Equal or more comfort; Comfort is not a well-defined notion; there is a so-called sliding scale. In general, this means that there will be no restrictions regarded as unpleasant, resulting from the system chosen, which implies some reliability and robustness. The factors of time and adjustability are important aspects. Aspects related to nuisance, such as sound, smell, use of space and appearance, are also important. Users prefer old proven techniques because of the great (proven) reliability. Practically applied new techniques often suffer from growing pains, which many users find disadvantageous. Instinctively, this results in heavy dependence on companies and institutions in order to

be able to have everything perform well. A different design of "standard" use elements of systems can also be experienced as a reduction of comfort.

2. Similar costs; A precondition for acceptance is the presentation of the alternative solution as a positive choice. In this, costs must not play a negative role. For the building skin, the costs first of all concern the material and building costs. This also implies costs for (specific) constructional measures. For the users, the use and exploitation costs are of importance. These result from the investment costs and maintenance and management costs. Remaining variables are the factors of time (depreciation time) and possible self-management by users where possible.
3. Equal or more ease of use; The ease of use of new systems to be introduced must always stay equal or become better than it was until that point in time. A possible secondary problem is that, through a certain extent of habituation, users' habits become engrained. Additionally, the application of more "high-tech" more and more often also requires so-called "high-touch". Ease of use can be divided into three aspects: the specific use, the general performance and the maintenance (possibly carried out by the users themselves).
4. Independence of specialized institutions, or 'empowerment'; What has led to a larger possibility for people to develop themselves through the (relatively) unlimited availability of energy, clean water, waste removal, etc. on the one hand, implies on the other hand that people have become more dependent: larger personal development possibilities go hand in hand with larger required self-control. It is closely related to the maintenance and disturbance behaviour of applied technology and its (free) influenceability by users. For example, in a joint heating grid or communal heating system, the feeling of dependence is strong (dependence is considered a negative aspect of heat distribution by many users). In general one could state that the application of advanced technology is creating an increasingly greater dependence.
5. Image and transparency: aesthetic quality and visibility of solutions; The aspect of aesthetic quality was dealt with implicitly together with the environment-technical and spatial criteria. The aesthetic quality of the system cannot easily be evaluated. The acceptance of a variant depends on the (often) subjective image of the technical solution or system. This is also known as the readability (defined as the quality that influences the extent to which people understand the possibilities offered by a location or system). The familiarity with and the informal nature (including ease of use) of a technical unit and its image are of importance. Without information, public opinion will soon designate new technology as complicated, too much ado or

too futuristic, and people will be afraid of growing pains. Here, the "transculturality" is part of the image. When processes are made visible that are usually not familiar or not very well known, this offers a sensation of "safety", which increases people's knowledge of the consequences of their own actions, and which causes the user to adopt a more positive attitude towards them. Moreover, it may lead to a further informality, less dependence, a (perceived) greater safety, and, above all, more attractive housing conditions. The visibility causes the environment and object to obtain a specific identity, and increases the users' commitment through the possibility of attuning to their own different identities. Various reference projects show that if the solutions are made more visible, this leads to more social control and, consequently, to more commitment.

With respect to the first stated user related condition, comfort (probably the most important condition), in the field of psychology, the terms 'internal' and 'external coping' are of importance. Stress may arise when the direct surroundings insufficiently match the individual needs of man. With external coping man is able to adjust its environment, reducing chances for stress. In case of internal coping man has to neglect his own needs and wishes too much and adjusts his own behaviour, causing stress. This primary instinct is driven by a number of aspects:

- Change. Man in general has a need for changing circumstances. This means change in temperature or fresh air, but also stimuli like smell, contrast, sound and visual contact. In a surrounding where there are insufficient or no stimuli people tend to feel uncomfortable. To compensate for that feeling he might perceive certain complaints.
- Control. Man wants to continuously alter his environment and notice the effects of those changes. When the environment cannot be altered physical sensations can arise: internal coping. In many office environments especially it is very difficult to alter one's environment: closed windows, artificial lighting, air conditioning, and constant sound levels.
- Meaning. It is only natural to be able to give meaning to different senses. An indefinable smell for example (paint, synthetics) can lead to a constant feeling of uneasiness.
- Territory. From early days man has a need for his own territory, something hard to find for instance in open space offices.
- Adjustment. Man has difficulty adjusting itself. Only since a relatively short period of time do we spend most of our time indoors, in an artificial environment. We have lost contact with our natural environment, which explains the importance of a view (points of orientation).

In 1954 the psychologist Maslow identified 5 basic needs that are essential for personal wellbeing (Voordt 2003):

- o Physiological. Needs related to the wellbeing of the human body. In an office environment these can be described with the aspects mentioned above (internal and external coping).
- o Security. Besides physical security against extreme temperatures, sickness and accidents there is a psychological need for safety and security. Privacy is also a part of this.
- o Social. Man is a social being with a longing for contact with other people, comfort, affection, sympathy and friendship.
- o Ego. Besides sympathy people want respect and appreciation for their actions as an acknowledgment of their ego.
- o Self development. The will to develop potential talents, both physically and intellectually and spiritually.

In indoor comfort psychological adaptation plays a very important role, particularly in naturally ventilated buildings. Since the indoor climate changes along with the outdoor climate, people experience more contact with the outdoors and, consequently, expect higher indoor temperatures – and even prefer them. Furthermore, in practice, people in naturally ventilated buildings turn out to adjust their clothing and metabolism to the weather conditions more actively. Users of air-conditioned buildings with closed façades adapt themselves to a smaller extent. This makes them more sensitive to changes in temperature, which causes comfort temperatures in air-conditioned buildings to fall within a smaller bandwidth. The users are getting adapted to the mechanically controlled indoor climate because of their expectations. So buildings with operable windows and good opportunities for adjusting the indoor climate on a personal level are most favourable for user satisfaction.

According to Fanger, it is impossible to create an indoor climate that pleases every person in the building. Because of differences between people's personal preferences, there will always be at least 5% of the people who are dissatisfied with the current ambient climate. Theoretically, by giving each person control over his/her immediate environment, he/she could adjust it to such an extent that an optimally comfortable climate would be the result. Of course, if all people were able to do this, and they would all be accommodated in the same room or area, the result would still be a blend of everybody's own personal taste, resulting in an average climate leaving again at least 5% of the people dissatisfied. For this reason, the research within the Skins group focuses on solutions for façades for individual office spaces, in general decentralized solutions and involving a small number of users. This way, adjusting the façade and altering the local indoor climate will have the desired effect on the user without compromising the desired climate of one (or many) other user(s). Prerequisite is that users of the same office space will find some consensus on the desired climate.

Unfortunately, there is no easy formula to determine whether a person feels comfortable or not. Although ‘comfortable’ is considered difficult to define, the definition of ‘uncomfortable’ is considered easier to explain. Many different aspects play a role, including aspects that cannot be controlled or manipulated by the building itself, such as certain psychological aspects (e.g. an annoying neighbour).

Other important topics, especially in relation to façades are daylight and view. It is not only the amount of daylight, but also the way daylight enters the room and is falling on walls etc. Furthermore the quality of the view outside is important for user satisfaction and well being.

Still, there are a number of factors that are generally related to SBS symptoms. SBS seems to appear mostly in modern, air-conditioned buildings, with most complaints dealing with the respiratory tract and asthma-like related symptoms. One must be careful linking complaints to certain building characteristics, since other aspects may be playing a role as well. Dissatisfaction with the working atmosphere, one’s position within a company, problems with the organisation structure or private problems may be expressed through complaints about one’s health.

On the other hand, research has shown that many health complaints are related to building characteristics. Minor problems that are not building related can be triggered to become major obstacles through an uncomfortable working environment. Depending on the source consulted, the annualised cost for the construction of an (office) building is stated to be between 5 and 10% of the total annual cost for an enterprise over 20 years, while employee cost varies between 75 and 92% of total expenditure (Ree and Hartjes, 2003; Winch, 2005). Judging from the fact that many people are dissatisfied to some extend with their working environment/climate and that part of that dissatisfaction is building related, a better building performance is likely to reduce health complaints of the workers, increasing worker efficiency. Considering further that 75-90% of the expenditure of a company is spent on personnel using the building, extra attention to the façade in the design process would pay itself back.

Elaboration of climate ID building skins

Our planet is changing, bringing new challenges to the way we live. Climate change already has a large impact on urban areas throughout the world. The effect will increase in the future, even if we would manage to keep emissions on today's level. The most recent developments and their requirements with respect to hard to be defined, continuous transformation are at the centre. It has turned out that the ability to incorporate continuous change, preferably through "regenerative design", is necessary to tune the complex structures of society, the "flows" considered (energy, materials, air/ventilation, water and even nutrients) nature (and the natural processes) to each other. The influence of the process of the transformation that was inspired by changes in the environment, its use, the technology applied, the market and the specific systems and technical infrastructure seems relevant. The issue is how building skins, integrated systems, infrastructure and most of all 'building inside conditions' can be better prepared for the consequences of such changes. This could be addressed to by use of kinetic structures / building envelopes, or by treating the built environment more as a "living system". Although it will always be a controlled system. Living complex systems do not develop into one ideal final state.

An approach focused on design of processes is a good starting point: changes in the dynamic quality lead to techniques and systems, which may result in synergy effects. Present-day design principles particularly emphasize the "extrinsic values". By changing these to "intrinsic values", a better tuning to site-specific (ecological) conditions and regenerativeness may be achieved. Regenerative systems are coming into wider use. Often, the starting point is Lovelock's theory (1979) claiming that "Gaia" (the earth), as a single living organism, has some capacity of self-maintenance and self-repair, which should be the basis for all (living) systems. These principles are often used as target values for the systems based on natural components. Management is an important phase in these kind of regenerative systems: as they continue to evolve after taking their initial form, management is necessarily a creative activity as well and differs dramatically from the maintenance of industrial systems, the purpose of which is essentially to prevent change. In general this implies a need for decentralization of systems (as stated before with respect to 'comfort' as well). This coincides with the fact that almost all sustainable energy sources have a low energy density. This, together with their variable character, will contribute to the obvious choice (at first) for a decentralized implementation (Timmeren, 2008).

Regarding the energy aspect of sustainable buildings, the limits of demand reduction can probably be found at the junction of maximising the use of available local resources in the built environment and fitting it closely to user needs, complemented with conserving and controlling strategies like energy recycling, recovery and storage as close to users. The building skin and integrated decentralized systems will be essential for this second step.

In any case, the present-day competitive advantage of "sunk costs" for conventional solutions within this context should be avoided. Strategic niche management can be of help here. The strategic approach should focus on the higher dynamic efficiency of the decentralized systems: changed circumstances are easier to be anticipated with the help of decentralized systems. The general idea behind smaller systems is their relative simplicity and adaptability, and therefore their possibility to create extra (sustainable) capacities in situations where:

- In existing buildings where centralized systems have not been built yet, are outdated, or are difficult to integrate, due to lack of space;
- In existing buildings systems have reached the limits of their capacity and new building parts, or higher user- and/or comfort related flows (ventilation, warmth, cold, electricity, etc.) are desired (or use as a (temporary) back-up provision);
- Bioclimatic, geological or circumstantial characteristics make interventions (e.g., in existing building structures or for instance subsoil) difficult or expensive;
- There is a desire for enhanced environmental performance, e.g., through interconnections with use related control (possibly combined with other "infra" systems);
- There are existing or new niches, as occasions for new technology (e.g., chameleon façades, cleaning façades);
- There is convergence of systems and belonging infrastructures, for the support of flexible development and restructuring concepts (e.g., so-called 'dynamic offices');
- Ideologically oriented considerations, possibly as an educational principle.

Generally speaking, the two main problems in decentralized solutions are scepticism of the leading (often dominant) stake holders involved and the larger influence of individual behavioural changes (larger total capacities needed). The former is particularly caused by maintenance, responsibility (certainty) and liability.

This scepticism however might decrease because of the necessary transition of the market or markets from supply of products to supply of services. The second aspect with respect to the different 'flow' sizes (in fact, the basis for the technical "economies of scale") can be met locally by modern techniques of planning and tuning, the so-called “Real Time Control” (RTC), and possibly by subdivision into parallel facilities. Thus, the remaining main points of interest for improving the competitiveness of decentralized systems and actually achieving the advantages for the environment and the users are the organization and implementation of maintenance, exploitation, provision of services and inspection of the various systems, together with the availability of back-up provisions if necessary.

Research scope and subjects of the TUD Climate Design Skins group

One means of adaptation with respect to the building skin is increased use of urban vegetation. In present-day (compact) towns and cities, there is a growing need for green areas that make use of the specific qualities of their locations, typical for them and possibly protected, for recreational and especially ‘climate adaptive’ reasons (so called ‘climate robustness). There are also processes that cause the actual public nature of green areas to become more and more restricted. Competition for urban space will make increased urban park areas unlikely, but cities can be greener by utilizing streets, roof tops, and walls. Large scale city greening, by e.g. greening roof tops, increasing the number of street trees and using climbing plants on walls (fig. 1), can significantly cool the local climate by evapotranspiration. The urban heat island effect and heavy storms caused by large temperature differences between cities and their surroundings, are therefore reduced. Climbing plants can cool buildings during the green season through shading. Green roofs can cool buildings with poor insulation during the warm season due to evapotranspiration.

Urban vegetation will also reduce local flooding by its water uptake during the growing season. Using nature’s processes usually means using them on the site where they occur. Distribution routes are thus much shorter than those of most (conventional) industrial

Fig. 1 From left to right: ‘Maché des Halles, Luc LeBlanc, Avignon (France); Musée Du Quai Branly, Luc LeBlanc, Paris (France); Quantas Lounge, Sydney Int. Airport (Australia) and : ‘Living wall’, Tokyo (Japan).

processes, which usually require transport of both energy and materials. Mostly for this reason an essential step is an inventory of on-site resources and processes. But it might also mean that we need to include more ‘water based’ systems inside façades, in stead of trying to ventilate water (damp) as soon as possible. Including open water based flows and/or PCM inside façades will imply an entirely new approach of material use, methodology and structural layout of building skins.

Besides solutions that are based on a strategy of adaptation – handling impact(s)– , like the previous mentioned, an approach based on mitigation –tackling cause(s)– is even preferable. An example of the latter are energy generating façades, water treatment façades, or energy and/or CO2 storing façades. A good example of the energy generating façades is the ‘Redaktionsgebäude’ by Axel Schlueter in Albstadt (Germany) in which sun-shading photovoltaic louvre-like elements are integrated in the façade (fig. 2). The charge state of

Fig. 2 The ‘Senior Citizens Apartment’ building by Dietrich Schwarz (top right: uncharged, and top middle charged state).

this latent heat storing glass façade can be observed directly from its optical appearance, which is determined by the different phases of the salt hydrate. An interesting example of the energy storing façades is the ‘Senior Citizens Apartment’ building by Dietrich Schwarz in Ebnat-Kappen (Switzerland), which uses prisms to reflect sunlight and PCM material to store energy.

The façade of the planned 'EVA Centre' by Atelier 2T in Culemborg (the Netherlands) is an example of the introduction of CO2 storage and water treatment inside a double layered façade (fig. 3). Here a sealed double skin façade contains the waste water treatment of the EVA Centre and the heat recovery installations with seasonal storage in aquifer. Three of the installations within this system component (the façade, the solar-cavity spaces with hanging gardens and the agricultural glasshouses on top of the building) are fully integrated in the design of the EVA Centre. Besides of this façade, a so-called "Sustainable Implant" contains installations for anaerobic treatment of organic waste and waste water of the residential district in which the building is situated. The double skin façade in this project in fact can better be defined as a 'Vertical glasshouse' (Timmeren, 2007).

Cleaning façades are another innovation of the last decade. Mostly they address to the PM10 (and other related matter) problems sticking to façades at heights that are difficult to reach and thus costly to clean. There are two main applications: elements that keep themselves clean and elements that filter the air. Best known product here is self-cleaning glass, but also similar other self-cleaning materials exist. Relevant examples for this are the 'SmartWrap' building by AN_Architects in Vienna (Austria), which

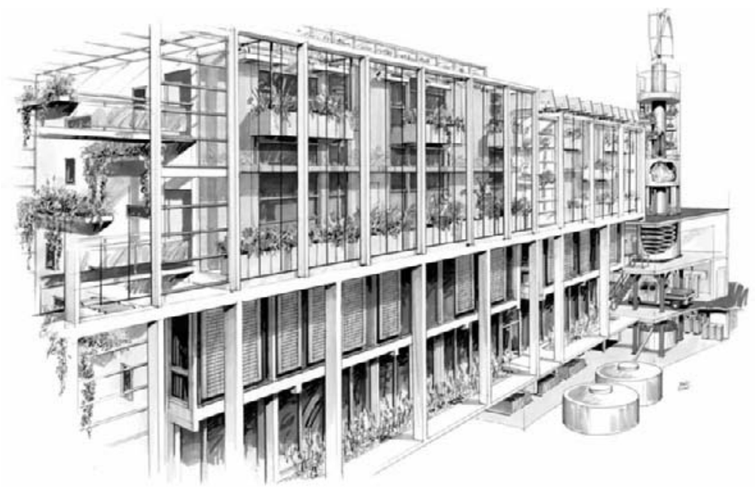


Fig. 3 Impression of the sealed double skin façade of the hotel part within the EVA centre along with "Sustainable Implant" (SI).

concerns a photocatalytic self-cleaning ceramic façade, and the 'Garden Chapel' by the Obayashi Corporation in Osaka (Japan), a self-cleaning membrane skin. As to elements that filter the air, e.g. the "Naturaire system" by 'Air Quality Solutions' is exemplary. It consists of a hybridization of two technologies that are quickly gaining in usage as means of remediating contaminated soils, water and air in outdoor, industrial setting. These technologies are biofiltration, the use of biological systems of beneficial microbes to break organic pollutants down their benign constituents and phytoremediation, the use of green plants to facilitate the remediation or reclamation of contaminated soils or water.

At the same time façades more and more often are used as well for a combination of environmental technology and combined 'image-building' or even advertisements responding to certain influences. Examples are the 'Chanel Headquarters' by Peter Marino Associates in Tokyo (Japan), in which LED advertising and electrooptic glass has been used, the 'SmartWrap' by Kieran Timberlake Associates in New York (USA), which incorporates mechanically driven diaphragms with photo electric cells to adjust to the intensity of sunlight, and the 'Aegis Hyposurface' by dECOi Architects for a changing exhibition, which consists of mechanically driven triangles that react to sound, light and movement. Other examples in this field, though from the point of view of Climate Integrated Design less interesting are the 'chameleon like façades' of Michael Bleyenberg's 'DFG Building' in Bonn (Germany), which concerns a holographic façade, and the still not realized hotel 'Habitat H&R' by Cloud 9 in Barcelona (Spain) with colour and light changes dependent on daylight and software.

In the following section, some of the innovative research projects within the 'Skins' program will be discussed:

The 'breathing window'

A climate adaptive skin acknowledges the advantages of naturally ventilated buildings, but also takes the benefits of mechanical ventilation into account. It is intended to be able to provide a comfortable indoor climate to the user, while using as little primary energy as possible. Building services are integrated into the façade itself at office-room scale, making the office adjacent to the façade independent of centralised HVAC systems and the indoor environment optimally adjustable by the user.

The recent development of a fine-wire heat exchanger created new, possibilities to heat buildings with extremely low water temperatures. The improbably small temperature difference of 3˚C is already applicable. Until recently, waste water of 24 to 25˚C could only be used for heating up buildings by means of a heat pump. Now we cool greenhouses with water of 16 to 17˚C using the same fine-wire heat exchanger. This new technology is applied on a large scale – to transform Dutch greenhouse horticulture from using natural gas to solar energy with seasonal heat storage in the aquifer or wet sand. The translation of engineering into private houses is not yet finished, though in concept and laboratory based research well developed. It comes down to a combination of (extra) low temperature floor/wall radiation heat with additional fast decentralized air heating and air cooling seems to be the most logical option. Another application of fine-wire technology, which is of more interest to the building skin is a decentralized, balanced room ventilation with 80–90% heat recovery. The breathing window concept tries to find the right answer tot the question of desired customized ventilation (fig. 4).

It is based on a twinned air/air heat exchanger which at the same time reacts on the humidity and measures CO2 -concentration of the inside air (and indirectly is also a very accurate smoke detector) and breathes only when needed. The air/air heat exchanger measures 16 x 200 x 440 mm. Each heat exchanger consists of a warp of 15 km of 1/10 mm diameter copper wire weighing 500 gr. The weft is glued nylon thread with a centre-to-centre distance of 12,5 mm. Its small size makes it easy to take the heat exchanger out of its housing in order to clean it under a shower or in a dishwasher. The stacked

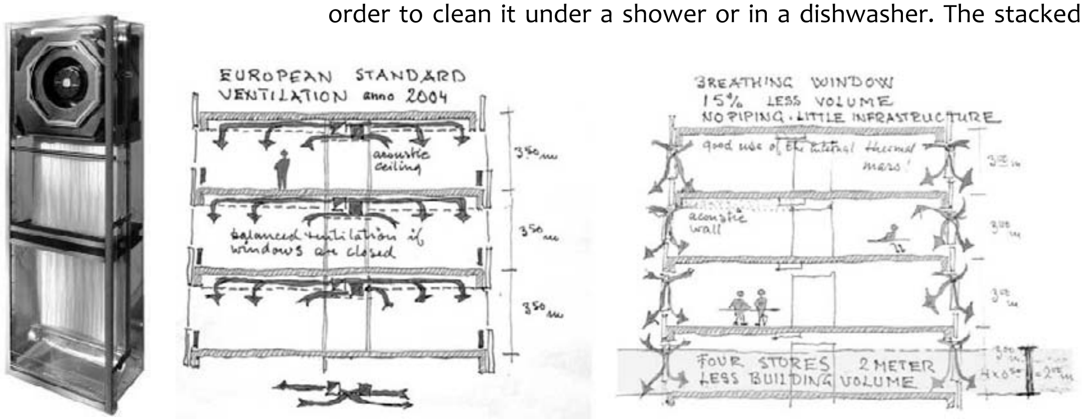


Fig. 4 From left to right the mock up (in tranparent box to give insight) as it has been tested in Iceland and the Netherlands, and the comparison between European standard ventilation of offices in section (middle) and the same section with integrated breathing windows.

wefts must be mutually airtight, forming 13 small air channels of 2x220mm, each having a width of 16 mm. Due to two counter-current flows evenly distributed by conical air ducts the channels are alternately hot and cold. The fine-wire warp ensures that the heat exchange is at right angles to the air current. At the same time a coincidental, unforeseen advantage compared to the usual plate heat exchangers is that the fine-wire heat exchanger hardly gets frosted up. A fine-wire heat exchanger is about 8x more efficient than a plate heat exchanger. Thus this compact heat exchanger has the smallest possible size, which results in excellent integration possibilities, even in existing façades. Although the breathing window is still in statu nascendi, it is expected that for office buildings gains at equal installation costs approximately will be 35% energy saving, 15% less built volume and 10% less building costs (cf fig. 4). [for information: contact prof.ir. J. Kristinsson and dr.ir. A. van Timmeren]

Adaptable Insulation

The insulation of opaque building envelopes has significantly increased in the last decades, mainly with the aim to lower the energy need for heating and cooling. Although appropriate in most situations, a thermal separation between the in- and outside environment on the other hand impedes possible beneficial energy flows pertaining to e.g. passive solar gain in winter and passive cooling in summer. Therefore, the energy performance of an envelope could be further optimised by adapting its insulation value depending on circumstances (Spoel et al., 2008). Adaptable insulation (AI) may be technically realized using a gas-filled panel (GFP), which is a air-tight inflatable plastic bag. When evacuated, its small thickness results in almost no thermal resistance. When air-inflated, its thermal conductance equals that of traditional insulation material (fig. 5). However, inflatable prototypes have not been fabricated yet.

Fig. 5 Impression of a building façade with adaptable insulation.

The possible advantages of AI with respect to energy saving and improvement of indoor thermal comfort have been examined based on theoretical considerations and dynamic numerical simulations. These calculations showed that for a Dutch climate, AI can be well utilised for passive cooling if it is situated in the roof and/or façade of a building. The positive effect on passive solar heating appeared marginal. AI in the ground floor appeared less effective for passive cooling as it can not utilize the deeper soil as a heat sink. The attention has therefore been limited to the cooling performance of adaptable insulation in the roof and/or façade.

