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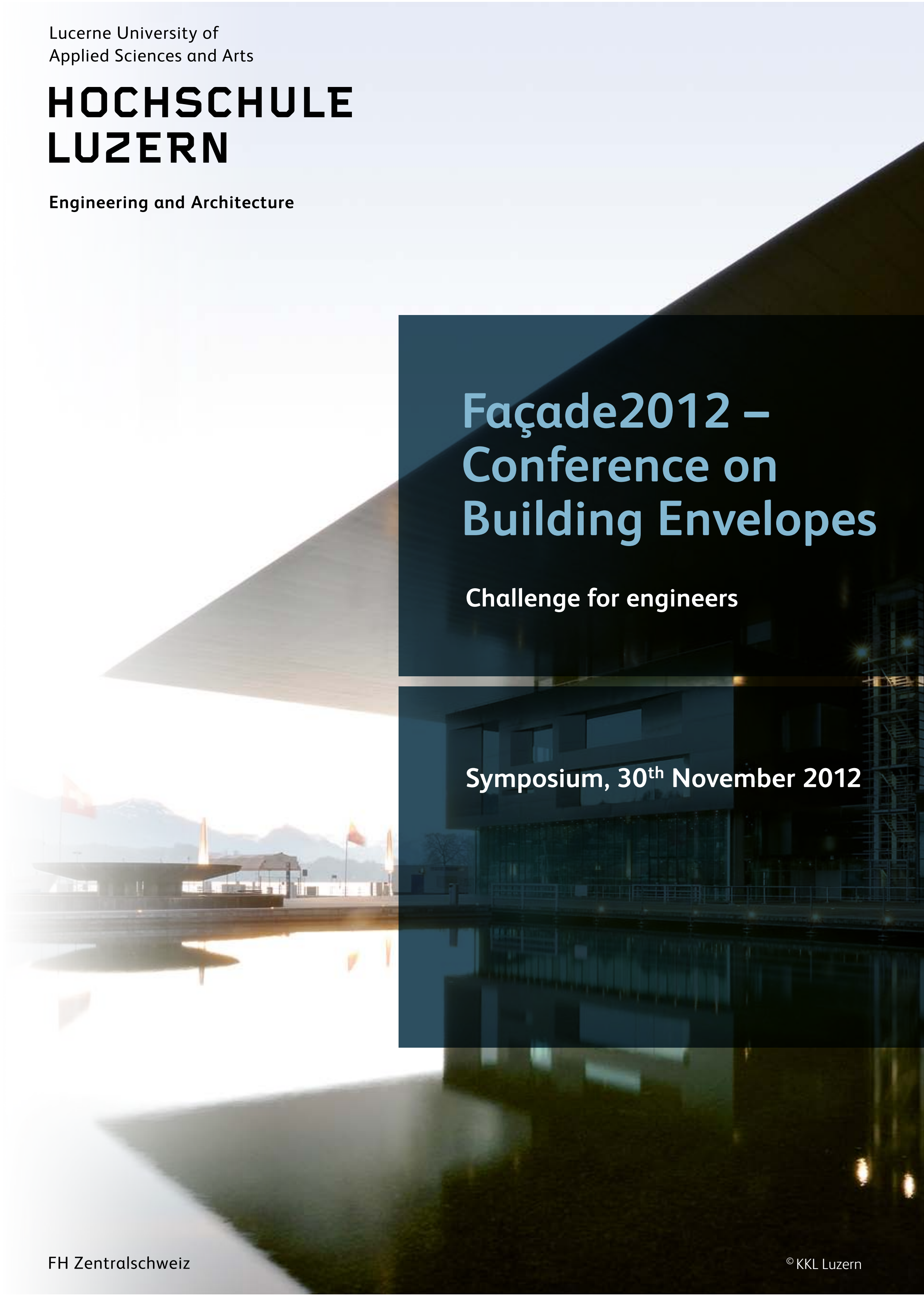

Façade2012 – Conference on Building Envelopes

Challenge for engineers

Symposium, 30th November 2012

FH Zentralschweiz

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Imprint
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PREFACE

Prof Dr Andreas Luible
HEAD FAÇADE ENGINEERING CENTRE
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Until just a few years ago, the main functionality of façades was focused on mere protection from wind and rain. Today, the façade is one of the most complex parts of a building; situated in a tension field between architecture, load-bearing structure, building services and building physics. Planning must involve conciliating ecologic, building physical and economic requirements with cultural, aesthetic and climatic conditions. In addition to thermal insulation and vapour tightness, modern façades also fulfil safety related functions. And at the same time, they provide noise protection in congested urban areas, protection from direct solar radiation, and aid in lighting the inside spaces of a building by permitting daylight to penetrate. As a significant part of the overall energy concept of buildings, there is an increasing use of multi-layered and multi-functional façade systems that actively adapt to occurring weather conditions by changing certain properties. In addition, façades equipped with photovoltaic elements or solar collectors make an important contribution to energy generation in the building, and thereby to climate protection.

Sophisticated modern façades are the product of successful interdisciplinary collaboration between architect, structural planner, façade planner, façade engineer, building physics engineer and building services engineer. With the growing technical complexity, planning and coordinating façade engineers are taking on an increasingly important role; that, at the same time, poses an immense challenge. The conference «façade 2012» under the motto «Challenge for engineers» illustrates the broad spectrum of current and future engineering tasks in the building envelope.

The conference is the 8th edition of an international conference series. The conference is a part of the European Facade Network (EFN), a networking of interest groups from universities with the aim of training and research in the area of the building envelope in Europe. For the second time in its history it is being held in Switzerland. The conference is organised by the Façade Engineering Centre (CCFM) of the University of Applied Science Lucerne and the University Ost-Westfalen-Lippe in Detmold (Germany), together with the Swiss Centre for Windows and Curtain Walls (SZFF).

In parallel with the conference «façade 2012», a one-week workshop was held with master and bachelor students from our partner universities of the EFN (TU Delft (NL), University Ost-Westfalen-Lippe in Detmold (D), Universidad del Pais Vasco (E), University of Bath (UK).

I would like to thank our organising partner SZFF and sponsors Forster Profile System AG, Ernst Schweizer AG, Sika Schweiz AG, Glas Trösch Holding AG and Wicona Hydro Building Systems AG for their generous donation of staff time, materials and/or funding. Thanks also to the partners of the European Competence Network.

Finally, my very special thanks go to Mr. Ueli Zihlmann, scientific assistant of the Façade Engineering Centre at the Lucerne University of Applied Science and Arts, for the professional organisation of this year’s conference.

JEAN NOUVEL

Stacy A. Eisenberg
ATELIERS JEAN NOUVEL, PARIS (F)

Recent Projetcts

To Jean Nouvel what is truly modern is an architectural language and vocabulary which insists on challenging the static stability of the object, by positioning this object within a particular frame of reference, alleviating expressions of the obvious and mostly by investigating and interpreting the existing conditions which typically may not seem significant at first glance.

It is essential that the building form does not identify, express or reveal itself; either its structural, constructive or programmatic essence. It exists as an absolute and formal response to its surroundings, to overriding regulations, to its right and ability to materialize within the imposed limitations.

And what imposed limitations it has… from regulatory restrictions, to budgets, briefs and time frames, to local historical and political urban fibre and context, to environmental and technical aspirations…

It is in this context, where the form has reacted to its environment, has refrained from revealing its constructed truth, has allowed its surroundings to reverberate off of its skin, that we understand, unconsciously perhaps, the incredible effort that has been made to make it so – the technical systems which allow a certain mystery to reveal itself.

What is and has always been important is the transformation, of the idea into reality, into materiality; and the material itself, its multiplicity and its infinite possibilities.

Process and transformation

The overview of these current projects focuses on transformation – the path from an idea to reality. From the first sketches, to the search for form and materials (and meaning), to technical constraints, experimentation with reality, and the final results – there is no constant. Each project has its own context, set of parameters, requirements and constraints. The architectural intention is to develop the principle ideas, the concept, allow required transformation and mould this into an appropriate reality without letting go of the essential basic assumptions.

But this is a collaborative effort with a multiplicity of objectives. Our basic assumptions are not always the basic assumptions of others. As in the parametric model, «there exists a set of related mathematical equations in *which alternative* scenarios are defined by changing the assumed *values of a* set of fixed coefficients (parameters)»; we are only one of the many parameters within the equation, participating in the creation of many alternate and evolving scenarios.

LOUVRE INTERNATIONAL, ABU DHABI, UAE

Project Location:	Sadiyaat Island, Abu Dhabi, UAE
Gross / Net Surface Area:	63,000 m² / 22,500 m²
Client:	TDIC / AFM
Dates:	2007–2014
Phase:	Under Construction

Louvre Abu Dhabi – Micro City / Micro Climat: The Museum of Classical Art is part of an ambitious new cultural district in Abu Dhabi, elaborated under the patronage of the TDIC. The Museum takes its place among other cultural landmarks along the inlet which separates Saadiyat Island from the city: a contemporary art museum, a performing arts centre, a maritime museum…

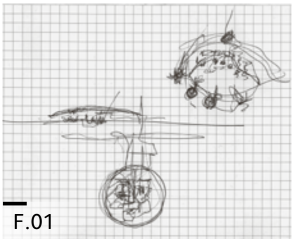
Devoted to exhibiting works and artefacts from the past, the Museum of Classical Art is bound to features both remote and familiar, deriving naturally from the spirit of the place. The island offers a harsh landscape, tempered by its meeting with the inlet, a striking image of the aridity of the earth versus the fluidity of the waters. How to tame this wilderness? We could not help but let our imagination drift into flights of fancy, forgotten chimeras of unknown cities buried deep into the sands or sunk under water through immemorial floods and earthquakes. These dreamlike thoughts have merged into a simple plan, an archaeological field revived as a small city, a cluster of one-room buildings placed along a leisurely promenade.

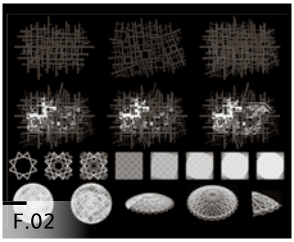
This micro-city requires a micro-climate that would give the visitor a feeling of entering a different world. We have covered it with a large dome, a form common to all civilizations. This one is made of a web of different patterns interlaced into a translucent ceiling which lets a diffuse, magical light come through in the best tradition of great Arabian architecture. Water is given a crucial role, both in reflecting every part of the building and thus acting as a psyche, and in creating, with a little help from the wind, a comfortable micro-climate.

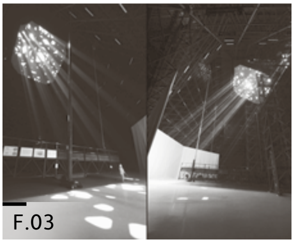
The landscaping is a microcosm of different situations found in the region, from the oasis to the dune, from the pond to the archipelago, each layer exposing its own specific plants and enhancing the character of an island on the island.