To obtain a good AI performance, a thermally heavy layer should be present in the construction, situated between the adaptable insulation and inside. During daytime, excess heat in the room is stored in this layer while during night time, the stored heat is discharged to the outside via the adaptable insulation in its conducting state. For optimal functioning, thermal resistances in the construction should be as low as possible.

In terms of the ratio ψ, AI can most effectively improve the summer indoor thermal comfort at a low ventilation rate. At a high ventilation rate, the contribution of AI decreases. For a typical Dutch office room with a ventilation rate of 1.3 $dm^3 s^{-1} m^{-2}$ (and conditional ventilation during the night), adaptable insulation in the roof is able to reduce the number of TO-hours by a factor 7.

As for equivalent cooling capacity, in terms of indoor thermal comfort, for a standard office room AI performs similar to an active system with a maximum capacity of 8 to 10 Wm^2. If the active system is only operational during daytime, the corresponding capacity is 20 to 25 Wm^2. The latter is in the range of the capacity of radiant floor cooling, and about one third of an active cooling ceiling.

As for passive cooling energy applications a possible alternative for AI is extra night-time ventilation. It was however found that the contribution of AI to the total amount of free cooling seems quite independent of the degree of extra night-time ventilation, provided that the material layer between AI and inside has a large thermal capacity. So both effects are more or less additive in terms of free cooling energy.

Based on the findings in this study, it is concluded that adaptable insulation in the façade or roof provides a good potential for cooling energy savings and summer indoor comfort improvement. The application is not limited to offices and dwellings. For a Dutch climate, adaptable insulation will be appropriate in situations with performance requirements for the indoor temperature in the range between ca. 5°C and 25°C. [for information: contact: dr.ir. W.S. van der Spoel]

Vacuum insulation panels (VIP)

Thick façade and wall constructions as result to applied thermal insulation thickness result in an unfavourable net-to-gross floor space area and height, conducting to less usable space or a larger required building area, in most cases leading to higher building costs per floor area or building volume. It may result in an increased complexity of building constructional junctions within and between building components and parts, leading to increased risk of design errors. At the same time thick façade and wall constructions impede the possibility for architects and designers to create slender façades, at least under the actual (and future) legal requirements.

As for the environmental impact, thick façade and wall constructions conduct to an increase in material use and result in heavier load transmitting cantilevers to connect the outermost façade layer to the load bearing system.

Besides of that, thick façade and wall constructions reduce the amount of daylight penetrating this façade since the projected area onto the part of the atmosphere with high illuminance reduces. A strategy for reducing energy losses through the building enclosure is the application of more effective thermal insulators, leading to less building skin thickness. The phenomenological material property that represents the effectiveness of a thermal insulator is its thermal conductivity. The lower the thermal conductivity, the less heat is flowing through the material per unit thickness and per unit temperature difference, thus the better its thermal effectiveness. Fig. 6 presents the thermal conductivity of several conventional and non-conventional thermal insulators.

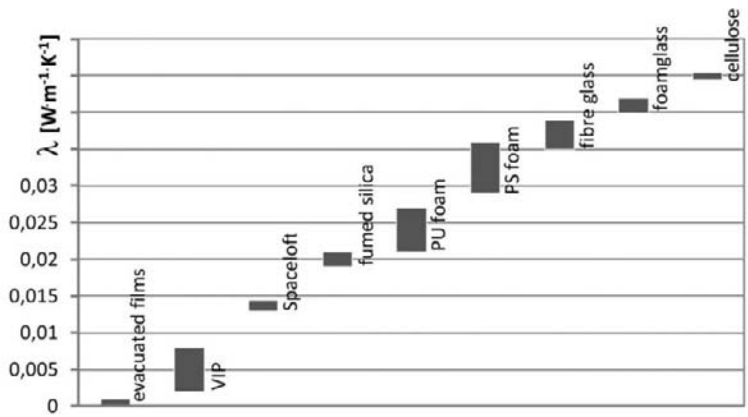


Fig. 6 Comparison of the thermal conductivity of vacuum insulation panels to other thermal insulators. Divided by the thickness of the material, it provides a measure for the thermal performance of the insulation layer.

As can be seen, evacuated multi layered foil insulation, which consist of a multitude of highly reflecting metal foils or metallized films and thin fibrous separating layers put together in a thin evacuated cavity, have the lowest thermal conductivity at the moment technically achievable. But although their thermal conductivity can then be very low, the high vacuum needed for obtaining this high performance is not practical and feasible for application in buildings.

The second best thermal insulators are so-called vacuum insulation panels, or VIPs. They consist of a meso-porous core material, after evacuation tightly sealed into a thin film/foil high barrier envelope, conceptually similar to a typical evacuated pack of coffee (fig. 7).

Since vacuum insulation panels (VIPs) combine high thermal performance with limited material thickness due to their very low initial thermal conductivity, which is about a factor 5 to 10 lower than that of mineral fibre insulation. However, integration of VIPs into the building enclose must be performed very meticulously for several reasons; first, a VIP is to be regarded as a system or component by itself as a consequence of which it cannot be processed on site and thus needs careful planning in advance; second, the product is

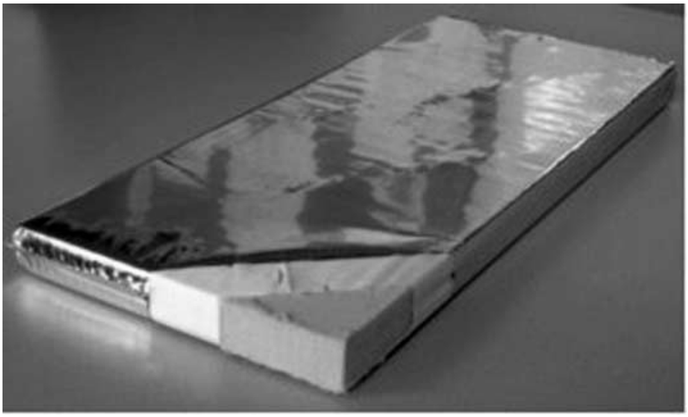


Fig. 7 Example of a film based vacuum insulation pane, consisting of a fumed silica core which tightly sealed into a high barier envelope of a three-layer metallized polymer film after evacuation.

very sensitive to mechanical damage thus requiring careful handling during production, transportation, storage and installation; third, careful design is required due to thermal bridges along the edges of the panel; fourth, a decrease of the thermal performance of VIPs over time needs to be considered, especially for applications with long lifetimes.

The design of this doctoral study follows a sequence from more fundamental to applied research. The results obtained through the fundamental research are applied and validated using several cases.

In the first case study an opaque façade system using vacuum insulation panels as thermal insulator was designed. When designing building panels, several types can be distinguished. A first criterion of distinction is the number of layers: two or three main layers. Since VIPs are very prone to damage during the production and installation process, a protective coverage could reduce this risk of damage thus decreasing the amount of panels that fail. Therefore building components having a protective layer on either side of the VIP are preferred. This type of component can furthermore be subdivided based upon their structural action: edge spacer constructions and sandwich constructions. The difference between both types is that a sandwich component is able to exhibit sandwich behaviour since both face sheets are structurally adhered to the VIP core while an edge spacer component is not. A sandwich panel does therefore not require a structural profile along the panel's edge thus reducing thermal shunting significantly.

The first VIP-integrated building panel thus conceived was a sandwich panel consisting of a core of 4 cm VIP and two 1 mm thick stainless steel face sheets, as presented in fig. 8. This panel has a centre-of-panel thermal transmittance, Ucop, of 0.10 $Wm^{-2}K$. Due to thermal bridge effects however this centre-of-panel value does not represent the overall thermal behaviour of the entire façade system. The overall thermal transmittance, Ueq, is determined numerically and found to be about 0.18 $Wm^{-2}K$ (panel size 0.9 x 0.9 m^2) which is almost below the requirement for a passive house. However, experiments have shown that it is very difficult to obtain a strong and stiff bond between the VIP barrier envelope and the face sheets resulting in too large deflections.

Improvement of this bond by UV/ozone treatment of the barrier film is still under investigation. Moreover, a completely glued panel is no longer demountable and therefore difficult to recycle. A different type of façade component has therefore been developed too. This second façade component, dubbed high performance 'Cradle to Cradle' façade component, attempts to resolve the aforementioned issues of adhering and recycling. It consists of a 4 cm thick VIP core, which is enveloped by two polymer encasings.

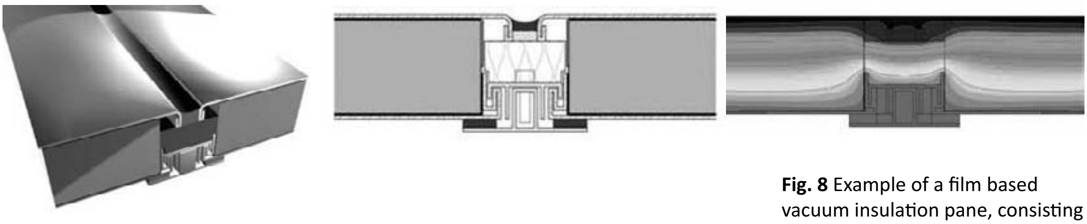


Fig. 8 Example of a film based vacuum insulation pane, consisting of a fumed silica core which tightly sealed into a high barier envelope of a three-layer metallized polymer film after evacuation.

This system of VIP and encasing then is encapsulated in a thin pre-stressed membrane that takes up part of the loads on the panel. It is however important to realise that the stiffness of entire panel depends on the stiffness and pre-stress of the membrane. Due to lack of sandwich action the stiffness can never be as high as that of true sandwich panels. Numerous simulations have shown that the overall thermal transmittance of these panels, including connector system, equals approximately 0.24 $Wm^{-2}K$ for a panel size of 0.9 x 0.9 m^2 (fig. 9). This is however still far above passive house standard. An improved version of this panel has also been developed but needs to be thermally simulated still. It is expected that this improved version will approach this requirement of 0.15 $Wm^{-2}K$. [for information: contact: ir. M.J.M. Tenpierik]

The Climate Adaptive Skin

Fig. 9 Example of a film based vacuum insulation pane, consisting of a fumed silica core which tightly sealed into a high barier envelope of a three-layer metallized polymer film after evacuation.

This doctoral study concerns a new façade concept that takes a different approach to both climate control and user comfort perception. Adaptive temperature limits (Linden et al., 2006) are taken as guidelines to create a façade that changes with the outdoor climate, optimally utilising outdoor influences as an aid to create a comfortable indoor climate while minimising the amount of primary energy to condition the indoor environment.

The basic concept behind the façade is that it is able to create a comfortable indoor climate using both the indoor and outdoor climate. This means that characteristics of the indoor office space, i.e. presence of internal heat sources, a need for fresh air and daylight, and room temperature between certain boundaries, are used and combined with outdoor (temperature and solar) influences to create a comfortable indoor climate, with the goal to minimise (primary) energy consumption. Besides the energetic desires for the façade, there are additional conditions formulated, such as a limited façade width and a simple, 'robust' façade design to minimise maintenance and reduce the likelihood of malfunction.

The desire to create a 'simple' façade that can function, i.e. create a comfortable indoor climate while requiring little maintenance, has its implications. A façade independent of warm/cold air/water needs no pipes or ducts for climate control. No ducts or pipes means that installation of the façade is much easier, quicker, and that there is no need for a lowered ceiling or duct along the façade to accommodate the space these services require. By choosing technologies that are relatively low-tech, the chance of malfunction is reduced because fewer moving parts or electronics means less maintenance.

There are three components that play an important role in the provision of fresh air (fig. 10): an air to air heat exchanger (1), two tangential fans (3) and a stack of PCM (Phase Change Material) plates with a phase change temperature range of 17-19°C (2). Fresh air is drawn directly from outside, preheated by the heat exchanger and then forced through the PCM plates before being distributed into the indoor environment. Stale air is drawn from the indoor environment at the top end of the ventilation unit, forced through the heat exchanger where thermal energy is exchanged with the incoming outdoor air, before being discharged through the cavity to the outside.

The part of the façade above the ventilation units is almost fully transparent. To prevent potential overheating in summer, thermotropic glass is used. Users are given the option to manually open the window for additional ventilation and for the psychological

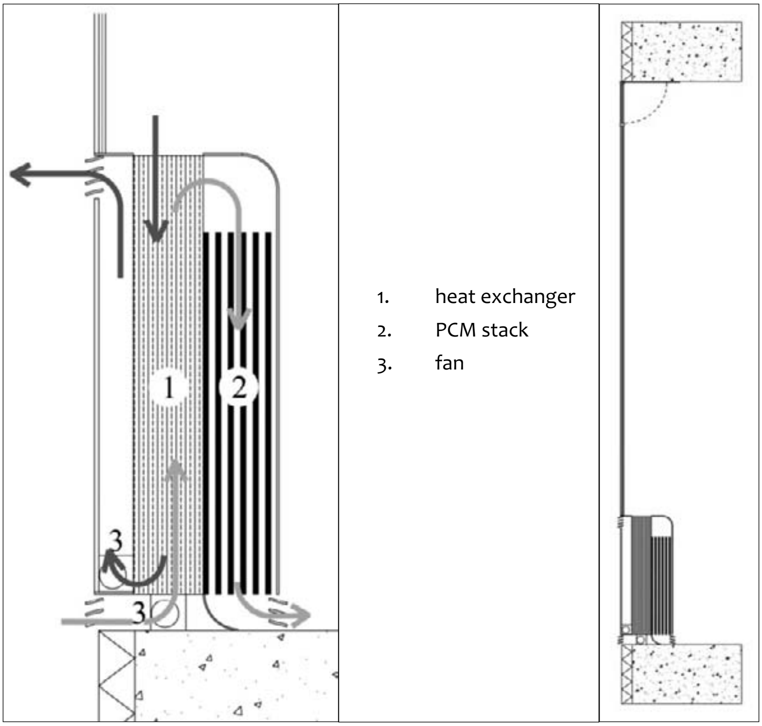


Fig. 10 Schematic vertical cross-section of the Climate Adaptive Skin concept.

advantage of being able to control their immediate environment.

The façade is initially aimed at office use. This means that during normal use, daytime hours are considered to be from 7 am to 7 pm. The performance of the façade is adjusted to these working hours, meaning that for example the capacity of the PCM is aimed at daytime use, to be regenerated during the night. Night ventilation, or night flushing, is used to shed unwanted thermal energy accumulated in the PCM during the day by forcing cool outdoor air along the PCM during the night. Since there is a chance that the temperature difference between phase change and the outdoor temperature is lower during the night than during day, the ventilation rate is doubled during the night to increase heat exchange.

In the Netherlands, especially in winter, there will be need for additional heating of the PCM to enable it to stay in phase change stage and utilise its latent heat storage to condition incoming ventilation air. The heating of the PCM plates happens through electric heating foil or strips that heat up through an electric current.

Simulations suggest that it should be possible to ventilate an office space and create comfortable indoor temperatures throughout the year using passive technologies without consuming any primary energy. Although it will be necessary to provide electricity to power the fans that force the ventilation and, very occasionally, to heat the PCM, if a photovoltaic panel would be fitted in combination with a battery, the façade could theoretically be able to function autonomously throughout the year. [for information: contact: ir. B.L.H. Hasselaar]

Climate responsive building design

The concept of climate-responsive design is a successive step of bioclimatic design, which is about using specific features of local climate and environment smartly, and integrates design solutions into the architectural concept. The main goal of this doctoral study is to validate the potential of climate-responsive design principles in building design of dwellings by introducing knowledge and skills to the design process in such a way that it assists architects/designers in their design practice.

One of the features of adaptive buildings is the application of climate-responsive building elements. Such elements are building elements that 'actively' harvest or harness natural energy resources (e.g. sunlight, sun's radiance, water pools, precipitation, natural air flows and geothermal energy) in order to provide (initial) comfort to the building. Furthermore the building elements are extensively integrated into the architectural and / or structural concept.

With climate-responsive design the building becomes an intermediary between supply and demand of energy in the built environment. The concept can be seen as a synthesis between comfort and energy-efficiency in building design and must be seen as (part of) an integrated design solution towards more sustainable, comfortable and healthy buildings. The essence of the 'operating principle' of a climate-responsive building element can be given by four main characteristics. It starts with the presence of some natural energy resource in the building environment that the building encounters. Then the building (or a building part) that is exposed to these natural energy flows can interact with this energy source and treat it according to the building energy demand. Finally the energy is directly provided to the building and its occupants as a building service.

A non-exhaustive overview of climate-responsive building elements are collected in a table (fig. 11), sorted to their main bioclimatic principle (e.g. thermal mass) and marked according to the four characteristics (energy source, building element, energy treatment and service delivery). A large part of the CR building elements relate directly to, or form part of the building façade.

Catalogue of climate-responsive building components

	Characteristics																					
	Natural energy source					Energy flow treatment						Building element integration							Building service delivery			
	Earth	Sun	Wind	Waste	Water	Exchange	Prevent	Promote	Redirect	Long-term storage	Short-term storage	Façade / External wall	Foundation	Internal floor	Internal wall	Roof	Space	Window / Opening	Cooling	Daylighting	Heating	Ventilation
Daylight systems																						
Advanced passive glazing		✓					✓											✓		✓		
Light shelves		✓					✓		✓									✓		✓		
Skylights		✓						✓								✓				✓		
Insulation systems																						
Dynamic insulation			✓	✓		✓						✓				✓					✓	✓
Translucent insulation		✓					✓	✓				✓				✓				✓	✓	
Thermal shutters				✓			✓											✓			✓	
Geothermal systems																						
Direct earth coupling	✓					✓							✓						✓			
Earth-to-air heat exchanger	✓		✓			✓							✓						✓		✓	✓
Energy piles	✓					✓				✓			✓						✓		✓	
Roof systems																						
Green roof		✓			✓		✓				✓					✓			✓		✓	
Roof pond		✓	✓		✓			✓								✓			✓			
Spaces																						
Atrium		✓						✓			✓						✓			✓	✓	
Solar space		✓						✓									✓				✓	
Thermal storage systems																						
Thermo-activation				✓							✓		✓	✓					✓		✓	
Phase change materals		✓		✓							✓	✓			✓	✓			✓		✓	
Passive thermal mass		✓		✓							✓	✓	✓	✓	✓				✓		✓	
Trombe wall		✓		✓							✓	✓									✓	✓
Ventilation systems																						
Hollow core				✓							✓			✓					✓		✓	✓
Solar chimney		✓						✓				✓									✓	✓

Fig. 11 Overview of climate responsive building components and their characteristics.

The largest potential of climate-responsive design is in their combined integration into a single adaptive building concept. The combination of multiple techniques can strengthen each other, but can also weaken the concept as a whole. Therefore more insight into the combined performance of design are needed (see fig. 12).

Different climate-responsive concepts integrated in the design of dwellings are assessed on both energy and comfort performance. An integral assessment of outcomes is assured while all concepts are implemented into a reference building model or base case for which values were calculated with aid of TRNSYS, a dynamic simulation tool. [for information: contact: ir. R.H.J. Looman]

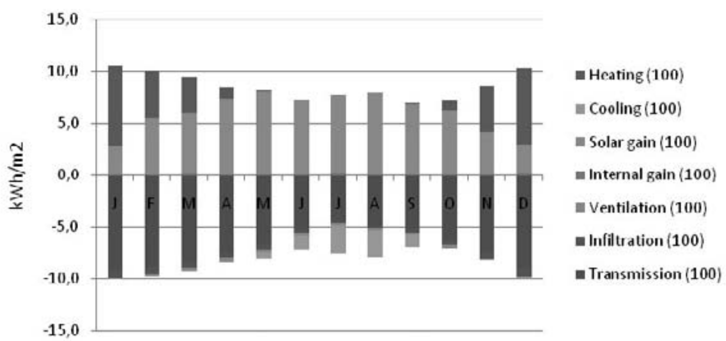


Fig. 12 Thermal energy balance of the reference building model; a typical building regulations home in the Netherlands.

References

Dorst, M. van: Een duurzaam leefbare woonomgeving. Fysieke voorwaarden voor privacyregulering, Doctoral research, Delft University of Technology (TUD), Faculty of Architecture, Eburon, Delft (2005).

Hoek, L. van der: Handboek ruimtelijke aanpak van sociale veiligheid en criminaliteitspreventie in de gemeentelijke praktijk, Uitgeverij Toth, Bussum (1994).

Kennedy, M. & Kennedy, D.: Designing ecological settlements, European Açademy of the Urban Environment, Dietrich Reimer Verlag, Berlin (1997).

Kristinsson, J., Timmeren, A. van: Fine wire Heat Exchanger for heating and cooling Passive Houses, Proceedings International Conference 'Passiv Haus', Nürenberg, Gemany (2008).

Linden, A.C. van den, Boerstra, A.C., Raue, A.K., Kurvers, S.R., De Dear, R.J.: Adaptive temperature limits: A new guideline in The Netherlands a new approach for the assessment of building performance with respect to thermal indoor climate. Energy and Buildings, vol. 38, (2006) 8-17.

Lovelock, J.: A new look at life on Earth (1979), in Dutch translation (1980): Gaia, de natuur als organisme, Bruna, Utrecht.

McDonnough, W., Braungart, M.: Cradle to cradle. Remaking the way we make things, North Point Press, New York (2002).

Ree, H.J.van, Hartjes, A. Huisvesting in dienst van de medewerker, BOSS Magazine: 4-7 (2003).

Spoel, W.H. van der, Phillippa, R.A., Swieten, P.M.J. van: Passive cooling using adaptable insulation, SenterNovem research BSE-2005 NEO 0268-05-04-02-012 (2008).

Suddle, S.I. & Waarts, P.H.: The risk of safety –an integration of psychological and mathematical approaches, Risk Decision and Policy, October (2003).

Timmeren, A. van: Sustainable decentralized energy generation & sanitation: Case EVA Lanxmeer, Culemborg (the Netherlands), Journal of Green Building, Vol.2 nr. 4. (2007).

Timmeren, A. van: Reciprocity of Autonomy & Heteronomy. Decentralization vs. Centralization of essential services in the built environment. Research in Urbanism Series, IOS Press, Amsterdam (2008).

Voordt, D.J.M. van der & Wegen, H.B.R. van: Sociaal Veilig Ontwerpen. Checklist ten Behoeve van het Ontwikkelen en Toetsen van (Plannen voor) de Gebouwde Omgeving, Publikatieburo Bouwkunde, Technische Universiteit Delft (TUD), Faculteit Bouwkunde, (1990).

Winblad, U. (ed.): Ecological Sanitation, Sida, Novum Grafiska AB, Stockholm, Sweden (1998).

Winch, G.M.: Why should we revalue construction, Revaluing construction 2005: the challenge of change in construction, Rotterdam (2005).

Ing. Bert Lieverse is general secretary of the FAECF (Federation of European Window and Curtain Walling Manufacturers Association). The impact of Climate oriented architecture on the façade industry is immanent. Climate orientation does not only mean geometrical adjustment of functions or increasing the insulation value, but the integration of new technologies in the physical façade space. This is challenging the traditional building teams. The "Living façade" is a model to describe the impact and the chances of climate oriented architecture on the façade industry.

The Future Envelope 2 – Architecture-Climate-Skin. U. Knaack and T. Klein (Eds.). IOS Press, 2009.

'THE LIVING FAÇADE'®

Bert Lieverse

General Secretary FAECF

1. Introduction

The façade sector is one big consortium that consists of many firms with the most different disciplines. Cooperation between varied companies accelerates the possibilities for new and dynamic innovations. The VMRG in the Netherlands and FAECF in Europe have the role to bring those companies together, to stimulate them and to create networks of experts and companies. Besides that, both VMRG as well as FAECF formulate a integral vision about the development of the façade sector. This vision is available for all companies to use it for their individual development.

Fig. 1 The hands of outdoor nature and indoor nature together.

2. Outside

Our world knows no boundaries. On the contrary, we are part of living nature; we live in a natural environment. Nature not only refers to natural beauty or climate, but is also our driving force. We are entirely dependent on nature, inseparably connected. Our food is natural. Nature is our oxygen.

We also know that nature is, originally, a balanced system, consisting of, connected to and related to multiple other systems. The distinguishing characteristic of a system is coherence! Thus, movements or changes in one system lead to changes in other systems.

The beauty of nature is this interdependence, this coherence and the corrective capability that focuses on the restoration of balance in the event of disturbances. During disturbances, balance-based systems focus on either returning to their original state or assuming another equilibrium.

3. Disturbances, changes

No-one can currently deny that originally balanced natural systems are being disturbed as a result of the behaviour of one of nature's elements - humanity.