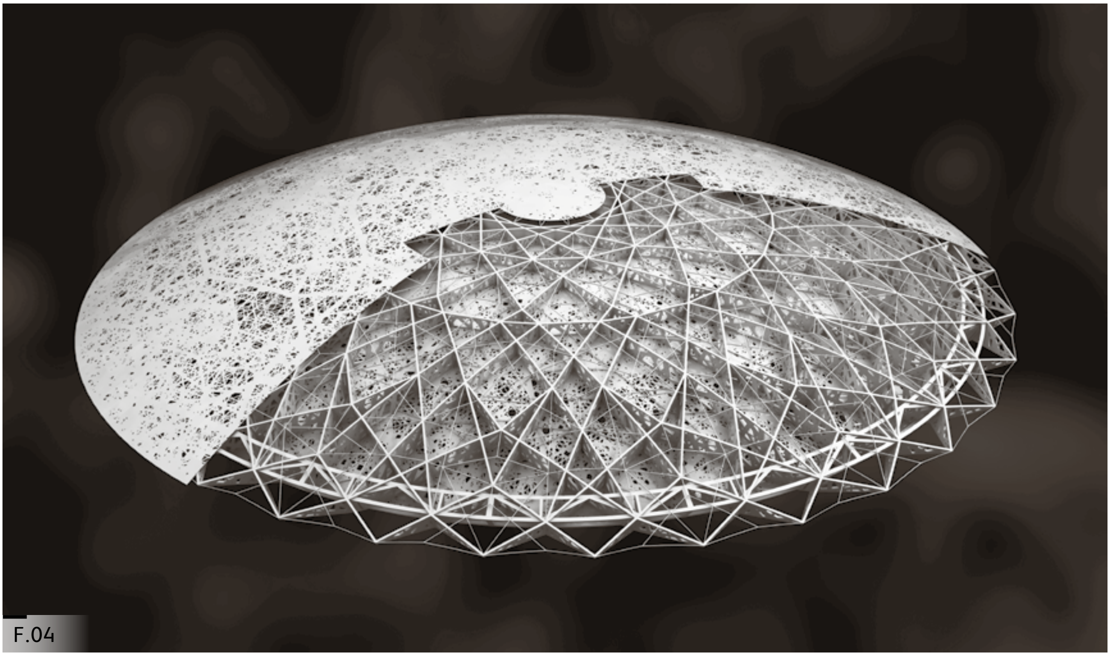
The whole territory is envisioned not so much as a nostalgic longing for some remote, ancient world, some lost paradise, but as a trigger to question one’s sense of time. Its ultimate ambition is to participate fully in making Abu Dhabi a new crossroads of world culture.

Light and Shadow









F.01
Sketch – Jean Nouvel

F.02
Museum and Dome Studies

F.03
Full Scale Mock Up –
Abu Dhabi

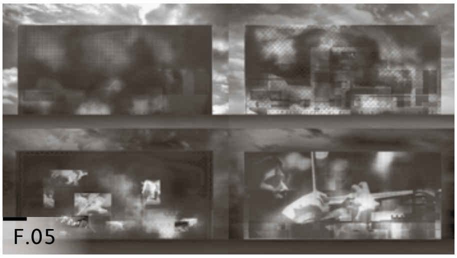
F.04
3D Rendered Model – Dome

DANISH RADIO CONCERT HALL, COPENHAGEN, DENMARK

Project Location:	Copenhagen, Denmark
Gross / Net Surface Area:	50,000 m² / 25,000 m²
Client:	Danish Public Radio
Dates:	2002–2009
Phase:	Built

Abstraction in layering: Building in a constantly evolving neighbourhood is a risk that has often proved fatal over the last few decades. It is not reasonable to rely on a built environment for which we cannot evaluate the urban potential. We should reason the other way around: what qualities can we bring to this uncertain future? How can we, in the worst case scenario, meaning almost alone, exist in the right conditions? With an uncertain future one can only reply on the positive force of uncertainty: through mystery – mystery, never far from seduction and attraction. If the neighbourhood is too neutral, we have to create a transition, a sense of distance which is under no circumstances a withdrawal into oneself but simply the setting in place of developing conditions within a particular territory. In short, we must evaluate and engage the context, whatever it is. And to achieve this we have to affirm a priori a presence, an identity. We must «materialize» the territory and give it another scale, one adapted to an exceptional urban function, related directly to the urban geometry. In this case, we see through the volume to its interior; it is a mysterious parallelepiped, changing according to the light of day and night. At night the volume becomes a place for images, colours, lights, expressions which reveal a complex interior life. An interior street follows the urban canal, accompanied by shops, and a restaurant, and dominated by a covered square, a large empty volume beneath the wooden scales of the concert hall. It is a world of contrasts, of surprises, a spatial labyrinth, and an interior landscape. On one side is the world of musicians, courtyards and exterior planted terraces, on the other side, public Piranesian interior spaces linking the diverse music halls, the restaurant, and the street. The abstraction is occupied. The permanent is complemented by the ephemeral. The façades are fine filters permitting views of the city beyond, the canal, and the neighbouring architecture. At night these façades are also a means for projected coloured images. Each place becomes a discovery, each detail an invention. This is a lesson learnt from an architecture that should never be forgotten, a discrete homage to Mr. Theodor Lauritzen and Mr. Hans Sharoun… architecture is like music, it is made to move us and to bring us pleasure.

Light and Sound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F.05
Competition Elevation Studies

F.06
Light projection – Site testing

F.07
Southern View

PARIS PHILHARMONIC, PARIS, FRANCE

Project Location:	Parc de la Villette 75020, Paris
Gross / Net Surface Area:	79,000 m² / 42,000 m²
Client:	Paris Philharmonic, City of Paris
Dates:	2007–present
Phase:	Under Construction

The Paris Philharmonic – harmonies and chords: The word Philharmonic, roughly translated, means the love of music, of harmony. We perform in successive harmonies, and in this case in urban harmonies. The Paris Philharmonic exists as a culminating event made to complete a harmonious relationship with its surroundings… A place in harmony with the light of Paris, the rays of sunlight through the grey clouds, the rain… this architecture is a measured and composed reflection created by the subtle relief of cast aluminum paving, drawing Escher like patterns on the ground.

A place in harmony with the surrounding Parc, a continuation of Tschumian themes, with horizontal sheltered gardens beneath the building, punctuated follies, reflections of shade in the shining surfaces, and the creation of an accessible «Hill», which forms an observatory hovering over the urban landscape.

A place in harmony with the Cité de la Musique – following the existing paved lines, duplicating them with oblique plans.

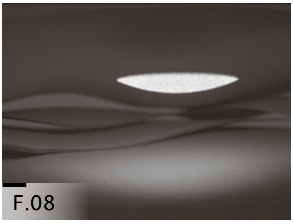
A place in harmony with the city ring road and the suburbs beyond, through dynamic signage, perceived from a distance, an illuminated apparition that cuts through the relief, displaying upcoming events… The Paris Philharmonic offers an arena – and advocates interaction.

The Hall and Foyers offer all amenities, meeting places, boutiques, bistros, reading lounges – all with a view of the garden…

The Hall evokes mysterious, non-material sheets of music and rays of light, suspending the listeners in a place of long, open balconies with beckoning seats. The suspended architectural elements give the impression that one is surrounded, immersed in music and light. The shell of the Hall, a «volumetric cyclorama», is covered with theatrical lighting related to the repertoire being performed. All of the glazing facing the park and suburbs are operable – allowing these spaces to be completely open, weather permitting.

This place is about restoring certain radiance to each concert and the unique experience that it represents. This is an experience, not just about the rapture of music, but about visual and sensory delight, about participating in and sharing of the fascination, eagerness and desire that exist in the most prestigious of Philharmonic halls. The Paris Philharmonic will belong to this group, assisted by powerful aesthetics and materials, and by the mystery and presence of its Hall, softly glowing within the grey and silver folds of the edifice.

The Movement of Music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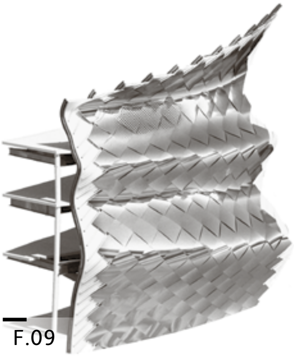
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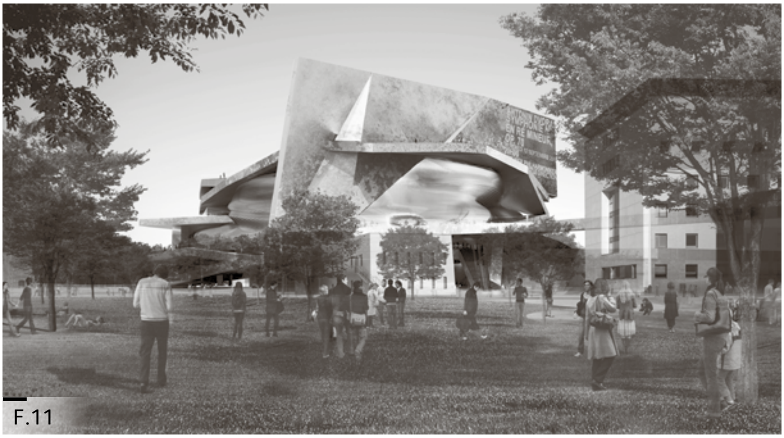
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F.08
Sketch – the Concert Hall

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3D sketches –
Whirlwind Wall

F.10
Prototype –
the Whirlwind Wall

F.11
North View – perspective

ONE NEW CHANGE, RETAIL AND OFFICE PROJECT, LONDON, ENGLAND

Project Location:	London, England
Gross / Net Surface Area:	84,000 m² / 52,000 m²
Client:	Land Securities Development
Dates:	2003–2010
Phase:	Built

St. Paul's Crossing: In the city center of London, the rebuilding of the block bounded by New Change, Cheapside, Bread and Watling streets sets out to enrich the entire neighborhood. There were questions to be answered: how do we complete the existing shopping streets? How do we build next to Saint Paul's Cathedral in a way that both pays homage and is in constant dialogue? How do we create a roof façade, worthy of being viewed from the Dome, an attractive, sober, roof landscape that is «in its place» in harmony with the surrounding rooftops?

The present scheme is a development of two initial proposals, one in which a new street is created to bisect the site, beginning as a covered passageway at the intersection of Cheapside and Bread Street and opening a view to the Cathedral Dome; and the other, is the folding and bending of the volume to remain within the height and setback limitations imposed by the city and by St. Paul's. The ambition was to create passageways to link all of the surrounding streets, creating a crossroads within the block, and a sign at the center, reflecting Wren's St. Paul's to all of the entries of the site.

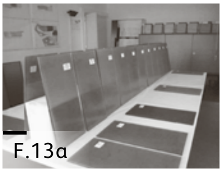
Shops and offices are organized around the arcade crossing, where there is also a panoramic lift giving direct access to the roof terrace. The view of Saint Paul's dome from the terrace is unique, striking in its proximity. There are also sweeping 360° views of the city from this terrace.

The materials of the exterior façades set up a dialogue with the neighboring buildings and with Saint Paul's. They are matte and smooth; their colors echo the surrounding stone and brick façades. All shine is reserved for the inner passages. The contrast between matte exterior and polished interior creates the desire to enter and explore.

This is a new sort of modernity, attempting to reach beyond itself to speak to, and reveal the diverse character of its surroundings.

The Reflections of St. Paul's

F.12



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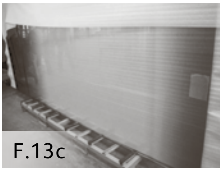
F.13b



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Concept Sketch

F.13 a–d
Frit Samples /
Color Samples

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View from Central Atrium

F.15

THE NATIONAL MUSEUM OF QUATAR, DOHA, QUATAR

Project Location:	Doha, Quatar
Gross / Net Surface Area:	53,000 m² / 21,000 m²
Client:	Quatar Museum Authority
Dates:	2008–2013
Phase:	Under Construction

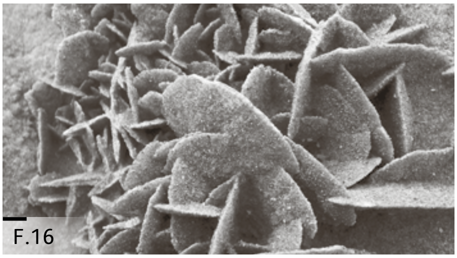
An Identity Takes Form: Qatar is a young nation in the Persian Gulf, a peninsula surrounded by water where the desert reaches the sea. The programming study, part of the initial stages of the architectural study, brought to light the underlying paradox of this project: to show what is hidden, to fix a fading image, to anchor the ephemeral, to put the unspoken into words, to reveal a history still too young to have left an imprint; a history that is a present in flight, energy in action.

The National Museum of Qatar is the symbol of this energy. It will be home to the traditional geological and archaeological artifacts; tents, saddles and utensils bearing witness to nomadic life; there will be fishing boats and nets, but most importantly, it will speak of an awareness that could only otherwise be experienced, by spending months in the desert, searching for the particularities that elude our grasp except when the whims of time and Nature allow.

Everything in this museum comes together to demonstrate the symbiosis of the desert and the sea. The architecture and structure symbolize the mysteries of the desert's accumulations and crystallizations, suggesting the interlocking pattern of the bladelike petals of the desert rose.

This will be an emblematic monument, a contemporary construction of steel, glass and concrete fiber panels, a modern-day caravanserai. From here you will leave the desert behind, returning with treasures and images that remain engraved in your memory. This place is more than just a metaphor of modernity, it is the metamorphosis and the beauty of what happens when the desert meets the sea.

The Desert Rose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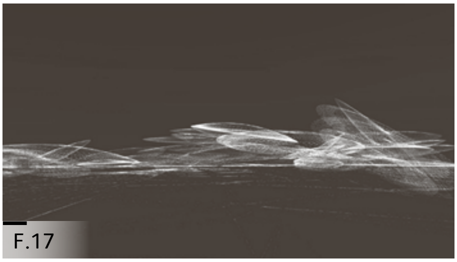
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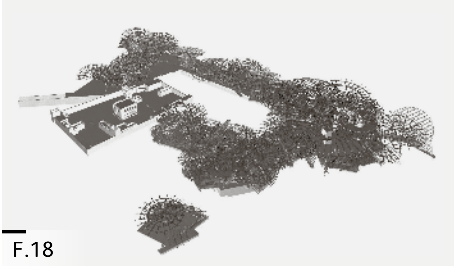
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West View from Doha Bay


F.19

ENERGY PERFORMANCE OF GLAZINGS

Heinrich Manz
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Abstract
Windows can cause significant thermal energy gains or losses in buildings. Focusing on wintertime, a simple method for analyzing and discussing energy flows through glazings is presented. The impact of the glazing quality, the façade orientation, and the severity of the climate on the ratio of solar gains to thermal losses through glazings is shown.

Keywords: Thermal transmittance; total solar energy transmittance; climate; façade orientation; solar gain; thermal loss

1. Introduction

Because of the needs of modern architecture for transparency and the advancement of glazing technologies in the past couple of decades, glass has been increasingly used and is today a key material in façade technology. When employing glazings in modern buildings, numerous physical and physiological aspects need to be considered such as visual contact between interior and exterior, use of daylight, optimizing and controlling solar energy gains, minimizing thermal losses, optimizing thermal comfort, minimizing glare, noise protection, air and driving rain tightness, and fire safety.

A large number of research papers, professional articles and books on architectural glazings is available today and it seems that the interest in this fascinating building material is even on the increase.

However, the extensive use of glass in building façades is also associated with problems such as overheating of the building in summertime, lack of visual and thermal comfort, and increased thermal losses in wintertime. Despite major technological advancements in insulating glazing technology in recent years, windows still constitute weak spots in the building envelope in terms of energy loss in cold climates.[1] The thermal transmittance of windows tends to be much higher than that one of the neighbouring opaque elements. For instance, the thermal transmittance targets specified by the Swiss energy standard for buildings**2** for walls incorporating state-of-the-art technologies are roughly eight times lower than that one for windows (0.11 Wm^{-2}K^{-1} and 0.9 Wm^{-2}K^{-1} respectively). In addition to being an important parameter with respect to thermal losses, glazing can also be significant in terms of solar energy gains.

In practice, architects and engineers need simple and clear guidance in building design. The starting point for this study was, therefore, to develop simple design charts, which show the impact of the local climate, the glazing quality and the façade orientation on the ratio of solar gains to thermal losses in wintertime.

2. Methodology

In terms of energy flows, glazings can be characterized by two parameters: Firstly, the total solar energy transmittance g, which denotes the share of the incoming solar energy, which is converted into heat inside the indoor space. Secondly, the thermal transmittance U that describes how much heat is transferred through the glazing per square meter and Kelvin temperature difference between interior and exterior. Therefore, the parameter g characterizes the solar gain of a glazing, whereas U stands for the thermal loss of a glazing.

As regards the energy flows through a glazing in a building façade, three cases can be distinguished:

$g \cdot I > U \cdot \Delta\theta$ net energy gain (1)

$g \cdot I = U \cdot \Delta\theta$ energy gain = energy loss (2)

$g \cdot I < U \cdot \Delta\theta$ net energy loss (3)

where I denotes the solar irradiance and $\Delta\theta$ stands for the temperature difference between interior and exterior. The ratio of solar gains to thermal losses, α, is given by:

$$\alpha = \frac{g \cdot I}{U \cdot \Delta\theta} \qquad (4)$$

If glazing properties and climatic boundary conditions are put each to different sides of the equation, one obtains:

$$\frac{g}{U} = \alpha \cdot \frac{\Delta\theta}{I} \qquad (5)$$

As regards the passive solar heating of the building, g/U stands for the glazing quality: A high value of g results in high solar gains, a low value of U in low thermal losses. $\Delta\theta/I$ characterizes the severity of a climate: Large temperature differences between interior and exterior lead to high thermal losses, high values of solar irradiance result in high solar gains.

Discussing equation 4, again, three cases can be distinguished:

$\alpha > 1$	net energy gain
$\alpha = 1$	energy gain = energy loss
$\alpha < 1$	net energy loss

Equation 5 is a simple linear equation and can be used to discuss the impact of the glazing quality and the severity of the climate on the gain-to-loss ratio of a glazing. At a given location, the climatic parameter $\Delta\theta/I$ is different for different façade orientations.

The net gain through a glazing is given by

$$\dot{q}_{net\ gain} = g \cdot I - U \cdot \Delta\theta \qquad (6)$$

Equation 4 can also be written as

$$g \cdot I = (\alpha - 1) \cdot U \cdot \Delta\theta + U \cdot \Delta\theta \qquad (7)$$

and, therefore, the net gain is also given by

$$\dot{q}_{net\ gain} = (\alpha - 1) \cdot U \cdot \Delta\theta \qquad (8)$$

3. Case study locations

The case study locations comprise of London, Moscow, Rome and Zurich. Where London and Rome are very close to the sea particularly Moscow is far away from large bodies of water and experiences, therefore, a more continental climate. Geographical and meteorological data for all locations were taken from the meteorological database Meteonorm.[3]

4. Climate and meteorological data at case study locations

Tables 01 and 02 provide an overview of monthly mean values of solar irradiation and temperature at case study locations in Europe.

The climate at the different locations can be briefly summarized as follows. The southern European location of Rome experience mild winters, warm summers, and quite high solar irradiation over the whole year. Moscow has cold winters with little irradiation and quite warm summers. In London winters and summers are mild and there is relatively little irradiation throughout the year. Winters are relatively cold in Zurich, summers are mild and the weather is slightly sunnier than in London.

A constant interior temperature of 20 °C was assumed for this study. The ratio $\Delta\theta/I_i$ is highest for virtually all locations and façade orientation in December. In other words, climatic boundary conditions are most severe in December in terms of solar gains and thermal losses through glazings. Therefore, the meteorological data for December were used for all figures.

Horizontal Irradiation (MJ/m²)	*London Weather C.*	*Moscow*	*Rome Ciampino*	*Zurich SMA*
January	68	58	209	101
February	115	126	263	166
March	241	266	443	306
April	360	382	554	414
May	486	569	691	529
June	515	605	727	558
July	508	580	778	590
August	439	479	684	518
September	306	281	515	353
October	184	148	364	212
November	86	58	227	112
December	54	36	180	79
Year	3352	3578	5620	3928

Tab.01
Horizontal solar irradiation at case study locations in Europe (Data from[3])

Temperature (°C)	*London Weather C.*	*Moscow*	*Rome Ciampino*	*Zurich SMA*
January	6.5	–5.9	7.2	0.6
February	6.9	–6.3	7.6	1.9
March	8.6	–1.4	10.4	6.0
April	10.5	7.1	13.2	9.0
May	13.8	12.6	18.3	13.9
June	17.0	17	22.9	17.4
July	18.5	20.2	24.6	18.0
August	19.2	17.0	24.9	18.5
September	16.3	11.1	20.4	14.0
October	12.8	5.5	16.9	10.0
November	9.1	–1.1	12.6	4.3
December	6.8	–5.7	8.4	1.4
Year	12.2	5.8	15.6	9.6

Tab.02
Temperature at case study locations in Europe (Data from[3])

5. Glazing data

As described earlier, glazings can be characterized in terms of energy flows by two parameters: Firstly, the total solar energy transmittance g and, secondly, the thermal transmittance U. Both parameters depend on the glazing type, i.e. on the number of glass panes, the distances between the glass panes, the filling gas and the number and properties of the coatings used. As a rule of thumb, an increasing number of panes leads to decreasing values of U and g. The physical reason for that is that more cavities provide better thermal insulation whereas more light is reflected due to more glass-gas interfaces. In *figure 01*, each dot represents a glazing type. All data for U and g were taken from references.[4–6] Glazings A, B, C and D were chosen for this study. Glazing A is a modern insulating glazing unit with three panes (3-IGU), both cavities filled with krypton and two low emissivity coatings. Glazing B is also a modern insulating glazing unit but with two panes (2-IGU), the cavity is filled with argon and one low emissivity coating. Glazings C is an «old» double glazing without any coatings and with an air filled cavity. Glazing D is an «old» single glazing without any coatings. *Table 03* shows the numerical values of U and g for the four different glazing types used.