In their uncontrolled need to develop, the human race is perpetrating an unremitting attack on nature, leaving countless natural systems blocked or out of balance. As a result, we are confronted with counter-corrective actions carried out by nature such as climate change, while some people feel that we, too, need to take action concerning our own behavioural patterns. Examples are the implementation of traffic speed limits as well as other measures to conserve energy.

One important characteristic of this cause and effect concerning nature or the natural environment is the absolute necessity for correction. This leads to drastic changes. And as indicated, these corrections to human behaviour must begin with human systems or with human behaviour itself. After all, the balance of natural systems has been disrupted.

Nature, however, cannot recover without changes to human behaviour. Humanity – itself an element of nature – has a duty to repair the damage done to its environment as a result of its continual attack on nature.

4. Market

This need to interact differently with nature and natural systems has also prompted a market demand. This market experiences impulses from such themes as energy control, energy conservation, energy generation from renewable sources, energy storage, etc.

In short, this concerns energy systems and that is something that is pre-eminently related to buildings and façades, which, therefore, can provide solutions for problems relating to society or nature. Technically speaking, we are talking about photovoltaic elements, light regulation, awnings, smart cooling systems, etc.

The conclusion is that new, necessary and urgent markets demand supply and suppliers.

This will result in assignments of the most diverse nature for the façade industry, which will create a future role for the industry as one that is capable of creating solutions for the urgent questions regarding our climate. This, then, is a market in which the façade industry contributes to what is known as outside comfort. And this outside comfort is what constitutes the theatre of outdoor life.

5. Inside

Throughout human evolution, life has shifted from outdoors to indoors. A large proportion of our current way of life is played out indoors, with the human workplace having undergone the most radical transformation. Our buildings can, in fact, be seen as areas separated from nature; a phenomenon we could call the 'indoor environment', which also creates conditions for our lives.

The better we care for and regulate the indoor environment, the better our lives there will be. The indoor climate demands strong personal manageability and users want to be able to regulate it themselves. Energy plays a key role not only in terms of regulation but also in terms of creating an indoor climate, which involves heating, cooling, ventilation, lighting, etc.

This also creates a new market. Not one concerned with window/door frames or ventilation grids or air-conditioning systems, but a market for an optimum indoor environment and comfort. Focusing on the means (window/door frames, etc.) is simple but insufficient and this is why it is important to heed the final goal, the desired result.

The aim of every market is to add value to the building, and our market demands value in terms of indoor climate and comfort. This market is just as urgent and just as necessary as the market for outdoor comfort, where the preconditions for living also need to be met. However, life itself makes ever increasing demands for more nature and more comfort.

Another motive in this market concerns the possibilities that technology can offer us, providing a market for the façade industry that will deliver a better indoor comfort value. This value – like that of outdoor comfort – depends on various systems, which are also interdependent. No system is dominant enough that all the others are subordinate to it. The indoor comfort market is therefore a market that functions when multidisciplinary solutions are offered in which different systems co-exist, including electronics, façade technology, ventilation technology, entrance technology, etc.).

6. Together

Our industry, therefore, has two key markets:

1. The market for indoor comfort (a condition for living inside)
2. The market for outdoor comfort (a condition for living outside)

The product consists of systems that contribute to the life-giving systems indoors and outdoors.

The product is a reactive system that reacts to changes and influences comfort levels indoors as well as outdoors. This product is therefore capable of realising exchanges between the indoors and the outdoors and must provide the answers and solutions to problems relating to climate and comfort. A precondition for use of the product in the transitional area between the indoors and the outdoors is that it suits our lifestyle.

The system, therefore, is called:

'The Living Façade'®

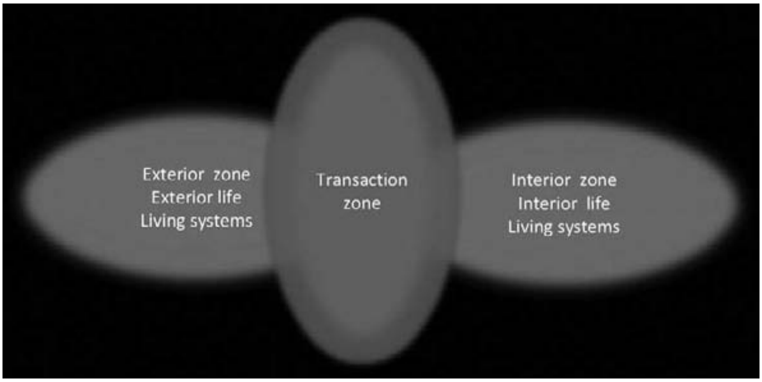


Fig. 2 Interaction of three zones

7. Characteristic of 'The Living Façade'®

a. The **'Living Façade'®** is a system that is linked to all relevant environmental systems, both indoors and outdoors. Both environments aim to optimise comfort, which will have substantial positive effects on life in and with both environments. Effects such as energy generation, especially from renewable (clean) sources, as well as expressive and aesthetic experience go hand in hand with effects such as comfort, adjustability and an ideal working environment with high levels of productivity.

b. The **'Living Façade'®** is also a zone, an area with numerous facilities rather than a rigid and protective shell. Interaction with other systems employed by users, managers and external observers is a fundamental characteristic of the **'Living Façade'**®.

c. Another characteristic aspect of the **'Living Façade'**® is the transitional assignment that the façade has, in which it combats and regulates all kinds of undesired or extreme effects that indoor environments have on outdoor ones and vice versa. The façade has a subduing character that functions as a spring system moving in tune with changes to conditions indoors and outdoors. The façade has the capacity to be adaptive and to regulate the balance.

d. The balance is adjusted by the **'Living Façade'**® based on situations inside or outside (managers or automatic systems).

e. The **'Living Façade'**® is a living, intelligent system that can also be adjusted itself to changing possibilities in technology or changing demands. The **'Living Façade'**® system is sustainable due to the fact that the specifications, developments and engineering focus on this desire to be adjustable. Designers can also use these capabilities – which are initially driven by functionality or technology – to alter appearance and material use.

f. The **'Living Façade'**® will create numerous links to other functional building systems, and the expectation is that there will be integration with climate installations, security systems, logistic systems, domotics, etc.

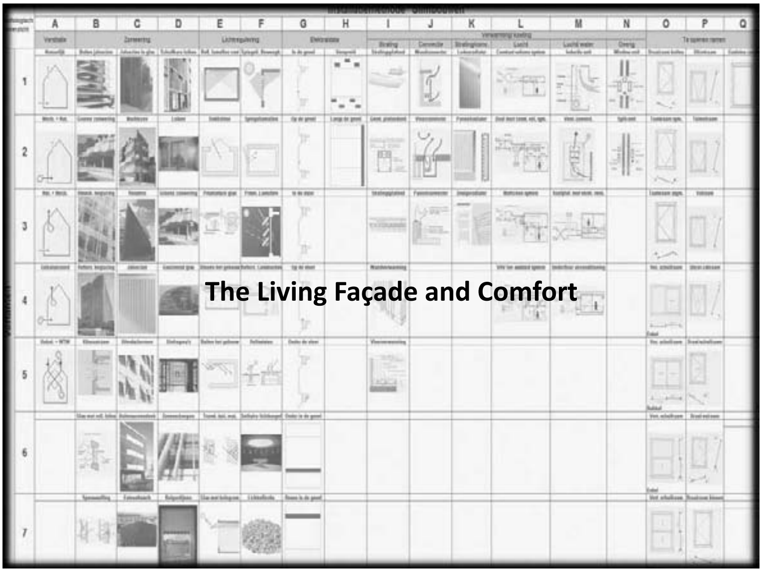


Fig. 3 The basic morphology of comfort and façades

For a more detailed overview of functionality, please refer to the research publications, including a publication by Harm van Dartel from the Knowledge Centre for Façade Manufacturing (KCG, www.kenniscentrumgevelbouw.nl).

The research publication Façades and Installations describes a design method for designing integral façade systems in which installations are given a fixed place in façade technology. The report on comfort introduces a multi-dimensional model concerning comfort and how it is perceived. This model defines the term ‘comfort’ and shows which factors determine comfort. One of the tasks of the **‘Living Façade’**® is to influence and optimise these factors.

The report contains 8 comfort-determining factors:

- Air comfort (humidity and purification)
- Thermal comfort
- Light comfort
- Noise comfort
- Ergonomic comfort
- Personal control
- Spatial experience
- Safety

The **‘Living Façade’**® efficiently and effectively ensures comfort. The comfort-determining factors are variable through comfort technology. Trends are indicated that greatly stimulate the relationship between comfort and the façade. Trends such as:

- Safety
- Better management of energy and the environment
- Electronic control (domotics)
- Climate regulation, climate control
- High-quality façade architecture
- Optimisation of knowledge and innovation

The study describes the role that the façade plays in terms of the effect that comfort experience has on the perception of well-being and, in particular, on how we perform. With regard to the latter, human productivity is a key variable that can be influenced by comfort.

8. Effects of the ‘Living Façade’® for the industry

The industry currently engaged in manufacturing façades and façade elements will change.

Fragmentation – an entire structure of fixed partitions in the production chain (for the most part a reflection of the similar structure in the building industry) – will disappear. Specialisation and specialist expertise will continue to stimulate depth-innovation and product improvement, but will be complemented by broader multidisciplinary innovation. Individual specialist companies will develop into multidisciplinary companies. They work with other multidisciplinary companies permanently in the most appropriate combination of capabilities.

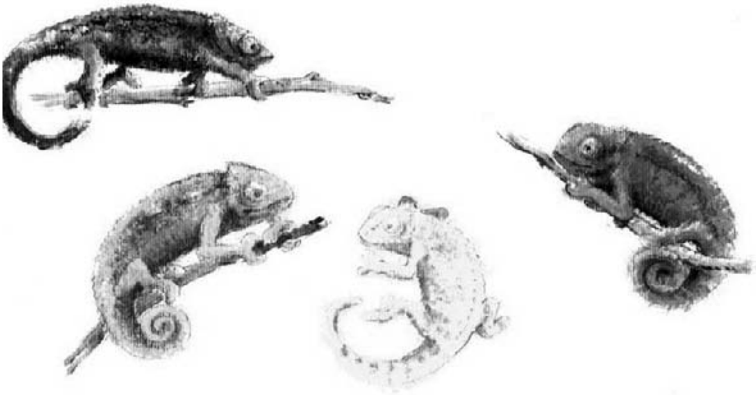


Fig. 4 Adaptable life

This is the only way in which the necessary harmonisation and integration in façade systems can be realised.

The Slimbouwen® philosophy (Smart Building, in English) could serve this purpose perfectly. (Proposed by Prof. Dr. Jos Lichtenberg of TU Eindhoven, www.slimbouwen.nl)

Of course, the means of production will be industrial. Investments will only be justified and implemented with the help of an industrial working method – which in turn will produce top-quality products. Such investments come from a variety of sources.

The owner of a building, for example, will provide a greater initial investment in the façade installation in order to reap long-term profits. Designers will also invest more in knowledge acquisition in order to make optimum use of the possibilities that exist within the façade industry. Entrepreneurs in the façade industry and other associated industries must make the necessary investments in the development, production and introduction of new façade systems.

The question is, then, where these entrepreneurs can be found in the chain and above all in which way a collective vision and collective change can be realised in the façade industry and the other relevant industries or disciplines connected to it. Companies will change both internally and in terms of their relationships with partners in the regular production chain as well as in relation to new business partners that are currently at a distance.

It is good to realise that the necessary innovations in the façade industry are linked to deep-set changes in individual businesses, changes with partners in and outside the production chain and changes in the structure of markets, both private and professional, and the rules according to which we function. In short, investments need to be made in a number of places in order that the vision be realised.

Rather than the functional director of the façade company, the entrepreneur – as a person transcending this more functional role – occupies a crucial position, demonstrating leadership through his proximity to the company and by forming a time and function-transcending vision. This leadership – which includes all pertinent risks and investments – forms the direction and motivation required for a successful future, a future that by definition differs from the current situation.

Using this collective vision to sketch an image of this future is an initial step in that direction.

9. Investments and value

Considering the necessary future investments should be done from the perspective of value creation. An investment should generate value, no matter what. From the perspective of the **'Living Façade'**®, there are different investors, investments and, of course, different value creations. It is also important to consider the period in which the value creation will be realised, which is an issue in both the façade and the building industry.

The façade industry is largely dependent on internationally operating systems suppliers. This dependence is partly a result of the primacy that systems suppliers have for the development of their systems. Façade companies often see these systems as a sort of raw material or semi-manufacture and underestimate the intellectual value and investment that are initially required. Systems suppliers often regard the façade companies as so-called processing companies. Moreover, they underestimate the creative task of engineering and the legal and contractual responsibilities of the companies that are, in fact, their customers.

This underestimation of each other's intrinsic value and investments places a partition between the partners, both of which could generate more return from their investment if they were to collaborate more.

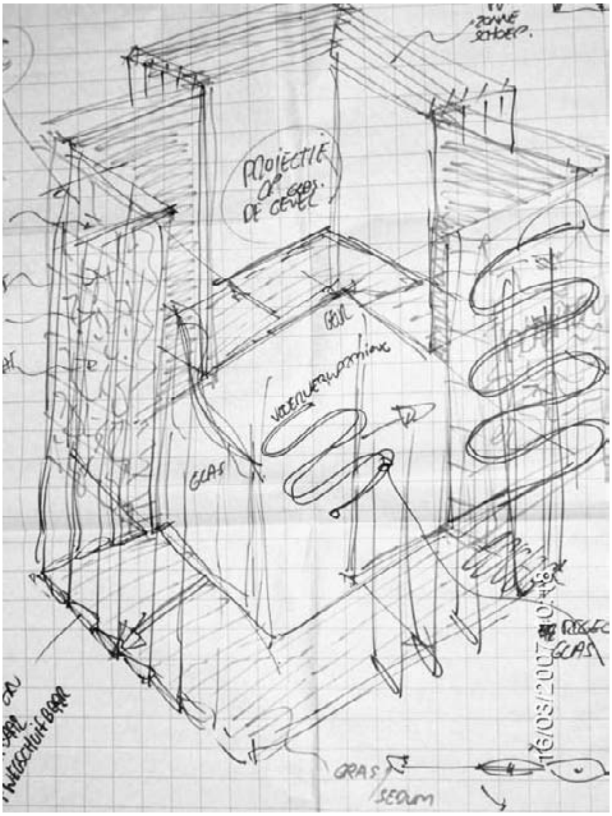


Fig. 5 Brainstorm result

In addition, the focus is short-term. For decisions regarding investments for the benefit of future façade systems, the entrepreneurs involved will have to take another stance in relation to one another. Efforts will also need to be made to reorganise the industry from the perspective of a collective entrepreneurial vision.

In this respect, many interested parties will want to see the long-term value creation overcome the continual focus on the short-term and on the industry's own, traditional core tasks (for systems suppliers: selling, for façade companies: manufacturing).

Buyers of façade products are facing a similar dilemma. The various interests and positions of power taken by the building partners, linked with the length of time in which these interests apply, hinder renewed investments.

Façade systems that can realise comfort value for the end-user (indoors and outdoors) will be achieved if we can ensure breakthroughs in:

1. Traditions in the façade industry and the terms of visions;
2. Traditions in the building industry and the terms of visions.

Such breakthroughs will come about if business partners successfully effect two investment strategies through industrial and market networking:

1. Value creation from innovation of comfort products and from the creative method (focus on new concepts, products);
2. Value creation from a collective, completely new approach to that market (focus on value creation for customers).

10. Business

Creating breakthroughs requires courage, initiative, charisma and the willingness to take risks. In addition, the playing field is very diverse. People look at the problem from different perspectives and disciplines and generate ideas, provide opinions or request legislation.

The actual solutions come from those companies that show themselves to be capable of providing solutions. Of course, while only being one part of a greater whole, they are nevertheless an important part consisting of people and companies that are willing to shoulder responsibility.

Entrepreneurs will offer their vision on outdoor and indoor comfort at the same time as making initiatives concrete. This is also something that involves value. Realism, cost awareness and feasibility then form part of the value that eventually reaches the market. The primary task of the entrepreneur is to organise everything from the perspective of leadership. Business and organisation go hand in hand. The term business as used here is not limited to business organisation. Rather it involves organisational capacity in all relevant markets in various fields, relating to more than simply technique or technology.

The entrepreneur thinks in terms of networks, particularly Industrial Networks that are viewed from different organisational perspectives:

1. Physical, technical
2. Economic, managerial, organisational
3. Social (societal, relationships), psychological (people, persuade, motivate)
4. Aspects relating to the search for meaning

11. Renewal and/or innovation

Firstly, the entrepreneur described will convince his other business partners, employees and other interested parties of his analysis of the current situation. Then his vision will indicate trends within and outside his own sector. He will also demonstrate links between these trends, and in particular the relevance of these trends to his own business. An immediate reaction is normally the local alteration of the current working method or the current technology. This is often enthusiastically called innovating, and means that external trends or ideas lead to changes and the abolition of accepted methods.

However, it is better – and this is real innovation – to listen and to look at the business person's image of the future. This analysis, along with his vision of trends, allows him to establish a position for his company in the markets of the future. He also indicates what the company and the sector will look like. Everyone with an interest in it will then imagines themselves in that image and draw conclusions regarding the necessary changes, renewals and innovations (breakthroughs) that are required now in order to attain their future position.

It may be clear that the **'Living Façade'®** vision will also lead to a new vision concerning the type of company, business configuration or sector that is necessary to realise the desired results in these new markets with new products.

12. Corporate policy guide for future 'Living Façade'® companies

The seven I's are the quickest way of sketching a picture of the dynamism with which markets and businesses are affected by change.

I1: The first I stands for integration. Integration of different knowledge fields, technologies, products, functions, markets, etc., is the basis of and a precondition for success. Façade technology, comfort technology, installation technique, control technology and building management will then go hand in hand. The separately operating disciplines outlined earlier will also disappear. Multidisciplinary teams will be set up within the company as well as in combination with external experts. Integrated products that are being sought such as the **'Living Façade'®** will be realised on the basis of this integration of thought and action.

I2: The second 'I' stands for intellect. Renewal and innovation in respect of products, services and technology demand intellectual labour, which also means that the focus on the physical qualities and the factual techniques will be relegated to the background somewhat. The abstract understanding of different technologies as well as the systems and their coherence becomes a key aspect. The relationship with aspects of sustainability, with other disciplines and with the operational or user phase will also lay a claim on intellectual labour. We are already seeing that engineering is becoming ever more important within façade companies, and the interaction of engineering with the designers and architects has demonstrably created favourable conditions for successful products. The concept of the **'Living Façade'**® is also party the result of sessions in which these other disciplines were involved.

I3: The third 'I' stands for internationalisation. Everything on which we are working and everything that we use has an international aspect. Our markets, the markets for our façade installations, and our sourcing markets are all international. International suppliers, for example systems suppliers, produce for international markets. And let's not forget international legislation. European commission guidelines, CEN and ISO standards transcend national regulations and legislation. Today's façade industry, as well as the industry of tomorrow, is concentrating on the international side of every aspect of work and business. We are seeing international communities of employees within companies and will be sourcing services (designing, computation) from foreign suppliers.

I4: The fourth 'I' stands for innovation. Continuous innovation is a necessity of life, needed to guarantee the continuity of the business. While today's solutions and products require a level of sustainability, their lifespan (economically, psychologically, technologically) is becoming ever shorter. Moreover, the transparency of the market is such that all the ins and outs of a successful solution are already widely known. Therefore, a competitive edge also offers only short-term advantages. Engineering and designing with this foreshortened image of time in mind constitute the necessity for continual innovation.

I5: Interaction is as important as it ever was. No-one has a monopoly on wisdom. Permanent interaction should take place between those parties involved in the product and the service. Those parties communicate and work interactively in numerous fields. Every possible discipline gets an opportunity: designers, clients, users, suppliers, consultants, etc. Interactive working invites equal involvement. Mutual respect and teamwork are conditions for the creation of a successful future.

I6: Everything in the industry is manufactured using industrial means. The traditions of pottering around in the building industry are not suited to the high-quality technologies that we use in the façade industry. Industrial working methods guarantee quality – quality in terms of the end product and the production processes. The integration mentioned earlier is a combination of high-quality elements.

I7: The seventh 'I' stands for the first person singular: I. The changes will affect everyone. Everyone will have to determine their stance with regard to the future and the **'Living Façade'**®. After that, everyone is free to link their personal motivation to the direction in which the business is heading. This initial 'I' begins, of course, with the personal insight and the personal motivation and charisma of the leadership needed to attain that future position. Of course, the others must accompany the 'I' and are invited to contribute and to connect their personal insights and vision to the collective future goal. The façade sector exist out of companies and those companies host the most different people. Normally such a social productive community is not very eager to change and to take risks. Innovation means that the structural aspects of a productive community should change to be successful. Individuals are both initiators of change as well as strong fighters against change. To make a company successful and to create futures an continuity everybody in a companies should cooperate to realize its innovative goals. Otherwise the should leave the company.

The intellectually well-though-out (industrial) contributions are of such value that their results may not come to nothing due to an outdated and traditional means of working.

13. Consequences for companies and the industry

This modernisation of markets and products is not for everyone. Some people cannot or will not follow. And there will always be leaders and followers. The picture outlined here is expected to take shape in various markets, including the construction (utilities and housing) as well as those huge markets that centre on renovation or replacement.

For the façade industry, these latter markets are simply part of the market for new housing development. At worst, alterations are required in planning, production, preparation and assembly. The principles of the **'Living Façade'**® concept can be implemented on a broad scale.

In its own way, the entire industry (large and small companies) can latch onto the perspective as outlined here. The development is a challenge for multiple façade companies and their partners.

14. Introduction and realisation

The perspectives outlined here, the vision, which has an abstract and high-quality set up, transcend the company level. Not because of a lack of quality but because visions and collaborations must be made possible. The translation into what is important to the company and the individual must be made at company level.

However, the façade industry, the architecture sector, the installation technology sector can facilitate knowledge transfer with the support of a completely uniform vision. The **'Living Façade'**® concept consists of challenges for a wide variety of companies.

It is important for those companies to progress, to modernise and to acquire their future position, in the same way as this has been done for the **'Living Façade'**®. It is a strategy and direction based on innovation that applies to both this and other sectors concerned with this kind of work.

Clearly, designers, architects, small and large façade companies, installers and suppliers will hopefully use the **'Living Façade'**®.

The **'Living Façade'**® includes themes such as:

Sustainability, flexibility, adaptive capacity, sensor technology, integration of installations and façades, building management systems, security, energy control (particularly renewable energy), development and management, maintenance and operational services during the lifespan of the product, a leading position for the 'new industry', multidisciplinary processes and organisations:

a challenging future for many!

The general conclusion is that the Living Façade is a concept for change. It represents a direction in which the façade sector can develop and its companies as well. It creates a working field for many companies and other related disciplines. Their creative solutions individually caught in a general concept will change the markets. Both the market with customers and users of façades and building but also the productive side of the market, companies, architects.

It will initiate new façade systems and uses the most advanced technological capabilities from the most different disciplines.

The end product will be a combination of building components, electronic devices, installations and of course services and lifetime involvement of the industry with the lives of its clients.

Potentially, the first design phases have the biggest influence on the performance of buildings. Fundamental decisions are made during this stage because it is more difficult to introduce new ideas at a later stage of the process. Often, the Central European architectural style is exported to various other climate zones. The result are façades that counteract traditional climate concepts. In the scope of his PhD work **Dipl.-Ing. Marcel Bilow** develops a tool that explains the relationship between climate zone, façade layout and the technical building concept specifically for the design process.

The Future Envelope 2 – Architecture-Climate-Skin. U. Knaack and T. Klein (Eds.). IOS Press, 2009.

CROFT – CLIMATE RELATED OPTIMIZED FAÇADE TECHNOLOGIES

Marcel Bilow

TU Delft / Façade Research Group

Abstract

Following the international style trend, fully glazed office buildings are erected worldwide. These office buildings and their façades require the application of a vast amount of technology and energy. The purpose of the research project is the development of a design tool or guideline that supports the architect in the early planning stages, to indicate the requirements for façades in different climate zones utilizing a sensible combination of façade technologies and mechanical service components. The result should drive building development that provides the desired comfort and an energy reduced operation not fighting, but rather going conform with the prevailing local climate.