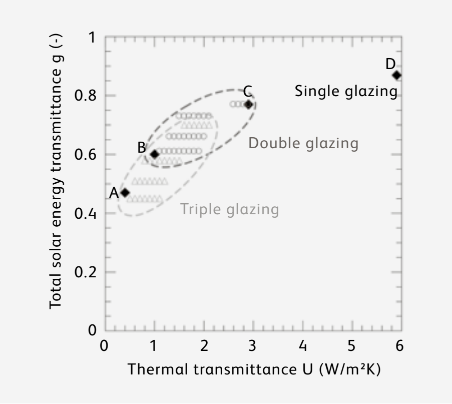
6. Results

Figure 02 shows an array of lines according to equation 5 with the gain-to-loss ratio as a parameter in the range of $\alpha = \frac{1}{16}$ to $\alpha = 8$. For the month of December, the ratios of temperature difference to solar irradiance, $\Delta\theta/I_i$, at the façade orientations south, west, north and east in Zurich, as well as the ratio g/U of glazings A to D were employed. Each dot determines the gain-to-loss ratio of a specific glazing type at a façade orientation in Zurich. It can be seen in *figure 02* that even in December glazing A features a net energy gain at all façade orientations except for north. Glazing B provides a net gain only at the south façade whereas for all other orientation a net loss results. Glazing C and D show net losses at all façade orientations.

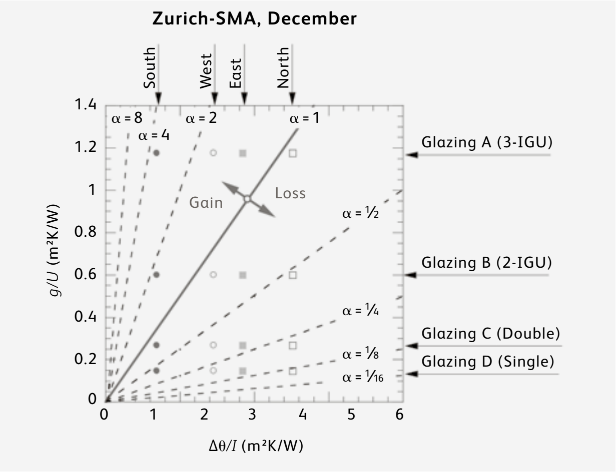
Figures 03 to 05 display in the same way the gain-to-loss ratios for the glazing types A to D at different façade orientations and at other locations.

Because of the wide range of the climate parameter $\Delta\theta/I_i$ at the different locations, two different scales were used.

It can be seen in *figure 03* that in London glazings of type A have net gains at south, west and east façades whereas glazings of type B display net gains only at south façades.



F.01
Thermal transmittance U and total solar energy transmittance g of different glazing types (Data from[4–6]). Glazings A, B, C and D were used in this study.



F.02
Gain-to-loss ratios at different façade orientations and for different glazing types in Zurich.

Nr.	*Glazing type*	*U (W/m²K)*	*g (-)*	*g/U (m²K/W)*	*Data source*
A	3-IGU	0.4	0.47	1.175	[6]
B	2-IGU	1.0	0.60	0.600	[6]
C	Double	2.9	0.77	0.266	[5]
D	Single	5.9	0.87	0.147	[4]

Tab.03
Thermal transmittance U and total solar energy transmittance g of the four different glazing types used in the *figures 02 to 05* (Data from[4–6]).

According to *figure 04*, modern glazings of types A and B provide net gains at all façade orientation in Rome.

Figure 05 for Moscow displays that in this climate only south oriented modern triple glazing of type A feature positive net gains. For all other façade orientations and glazing types net losses are obtained.

Old single and double glazings of types C and D lead to net losses in all climates and at all façades – except for south oriented façades in Rome.
In a given climate, the mean net energy flux through a specific glazing into the interior space can be computed according to equation 8.

In Zurich, the mean temperature difference between interior and exterior is $\Delta\theta = 18.6$ K in December. Assuming glazing of type A and $\alpha = 3$ (south), an average net gain of 15 W/m² is obtained. If the glazed area is large enough, a quite significant heat gain results for the interior space (Note: Taking the room geometry into account, this value can e. g. be compared with the maximum heating power per floor area of 10 W/m² as defined for passive houses).

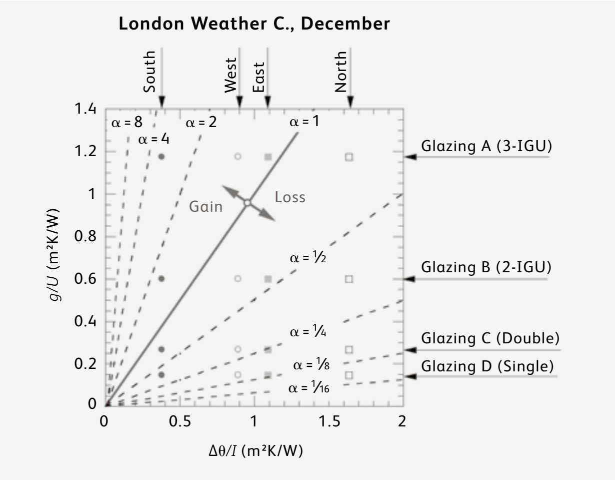
For Moscow, assuming $\alpha = 2$ (south) and glazing A, the net gain is 10 W/m².
Figures 03 to 05 show that at a given location, the gain-to-loss ratio varies by a factor of roughly 30 depending on the glazing quality and the façade orientation.

7. Discussion

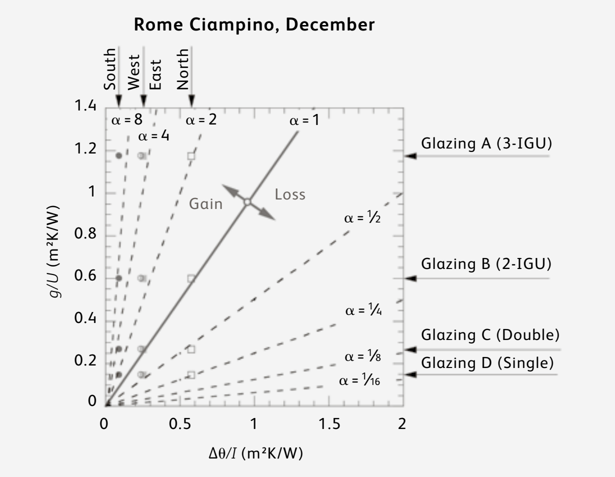
The energy performance of glazings in European climates was analysed. A simple method for quantifying energy flows through glazings was presented, which is based on steady-state modelling of solar gains and thermal losses. Focusing on wintertime, the impact of the glazing quality, the façade orientation and the local climate on the gain-to-loss ratio was shown. As the climate is most severe at all European locations in December, meteorological data for this month were used.

As regards energy performance of glazings in European climates the following conclusions can be drawn:

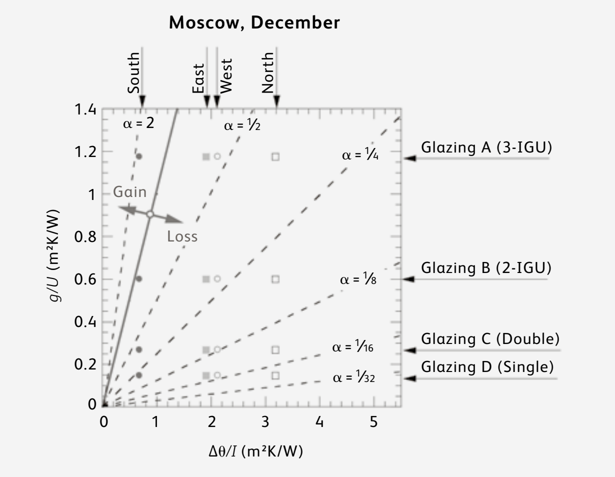
- At all case study locations, modern triple insulating glazing units (glazing A) exhibit the highest gain-to-loss ratios.
- Only modern triple insulating glazing units (glazing A) guarantee net energy gains at all case study locations at south façades.
- Modern double insulating glazing units (glazing B) display only at certain locations and mainly at south façades net gains.



F.03
Gain-to-loss ratios
in London Weather C.



F.04
Gain-to-loss ratios
in Rome Ciampino.



F.05
Gain-to-loss ratios
in Moscow.

- «Old» double and single glazings (glazings C and D) lead to net losses at all façades and locations (except for Rome).
- At all locations, gain-to-loss ratios are best at south façades and worst at north façades. West and east façades perform similarly, with only minor differences between locations. (Note: As all locations considered are on the northern hemisphere, solar irradiance is highest on the south and lowest on the north façade. Of course, on the southern hemisphere, the opposite would be true.)
- Depending on the location, absolute net gains of modern triple insulating glazing units at south façades in December become significant in low energy buildings if glazing areas are sufficiently large.

At a given location, solar irradiance and temperature vary as a function of time. Hence, also net fluxes vary and change the sign, even during the course of a single day. The utilization of the solar energy gains requires sufficient activatable thermal mass in the interior space such as concrete ceilings, brick walls etc. Buildings with high time constants – well insulated, air tight buildings with a large amount of thermal mass – are well-suited to dampen temperature fluctuations and to maintain the room temperature within the comfort limits.

Limitations to passive solar energy use in buildings do occur, of course, particularly in urban areas due to shadowing by neighbouring buildings. Nevertheless, this study shows the importance of solar energy gains for saving energy for heating in buildings in temperate and cold climates. For the sake of completeness it has to be added that an extensive use of glass in the building envelope can also lead to an overheating of the building in summertime and result in poor thermal comfort and/or cooling loads, which has to be avoided by measures such as an appropriate glazed area and shading devices.