1. Background

Nobody packs nothing but their bathing suits for a trip to Moscow in December, and you won't find winter coats in suitcases destined to Dubai. Our experience has taught us which temperatures to expect when travelling to foreign countries.

A picture taken during the holidays shows us the climate of the area in which the picture was taken; and we can recognize the origin of people from different climate zones relatively easily by their clothes and their dwellings. Every climate zone has its own skin. This skin is mirrored in the local attire as well as in the prevailing architecture. The materials used are determined by regional availability and are adaptable according to seasonal changes or other external influences.

For example, the materials that the Inuit – as an inhabitant of the northern Arctic region – uses, are largely taken from the full utilization of hunted animals. Besides meat and fat for food and heat, these animals also provide coats and leather for the production of clothes and lodging. The often wrongly used term 'Eskimo' was translated into "raw meat eater"; however, according to the language of the Cree, a large Native American tribe, a more suitable meaning is "snow shoe maker". This term is a far better description of the autonomous self-sufficiency of the Inuit.

Worldwide, traditional construction methods are generally adapted to the local resources and the prevailing climate. The goal was to reach the optimum comfort level with locally available means. If we look at current building projects in the boomtowns around the world, this knowledge seems to have been pushed aside. The international style - as a synonym for cosmopolitanism, success, but also for power and wealth with its fully glazed buildings that fight the elements - seems to have eliminated the knowledge about energy efficient construction methods and the exploitation of the local active energy.

A provocative comparison; traditional architecture is usually related to residential buildings, and the achievable comfort level can be described as 'bearable' rather than 'good'. Current buildings, independent of the location, have higher requirements than traditional construction methods are able to fulfil.

And office buildings with their differentiated demands pose an even higher requirement profile for planning and executing parties. Naturally, we will not want to build high-rises in Dubai with clay; however, we can learn form the traditional construction methods in order to work with the prevailing climatic conditions, instead of fighting them with all our power – often with giant air conditioning units and accordingly high energy consumption.

2. Objective of the research project

The goal of a research project at the Technical University Delft titled 'International Façade' is to determine the requirements of building envelopes in different climate zones.

The result will not be the development of a specific façade which, as a product, can be employed in any climate zone, but rather a requirement catalogue. This requirement catalogue shall serve as a guideline for architects, providing pointers for the façade design at an early stage.

The main research question of the project can be summarised as follows: "How and with which methods can we realise optimised façades that provide comfort as well as economic efficiency in the facility operation for specific climate zones?"

The subject can be compared with travelling on water; anybody can drive a motorboat if the means are there to pay for the fuel. A more economic method, however, is to sail. But with sailing, we need to understand the techniques of utilizing the power of the wind. Those who have never learned to beat will not be able to cross the water in a sailboat. Thus, the goal is to learn to sail! But how do we learn to sail with buildings?

In order to limit the scope of the research project to a manageable size, eight boomtowns across the globe and various climate zones were selected that exhibit strong building activity. These boomtowns are used to show the current state of building, to analyse the principles of climate-oriented building and examine the options for technology transfer. The exhaust chimneys in Pakistan, for example, are an efficient principle to use the prevailing wind direction for natural ventilation of the entire building.

Employing the principle of thermal mass is another example of climate-oriented building. Thermal mass can be used to protect against overheating due to the slow warming and temperature buffering characteristics. This principle can be found in many Arabic clay constructions as well as the subterranean earth dwellings in Southern China, with the entire usable area is arranged under the ground. To keep with the metaphor of 'sailing', the main work is preceded by a climate analysis, to better understand the factor 'wind'.

3. Use of Psychometric charts / Carrier diagram

3.1 Basics of Psychometric charts

In the field of building physics and in mechanical service engineering, the Mollier diagram or h-x diagram is well known; this diagram helps to calculate and show the aerial states and change of state. In international practice, it is used as a Carrier diagram or Psychometric Chart with exchanged axes. The name Carrier derives from the name of the inventor of air-conditioning, Willi Carrier, whose company still produces climate devices under this name today. In the following, the Carrier diagram is used as a basis of the internationally oriented research project. On the X axis, the diagram shows temperature in °C, and on the Y axis the absolute dampness in gram per kilogram of dry air. The heat content h (enthalpy) is given in kJ/kg and runs diagonally from the top left to the lower right.

Detailed information about the heat content – the enthalpy – is not included here, as this function of the diagram is not important for the following considerations. Looking at the change of state of the air when entered by means of the Psychometric charts, distinct directions can be observed, if the characteristics and parameters of the air are to be changed.

Fig. 1 shows the possible change of state that the air must or can be submitted to, in order to adapt it to the requirements. For example, the dry energy supply as a heating process is registered from the low temperatures on the left running parallel with x axis. As soon as temperature and humidity have to be adjusted, the state changes run in diagonal direction, easily identifiable in the graphic.

3.2 Overlapping of comfort area

In addition to the changes of state of the air, thermal comfort

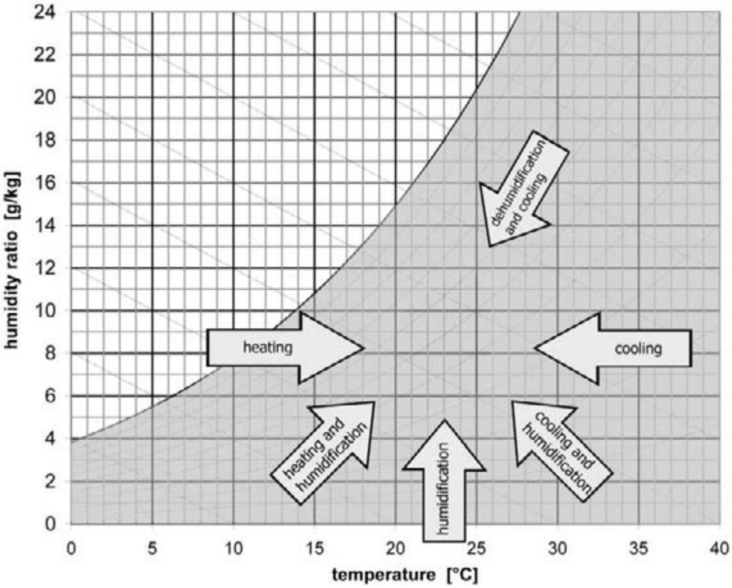


Fig. 1
Change of state of air, registered in the Carrier diagram

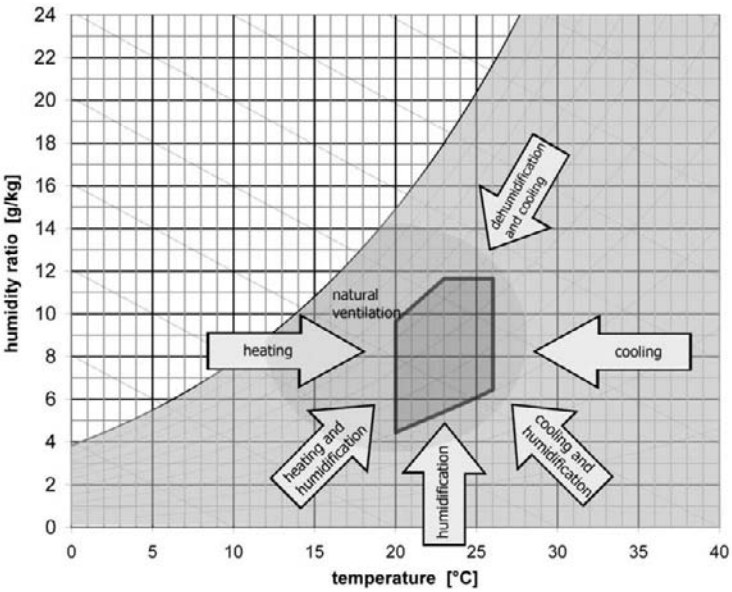


Fig. 2
Registration of the comfort area referenced to ASHRAE and the area of natural ventilation in the Psychometric chart

can also be illustrated in the diagram. The thermal comfort can be described by temperature and absolute as well as relative humidity. The specifications determined by ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) are recognised as international comfort parameters. Even though these specifications, discussed for the area of natural ventilation with raised tolerance of the users, can be viewed critically, in this procedure they serve as a starting definition.

The comfort area illustrated in fig. 2 is described by a minimum temperature of 20°C, a relative minimum humidity of 30%, maximum temperature of 26°C and a relative maximum humidity of 65%. An absolute humidity of 11.5 g per kg of dry air further limits this area. 12 g/kg are sensed as muggy; as a comparison: the absolute humidity of a swimming pool is approx. 14 g.

As long as the temperatures are within the above mentioned comfort area, the user feels comfortable. If we overlay the contents of the changes of state of the air and the comfort area, this graphic already serves as a guide to choose suitable strategies for air conditioning to reach the comfort zone.

Another area can be laid out around the comfort zone describing the possibility of natural ventilation. Here, the air is similar to that within the comfort zone; however the expansion contains the phenomenon that the user can control individual ventilation, for example by using a window, and therewith enhance moisture and temperature variations.

3.3 Climate analysis

Based on long-term weather measurements, test reference years are generated, which depict the climate of a city or region for scientific calculations. Since the measurements were taken over 30 years and include all extremes, test reference years are the best basis for the analysis of climatic conditions in a give region. Temperature curves and humidity levels can be determined from the weather data, and then be entered into the Psychometric chart as a coordinate of temperature and absolute humidity.

Fig. 3 illustrates the test reference years of Abu Dhabi, Singapore and Berlin as a scatter-plot. This scatter-plot is as characteristic as a fingerprint of the city and allows us to conclude the climate zone and the prevailing air conditions. Each climate zone has its own typical geometrical expansion; the diagram in fig. 4 summarises these characteristic signs of the scatter-plots. If we lay these scatter-plots over the diagram shown in fig. 2, the measures needed to achieve the comfort zone can be seen.

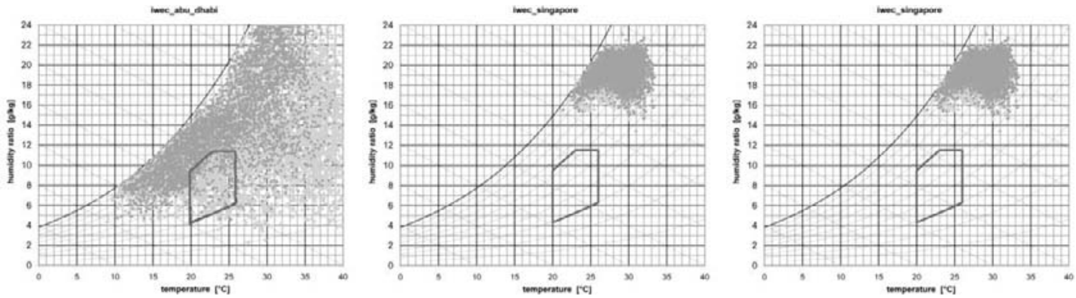


Fig. 3
The test reference years of Abu Dhabi, Singapore and Berlin show a clearly distinguishable signature in the Psychometric chart

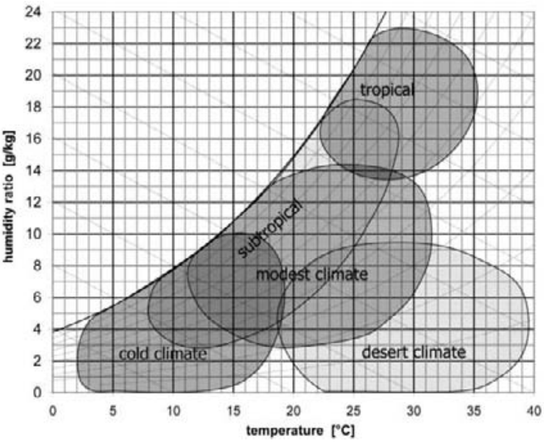


Fig. 4
The classification of the climate zones can be derived from the respective scatter-plots of the investigated cities

3.4 Overlapping of façades and building services components

Based on the weather analysis and the preceding investigations, we can evaluate the different building services components and façade technologies with reference to their air conditioning options and enter this in the chart as an initial estimate. Various double façade technologies, such as box window façades, second skin façades or chimney façades, are suited for natural ventilation in exposed locations. [1] These façades can be entered in a psychometric chart near the comfort zone in the enlarged area of the natural ventilation.

Component façades, disposing of integrated building services components such as decentralised climate devices, are as suited to change the temperature and humidity to a lower level as are traditional air-conditioning units or decentralised climate devices located near the façade. They can be entered into the upper right area of the diagram in the upper right area. Concrete core activation, chill sails and chill ceilings can be entered as technical components of the cooling area. With regards to cooling and humidification, the component façade as well as centralised and decentralised air-conditioning systems can be entered into the diagram. With regards to heating, traditional convectors near the façade or subsurface, as well as radiators can be entered.

3.5 Overlapping of climate analyses

It is easy to read the requirements of the façade and the building services related to a specific climate zone or location when overlaying the diagram with die scatter plot of a test reference year of a city. If we consider the climate of Las Vegas in fig. 5, for example, we can conclude that the façades and building services components need to fulfil heating, cooling and humidification requirements.

For better legibility, the graphic is divided into separate areas, making it easier to derive clear definitions. The proposed approach has yet to be scientifically specified; individual examinations and calculations need to be done in order to determine the performance

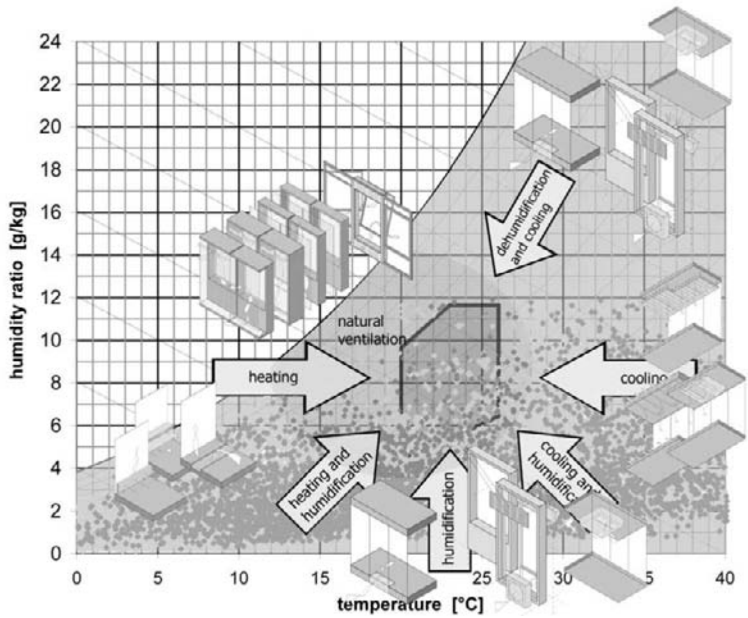


Fig. 5
An overlay of the façades and building services components and the test reference year of Las Vegas clearly shows the requirements in this climate zone

capability and the specific allocation within the diagram.

4. Conclusion

As an initial result, the diagram shows a distinct development potential for decentralised façades or component façades. When taking a close look at the performance capability of these components, e.g. for the planning area Singapore (fig. 6), we can conclude that the requirements of façades for this area are cooling and dehumidification. The diagram shows that, besides component façades such as the one enveloping the Capricorn building in Düsseldorf, decentralised and central air-conditioning systems are sensible solutions (fig. 7).

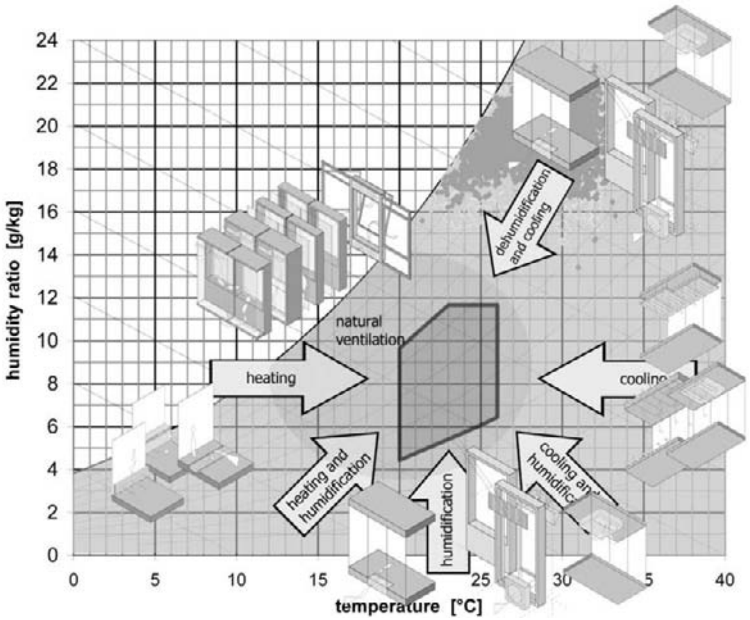


Fig. 6
Overlaying the diagram with the test reference year of Singapore clearly illustrates the requirements cooling and dehumidification

The central air-conditioning provides controlled dehumidification; it essentially cools the air to reach the dew point, resulting in condensation; while temperature and the absolute humidity decrease as well. Then the cold air is warmed up again to reach the requirements of the comfort zone. The condensate is led away centrally. However, decentralised climate units are currently only able to de-humidify uncontrolled, i.e. the air is cooled down, and the absolute humidity does indeed ink – but reaching the comfort zone is not possible. What does this mean for practical building purposes? In all tropical and subtropical climate zones, sophisticated high-tech façades with integrated climate components cannot be used; the only solution remains to be large central air conditioning units.

If we want to continue to position ourselves in the international market with sophisticated façades and building services integrated components, there is a need and potential for developing technologies which are suited to this market and its climatic requirements. The topic dehumidification plays an essential role for the operation of buildings in tropical and subtropical areas.

No current façade technology provides a solution for natural ventilation. One possible development could be elements that lower the humidity level by condensation by outside air flowing through cold pipe registers. This concept could offer increased comfort due to the possibility as an individual ventilation device.

Cooling devices such as chilled ceilings or concrete core activations, elements often used in Central Europe, cannot be used in these

Fig. 7
Component façade of the Capricorn building in Düsseldorf by Gatermann and Schossig architects with façade-integrated decentralised climate modules in the unglazed areas

climate zones. Due to the high temperature and high air humidity, the temperature below these elements would fall below the dew point and would generate condensate.

In a subsequent process, the approach described above will be developed into an easily readable planning tool, illustrating the prognosticated amount of energy needed to achieve the respective comfort level for different climate zones. Further research will investigate the wind, for example, as well as other climate conditions and result in a requirement catalogue and guide for the architect's early planning. The goal is to develop buildings that utilise rather then fight the surroundings – in brief, are able to sail!

References

[1] see classification of the façades: Knaack, U.; Klein, T.; Bilow, M.; Auer, T.: "Principles of construction - façades ", Berlin: Birkhäuser in 2007.

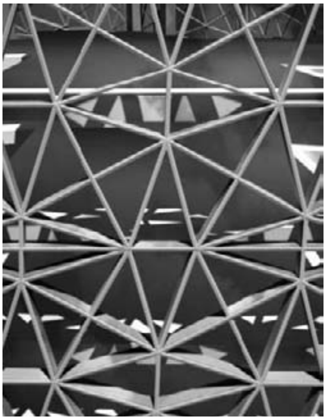
Together with Yasmin Watts, **Andrew Watts BA DipArch** leads the façade planning office Newtecnic in London. His work focuses on new ways of construction and digital techniques. He is a teacher at the University of Bath and has published several books about façade construction. Andrew Watts believes that especially new digital design tools will be necessary to cope with the growing complexity of the future façade.

The Future Envelope 2 – Architecture-Climate-Skin. U. Knaack and T. Klein (Eds.). IOS Press, 2009.

RESEARCH INTO COMPLEX FAÇADE GEOMETRIES AS A RESPONSE TO CLIMATE IN THE WORK OF NEWTECNIC ARCHITECTS

Andrew Watts

Newtecnic / Façade Architecture



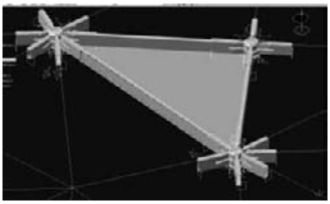
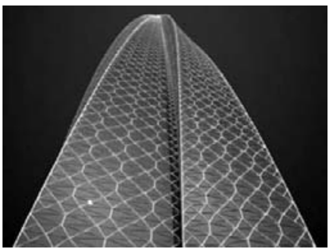


Fig. 1-3 Above and below: This project for a tower in Russia, currently completing the detailed design stage, has a cladding design developed as a mathematical model from which we generated engineering data that allowed us to modify the design to optimise shading created by the geometry of the framing.



Newtecnic is a firm of London-based specialist architects who create façades in collaboration with leading architects. In projects where climate control and natural ventilation are primary design criteria for the façades, with both glazed double skin façades and metal screen double skin façades being used. Rather than follow the geometry of rectilinear design, the outer skins of façades of our projects are required increasingly to be shaped in response to specific environmental issues of solar shading, daylight control and the provision of natural ventilation. The resulting façade forms are typically twisted, curved or folded. This paper discusses research undertaken by Newtecnic in recent projects which exhibit these tendencies in terms of the possible solutions for the design of the cladding. This paper also compares the approach with experience in both temperate and hot climates.

'Behaviour-led' façade systems

A recent trend in contemporary façade design is that of the influence of digital environmental data, generated from environmental design computer programmes, which has resulted in some of the twisted and folded geometric forms seen in recent building projects. Where most 'modern' architecture can be regarded as being a collage of separate volumes and objects linked as a formal composition, an architectural approach that uses 'material systems' looks at the possibilities inherent in the use of a specific technique when applied to a single building material to suit different environmental requirements. Where a single material system is used for a building envelope, that system can be adapted to suit different conditions at junctions and interfaces rather than being combined with another material system.

Where sheet metal is used, for example, the material can be made in lengths that can follow long, curving forms of a building, which suits the possibilities of the material rather than asking the material to be wrapped around a form conceived quite independently of the choice of material or how it is used as a façade system. This principle has been used in the design of buildings which display a continuity of form, such as where a single expression is used for both wall and roof in a visually complex solution. In such designs, the outer wall is often separated from the inner wall, which responds to specific functional requirements within the building. The resulting double skin façade typically uses the zone between the inner and outer walls to provide higher levels of thermal insulation as well as to allow larger buildings to be naturally ventilated rather than relying on mechanical ventilation systems. This method can also be applied to single skin façades where a material system is varied to suit specific performance requirements in different spaces behind the same external wall.

The use of both double skin and single skin façades has led to building forms being shaped to suit specific requirements such as encouraging air movement in internal spaces that are required to be naturally ventilated. Façades can also be visually sculpted in order to optimise the form of double skin façade or louvered single skin façade in order to reduce the amount of energy that would be required to temper the space. This might be achieved by making the volume between inner and outer skins wider at the floor level than at the high level of the space. Where adjacent spaces are linked vertically, such as in so-called 'sky gardens' in taller buildings, the resulting form of the building envelope might be twisted, curved or folded. For the design of façades, the definition of this geometry and the form of façade construction used become primary issues for the façade designer.

Double skin façades in cool climates

In climates which experience cold climates in winter and warm climates in summer, the buffer zone between the skins of a double skin wall can be used as an atrium space in some areas and as a narrow thermal buffer zone in other areas of buildings. The interstitial façade zone can be used in winter as a sealed thermal buffer, and be used as a partially ventilated thermal flue in summer by specifically shaping the space to enhance natural air movement.

From a visual point of view, the design of the outer glass can express technical functions in the space behind. Glazed panels can be formed as repeated, but not rectangular, shapes that use a continuous glazing system for different wall conditions behind. Rather than change the glazing system for each part of the façade as would be experienced with conventional façades, this approach uses a limited number of panel types of non-rectangular form which are set at different angles to create a façade that can express air movement in a complex folded form without using special components. The

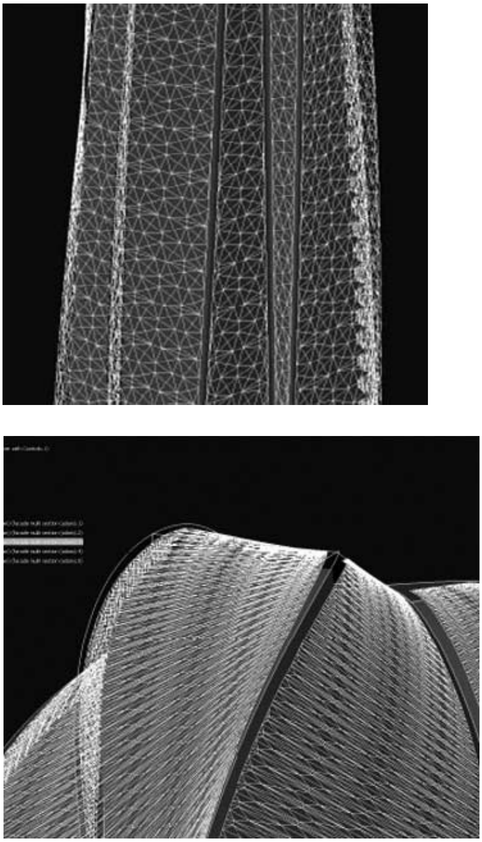


Fig. 4 & 5
Hexagonal panels on a tower in Russia

panels can be set out from a few façade panel types which are placed to suit the lines of movement where the façade becomes a form of visual 'map' of air movement.

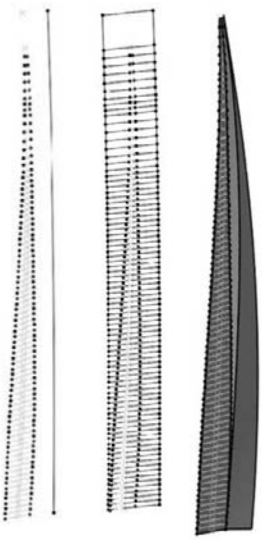


Fig. 6
A single panel type is mapped across a twisted surface

Single skin shaded façades for temperate climates

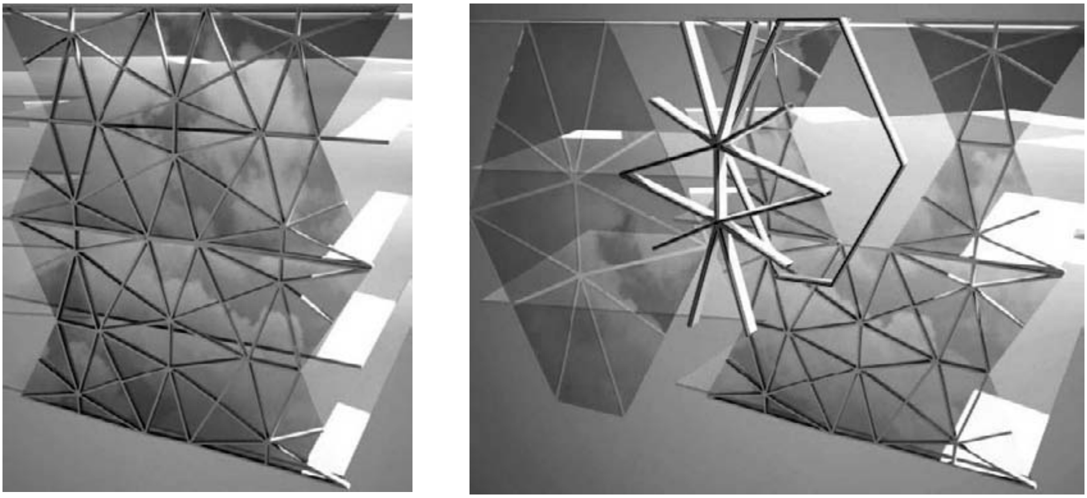
In addition to double skin façades, solar shading can also be applied to single skin façades, where daylight control and natural ventilation can be more effective than when a double skin façade is used. Solar shading in double skin façades typically comprises roller blinds or Venetian blind arrangements that can be raised or lowered in response to the path of the sun. In single skin façades, large-scale external louvres can be set forward of the external wall, at different angles, to suit the amount of daylight required. In one project, louvres were set at constantly varying depths to suit the varying amounts of daylight required, which could be balanced with the number of hours of sunlight incident on the façades. This gave a rich visual pattern of louvres that were performance-based in their set-out.

In another project for a university building, a similar strategy for solar shading was combined with information gathered from a CFD (computational fluid dynamics) study that focused on a wind movements around the building. A series of curves introduced into the solar shading ensured that most of the effects of the wind would not reach opening lights set between the shading, by deflecting wind away from the windows. This approach allows windows to be opened in a single storey building of 10 storeys in height without the risk of wind gusts for most of the year. The solar shading was then designed to suit the resulting wind pressures from these wind baffles.

Complex geometry in the outer skin

The development of curved, twisted and folded façade have been possible as a result of computer numerically controlled (CNC) tools in the construction industry which use digitally generated drawings to undertake complex manufacturing tasks such as cutting, drilling and routing. These tools have allowed a greater diversity of components to be manufactured, which has the effect of reducing the need for standardisation of façade systems of all types, including load-bearing concrete façades, where formwork can be manufactured using the new technology. However, standardisation is still a requirement on larger projects to make the façades economic to install on site, even where the panels themselves have a geometric complexity in their form. The complex forms generated by architects which eventually suit digital fabrication techniques often correspond to an approximation of a form that can be optimised mathematically in order to increase repeatability of façade panels or components needed. For example, curved forms can be optimized to create surfaces set out on the arc of a circle, sphere or torus, in order that a single panel can be used, allowing the complex form of the envelope to be created from a small number of panel types.

At Newtecnic we have investigated different options for façade geometries that can accommodate curves, twists, folds and their combination. Generally for curved surfaces, a solution we have researched is the use of triangular panels. This has several advantages, as the panels are able to take up a circular geometry in the manner of a geodesic dome, formed as a sphere of triangles. Another advantage of this solution is in adapting to non-standard conditions such as at façade corners where, for example, panels change in size through the height of a building as a result in a complex geometry of building form. Two preferred façade systems are being researched for use as triangular panels: a node system similar to that used in large scale stick-built glazed roofs, and a unitised panel system. We are specifically looking at how they could be used together as a combination of stick and unitized methods, with a stick-built node



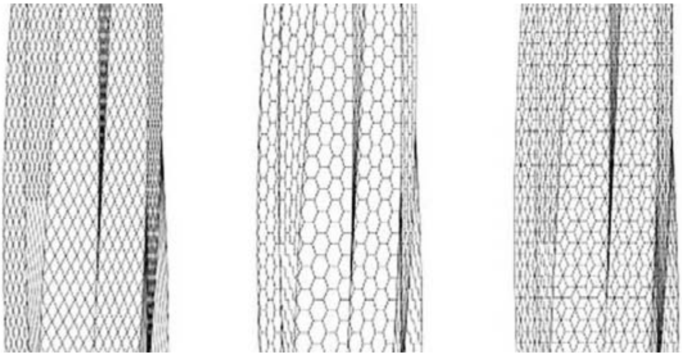


Fig 7. above: This façade for a tower in Russia uses a set of interlocking hexagonal panels, which are in turn subdivided into triangular panels of glass. The triangles allow curved surfaces to be formed from flat surfaces, with the hexagons (which are not visible as distinct forms) being the 'building block' of the façade.

Fig. 8 left: Different options for façade systems based on similar glass sizes explored through a parametric model.

Fig. 9 below: A node based façade system used in a combination of stick and unitised method of façade construction.

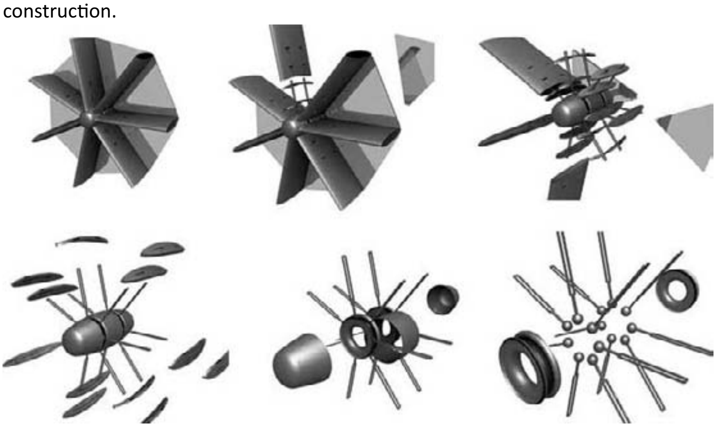


Fig. 10 above:The form of the building is formed by twisting the outside form of the building and curving each façade by a different amount. This creates a complex form which can be constructed from repeated panel types.

Fig. 11-13 At Great Ormond Street Childrens' Hospital our brief was to create a folded glass wall design including final construction details. An original wireframe model for the building was provided and input to a paramtric model. Architect: Llewelyn Davies Yeang

Fig. 14-16 The parametric model allowed allowed us to change the design easily to meet the demand of client, designers, planners and others involved in the process. The final design will be a crafted, friendly building that aims to be sensitive to the functional and emotional needs of its users.

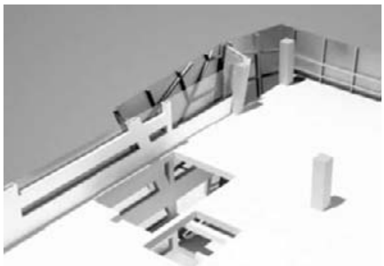


Fig. 17-19 A new building for Great Ormond Street Hospital in London, approaching the construction phase, uses a double façade where expelled air from the building is passed between the outer walls to reduce the need for mechanical ventilation in the building. The outer glass expresses the direction of air movement in the thermal flue behind. Architect: Llewelyn Davies Yeang

system in areas where a standard system cannot be applied easily, and unitised panels used in main areas. This mixture of site-based and factory-based work is different from current methods in that a single façade system will have some panels assembled in the factory while other elements will be site assembled.

Structure and twist

A roof structure that we designed for an office building in Moscow is both curved and twisted to create a complex shape. The roof covering comprises an opaque lightweight deck protected by an outer membrane. The supporting structure was required to be visible and formed a 'lid' to the twisting façades of the tower. The roof was designed by establishing primary points of support on the supporting core as well as points on the roof plane. These points were then connected with struts springing from a set of points on the central structural core of the building to form a series of notional 'tree' structures. The roof structure was then re-rotated, or 'un-twisted', in order to align the roof with the floor level forming an atrium space at the top of the building. The structure was then adjusted to suit this position, as if the roof structure were to be constructed as an 'un-twisted' design. The roof structure was then twisted back to its actual position, causing distortion in the structure. The revised structure now looked 'twisted' as opposed being a twisted form that had a more rectilinear solution imposed upon it. This new twisted form was then adjusted a second time to make it more suitable as a structure that would carry the loads of a roof deck. Triangular structural members were added for this purpose. Once again the structure was un-twisted to align with the floor deck beneath and adjusted to suit a more rectilinear solution. The structure was twisted back to its actual position, and the process of adjustment was done one more time. This process of twisting and un-twisting the roof structure allowed us to understand the 'behaviour' of the structure when undergoing twisting from a rectilinear concept to a solution that both visually expressed the idea of a twisted structure as well as functioning as an economic and logical structure in its own right.

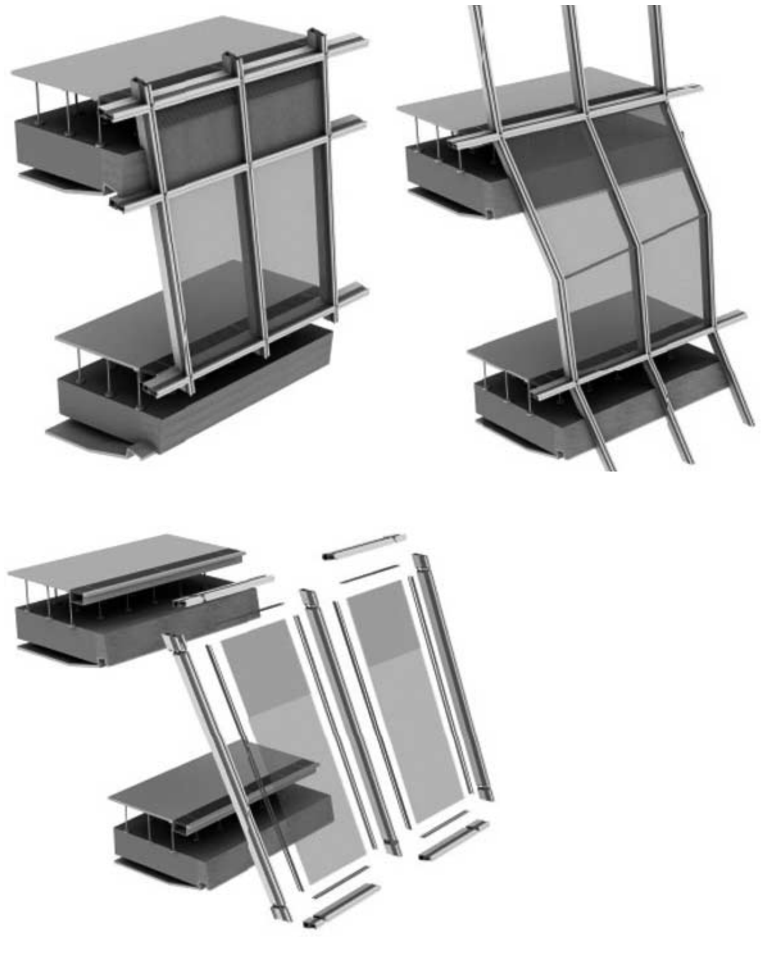


Fig 20-22 The panels on this Moscow office building use flat glass panels set into a twisted frame. Angled glazing clips are use to create a twisted panel from standard components. Architect: RMJM

Cladding in single twist façades

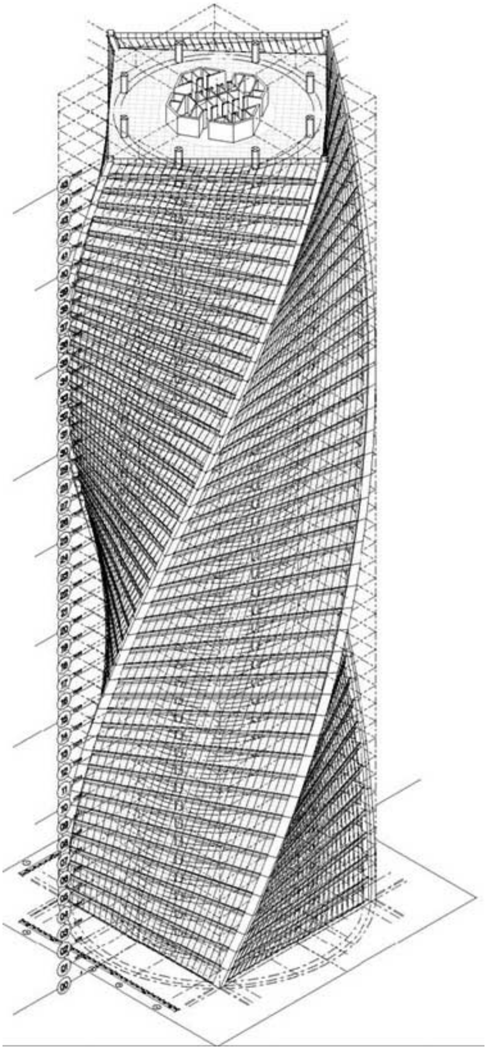
Façade panels in single twist façades are created typically by pulling one corner of a notionally flat panel out of plane. As individual twisted panels are set together, they follow the floor plate as a straight line of panels at the floor level, but their twist creates another straight line in the floor above at a different angle to the floor below. Typically, a façade twists along its centre line (with vertically set mullions in mid façade), panels in a single floor are of different shape. However, panels set above each other are of a single type. As a result, the design of twisted façades require continuity vertically in order to make the panels economic to manufacture, as the use of all different panels on any floor obviously require more panel types than a typical unitised façade.

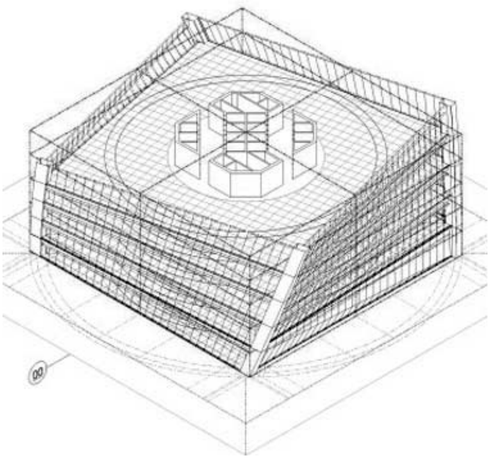
Within each façade panel, flat double glazed units can be inserted into straight aluminium profiles by using diagonally cut inserts that allow the glass to fit into a twisted shape. This method allows the aluminium extrusions used for the framing to follow regular panel construction methods that incorporate standard methods of providing structural thermal breaks, seals, internal drainage and ventilation. The all-important corner junctions of panels are able to meet with smooth mitred joints, an aspect of design that we have explored through the use of full size physical mock-ups.

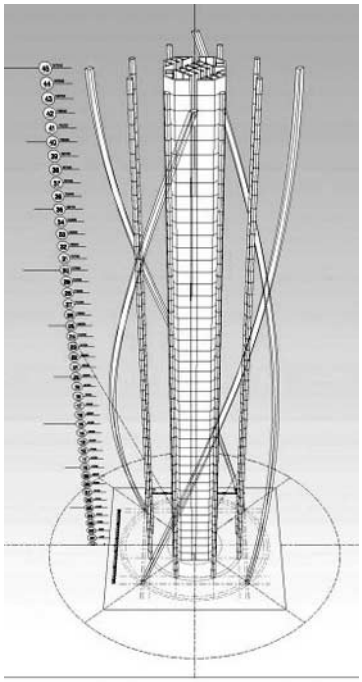
Cladding in curved and twisted façades

Further complexity in twisted façades is the addition of curves to the surface and tapers to the edges, allowing the forms of external envelopes to vary over their height. Where a taper is used, the façade has panels which are not simply curving out in one direction over their height but are tapering as well, resulting in non-standard corner conditions. An additional level of complexity arises if a façade has a double curvature. Unitised cladding panels can be set in a curve in one direction, as is often the case with façades curving either in plan or vertically through their height, but two way curving presents makes it much more difficult to use rectilinear panels which are repeated across the façade. The two methods we have developed to deal with such geometry is either folds in areas of flat façade, which gives a visual approximation of an overall curvature, or alternatively using triangular panels, as pioneered in the domes of Buckminster Fuller during the 1960's and developed as node-based space frames.

The triangular panel solution has presented greater challenges when used in unitised panels that are required to span not only from floor to floor but also where greater heights are required to be enclosed, such as double skin façades which span two floors at a time. Where







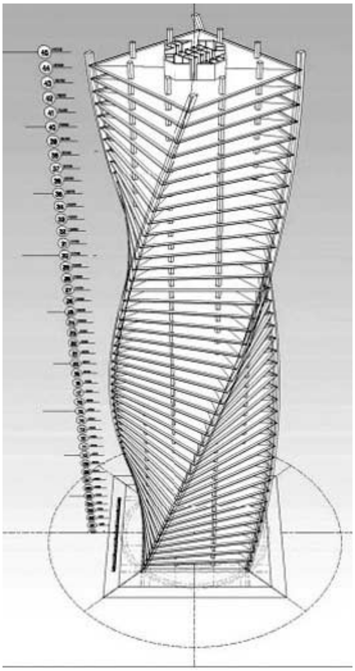
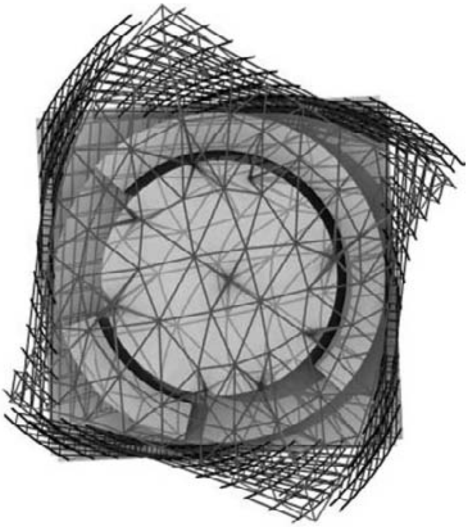


Fig. 23-26 The City Palace Tower in Moscow is conceived as a regular shaped tall building which is then twisted through its height. The façade panels are twisted, with flat glass set into them to create the complex form.



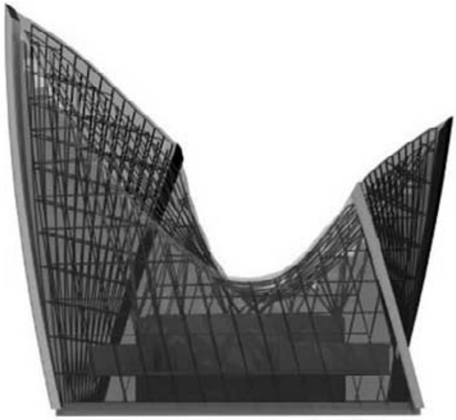


Fig. 27-29 The twisted roof structure at the top of the building is designed with steel 'branches' in the manner of a tree. Architect: RMJM

triangular panels are around 2.0 metres x 3.5 metres to suit large (relatively economic glass sizes), glazed units are set either within a larger panel assembly or onto a structurally supporting frame, typically in mild steel. Regardless of the method of panel support, an essential issue in our research has been in the geometry of panels. Specific issues of weatherproofing as the result of a need to ensure correct alignment of joints are not discussed here. The flat triangular panels designed for economy are required to meet at fold lines. Since folds need to occur on a plane of infinite thickness, parts of the panel meeting either forward or behind this plane will always be out of alignment at the point of intersection. We are developing two solutions for this condition: either a shadow gap between adjacent panels or a node connector at the intersection of several panels, still using a shadow gap between the edges of adjacent panels.

Where most node systems are destined for use as stick systems assembled on site, we have proposed using unitised panels assembled from nodes, with only the corner conditions being site assembled. This method would be used both where aluminium framed panels span two floors vertically without additional steel support or where smaller unitised panels are fixed to a mild steel frame which spans the two floors in the same way.

Shaded façades in hot climates

The approach taken in exploring complex geometries in sealed or ventilated double façades is finding a parallel in façades for hot climates. In the Middle East the winter conditions correspond, to

Fig. 30 The Office Tower at the Burjuman Centre in Dubai has fixed perforated metal shading on the south façade to provide solar shading to a fully glazed façade which consequently does not require electrical lighting during any working hours through the year. The north façade of the office tower has vertically set solar shading at the north and south ends of the tower to provide protection against low angle sun in the early morning and late afternoon for different times of year. Architect: KPF

Fig. 31 The apartment buildings at the Burjuman Centre in Dubai have their main façades facing east-west, with narrow opaque façades facing north and south. The west façades experience low angle sun in the afternoon in the winter as well as in mid season. The east façade experiences morning sun at all times of the year. The façades are glazed, with landscaped terraces in all apartments. The glazed façades and terraces are provided with a motorised system of solar shading which can slide vertically to enjoy uninterrupted views out to the desert in the afternoons at all times of the year. Metal panels slide vertically to nest together at spandrel level.

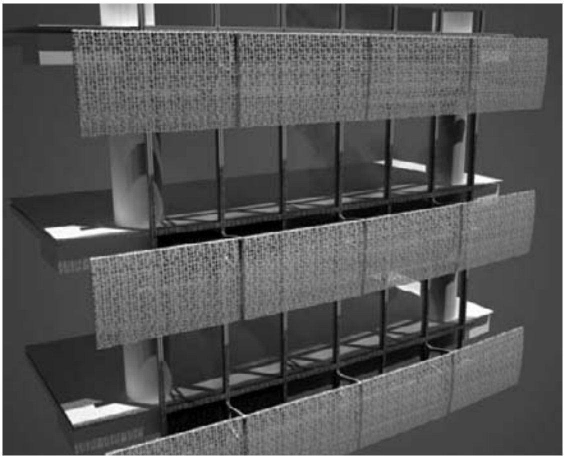
some extent, to the summer conditions experienced in temperate climates. For most of the year, glazed double skin façades are impractical due a high build-up of heat that would occur behind a sealed outer glazed skin that would not be mechanically ventilated. Consequently, where two glazed skins are provided, the outer skin serves only as solar shading set forward of a sealed glazed wall. Where external shading devices have been introduced in this region, significant reductions have been made in the cooling requirement for mechanical ventilation within the buildings when compared to the classic solution of a curtain wall with reflective glass.