The presented findings are not surprising and in accordance with results of previous investigations. Therefore, the major point of this study is that employing the ratio between total solar energy transmittance and thermal transmittance (g/U) for characterizing the quality of a glazing and the ratio between interior-exterior temperature difference and solar irradiance ($\Delta\theta/I$) for characterizing the severity of the climate, the energy performance of glazings at different façade orientations can be discussed in a graphic way by means of the presented figures and the ratio between solar gains to thermal losses (α). To the author's knowledge, this straightforward approach of displaying the energy performance of glazings is novel. Not at least because of the simplicity of the method, it might also be valuable for educational purposes.

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FREE-FORM AND ENVIRONMENTAL APPROACH IN THE DESIGN OF TRANSPARENT SKINS

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RFR, PARIS (F)

1 – Introduction

Architecture has been evolving fast in the last fifty years and previous visions *(Figure 01)* have now become a well established reality.

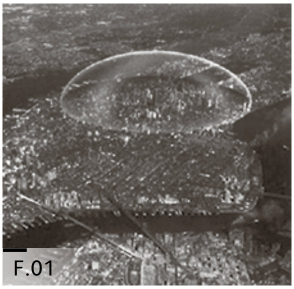
Currently, architects are strongly interested in free-form design. «Blobs» have become common since the realisation in Bilbao of the Guggenheim Museum by Frank Gehry. In parallel, the architectural community has developed an interest in transparency and in structural glass. The ephemeral and immaterial skins are now «de rigour». Transparency is not only applied to standard Cartesian forms but is also highly sought after in the case of double curved surfaces.

The changing society, the changing economy, the reduced natural resources and the necessity to contain the CO_2 foot print have largely contributed to creating a new culture that seeks out the minimisation of energy consumption. Such a point is fundamental in the case of transparent skins and the design process is already adapting to this new requirement. The achievement of the opaque Bilbao Guggenheim Museum has now transformed itself into the dream for a new generation of transparent «blob» architecture that, thanks to the developments of these last twenty years, is now constructively possible and energetically sustainable.

2 – Security issues: robust design

Before going further into the above topic it is worth stressing that, by default, designing with glass implies a special attention to the post-breakage behaviour since glass is a fragile material that can break for various unexpected reasons *(Figure 03)*. The experimental project of a glass structural vault, run by Prof. Sobeck in 1998 *(Figure 04)*, shows the possibilities for achievement in damage tolerance when using glass. This opens a path towards the application of a safety approach which is not only limited to façades.

By now a fail-safe and damage tolerance approach has become a common design parameter and is applied to



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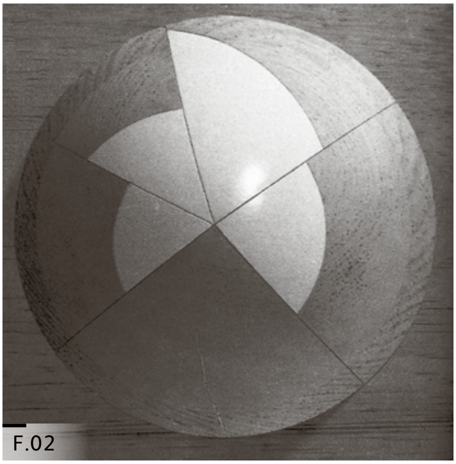

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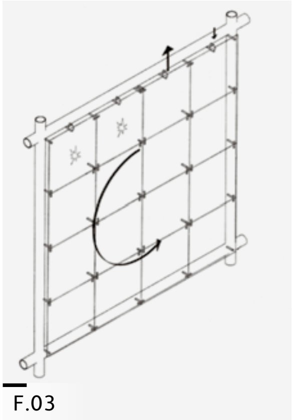


F.03

F.01
Manhattan shelter, Buckminster Fuller (1968)

F.02
Geometry concept of the roof of the Sidney Opera House (1961)

F.03
RFR/Peter Rice fail-safe approach developed for the Bioclimatic Glass House of La Villette (1982).

F.04
Experimental vault (Ilek, prof. W. Sobeck with M. Kutterer) presented at the Glastec 1998

F.05
Intesa-San Paolo double facade:
a) Prototype
b) integrity of a glass blade after a repeated shock test.

F.06
Limoges Stadium skin realised using quadrangular flat panes

F.07
Decomposition of a glass skin in single curvature strips

F.08
Approximation of a doubly curved surface using cylindrical panels.

F.09
Cylindrical approximation:
a) double curvature facade of the first floor pavilions of the Eiffel Tower
b) Single curvature «sails» of the Foundation Louis Vuitton pour la Création (RFR+TESS)

simpler elements such as, for example, the glass blades of the Intesa-San Paolo Tower facade *(Figure 05a)*. These blades are fixed only on four points and are able to resist multiple shocks *(Figure 05b)*. They can open and close for one month while having both glass panes broken and are capable to withstand short term loading even with partially broken connections (damaged structural silicone).

3 – Transparent free form design

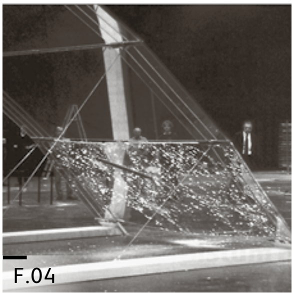
Coming back to the main subject of this paper, the design of a double curved skin has relied, up unto to few years ago on the utilisation of translational/revolutional/homothetical surfaces. In the case of more complex shapes the surface was decomposed into triangles as in the case of the now famous British Museum roof.

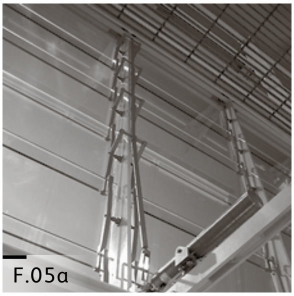
The culture of geometry and the latest numerical evolutions allow now to discretise the surface according to patterns that are correlated to construction and production methods. Planar quadrangular discretisation *(Figure 06)* is now possible which brings advantages to the economy of materials: fewer waste and less linear joints, but still with facetted look. Surfaces can also be decomposed into single curvature strips that can be realised using cold bent glass with great advantage in the optical quality off the glass and in cost. Compared with triangular and quadrangular meshes, the quality of the surface is much better and the surface appears with virtually perfect smoothness.

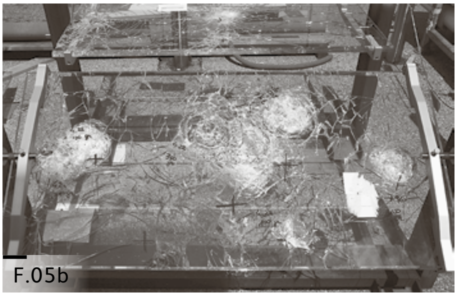
The D-Strip theory and discretisation (single curvature strip of variable radii – *Figure 07/08*) leads easily to the approximation of the reference surface using only cylindrical glass. In the former method, glass can be realised by cold-bending whereas in the latter they can be produced using variable mould tempering machines thus producing glass of high mechanical performance at a reasonable costs *(Figure 09a/09b)*.

4 – Environmental design

Energy consumption and energy saving are nowadays a key design issues. Transparent façades and large glazed skins make it necessary to carefully evaluate the interaction with the building system. The original double façades of the early 80s have developed and nowadays they have highly increased their performance thanks to design principles which do not consider them in isolation, as an added part of the building: the facade and the building are conceived of as a synergy assembly. In the case of the the Intesa-San Paolo Tower in Turin the double facade is as screen which re-


F.04


F.05a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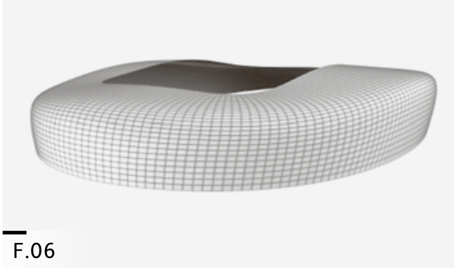
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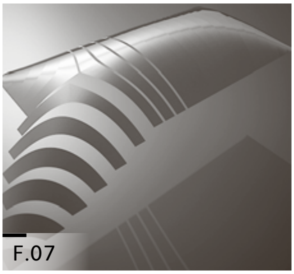
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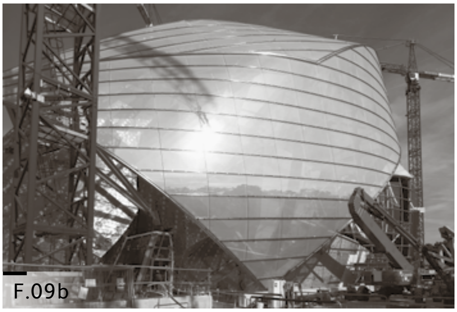
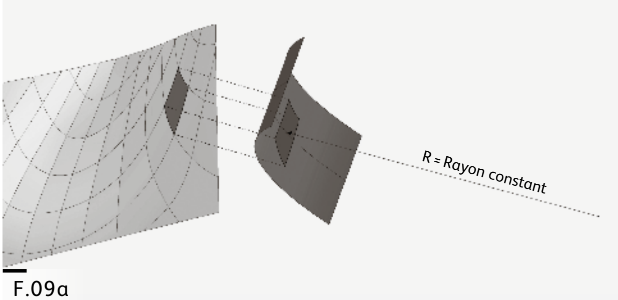

F.09b



F.09a

duces the thermal exchanges *(Figure 11a)*. The cooling effect is realised by the air flowing into the slab *(Figure 11b)* and not into the inner space as in case of the standard cross ventilation. The air is then drawn by the wind in particular by the differential pressure as results of the shape of the tower characterised by a squared shape with edge screen that create strong edge vortex.

This approach is not limited to the facade but offers a valuable strategy for different configurations of spaces such as atriums or whole building typologies as in the case of the Strasbourg TGV Station *(Figure 12b)*.

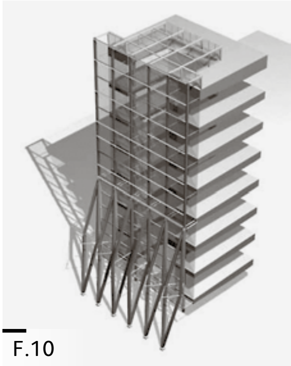
The Strasbourg TGV Station inverted the trend and for the first time it was possible to realise a south facing glazed shelter which was not considered as a «glass house» but as an enjoyable space for a commercial gallery (semi-closed not heated space). The combination of the glass properties with natural ventilation and the air intake from underground cooler spaces permitted a control of the inner temperature to deal with the peak during the summer period. This project shows the developememnt improvements with respect to the Avignon TGV Station *(Figure 12a)* built six years before where the glass envelope only faces North in order to limit the solar gain.

5 – Increasing the skin performances

Both the skin of Avignon and Strasbourg TGV Station have limited thermal performances since the enclosed volumes are transition spaces for transport interchange nodes and the skin performances are consistent with these functions.

In the case of the «Musée de la mode et de la dentelle» *(Figure 13)* the skin had to provide good thermal properties as it was the internal space an exposition hall and not simply a buffer zone. The preferred solution which was the fabrication of double curvature, double glazing units using standard moulds were not realistic in term of construction tolerances and economic viability. In this case the geometry of the facade and the available technology imposed the solution of a double skin with an external and internal double curved laminated single glazed surface. In spite of the concept which is a hybrid solution between a screen and a double facade, this project is one of the first smooth double curvature skins with consistent thermal properties.

The new facade for the three Pavillions placed on the first floor terrace of the Eiffel Tower *(Figure 14)* takes advantage of the latest innovations. In particular it uses the discretisation and approximation principles using cy-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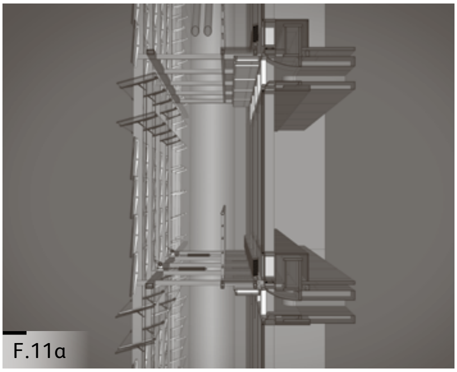
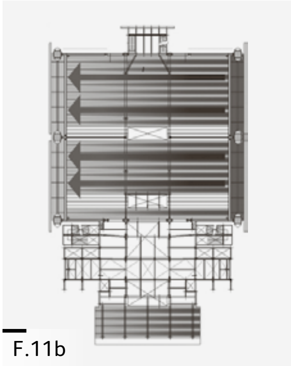

F.11a


F.11b

F.12a


F.12b

F.10
Elm Park Double facade with cross ventilation.

F.11
Intesa San Paolo Tower
a) double facade with air intakes
b) air flaw into the slab dran by the external pressure difference.

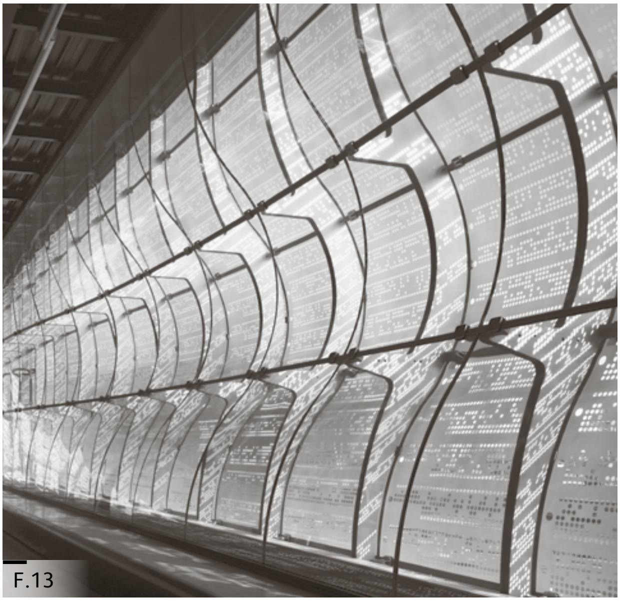
F.12
Naturally ventilated atriums:
a) Avignon TGV Station with transparent facade facing North,
b) Strasbourg TGV Station with transparent skin facing south.

lindrical glass. The facade is a nearly smooth double curvature skin realised with cylindrical DGU produced by a variable radii tempering machine. The result is a free form surface with thermal properties equivalent to high performance standard facade. The project will be revealed to the public at the end of the 2013.

6 – Conclusion

In the last ten years RFR have worked on double curvature skins which have moved away from facetted surfaces and towards smooth glass envelopes. During this process the thermal properties have improved in order to realise glass envelopes that comply with the necessity and requirement of the activity hosted in the building.

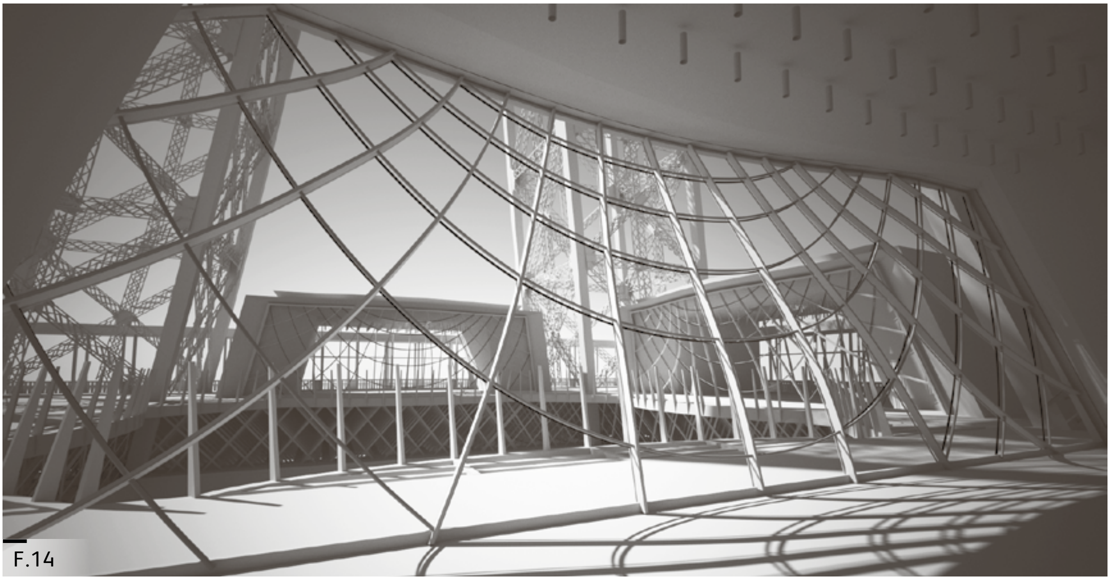
The next step will now be how to integrate reflections on the structural use of glass integrating robust design. The aim is to achieve smooth double curvature skins which are fully structural and thus eliminating frames. This will take us closer to the dream of a pure transparent architecture so strongly advocated by the German Expressionist architects at the beginning of the twentieth century.



F.13

F.13
«Musée de la mode et de la dentelle» free-form double facade.

F.14
Eiffel Tower first floor Pavilions with double curvature facade realised using cylindrical DGU.



F.14

ENVELOPES AND SOLAR ENERGY

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Introduction

The building envelope as a sustainable, space shaping, comfort-enhancing and energy-active element of architecture is one of the research areas at the Competence Centre Envelopes and Solar Energy (CC EASE). It studies innovative technology and materials and develops new systems and methods to integrate them into the architectural design. In the research groups of Materials and Energy, the focus lies in material qualities, as well as climate and comfort issues. In the research group of Photovoltaics and Light, innovative solutions for the architectural integration of photovoltaics and daylight are developed in international and interdisciplinary collaborations.

Solar energy surrounds our building during the day. We have learned how to use it for daylighting and heating and to control glare and overheating. This is usually referred to as passive strategies aimed at reducing the energy consumption of buildings and achieving visual and thermal comfort for the occupants. Active strategies exploit solar energy even further, e. g. for the production of electricity or heat, through photovoltaic (PV) and solar thermal technologies integrated in the building envelope. Without these technologies zero or plus-energy buildings would not be possible. However, these technologies are not popular due to their questionable architectural acceptance. Technology and design issue must be met; hence energy is the design challenge in architecture.

The paper focusses on architectural integrated photovoltaic modules. It introduces a recent case study from Switzerland and provides background information on the electricity generation potential of PV façades versus PV roofs for different climate regions and urban densities. It also introduces novel technical concepts as outlook for architectural integrated photovoltaics.

1. Case study for façade integrated photovoltaic modules

The Architects BF berger and frank AG in Sursee have integrated a solar façade on the prominent side of their new

F.01
Solar façade with good integration into cone shaped building form with irregular cuts. Source: brighthouse AG.

headquarter in Switzerland. The façade excels in the integration of PV modules in a complex cone shaped form with slanted cuts and openings as shown in *figure 01*. Every PV module is customized to a different shape. The PV system provides a significant part of the building's energy demand.

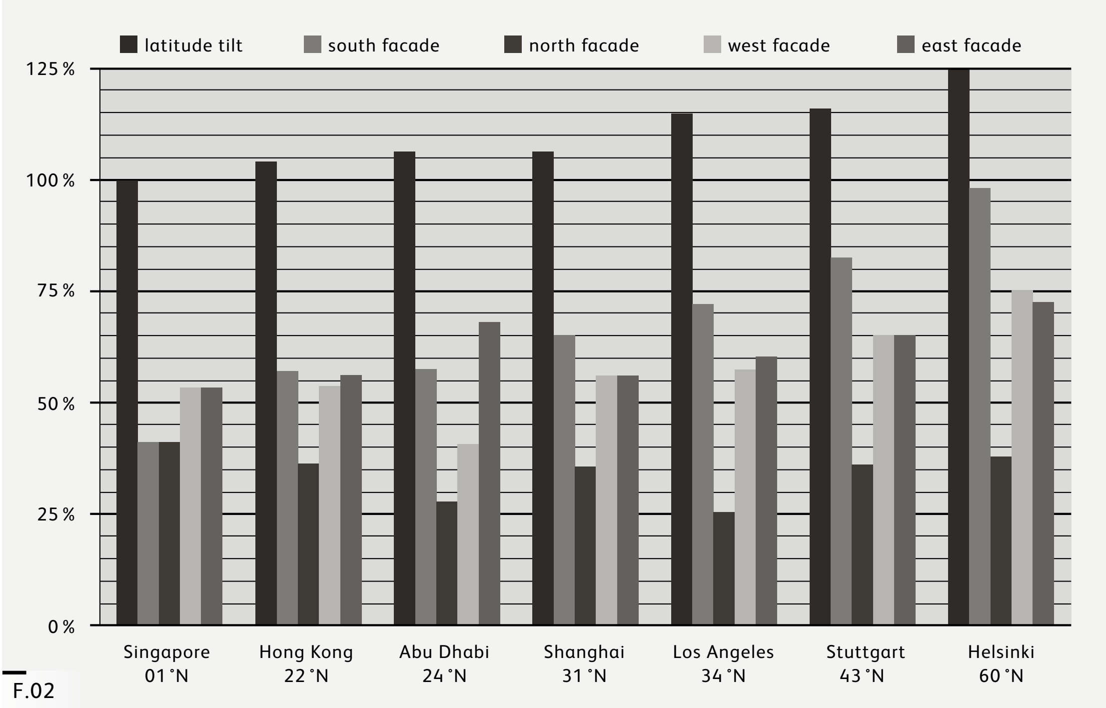
2. Electricity generation potential of PV façades versus PV roofs

In general, façades receive less solar radiation than horizontal surfaces, about 50 % at the equator to 30 % near the Arctic Circle. The relative difference between the façade orientations increases with latitude as well and is very pronounced for south façades in the northern hemisphere. *Figure 02* shows an overview of solar radiation values for roofs and façades across different locations. Latitude tilt refers to an optimal tilt angle of the PV modules towards the sun path.