Where shading devices are used forward of an outer glazed wall, an overall form of complex geometry can result from shading that is set specifically to respond to the path of the sun. While external shading devices often present fewer technical challenges than complex geometries for sealed façade panels, the visual aspect presents issues for architects and engineers. Again, a 'behaviour-led' architectural approach allows the façade to be viewed as an organism made up of a small number of components which have local variations of that system as a response to specific climate-based needs. Fixed shading devices are designed typically to be optimised to suit a range of conditions throughout the year. In our work, this is done by making studies of insulation and daylight levels throughout the year and setting shading devices at different fixed angles to follow the path of the sun in a position that would provide as much protection as possible throughout the year. In practice this has meant that the shading is least efficient for low angle winter sun in the early afternoon, but this situation is assisted by internal blinds which, although not providing any reduction in heat gain, reduce the effects of glare during this period.

We have also explored the idea of using motorised shading in order to better exclude solar radiation at different times of year in façade projects located in hot climates. This approach was found to be beneficial in conditions where glazed façades were exposed to the effects of the sun for only part of the day. Generally, mechanically operated shading was found to have little benefit in highly exposed conditions where the system would consume more energy to operate than the corresponding saving in mechanical ventilation from the reduced solar gain. However, on façades which experience direct solar radiation for only part of the day, we found that a mechanically operated shading system can be beneficial in reducing the energy load for mechanical ventilation within a building.

Conclusion

A central theme of this paper has been the idea of linking systems for solar shading, daylight and natural ventilation in double skin façades using both glazed twin walls and walls with an additional metal screen set forward on the outside. In temperate climates, glazed double skin façades can be used as a thermally insulating layer in winter and as a zone for natural ventilation, with windows opening



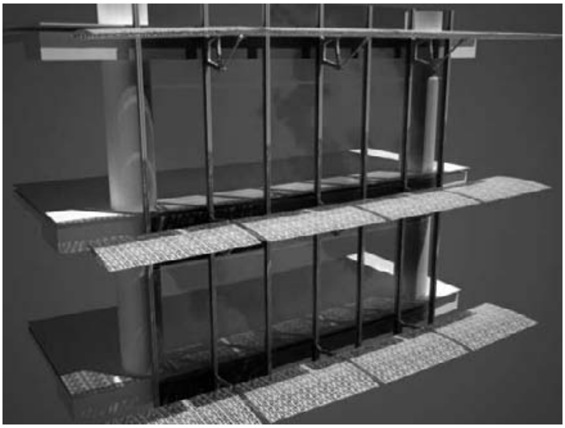
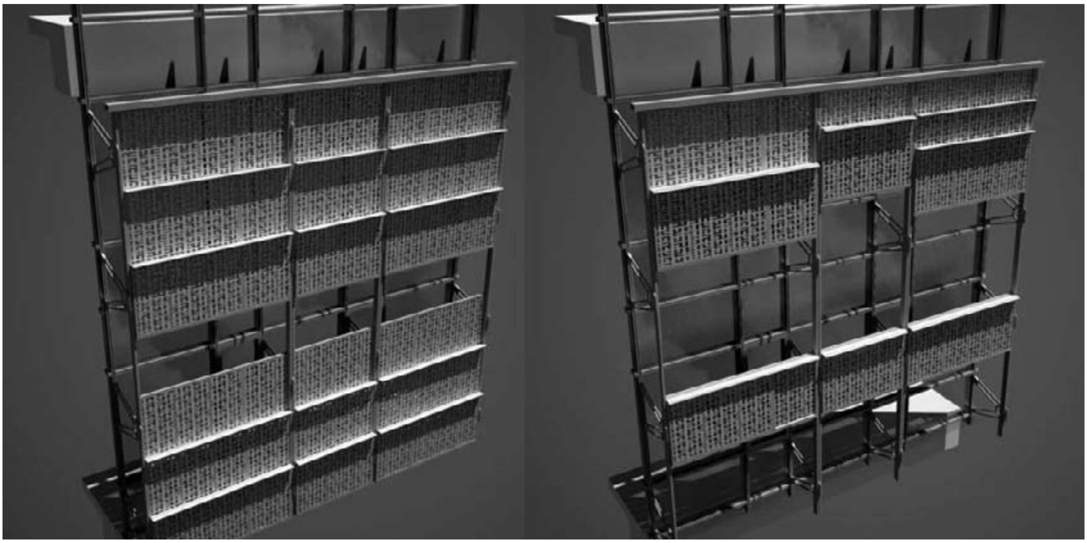


Fig. 32, 33 Office Tower at the Burjuman Centre in Dubai. Panels at edge of façade.

Fig. 34 Office Tower at the Burjuman Centre in Dubai. Panels in middle of façade.

Fig. 35 below: Office Tower at the Burjuman Centre in Dubai. For the apartment buildings at the Burjuman Centre in Dubai, a motorised shading system was used. The west façades experience low angle sun in the afternoon in the winter as well as in mid season. The east façade experiences morning sun at all times of the year. The façades are glazed, with landscaped terraces in all apartments. The glazed façades and terraces are provided with a motorised system of solar shading which can slide vertically to enjoy uninterrupted views out to the desert in the afternoons at all times of the year. Metal panels slide vertically to nest together at spandrel level. Architect: KPF



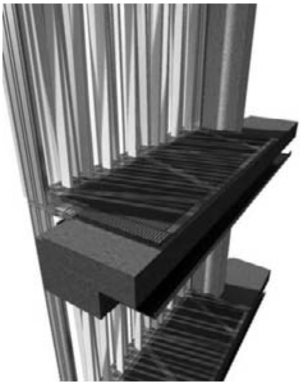
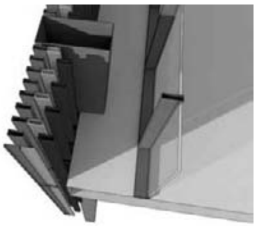


Fig. 36-38 above and below: Office building in hot climate with vertically-set louvres that move to change opacity with varying requirements for shading, daylight and natural ventilation.

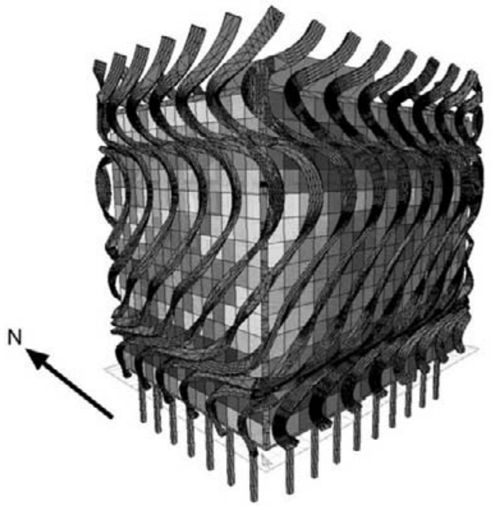


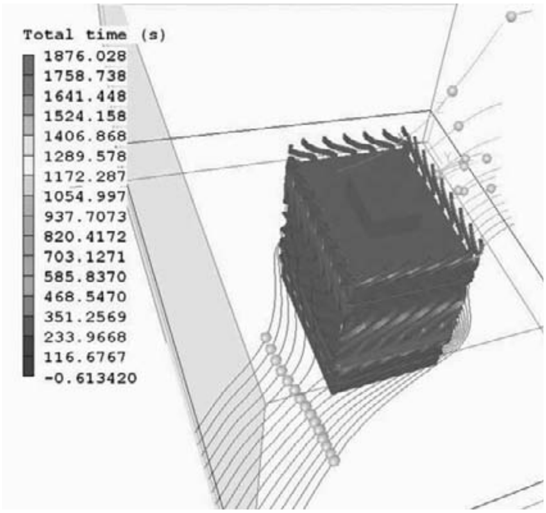
into the cavity, in taller buildings. Glazed double skin façades do not usually perform well in hot climates as their role as a thermal buffer zone is rarely needed, with the glazed void usually trapping heat rather than serving as an effective as a thermal flue. Double skin façades with metal solar shading panels set forward of a glazed wall perform much better in hot climates, allowing the outer screen to absorb and radiate solar energy, while allowing the passage of daylight, and allowing natural ventilation during the winter and part of the mid season, depending on specific location. The ability to provide moving panels allows the system to vary with the time of day and time of year without building users having to continually adjust the shading, though we consider the ability of people to override the controls to be essential to well-being in any building with motorised shading controls.

Where fixed external shading in hot countries is a solution which is optimised to work reasonably well throughout the year but not be continuously high performing, the motorised version allows variable arrangements of panels to suit mixed requirements of solar shading, natural ventilation and daylight.

In the Burjuman project, metal shading panels in the apartments could slide vertically to be either deployed or be stored away, providing a narrow opaque screen at high level in each space within the building. In a project for an office building in Saudi Arabia, the use of motorised blinds was developed by moving elements within a metal shading panel rather than moving the panel itself. This approach allowed varying effects of daylight to be combined with solar shading system set forward of a glazed wall. The blinds covered the building completely, but allowed views out where required through a low density screen. The use of motorized blinds allowed the shading to move to follow the path of the sun around the building, while allow moving to suit specific requirements for daylight within the building. This resulted in rich patterns of light and shade inside the building that varied within these spaces. In addition, the shading allows natural ventilation through the façade during winter months by serving as a wind baffle to deflect the effects of wind gusts. Visually, this produces forms which have a surface which is mainly flat, but which might be folded to create specifically different daylighting conditions within a building. Fixed metal panels were used in a project in Rabat, Morocco, where the shading was fixed, either as shading set forward of a glazed wall or as shading to balconies.

Since double skin façades are difficult to apply successfully in hot climates, even with high performing solar control glasses, as they still allow in significant levels of solar radiation when compared with the case when a modest screen is added to the outside of the wall. This contrasts with temperate climates, where natural ventilation is required for most of the year, but where solar shading is required primarily for summer months and for low level sun in the mid season. This favours the use of glazed double skin façades in taller buildings where natural ventilation is more of a priority, but also favours façades with a layer of variable sized louver panels as used in a school project in London. In this project, the surface depth of the louvres provided a much greater ability to control daylight as well as reduce solar gain, created a modelled façade of varied depth, rather than a flat façade of varied opacity that suits hot climates.





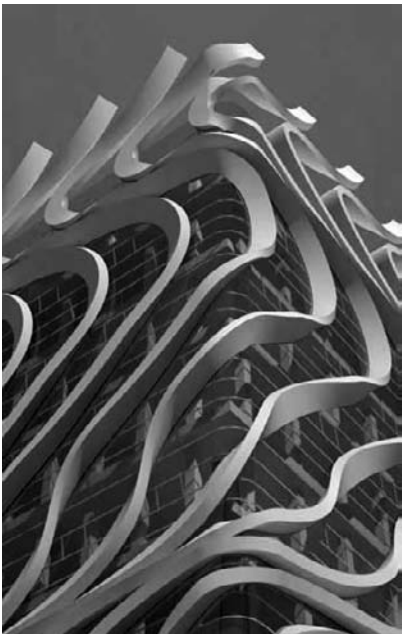


Fig. 39-41 Shaded façade directing air movement away from opening windows.

Fig. 42, 43 Shading of variable depth creates complex geometry to control daylight and provide solar shading.

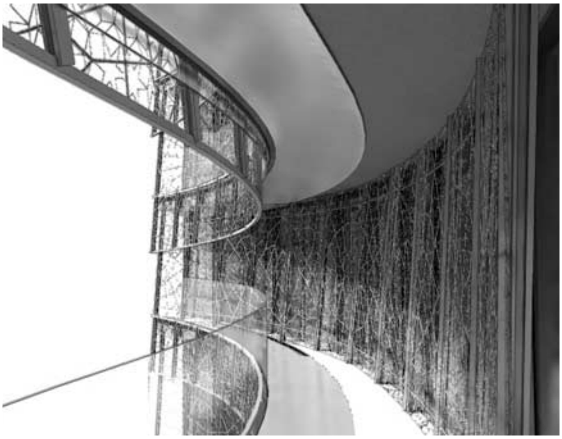


Fig. 44, 45 Shaded metal panels for hot climate.

Over the past decade façade planning has grown to be a firm discipline in the building industry. The façade planning firm Emmer Pfenninger und Partner in Basel, Switzerland supports reknown architecture firms around the world. Based on an amazing series of projects, **Dipl.-Ing. Kurt Pfenninger** answers the question whether climate-orientation has found it splace within avangarde architecture.

The Future Envelope 2 – Architecture-Climate-Skin. U. Knaack and T. Klein (Eds.). IOS Press, 2009.

DEVELOPMENT IN THE TECHNOLOGY OF FAÇADES

Kurt Pfenninger

Emmer Pfenninger Partner AG / Façade Design

Introduction

Worldwide, the development of building envelopes is becoming more complex and is mainly influenced by the following criteria:

- Today's modern and demanding architecture
- Complex geometry of the façades
- New material and techniques
- Increased statutory requirements and standards regarding energy efficiency (CO_2 emission)
- Different demands and requirements in various regions and countries
- Various climatic conditions (maritime, snow, ice, high winds, earth quake, high humidity and temperatures)

In order to fulfil the different criteria in the various countries and regions, the following basic requirements have to be fulfilled:

- Detailed knowledge and high experience of the Façade Engineer
- Special software (3D, simulations) to meet the Architect's requirements
- Continuous development in façade technology, design and systems
- Research on new material and manufacturing/installation process
- Knowledge of local statutory requirements (g-values, u-values, bird protection measurements)

Influenced by Architecture and Geometry

Peek & Cloppenburg, Cologne

The project has a complex geometry, in particular where the vertical façade meets the roof glazing. The external envelope comprises single skin façade in a shingle like pre-fabricated unitised construction out of thermally broken framing and high performance solar/thermal protective insulated double glazing units with special fixing devices installed to vertical secondary structure.

"BMW Welt", Munich

This project has an even more complex geometry and demanded a very high technology, especially regarding nodes and interfacing cross sections. The glazed façade comprises insulated high performance solar/thermal control glazing, partially only with low "E" coating. The façade consists of thermally broken mullion/transom system. The roof mainly comprises an insulated metal decking with rear ventilated aluminium cladding and photovoltaic cell units.

Fig. 1
BMW-Welt, Munich
Architect: CoopHimmelb(l)au, Vienna

Novartis Campus, Basel - "Gehry Building"

Of the various projects we are currently working on, this building has the most complex geometry. In order for us to carry out the design and development of the building envelope, we had to buy a special 3D program, called "CATIA" from Gehry Technologies. All the Engineers and Consultants including the Façade Contractor had to work with the same software in order to solve the very problematic geometry of this building. The entire façade consists of triple glazed high performance solar/thermal control glazing with partial fritting and integrated photovoltaic units. In accordance to the Swiss statutory requirements, a g-value of 0.15 through the glazing and an overall u-value of 1.2 W/m^2K had to be achieved. The solar protection is guaranteed by the high performance glazing, fritting and the translucent photovoltaic cells. The glare device is achieved by an internal automatic operable fabric roller blind in the different geometric sizes. The exhaust air within the building is guided between the internal fabric roller blinds and the glazed skin, thus achieving an increased comfort for the occupants.

Fig. 2
Novartis Campus, Basel
–GehryBuilding
Architect: GehryPartners, Los Angeles

Actelion Headquarters, Allschwil / Basel

This building is currently in the workshop design stage and comprises frameless storey high low "E" thermal protective insulated triple glazing with integrated automatically operated Venetian blinds. The façade system is based on supporting the insulated glazing unit at top and bottom only without using vertical mullions.

In accordance to the latest standard SIA 382, a g-value of 0.08 through the glazing had to be achieved. In order to prove the values, pre-testing was carried out on a typical glazing unit with integrated blinds. The results verified that these g-values can be achieved. The total light transmission through this glazing amounts to approximately 50%.

Fig. 3
Actelion Headquarters, Basel
Architect: Herzog & de Meuron, Basel

Football Stadium, Beijing

This building just shows the complexity of the steel structure and was quite a challenge for the Architect and the Engineers.

Herault Culture Sport, Montpellier/France

This façade comprises pre-cast concrete and glazed curtain walling with feature aluminium profiles in front of glazing. The main difficulty for this building envelope was to solve all the interfacing connections between the pre-cast and the glazed façade running at different angles. Sun shading and u-values are much less critical in France and were achieved by the brise-soleil and the solar/thermal control glazing.

Swiss Re, London

The building envelope comprises an exhaust air double skin façade with low "E" coated double glazing on the exterior and a single skin on the interior with Venetian blinds in between. As the climate is very moderate in London (-4°C in winter, +28°C in summer), the u-values and g-values were not so critical. However, low "E" glazing had to be used to prevent condensation within the cavity. The external skin has been made out of pre-fabricated unitised system with thermally broken framing members in a diagonal shape. The internal screen included single glazing with sliding windows, installed vertically. The member of the main structure of the building is located between the double skin façade.

Fig. 4
Swiss-Re, London
Architect: Foster + Partners, London

Fig. 5
Paul Klee Museum, Berne
ARGE ARB Arbeitsgruppe Bern / Renzo Piano, Paris

Paul Klee Museum, Berne

The façade comprises insulated double glazing units with external cantilevered fabric roller blinds. The glazed façade is constructed in a thermally broken mullion/transom stick system. Due to high deflection of the building steel structure, special joint connections had to be developed for the façade system.

Prada, Tokyo

The Prada project consists of a diamond shaped single skin façade with special bubbled/curved insulated double glazing units with a high performance solar/thermal protective coating.

Fig. 6
Prada, Tokyo
Architect: Herzog & de Meuron, Basel

Euskotren, Durango/Spain

The façade for this building is still in the design stage. The geometry of the façade has been simplified from a very complex stainless mesh to aluminium gratings in different shapes. The façade comprises of unitised system with high performance solar/thermal control double glazing and external walkways with gratings acting as shading and providing the required aesthetical features.

Fig. 7
Roche, Bau 1, Basel
Architect: Herzog & de Meuron, Basel

Roche "Bau 1", Basel

This building is still in the scheme design stage and the façade is still undergoing different concept designs. The geometry and in particular the external cleaning access is very difficult and needs further detailed studies. In accordance to SIA 382/1 and an anticipated glass area of 80%, the following g-values have to be achieved:

g-value < or = 0.08 (8%) for the East, South/East, South, South/West and West orientation of the building
g-value < or = 0.15 (15%) for North/East and North/West elevation of the building
g-value < or = 0.25 (25%) for the North elevation of the building

It is anticipated that the building achieves "Minergie" standard "P", thus an average u-value over the entire envelope of 0.90 – 1.00 W/m^2K has to be achieved.

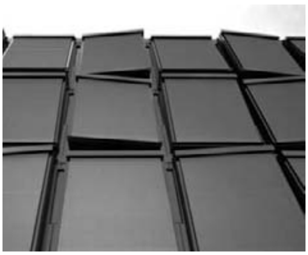


Fig. 8
Helvetia Patria, St. Gallen
Architect: Herzog & de Meuron, Basel

"Reichstag", Berlin

The skylight dome comprises single glazing with ventilation cavity constructed with overlapping glazing units. The refurbishment windows on the main building of the "Reichstag" comprise double skin with sliding windows for cleaning and ventilation purpose.

Helvetia Patria Insurance Company, St. Gallen/Switzerland

This building includes high performance triple glazing units; external special roller blinds resisting to over 50 km/h wind speed and openable casements for natural ventilation. The façades are installed in different angles to provide a special architectural image.

Influenced by Technology, Design and the Façade System

"Home of FIFA", Zurich

The building envelope comprises of an external combined stainless steel/aluminium mesh, fixed at an angle with tension cables. The primary façade consists of thermally broken system with incorporated triple low "E" thermal protective glazing units with opaque operable casements for natural ventilation. Cleaning can be carried out from walkways which are fitted between external mesh and primary façade system.

Fig. 9
Home of FIFA, Zurich
Architect: Tilla Theusund Partner, Zurich

Different Sun Shading Devices

Here, we show different sun shading devices, one being a new metal roller blind with special prism louvers and the others with Venetian blinds integrated into triple glazing units. From an energy point of view, in particular considering the cooling of the building, it is still the most efficient way to use external operable metal blind allowing sufficient ventilation between blinds and the face of façade. However, for aesthetical reasons, such blinds are not anymore a preferred solution. On almost every project, the shading device is an important issue, in particular as the total energy transmission through the external skin has continuously been reduced over the last few years. In Switzerland, a reduction of the required g-value from 0.15 to 0.08 has taken place. We find similar tendency in many other countries these days. Unfortunately, not much further development has been achieved for movable protection devices. The glazing industry however, is continuously developing on better high performance coating, increasing the daylight transmission and achieving better g-values.

Fig. 10
High performance roller blinds "CTB" by SCHÜCO

Courthouse Madrid

We have been closely working with the Architect in the competition phase and the team was successful and won the project. Due to the geometry and the required architecture, we have developed special panels, manufactured in deep drawn press method. The façade behind the panels will be storey high glazing with possibly integrating sun shading device within the cavity.

Novartis Campus, Shanghai

This is a very exciting project using natural vegetation on the roof to provide shading and a very natural feeling to the occupants. The geometry is very difficult and many of the interfacing connections still need to be solved.

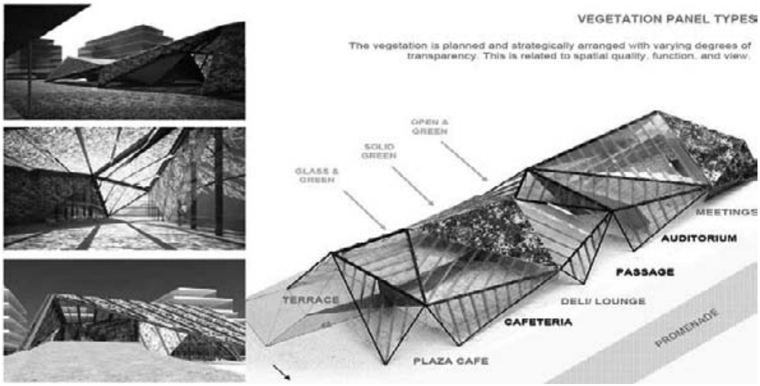


Fig. 11
Novartis Campus, Shanghai
Architect: KengoKuma& Associates, Tokyo

Application of Different Materials for Building Envelopes

Very often, we are confronted with the use of different materials, such as fabric membranes, carbon fibre, specially fritted glazing, terracotta cladding, timber, translucent stone, cast aluminium, specially formed glazing, colour interlayer, holographic glazed panels, natural stone plaster, etc.

Fig. 12
Forum 3 –Novartis Campus, Basel
Architect: Diener + Diener Architekten, Basel

The various pictures show some examples of different materials being required. As Façade Consultant, it is one of our major tasks to investigate the different materials and to review the life expectancy, maintenance, cleaning, aesthetical deficiencies, etc. This is to advise the building owner and the Client whether or not the different materials will meet with the Employer's requirements.

As regulations and requirements vary in the different countries, in particular regarding the climatic conditions, the fire and thermal requirements, it is our duty to investigate the various materials to be used. A typical example is the use of untreated wood for external walls. It is much more suitable to use timber material for the external use in Northern countries or at higher altitude with long and cold winter conditions. The danger in using untreated timber at lower altitude or warmer climate is the growth of fungus destroying the material.

A further example is the use of fabric membranes where high fire rating requirements prevail. This means that some material can easily be used for instance in the Emirates, but in no way in Germany or in England as these countries have much higher fire rating requirements.

Fig. 13
“ChesaFutura”, St. Moritz
Architect: Foster + Partners, London

Influence by Statutory Requirements and Standardisation

The standards and statutory requirements also differ in the various countries. Currently, all countries are increasing their requirements on solar protection and thermal properties. The work place guidelines also differ from country to country and even within the different regions.

Fig. 14
Basel “Grand Hotel Dolder”, Zurich
Architect: Foster + Partners, London / Itten+ Brechbühl, Zurich

For the “Taniguchi” Building at the Novartis Campus in Basel, we were not allowed to use fritted stripes on the glass panes due to the “Moirée effect” (= disturbing view when looking through the glazing). Even the position of the dot fritting and the colour had to be agreed by the inspector of the “Department of Employment” here in Basel.