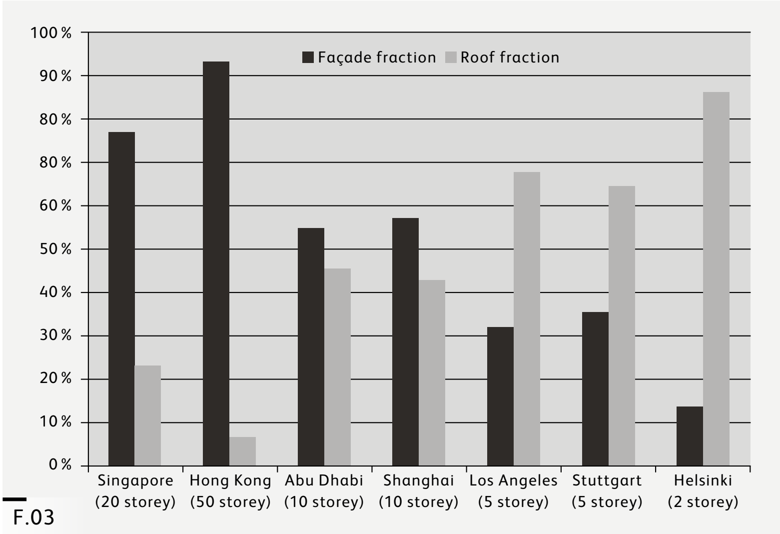
In high density locations such as Hong Kong, there are extremely high buildings compared cities such as Helsinki with predominately low-rise buildings. High-rise buildings have significantly more facade than roof area so much so that the accumulated solar radiation is higher on the façades. Horizontal surfaces would receive more solar radiation, but since their area is so small, their accumulated solar radiation is smaller. Around 60 % of the façade area and 75 % of the roof area can be covered with photovolaics, the so-called active area. Multiplying the incident solar radiation with the active area equals the useable solar radiation. *Figure 03* compares these values for roofs and façades in different locations assuming a building height typical for the specific location. Generally, façades of 10 to 50 storeys high buildings account for 70–90 % of the useable solar radiation (roof plus all four façades). The façade fraction becomes about the same as the roof fraction when buildings are around 10 storeys high. For low rise buildings of only two storeys the roof accounts for about 90 % of useable solar ration.

3.1 AIPV module with enhanced see-through and design

Common PV modules are usually optimized for power generation with the entire area filled with opaque solar cells. Glass-glass see-through PV modules for building integration are either wafer-based with gaps in between the wafers or based on thin films with fine scratches. Small gaps enable daylight transmission, with larger gaps or more free area see-through becomes possible. Wafer-based PV modules hinder see-through because of the large wafer size. Thin-film PV has smaller cell sizes and gaps appearing as tinted glass eventually providing a better see-through. However, thin-film PV is less efficient as silicium wafer-based PV. The idea is now to cut the wafers into smaller pieces, maintaining the high efficiencies but with improved see-through ability. The positive effect is similar to that of perforated wafers which are already available on the market. The difference is



F.02
Solar radiation in kWh/m²*y incident on different building surface orientations across different climates.



F.03
Façade and roof fractions for different building surface orientations across different locations.

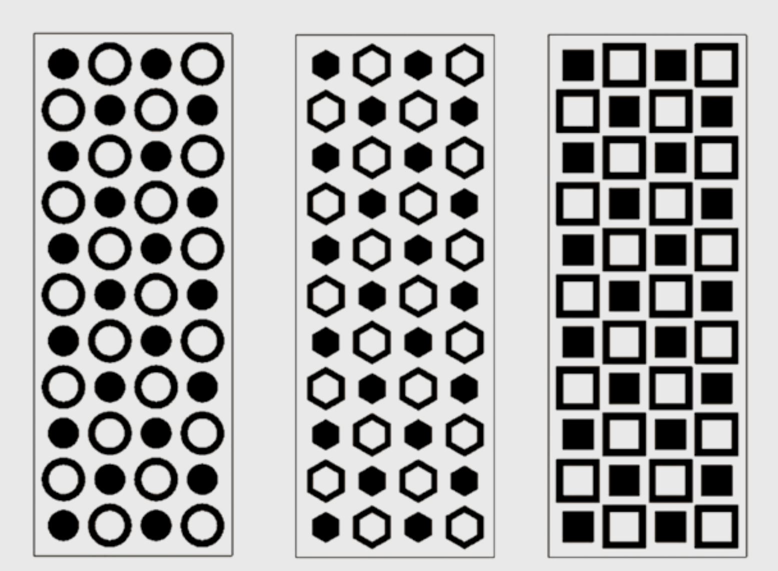
in the additional possibility of creating ornamental patterns as shown in *figure 04*. The patterns are optimized for energy efficiency, as every piece maintains the same area, crucial for avoiding blockages in the current flow. «The objective of the invention is to provide a photovoltaic module in which the solar cells do not necessarily have to be simply rectangular or approximately rectangular or have other simple forms but can rather also have more sophisticated and optically appealing forms as shown below. It is another objective of the invention to provide a method for manufacturing such photovoltaic modules where the waste of photovoltaic wafer material caused by cutoff is minimized as much as possible» (NUS, 2012, Internet: http://www.nus.edu.sg/enterprise/ilo/, last visited 24 April 2012).

3.2 AIPV module with enhanced daylighting

Daylight in buildings is usually provided by windows or skylights. They may have shading systems included to avoid glare through excessive lighting or overheating in summer. Advanced fenestration systems even include structures such as blinds for daylight redirection, so that light is provided where needed, e. g. in the deeper building zones. The idea is now to include PV in such systems, instead of blocking the light by reflecting it outwards, the surfaces of the shading systems keep the light for conversion into electricity. Such a multifunctional daylight redirection, shading and electricity generating system can be integrated in the cavity of double glazing units. The presented system has embedded blinds with two different materials, e. g. PV on top and reflective coatings at the back both on an ideally curved shape for light collection and light reflection respectively. The blinds can be rotated so that functions can be optimized for different purposes as shown in *figures 05a–d*. Setting 1 (from left to right) shows the blinds in a vertical position with the PV cells facing outwards (left) to fully utilize the daylight. This could be during a sunny day when full shading is needed and daylight is already sufficient or when privacy is required in the space behind. In this position, the outer appearance of the window is similar to an opaque PV module. In setting 2, the blinds are open with approximately 45 degree slant, enabling light to pass, while allowing some view through. Electrical power generation should be at its highest due to the perpendicular incident of sunlight and still small self-shading of the blinds. Setting 3 shows the blinds in horizontal position providing the best view and daylight redirection into the interior. Electricity can still be generated through light ray being reflected of the blinds onto the downwards facing PV surface. Setting 4 is similar to setting 1 in that the blinds are vertical, but dif-

F.04
Concept sketch of an AIPV Module with enhanced see-through and design

F.05 a–d
Concept sketches of different settings of an AIPV Module with enhanced daylighting



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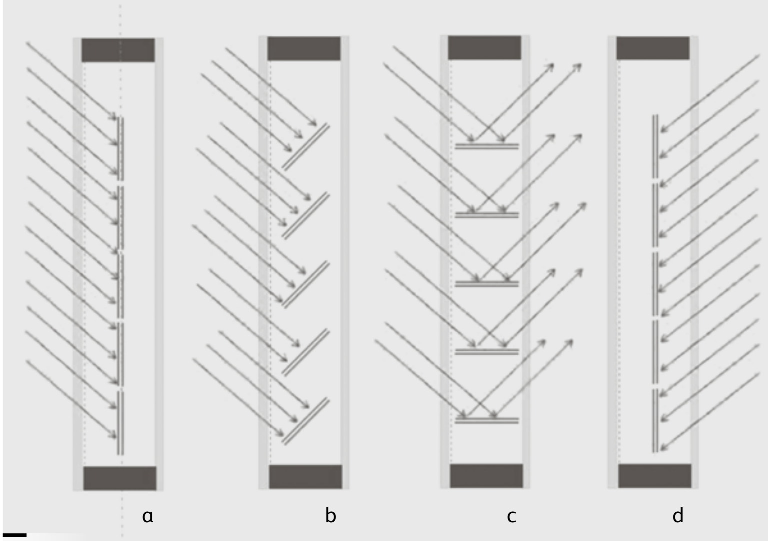
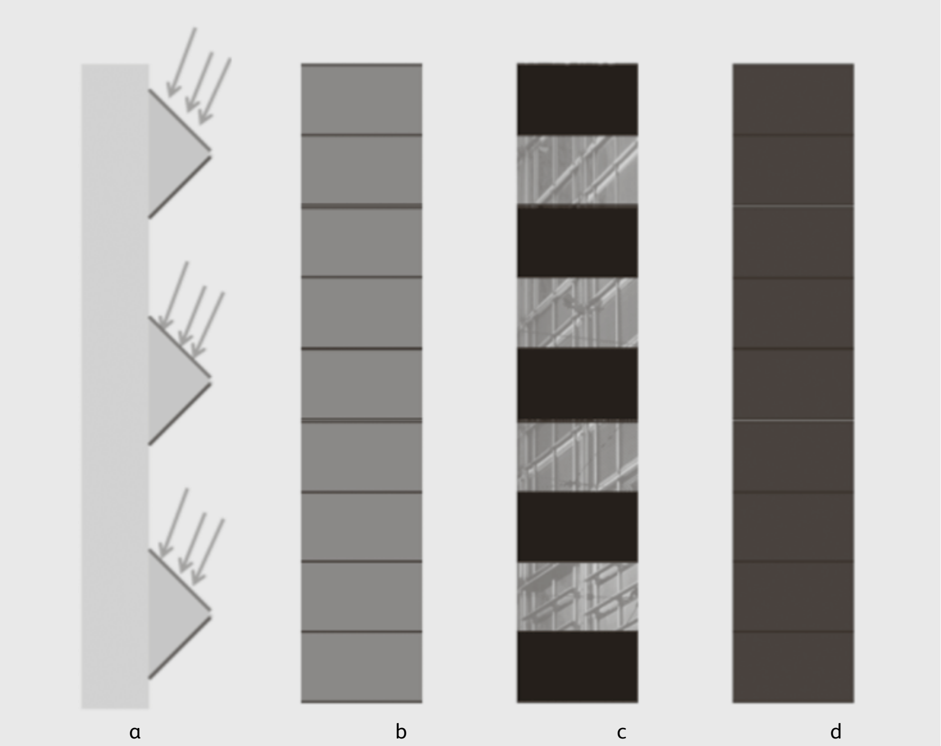


F.05

ferent as the PV is now facing inwards. This would be ideal for winter situation when the only light is that of the electrical lighting indoors. Some, admittedly small, electricity generation would be possible if rooms are illuminated brightly for specific tasks. «Our Invention enhances the commercial viability of BIPV modules by introducing enhanced daylighting functionality into BIPV module designs. The key feature of our invention is an integral blind module for integration in building façades with venetian blinds that comprise a photovoltaic coating or module for electricity production on one side and a specially-designed, highly reflective coating for natural lighting on the other side» (NUS, 2012, Internet: http://www.nus.edu.sg/enterprise/ilo/, last visited 24 April 2012).