Extract of Different Projects

In the following pages, different projects in various countries are shown in which we are involved as Façade Consultants. The projects include glazed façades, façades with punched out windows and stone cladding, façades with horizontal sliding windows and balconies, single and double skin façades (exhaust air and climate façade)

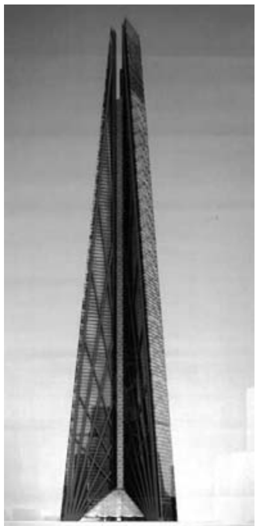


Fig. 15
Moscow City Power, Moscow
Architect: Foster + Partners

Demands on Future Envelopes

When designing and constructing future building envelopes, the following demands will have to be considered

- increased protection measurements on solar gain
- overall u-value of façade system to be reduced (i.e. less transparent areas, increased performance on framing members, insulation and glass edges)
- Variable sun shading device meeting the aesthetical demands of the Architect
- The integration of semi-transparent/translucent materials to allow visibility to the exterior, but achieving sufficient solar

protection

- Adjusted geometry of external envelope to consider the position and progression of the sun
- High comfort to occupants and possible integration of cooling and heating concept
- The orientation of the building to take into account the solar gain and thermal properties
- Reduction in cost by optimising unitisation of façade components
- To use material with a high sustainability, such as timber (to grow again) or recyclable material
- Compliance to international standards and quality procedures
- Façade components with low maintenance and cleaning requirements
- Long term life expectancy of material and surface finish

Influence of Building Envelopes regarding Climatic overall Concept of a Building

Buildings, especially with the increased architectural demand on a high percentage of transparency and the more complex geometry of today's and future façades will provide a conflict between the continuously increased demands on insulation and solar protection, required by the Authority (reduced CO_2 emission worldwide). This will definitely have an influence on the future climatic concept of the buildings.

Closing Words

The ongoing development in the Engineering of different building envelopes and the increased demands on architectural requirements assure also in the future a challenging working field for the Façade Engineer and indeed for the Façade Trade Contractor and System Supplier.

The Delft architecture firm, **cepezed,** claims to use an integral design method with multiple material use in which various aspects such as spatial design, construction and installation techniques are forged into an indivisible whole. cepezed preferes construction elements which are prefabricated, wherever possible. The application of components produced industrially and under controlled production circumstances has a favorable effect on both the functionality and sustainability of buildings, and also offers great gains in the domain of process control. It leads to less use of materials and less transport, demountability and in this way is a strong contribution to climate oriented architecture.

For future façades we can expect a higher grade of adaptability and the integration of building service components. High quality standards, laws and regulations, the certification and warranties will lead to an even be more product-driven approach. From the architectonic point of view this leads to applications of systems rather than free compositions of materials. cepezed embraces a product-oriented architectural thinking and in this sense their work is an interesting contribution to this book.

This essay by **Els Zijlstra** is an excerpt of the book on the work of cepezed – entitled Prototypes, published by 010 publishers in 2007 and shortlisted for the RIBA Book Awards 2008 for excellent writing on architecture.

Previously published In: Vollaard, P. (Ed.): Prototypes, The Work of Cepezed, 010 Publishers, Rotterdam 2007

PRODUCT DEVELOPMENT

Els Zijlstra

for cepezed architects

cepezed designs lightweight buildings that offer an optimum working and living climate with a minimum of materials and installations. Existing products are not always adequate for realizing such buildings, and it is occasionally necessary to develop new construction elements and building components.

cepezed has created a number of designs that have been mass produced, such as the transmission mast for KPN (1995) and an extended seat for Artifort (1998). The built-in system for the Primafoon telephone shops (1983) and the modular system for the distribution centres of PTT Post (1998-2002) were oriented to mass production. The (building) products discussed in this chapter, however, arose as a response to project-based design assignments. In other words, they issued from specific situations that arose with a certain design. Discounting isolated trial models that were applied prior to their first application, they followed the procedure that the architectonic product also follows: the prototype was directly the realized product. There was no time or budget available for an experimental series. However, these are no true prototypes. The further development took place when the product was again used in later designs.

The initiative for the vast majority of newly-developed building products comes from the industry itself and is, at most, influenced by demand from the market. However, cepezed is an active external party that not only stimulates industry toward innovation but also plays a designing and developing role itself in such renewal. In many cases, co-operation takes place with industries outside the particular sector, and technologies that are not yet in common use in the construction industry, but are already in use in other sectors, are utilized.

Sandwich panels

Nowadays, sandwich panels are a self-evident part of the assortment of building products. cepezed was one of the first architectural offices to apply such panels in construction. The direct motivation for this was the extension of the premises of Van de Wetering Port Repair in Rotterdam (1981). (fig. 1) In view of the fact that this concerned an office extension on the roof of an existing building, a lightweight construction was required. At that time, the extension would have been almost impossible with the traditional building products available at that time.

Fig. 1
Extension to Wetering Port Repair in Rotterdam, 1981. This type of lightweight panel was originally used in refrigerated trucks.

The solution was found in the panels by means of which the Heiwo Company from Wolvega constructed its refrigerated trucks. These satisfied extremely high insulation requirements and were also lightweight. cepezed investigated the extent to which the high-quality panels could be used in the construction industry. Initially, one had doubts about their strength and rigidity, but these were confirmed in trials by having a number of people stand on the panels that were supported at the ends. The first application turned out to be a success and the co-operation with Heiwo was continued in the development of a modular housing system that could be mass produced: the Heiwo House (1982). In the meantime, the self-supporting sandwich panel has become an important component of cepezed's façade typology.

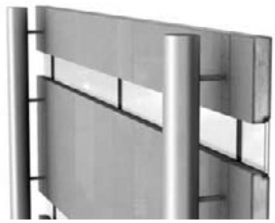


Fig. 2
Langerak commercial premises in Utrecht, 2001. The sandwich panel is constantly evolving. This design uses a panel that takes the load on the windows, as well as all the other external stresses. The profile of the panel edge also seats the glass.

The panels possess various degrees of load-bearing capacity. By far the most common application is a stiff panel extending from column to column that conveys all the forces without an auxiliary construction of struts or joists. For projects such as the High-tech Centre in Nieuwegein (1987) or the commercial premises for Langerak (2001), a particular panel has been used that also bears the weight of other construction components such as the windows. (fig. 2) In a third application, the sandwich panel forms a part of the main supporting construction. This is the case with the detached government-subsidized housing developed for Haarlem (1986), in which the sandwich panels are only interconnected by means of

Fig. 3
In the detached government-subsidized housing, the sandwich panels form a part of the main load-bearing construction; the panels are only connected by slender angle sections

thin angle sections. (fig. 3) On an odd occasion, the panels are glued together in such a way that they themselves form the main load-bearing construction. This happened with the extension of Van de Wetering Port Repair and will be applied again in a chain of car-wash facilities that are currently being designed. (fig. 4)

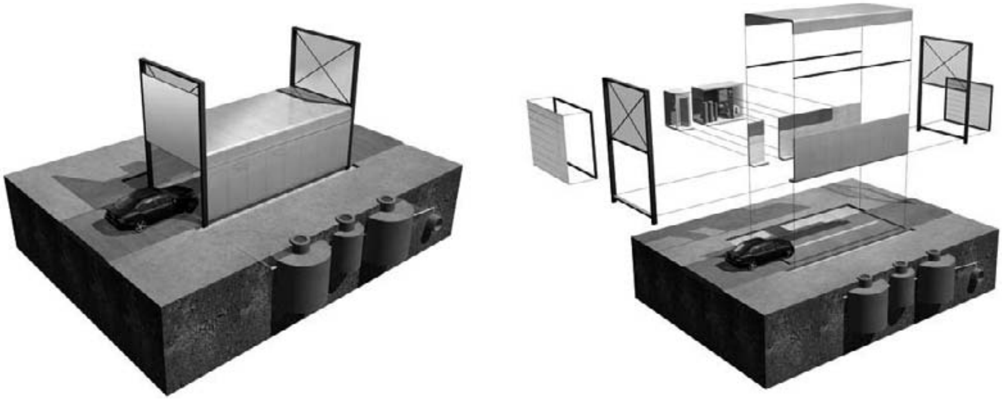


Fig. 4
On a few occasions, the sandwich panels have been glued together in such a way that they themselves form the main load-bearing construction. This is also the case with a chain of car-wash facilities that are currently being designed.

The structure and composition of the sandwich panels are subject to a continual process of improvement. Depending on the circumstances and the period, polystyrene, polyurethane foam (PUR) or rock wool are used as insulation. The plating, the mounting, and the edge-finishing have evolved in the course of time. Where the older panels were equipped with a simple tongue-and-groove connection, curved and glued variants were used for the commercial premises of Porsche in Stuttgart (2000) and Langerak in Utrecht (2001). Here, the setting of the panel edge also forms the mounting slot for the glass. More recent versions are equipped with aluminium mounting frames built into the panels, by means of which they function, along with the window sections, within an integral façade mounting system that is sealed off with rubber sinews at the joints.

With the distribution buildings created for PTT Post, the most conspicuous façades are furnished with an enamelled extra glass front. In conjunction with Rockwool and ZNS-Van Dam Innovative Metal Solutions (formerly Van Dam Plaatwerken) this invention has been further developed into a sandwich panel with an extremely thin adjustable joint and external plating made of glass. (figs. 5, 6) This panel was applied in the Porsche factory in Leipzig (2001), the commercial premises from Anker Drukkers in Lelystad (2002), and the radio studios of the VRT in Kortrijk and Hasselt (2004). At Westraven, the renewed office block of the Department of Public Works in Utrecht (2007), the integrated mounting system has been combined with stainless-steel plating for the first time.

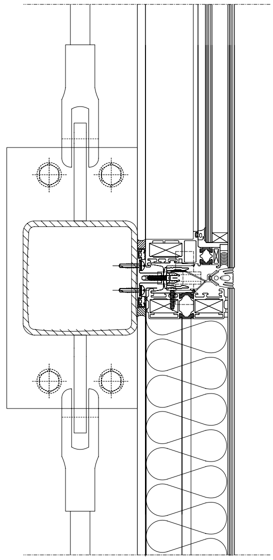


Fig. 5, 6
Anker Drukkers, Lelystad
Glass sandwich panel used in the Porsche factory in Leipzig, the VRT broadcasting studios in Belgium, and at Anker Drukkers (Printers) in Lelystad in the Netherlands. A thermally interrupted aluminium edge profile has been built into the panel.

An unorthodox variant was developed for the P22 office building at Schiphol Airport (2007). Due to the parking facilities in the lower storeys, this building has a minimum of columns. The floors span no less than 16.20 metres and thus have a relatively large flexure. The sandwich panels of the façade bridge this distance in one go, and are directly mounted in the main load-bearing construction. They consist of a frame of steel trusses, have internal steel plating, and black anodized aluminium external plating. Standard rock wool insulation has been used between the plating. The façades and floors are not interconnected, so that the latter can bend freely without exerting stress on the glass façade sections that are mounted without frame struts between the sandwich panels.

Climate screens

The desire to realize an optimum interior climate with a minimum of installations led, among other things, to the development of further façade innovations in the form of various kinds of climate screens: second façade screens that are installed on the exterior in front of the actual thermal façade. cepezed has used these repeatedly. They reduce infiltration of sound, wind and sun, and diminish the nocturnal radiation of heat from a building.

Fig. 7
Windscreen on the Plein der Verenigde Naties in Zoetermeer, 1992. The perforated screen, which formed the basis of the later double-skin system, yields considerable wind reduction while being largely transparent.

cepezed first gained experience with the application of screens with the layout of the Plein der Verenigde Naties in Zoetermeer (1992). (fig. 7) The square had to be protected from the wind, and a perforated aluminium screen was used for this purpose. The perforation ensured that the partition remained largely transparent, while a substantial reduction in the force of the wind was achieved.

The screen in Zoetermeer became the basis of the later dual-skin system in cepezed's designs. The first fully-fledged application took place at the Centre for Human Drug Research (CHDR) in Leiden (1995), a relatively small building between two elongated, semi-transparent screens of perforated steel. (figs. 8, 8a) The whole unit looks rather closed, an appearance reinforced by the closed sandwich panel façade at the end of the building. From the outside, the screens appear to be rather opaque. The silhouette of the building looms vaguely through the 'veil'. However, from inside the building one can look outside without difficulty and the screens suddenly seem to offer a large degree of openness and transparency.

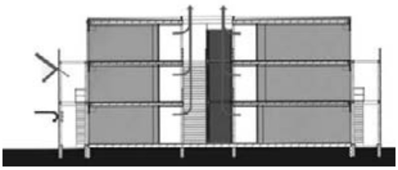


Fig. 8, 8a
Centre for Human Drug Research (CHDR) in Leiden, 1995. This was the first fully-fledged application of a second skin.

The generous proportions of the screens make the modest building look larger than it actually is, so that it harmonizes well with the urban context and the scale of the buildings in the immediate surroundings. The lateral façades of the building consist almost completely of large, transparent, glass sliding fronts. The spaces between the screens and the façades function as sheltered exterior areas and also serve as escape routes should fire break out. The screens extend further than the building itself, thus allowing scope for a closed, sheltered garden and an entrance area at the ends of the building. In 2004 – as foreseen – the building was extended by around 50% within the contours of the screens without the total appearance essentially changing.

The screens play a major role in the climate control of the building. Because they ward off the wind, the sliding fronts can be opened without causing inconvenience, even in high winds. Because the building's installations, the office equipment and the people themselves radiate a great deal of heat, buildings generally have to be cooled rather than heated. In this case, that takes place by means of natural ventilation via the sliding panels. It is only necessary to heat the building in the morning. For this purpose, radiation panels have been installed in the ceiling along the façades.

In addition to the previously mentioned functionality, the screens also offer a number of climatic benefits. While retaining the view, they also filter out a great deal of inconvenient sunlight. In addition, they function as a buffer: it the winter they prevent rapid radiation of heat from the building to the cold exterior air, and in the summer they protect the building against a surplus of heat from the sun. In practice, the screens enable energy-savings of around thirty per cent.

A good view through the screens required a special approach. The extent to which the screens appear to be almost entirely 'transparent' from the inside is determined by the interrelationship of various factors. (fig. 9) First of all, the resolution of the eye, or the minimum distance at which two lines or points can be distinguished. In addition, the distance to the screen is also important. The size of and mutual distance between the holes also plays a role. With a transparency of 50%, a degree of perforation has been realized that makes the separate holes no longer perceptible at a distance of two metres. The round perforations have a radius of 3 mm, a heart-to-heart size of 4 mm, and they have been applied in a triangular pattern. The relatively thin plate thickness of 1.5 mm prevents the holes closing quickly from a diagonal point of view, so that the view is retained even at this obtuse angle. Because normal vacuum spray paint technique carries the risk of sealing off the holes, the screens

Fig. 9
Perforated steel screen, details.

were sprayed by a car-spray company using an electrophoretic technique.

The climate screen has evolved in the course of time, due to its application in various projects. A hardened glass variant with a screen-printed mesh pattern was applied at cepezed's own office in Delft (1999). (figs. 10, 11) The most recent version was developed by the renovation of the Westraven office building in Utrecht. One

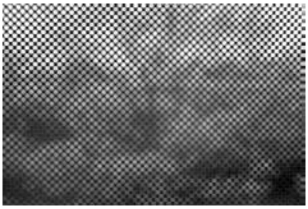


Fig. 10
Hardened glass screen of the cepezed office.

Fig. 11
cepezed office in Delft, 1999.
A hardened glass screen with a screen-printed mesh pattern has been applied as a second façade

of the starting points for this renovation was a wholly new climate system by means of which the climate of each workstation could be individually regulated.

The original façades were completely replaced by new ones with large glass surfaces so that the incidence of daylight as well as the view was greatly improved. Due to the fact that large parts of the façade can now be opened, the offices can be partly ventilated in a natural manner. In order to be able to open the windows on the upper floors, windbreaks are needed. A number of concepts

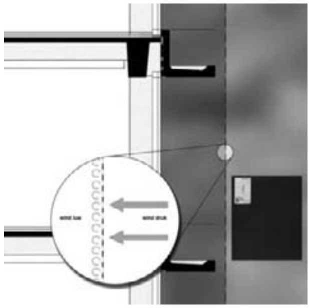


Fig. 12-14
Westraven office complex in Utrecht, 2007. A second skin of sun and wind-resistant, open-weave teflon-coated fibreglass fabric was developed for the high-rise section of the complex. At eye level, the fabric alternates with glass strips. The fabric evokes a rather closed impression from the outside, but nevertheless allows a good view of the external world from the offices themselves.
The force of the wind is neutralized into minor turbulence immediately behind the fabric. As a result, the cavity between the fabric and the thermal façade cloth becomes a sheltered area, which makes it possible to open the windows, even at great heights, without suffering from troublesome draughts.

for improved façades were formulated, and a choice was made in favour of a façade with a dual skin of sun and wind-resistant, open fibre-glass wrapping with a coating of PTFE (teflon). (figs. 12-14)

Just like the CHDR screens, this dual-skin façade offers the benefits of wind and sun-resistance, and direct ventilation by means of natural airflows. In addition, the system is much lighter than the steel screens and thus requires much less construction. A disadvantage is the fact that the wrapping has few soundproof properties. The greatest noise pollution, however, comes from the traffic on the A12 motorway, on the north side of the building, where there is no inconvenience from the sun. Accordingly, the second-skin façade has been made of transparent glass here.

The application of a textile second skin involves a number of severe technical and functional criteria, certainly on a scale such as that of the Westraven building. In functional terms, the wrapping must ward off the wind and the sun, while at the same time being sufficiently transparent and airy. In technical terms, the criteria are more complex. The wrapping must be durable, retain its colour, and repel water, grease and dirt. The textile must be able to withstand the vagaries of the weather, mildew, rust and insects, and must be easy to clean. In addition, any risks of ice-forming have to be kept under control and the wrapping should not shake or flutter to a disquieting degree.

There are many types, qualities and applications of architectonically deployed textile. For instance, open-weave canvas is used in horticulture as a wind-break: via the small holes, the force of the wind is converted into small turbulences behind the canvas. The textile used for Westraven is of an extremely high quality; in tightly-woven form it is applied mainly as façade wrapping or roof spanning in large-scale and durable projects such as architectonic tent constructions.

In matters of translucency and view from inside to out, the façade wrapping is also subject to a combination of factors. The difference between the light intensity inside and out, the colour and the degree of reflection of the wrapping, and the angle of incidence of sunlight also play a role. Furthermore, the distance to the wrapping and the size of the mesh and thickness of the fibres in relation to the human eye are also determining factors. Because the wrapping is thinner than the steel screens of the CHDR, the view remains good at even more obtuse angles.

Integrated floors

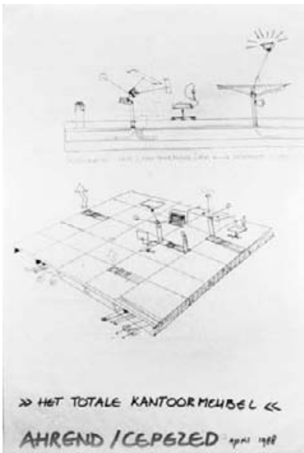


Fig. 15
Sketch of Ductile, the steel floor and workstation system with integrated furniture and ducts that cepezed developed in the eighties, in conjunction with Ahrend office furnishers.

Besides the renewals in the field of façades, cepezed has also realized a number of innovations in floor technology. Once again the office worked in close co-operation with other parties to generate a new product, this time a number of floor systems with integrated facilities.

In the 1970s, the previously mentioned ZNS-Van Dam Company used rockwool-filled steel cassettes to make explosion walls for the offshore industry. In 1988, based on this cassette principle, and in conjunction with Van Dam and office furnisher Ahrend, cepezed developed Ductile, a steel office-cum-workplace system with integrated furniture and integrated pipes and ducts. (figs. 15, 16) Because the integrated ducts were accessible almost everywhere in the floor area and the office elements could be placed at any position, the system offered a large degree of user flexibility. However, it was never actively introduced on to the market and never really applied.

More than ten years later, the system was simplified for cepezed's

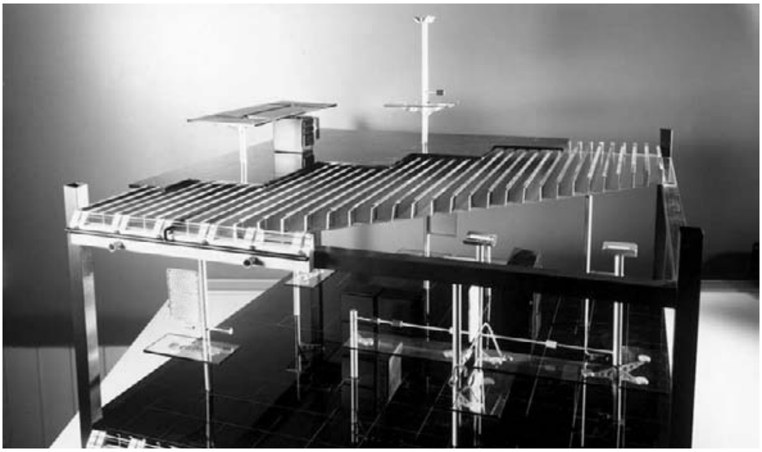


Fig. 16
The integrated pipes and ducts are accessible almost everywhere in the floor surface, and the office elements can be installed according to a flexible layout. As a result, the Ductile system offers great user flexibility.

own office in Delft, becoming a system in which the integrated furniture was omitted and the cassette system was combined with a variant of the steelplate anhydrite floors that were applied in the semi-detached houses in Delft in 1990. (fig. 17) IDES (Integrated Deck Extra Space), as the new system is called, is more generally applicable than the former Ahrend floor.

The IDES system consists of steel cassettes that rest upon asymmetric beams with a broad bottom flange. Ridged steel plates with a covering layer of anhydrite lie transversely across the cassettes on rubber strips. The lower side of the cassettes represents the ceiling finishing for the storey below. The hollow floor contains insulation material, it functions as an air reservoir, and enables the distribution of data and electricity cables. Due to its layered structure, the floor easily satisfies the criteria for fire-resistance and soundproofing. The floor is lightweight, facilitates a completely free layout of the office floor, and including ceiling finishing, is only 300 mm thick. As a consequence, the cepezed office can accommodate an extra storey within the authorized building height. (fig. 18)

IDES is a flexible system that is constructed from made-to-measure individual elements which can be put together either at the building site itself or in the factory. For building sites with logistics or spatial restrictions, it is occasionally more convenient to assemble all the elements on location, whereas more advanced prefabrication with elements already assembled in a 'plug and play' system may be more efficient with larger projects with greater surfaces, or projects requiring many similar activities.

The lessons on flexibility and integration that were learned in creating the Ahrend floor and the IDES system are now applied to existing products from other producers wherever possible. For example, the possibilities of the common Wingplate floor, produced

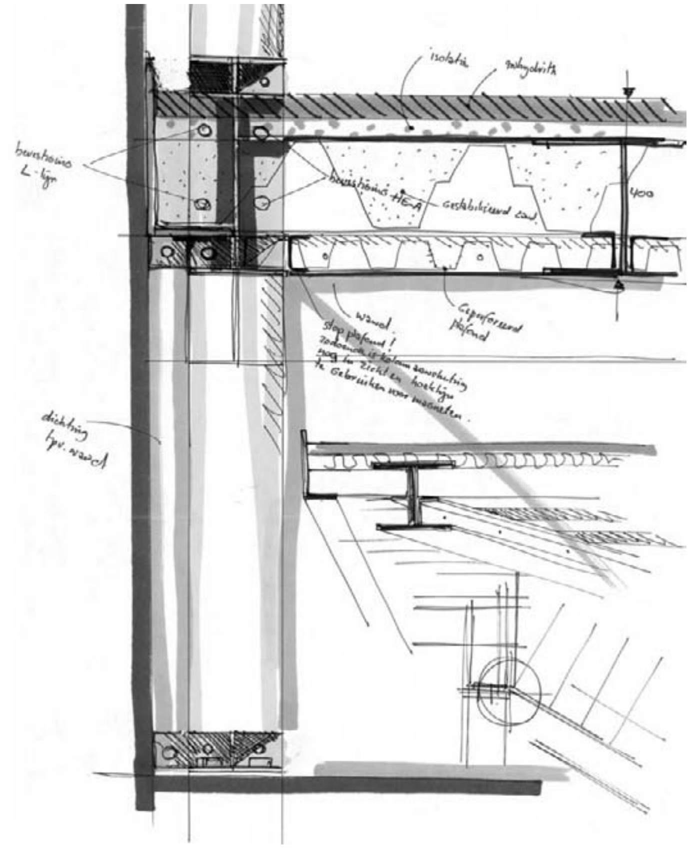


Fig. 17
Steel plate anhydrite floor
Applied in the semi-detached houses in Delft. The floor consists of profiled sheet piling filled with stabilized sand and a covering layer of anhydrite. This system is precursor of the IDES floor system.

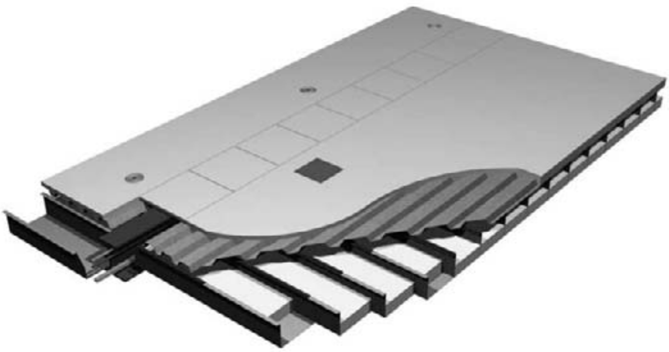


Fig. 18
Integrated Deck Extra Space (IDES) floor
Light-weight and only 300 mm thick including ceiling finishing. As a result, the cepezed office in Delft could be given an extra storey. The floor consists of hollow cassettes that rest upon asymmetric I-beams whose lower flange is wider than the upper one. The lower side of the cassette is simultaneously the ceiling finishing of the storey below. Ridged steel plates with a covering layer of anhydrite lie transversely across the cassette strips. The hollow floors contain insulation material, are fire-resistant, and contain all data and electricity cables and installation system ducts.

by Betonson, were used to the full for the Westraven office building in Utrecht. (fig. 19) The hollows in the channel plate sections of this hybrid concrete element have been drilled in transversely, so that more space to accommodate ducts has been created. In this way, all the pipes and ducts for electricity, data, air conditioning, the sprinkler system and other installations can be integrated in the floor itself, and it is no longer necessary to have a lowered ceiling to conceal the residual ducts. The practical workability of those complex and demanding Wingfloor applications has been demonstrated by

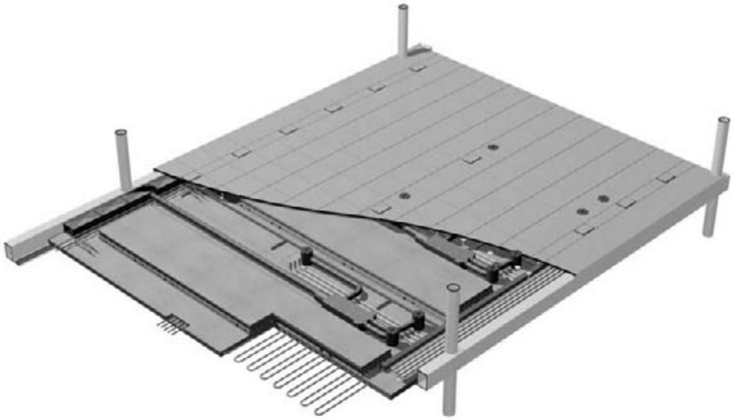


Fig. 19
Wing slab floor
In the low-rise part of the Westraven office complex, the existing prefab Wing slab floor system has been optimized and combined with an efficient engineering of the installation components. This has made it possible to pack all the supporting, structural, and technical-installation components into a space only 315 mm high. As a consequence, a gross storey height of 3150 mm and a usable height of more than 2700 mm could be realized.

means of calculations, detailed 3-D simulation drawings, and 1:1 trial set-ups.

Floors and façades combined

In the future, further investments of design expertise in innovative floor and façade concepts can lead to exceptional combinations by means of which even more benefits of a building-technical, climatological and energy-oriented nature can be realized.

For example, for the past few years, cepezed has participated in the development project entitled Zonwel (which translates literally as 'Sun well'), which is directed toward façade technology that aims at halving the energy performance coefficient (epc) and thus the energy use. The starting point is that the skin of the building is the place where the most important separation of climates occurs, and that it is sensible to situate the climate installations here. Zonwel is intended to make optimum use of the radiation of heat and light from the sun and offers the opportunity to create completely decentralized installations that can be adjusted individually in each space. A building manager thus no longer regulates the same climate for all users of the building.

The heart of the Zonwel façade is formed by the so-called 'Smartbox', a box accommodating a large concentration of advanced technology. Besides a heat pump and a number of electrically powered ventilators, a heat exchanger has also been included to make use of the temperature differences between inside and out, and preheats or cools fresh air with the assistance of the used air. The exchanger also recuperates the latent energy of the moisture in both the interior and the exterior climate. Accordingly, much energy that would normally be lost is reused. The box ought to be placed at the junction of the façades and the floors. (figs. 20, 20a) This means that, in the building itself, the façades remain completely free of obstacles between the floor and the ceiling. In addition, the boxes fit in to the floor surface exactly, so that it is easy to form combinations with integrated floors in which the data and electricity cables are distributed. No large installation areas are thus needed for the climate systems. Ceilings no longer need to be lowered to accommodate pipes and ducts, so each storey occupies less height.

As mentioned, all the above-cited developments, with the exception of the Zonwel façade, arose as a response to project-based assignments; the prototype was directly the final product. None the less, the one final product was more suitable for mass production than the other. For example, the sandwich panels have been mass produced for quite some time. The IDES floor system is also available as a mass-produced item. The steel climate screens that were designed for the CHDR are not mass-produced, but the

Fig. 20, 20a
For the junction of the floor and façade, the Zonwel project developed a box containing all the necessary installations. The climate of the interior spaces can be regulated on a completely individual basis, and the façade between the floor and the ceiling remains free of obstacles.

principle is widely used in all kinds of forms and materializations. A producer has now introduced the textile climate wrapping that cepezed conceived for the Westraven building.

Innovations in architecture arise mainly as a consequence of developments within technology and the production of construction components. cepezed actively contributes to this process by seeking the most suitable solution to the design assignment in each project. This often leads to innovative concepts, material applications and material combinations by means of which other parties in the sector can also benefit.

The Future Envelope is not conceivable without a direct and strong contribution to the climate concept of the entire building and the building environment. Climate design is one of the younger disciplines that relate to façade construction. **Prof. Dipl.-Ing. Matthias Schuler** is professor at Harvard, Graduated School of Design, Dep. of Architecture, and principle of his company Transsolar, has been involved in this subject matter for over 15 years. His projects are astonishing examples of how the performance of facades can be tailored to the requirements for energy consumption and comfort. If façade design is the micro level, urban planning is macro. In this paper Matthias Schuler explains why a successful sustainable build environment will have to start here.

The Future Envelope 2 – Architecture-Climate-Skin. U. Knaack and T. Klein (Eds.). IOS Press, 2009.

REQUIREMENTS FOR CO2 NEUTRAL BUILDINGS AND CITIES FROM MICROCLIMATE TO THE FAÇADE

The Masdar Development –Climate engineering for a carbon-neutral city

Matthias Schuler

Transsolar / Climate Design

The role of Transsolar in the design team for the master planning phase of the world's first carbon-neutral city.

Client: Masdar, Abu Dhabi
Area: 6.5 km²
Architect: Foster & Partner London, UK
Infrastructure: WSP Group plc, London, UK
Renewable Energies: ETA - Renewable Energies, Florence, Italy
Transportation Consultants: Systematica, Milano, Italy
Climate Engineers: Transsolar Energietechnik GmbH

Introduction

In 1998, WWF began its Living Planet Reports showing the state of the natural world and the impact of human activity upon it. The 2006 edition of the report confirms that we are using the planet's resources faster than they can be renewed – the latest data available (for 2003) indicate that humanity's Ecological Footprint has more than tripled since 1961. Our footprint now exceeds the world's ability to regenerate by about 25 percent. The other index in the report, the Living Planet Index, shows a rapid and continuing loss of biodiversity – populations of vertebrate species have declined by about one third since 1970. The message is clear: we have been exceeding the Earth's ability to support our lifestyles and we need to stop. If we do not, we risk irreversible damage. The biggest contributor to our footprint is the way in which we generate and use energy. The Living Planet Report indicates that our reliance on fossil fuels to meet our energy needs continues to grow and that greenhouse gas emissions now make up almost half of our global footprint. A significant part of this global footprint is used by the buildings we live and work in: about 40 percent of the world's energy is used for heating, cooling, and lighting buildings.

As with the growing worldwide recognition of the impacts of this energy use, Transsolar's views of its own role has grown, too. More than 15 years after Transsolar was founded, our purpose of climate engineering for buildings has changed from a focus on passive strategies and energy efficient systems to include how these principles fit into the global context.

Masdar City Master Plan

As member of the design team - consisting of the architects, traffic planners, infrastructure and renewable energy systems engineers and us as climate engineers - for the Masdar City Master Plan in Abu Dhabi, we developed a new and most holistic approach of defining sustainable urban development: The six square kilometer city, designed by Foster and Partner for the Abu Dhabi Future Energy Company, is eventually to house 50,000 people in accordance with WWF One Planet Living sustainability standards, which include specific targets for the city’s ecological footprint. Masdar City plans to exceed the requirements of the 10 sustainability principles - zero carbon, zero waste, sustainable transport, sustainable materials, sustainable food, sustainable water, habitats and wildlife, culture and heritage, equity and fair trade, and health and happiness.

Independent and public verification of Masdar City's performance in meeting these standards is just one of the features distinguishing the project. Another is the commitment that the project will not just preserve existing regional biodiversity but enhance it. The design team developed all of these targets that are to be achieved by the time Masdar City is completed and fully functioning, in 2012.

Masdar City is intended to be one of the world leading research and development hubs for renewable energy strategies and components based on the University Masdar Institute of Science and Technology. The laboratories and light industry production facilities are to support the vision of the UAE to develop from a technology importing into a technology exporting country with focus on renewable energy technologies. This also reflects the governments approach to prepare the UAE for the era after the oil.

Approach: Reflecting Local Conditions as Climate and Culture

The first step for the climate engineer is always to analyze the environment and setting of the buildings. A close look is taken at all existing weather data, which need to be compared before use, if more than one source exists. For Masdar this led to the decision that a environmental data measurement station should be set up on the building site to collect more data for verification. Also the proximity to the airport called for quantifying noise and other pollution to be taken into account for protection measures.

It is important in a second step to study the cultural background, reflecting solutions of city planning and building designs which have developed in this areas over the past. For Masdar City the closest relating cities with a historical cityscape are Dubai and Muscat. These cities built in a similar climate show certain patterns: buildings separated only by small streets (almost pathways) and shaded courtyards, all in order to minimize solar gains in the streets. By reviewing natural adaptations of flora and fauna in UAE, strategies of solar and sand dust protection for water collection from dew and minimized water consumption for body waste disposals were identified. We studied the historical height layering of plant growth in an oasis with mint growing below bushes and fruit trees that are shaded by date palms. We also analyzed the adaptation of the local mangroves to the increasing salinity of the Arabian Gulf.

All of these analyses are the basis for the masterplan of Masdar City.

What does a sustainable approach for Masdar City mean?

The urban density is one of the most important measures for the sustainable approach in Masdar City. It has the greatest impact reducing the energy demands in this hot and humid climate. All energy consumption must come from renewable sources and materials have to be recycled. Due to the limited capacities of renewable energies, like sun, wind and geothermal, the first essential step is to minimize the demands. The local natural adaptations showed us the way to reducing energy and material consumption. But a sustainable approach cannot be solved only by technical solutions, but demands rethinking lifestyles. This means a change in our daily behavior in respect of mobility, comfort expectations, water, energy and material consumption and waste production.

From Macro to Micro: Developing the Energy and Comfort Guidelines for the Masterplan, Building Guidelines and the Equipment using Simulation Tools

Sunlight and air are the most important natural resources for a city. Outdoor and indoor spaces need to illuminated and fresh air has to be provided for the citizens. Considering the local climate conditions in Abu Dhabi with high outdoor temperatures and humidity levels in summer and zenith sun positions this demands specific guidelines and recommendations.

As a base for an architectural design which could be evaluated and improved, the short project timeframe demanded to start based on generic models for streets and buildings. Using air flow evaluations by computational fluid dynamic CFD simulations using Fluent and daylight and shading analysis using a backward ray tracing method by Radiance, the generic models had been analyzed and the results had been used to direct the city design.

A similar approach was used for a first calculation of dynamic building loads, based on assumed construction types, external and internal gains and occupancies. Boundary conditions have been discussed and adjusted following team recommendations. Based on the final proposed exemplary building typologies the load calculations were updated, identifying the required adjustments in the boundary conditions to meet the possible energy production on site.

Fresh air without heat

The primary decision based on the CO_2 neutral approach for Masdar development was to ban cars with combustion engines from the inner city. This reduced the demand for ventilation in the city to simply providing fresh air and cool breezes, instead of also removing car emissions to a level people can tolerate. Even without these emissions the outdoor air quality demands a certain city ventilation, which has to consider predominant wind directions, annual temperature swings, heat island effects due to solar absorption and in-city emissions.

Starting with an isothermal air flow analysis to research the impact of air infiltration from the wind flow above the city into the street canyons, the model allowed to determine preferred street widths, length and piazza locations. To determine the micro climate above the city due to the high solar absorption of the photovoltaic roofs, a simplified calculation model of the whole street was defined. It was evaluated with and without wind in respect to the local temperature increases above the city. Based on the results of the generic models an optimal street and piazza design was found. More detailed models were used to study analysis of the dynamic behavior of a street and piazza climate in the arcade area and the rules to achieve a "cold island effect" for even lower temperatures than outside were identified. A new interpretation of the historic UAE wind tower for wind and sun protection and as a ventilation device concluded the air flow analysis.

With the proposed orientation and dimensions of the city grid the air quality demands could be met and the local climate demands optimized. In the Masdar development streets are mainly used for circulation, fresh air distribution and micro climate protection. Two green park bands through the whole city are oriented towards the sea breeze and the cool night winds. They create the necessary fresh air corridors through the large city grid.

Light in the shade

Being exposed to solar radiation is very important for the human body and soul. Due to the high outside light levels in Abu Dhabi in exposed locations, comfortable indoor and outdoor spaces have to be carefully sun-protected, but not totally darkened. The design guideline for the sizing of façade openings have to be adjusted respecting the high level of direct radiation on the project site.

In a first step the solar exposure and illumination of street locations for different street width were analyzed with the help of sun path diagrams and shading analysis. Using the generic building model, the impact of street or courtyard width, building level and glass façade ratios have been calculated and finally extended to a full matrix as a design support for the typology design development. Finally, the analysis for extreme conditions for direct sun exposure in the streets concluded the evaluations.

Based on the evaluations the project team decided to illuminate the buildings through the courtyards and not via openings to the streets. Therefore the streets can be narrow and a better thermal comfort can more easily be achieved. The courtyard design differs depending on the type of building usage. All courtyards need either a retractable shading – to protect this microclimate from high temperatures – or at least an external shading of each façade opening. Façade ratios have been determined for the different floor levels based on the final typology design.

Building loads in the city

The city design determines the city climate and city heat or cold island effect, which are important boundary conditions for the building loads. These depend on the building design and construction, the external loads and the internal loads which are determined by the use. Therefore each building type required a separate model, reflecting internal schedules and the hourly weather data for Abu Dhabi.

Using the simulation package TRNSYS and the generic building model annual hourly loads for air conditioning and electrical demands could be identified. Adjusted boundary conditions and the final typology design resulted in three iterations. The results of the total loads and the differentiation between sensible, latent and electrical loads and their hourly daily profiles have been important inputs for the central system discussions and the sizing of the infrastructure.

A fourth iteration was necessary because of new constraints concerning the energy production on site.

As a result new boundary conditions for building construction and building outfit were developed and consumer guidelines were determined in order to fulfill reduce the energy demand to match it with the limited sources.

Boundaries: 80% Demand Reduction

In a global evaluation solar energy is the way to go for Abu Dhabi, using an energy and heat source which keeps the global balance of our atmosphere and is not adding additional heat. The idea of the Masdar Development for a carbon neutral city as a concept, which can be spread around the globe, demands an applicability for any other location. Even when other locations have annual solar irradiation potentials of only 1,000 kWh/m²a, the energy concept and the solutions of the storage and distribution problems in the Masdar Development can be applied but have to be transferred with local adjustments.

The limitations of the energy production areas on the roofs combined with the decision to develop the small square as well necessitated reduction of the energy consumption even further. Compared to today's UAE standards, a reduction of 80% needs to be achieved. This has serious consequences for each different building typology, as office, laboratories, housing, retail, light industry etc. These boundary conditions are not only related to the building construction but also to the building equipment and outfit. Without their compliance, the targeted numbers cannot and will not be reached.

The three following steps will lead towards a sustainable development with a carbon neutral operation:

The first step is a load reduction through passive design strategies which will reduce primary energy consumption by 40% compared to today Abu Dhabi references. The second step is to optimize the supply systems and the energy demand strategies, which will allow a further saving of 30% to 40%. Finally, renewable energy sources and active renewable strategies will reduce the primary energy demand by the remaining 20 - 30%.

Conclusion

Our involvement in the Masdar City masterplan project has given us the chance to view the possibilities of our work differently. Up to this point, we saw ourselves as experts in planning highly comfortable environments for the building user with a minimized energy demand. Through our work in the design team for Masdar City we were challenged to set the highest targets possible for energy savings and comfort protection in a city, enabling the team to plan a self-sufficient sustainable city – by realizing high density living and working space, which will still allow a modern but responsible lifestyle. If this can be showcased this will have global impact. Some of the key concepts of Masdar City are very innovative and have never been built in such a large scale. They demand further development and adjustment. To plan and realize these concepts inert 7 years will be a great challenge.

The high standard living society in the world is responsible for the tripling of our ecological footprint. To prevent irreversible damage, we not only need to see our personal life style and its impact in a global context but also the chances that lie in our work and in the way we work. We see the vision of the Masdar Development for a carbon neutral city as a concept demanding replication in other location around the globe with each climate zone offering different opportunities and possibilities of meeting the challenge.

This page intentionally left blank

The Future Envelope 2 – Architecture-Climate-Skin. U. Knaack and T. Klein (Eds.). IOS Press, 2009.

ARCHITECTURE-CLIMATE-SKIN - A SUMMARY

Tillmann Klein
TU Delft / Façade Research Group

Climate-oriented architecture serves two goals: It must help minimize the negative impact buildings and their usage have on our environment as well as increase performance in terms of user comfort.

Exterior conditions change from minute to minute, day to night and season to season. Interior conditions, on the other hand, should be adapted to our requirements and must, depending on our sense of comfort, be more stable. To achieve such adaptation we need energy. Exterior air must be conditioned, e. g. heated, cooled and/or humidified. The more stringent the limits of the acceptable interior climate, the more energy is needed. In the past, the main concept of a building envelope was to separate the interior space from the "annoying" outside climate. A central climate conditioning unit provided the desired interior conditions. However, in the future, the façade will take on a new role.

Arjan van Timmeren's paper describes the vision of a climate-oriented building envelope: The façade should be an "intermediate between the supply and demand side of energy in the built environment. The building is exposed to natural energy flows such as sun radiation, heat, cold and wind. The façade should interact with the energy flows and provide energy to the building and its occupants as a building service."

We no longer comprehend the façade as a closed, separating element, but rather want it to be adaptive or more responsive to the prevailing conditions. In combination with the building properties such as mass, type of use and volume a building envelope evolves, whose goal it is to use the above mentioned exterior conditions as intelligently as possible. Similar to a sail boat, for which one adapts the position of the sail to each wind direction and speed, for each course and each wave pattern.

The bigger context

The papers in this book show that climate-orientation is a comprehensive concept that can be extended beyond the building process. We are not only talking about designing highly comfortable environments for the user with a minimized energy demand. Matthias Schuler is involved in climate engineering of Masdar City, Abu Dhabi, with the goal to create a carbon-neutral city. The project shows that the global context of strategies and energy efficient systems will lead to the optimum result. First of all, the local conditions in terms of climate and culture have to be reflected. It is not sufficient to only look for technical solutions but to rethink our lifestyles. This should be the starting point of our efforts.

Façades

The process of façade construction itself will change in many ways. In his contribution, Andrew Watts focuses on façade design. Today we can actually investigate climate issues with computer controlled environmental design tools. The computer also allows us to create and build façades with complex geometries and locally climate oriented adjustments in form.

Western European façade technology is exported throughout the whole world and thus determines the architectural style, regardless of the climate zone. Marcel Bilow sees development potential for decentralized façades and component façades. He is developing a tool for use in the early stages of the architectural decision making process which shows a useful combinations of façade layout and integrated building services according to the surrounding climate.

Jos Lichtenberg looks at the developments from the view point of a product developer. Buildings need to anticipate changes. They must be able to react more flexibly to outside conditions. In addition, building envelopes of the future will not only be aimed at fulfilling the primary function of separating the exterior from the interior climate but need to also provide emotional value. Climate-orientation is an important factor for façade and building services, and it is a marketable property. While others are thinking about integrating building services into the façade, Lichtenberg emphasises the need for disintegration: for an efficient planning and building process, building structure, building envelope, building services and finishing need to remain separable.

Industry

Ultimately, a design is realized in the execution process. Cost and risk are factors that demand full attention. Nico Kremers represents the façade industry. He states that the market situation has developed in a way that the façade supplier actually creates more value designing and engineering the façade than during the execution process itself. Today, profit margins for the execution are very small, because the product façade has become more complex than ever and requires increasingly high logistic expenditures that are disproportionate to the cost. What is needed is expert support during planning; and this is the area that involves profitable or unprofitable decisions for the façade supplier. Not only for this reason, the façade builder should be involved in the decision making process right from the beginning. How can sustainable solutions be achieved without the experience of the construction industry?

Bert Lieverse goes a step further by predicting that "the entire industry currently engaged in manufacturing façades and façade elements will change". All fixed separations in the production chain will disappear. There will be a development in two directions. On one hand, he sees multidisciplinary companies, combining the fields of façade construction and installations, and on the other specialist companies will stimulate in-depth innovation.

Architecture

The building envelope is not a mere machine, an instrument to solely solve the issues of energy and comfort. It also serves a societal purpose. Architectural quality is a cultural value; and a climate-oriented building skin must comply with the highest standards. Interestingly enough, only a few modern buildings emphasize the topic architecture-climate-skin in their architectural appearance. This is what Kurt Pfenninger describes in his contribution. Famous architects such as Zaha Hadid and Herzog DeMeuron are clients of his façade planning firm. He talks about an "increased architectural demand" that is characterized by hitherto unknown complex geometries and a requirement for almost total transparency. In his opinion this type of architecture stands in contrast to the continuously increasing demands for insulation and solar protection. Do we have to conclude that modern climate-oriented building envelopes prevent us from creating good architecture? It rather seems that architects, continuously searching for new ways of expression, have not discovered or embraced climate-orientation as a design characteristic.

There appears to be no mutual vision about what climate-oriented architecture should look like. This can be exemplified by the struggle to integrate solar cells into façades. Basically, solar cells are very ugly, but have a high emotional value. Whether it makes practical sense or not, we can observe a trend to integrate them into the façade. A lot of effort is taken to change their appearance in terms of colour or even transparency, without loosing too much capacity. This is a clear sign that as elements themselves, they are not architecturally accepted yet.

Besides the buildings interaction with and orientation towards sun and wind, it is the way how architects deal with products for climate integration that will determine climate-oriented architecture. In the future, architecture will increasingly depend on products such as sun-shading systems and façade integrated heat exchangers, on which the architect has limited architectonical influence. On the other hand, this means that the success of these products will strongly depend on their architectonical acceptance.

Cepezed follows a straight forward approach. Their projects are very efficient. They can be described as lean because they are aimed at fulfilling their function at minimal expenditure. According to Jan Pesman, the initiative for new developments is mostly driven by the industry responding to market demands. Cepezed takes up these developments, stimulates them and develops them further. The starting point is a project and the search for the optimum solution. For Jan Pesman, the climate-oriented façade will be a result of an alarming environmental situation.

The necessity is there. The share that buildings represent of the global energy consumption is too high to let us avoid climate-orientation for the future façade.

The contributions have shown that many technical as well as architectural developments are underway. They let us believe in the potential of the building industry and our technical and architectural inventive talent. The conference has also shown an increased awareness of the topic climate-orientation. If users demand it, architects and planners further it and the building industry uses this trend to its advantage, then it will come to fruition. We can look forward to an exciting future for the façade.

This page intentionally left blank

This page intentionally left blank