3.3 AIPV module with angular selective reflection and transmission

PV modules on façades usually appear as dark rectangular slabs. Variations in colour or texture are not common. Traditional façade materials however offer a full colour and texture range, a missing design feature often criticised in PV. Particularly in urban spaces, aesthetics is an important concern so much so that relevant authorities reject standard PV from becoming a visible feature of buildings. The idea is now to improve the appearance of visible PV modules without losing efficiency and while allowing see-through at the same time. For this purpose a three-dimensional horizontal structure of triangular shape is added in front of a glass-glass PV module. When this module is fitted to a façade, some faces of the structure are facing downwards, others are facing upwards, with some areas in between not covered to allow clear see-through. The downward facing surfaces are not meant to be transparent; instead they can be painted in any colour. Looking up towards these PV modules – a common view from within the streetscapes in between buildings – a person would predominately see these coloured surfaces and not the dark PV surfaces. These PV surfaces however are visible by the sun as they are facing upwards and provide an even better angle to harnessing the natural daylight. The gaps in between provide a clear horizontal view out from an occupant. The schematics of this concept is shown in *figures 06a–d*. *Figure 06a* (from left to right) shows a section illustrating the upwards and downwards facing PV and coloured surfaces respectively. *Figure 06b* is the view of the sun towards the upwards facing PV surfaces illustrating full exposure. *Figure 06c* shows the view of an occupant looking through this AIPV module. The backside of the structure remains black whiles the gaps in between provide



F.06

F.06 a–d
Concept sketches of different settings of an AIPV Module with angular selective appearance

clear view. *Figure 06d* illustrates the coloured appearance when viewing this AIPV module from the street level below. «The object of this invention is therefore to develop a BIPV module for use in building façades that satisfies aesthetic requirements of architects and clients and that achieves a better power output than common vertically mounted BIPV modules. The invention mainly consists in a microstructure for a BIPV module comprising a PV layer facing zenith, a color layer facing a street level observer, and gaps between groups of PV layers and color layers for see-through from inside (optional)» (NUS, 2012, Internet: http://www.nus.edu.sg/enterprise/ilo/, last visited 24 April 2012).

Summary

This paper has introduced a good example for façade integrated photovoltaics demonstrating a direction of building integrated photovoltaics where architecture is no longer compromised. The charts indicate that façades, albeit receiving lesser solar radiation than a roof, can still make a significant electricity contribution. For buildings higher than 10 storeys, the active are has become so large that the useable solar radiation exceeds that of the roof. The novel technical concepts for architectural photovoltaic modules provide an outlook into multifunctional solar façades, featuring daylight, electricity and improved design.

Acknowledgements

The concepts of the AIPV modules were developed by the author when working for the Solar Energy Research Institute of Singapore (SERIS) and while participating in the IEA-SHC Task 41: Solar Energy and Architecture. The AIPV modules have already been publicly presented by the National University of Singapore (NUS) as technology offers through its Industry Liaison Office website (ILO).

PASSIVE HOUSE CONCEPT FOR HEATED CURTAIN WALLING SYSTEMS

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Introduction

The basic idea behind the heated façade originated more than 40 years ago.

Hot water flows through the façade frame profiles *(Figure 01)*. In addition to their function as a supporting structure for insulating glass panes and panels, the hollow steel profiles become radiators.

Since this idea first originated, a large number of projects worldwide have been implemented using this technology.

Assessment

Besides the obvious aesthetic benefits resulting from the elimination of radiators, the design advantages of this concept are particularly impressive: a much greater feeling of comfort due to higher inside exterior wall temperatures and the prevention of radiative cooling and cold air downdraughts. In addition, the effective life of the insulating glass panes is increased because the formation of condensation around the edge of the glass is reliably prevented. Both effects are ideal prerequisites for the use of heated systems for large-scale glass designs.

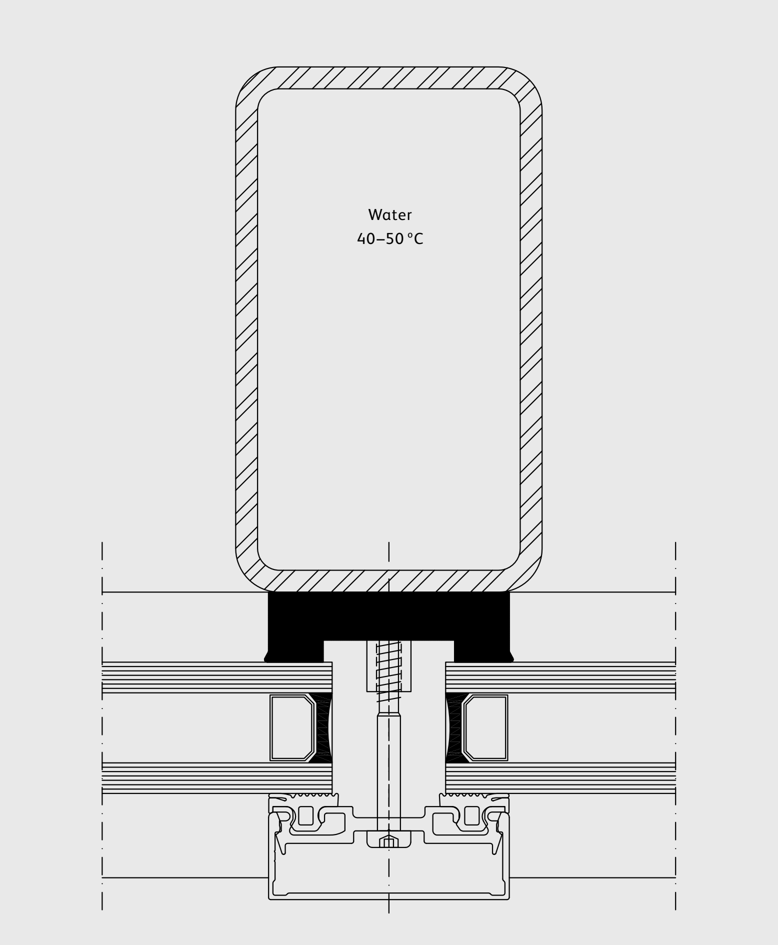
Important factors in terms of cost efficiency are the space gained and the simplified and hence cost-effective cleaning compared to façades with radiators.

Innovation

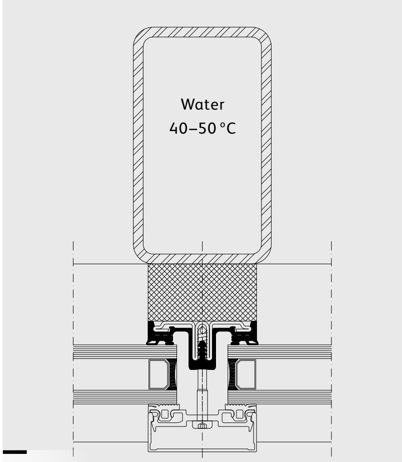
In terms of heat technology, the heated façade differs from a conventional façade in one respect: the inside profiles have surface temperatures that are significantly above room air temperatures – standard values range between 40 and 50 °C.

For that reason, thermal insulation in the profile area aimed at limiting heat losses is particularly important. Above-average thermal insulation between the profile and the external climate was critical.

Until recently, this has usually been achieved by using insulating blocks positioned on the inside – often also referred to as thermoblocks – with thicknesses of between 30 and 40 mm *(Figure 02)*.



F.01



F.02

F.01
Basic concept of a heated façade

F.02
Heated façade with interior insulating block – current principle

However, thermoblocks are far more complicated to manufacture and the solution is also unsatisfactory in terms of design

The first step, therefore, was to look for ways of eliminating the thermoblock. The new solution is based on the idea of placing a thermal insulation layer that is as homogeneous as possible and is made up of insulating glass or a panel and profile in front of the internal profiles, which have hot water flowing through them. Comprehensive tests prove that heat losses using the new concept are no greater than those using the current solution with thermoblocks.

The combination of several components has made this possible. The basis is and will remain high-quality heat protection glass in conjunction with warm edge spacer bars, such as Thermix, Swisspacer, TIS and the like, that provide above-average insulation, as well as a specially formed insulating block with very low conductivity in the glazing rebate and adequately dimensioned interior gaskets with heights of 12 mm and more.

The result is remarkable. The heated façade can now no longer be distinguished from standard façades. The previously mandatory, massive interior insulating block is no longer required *(Figure 05)*.

It not only improves the visual appearance but also makes the façade much simpler, and hence also more cost-effective, to manufacture (fewer parts – use of standard screws and standard glass supports). Even the elastomeric foam strip specially designed for this type of application does not increase the manufacturing workload compared to the standard system.

The Passive House Concept

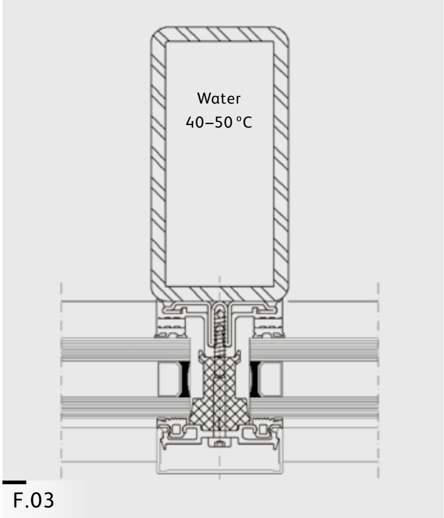
The logical further step is to develop the heated façade at passive house level.

value of $U_{cw} \leq 0.80$ W/(m²K) must be adhered to for the complete unit and a value of $U_f \leq 0.76$ W/(m²K) for the profile.

In relation to the heated façade, the concept is based on the highest thermal insulation and a drastic reduction in external heat losses from the interior façade profiles which have hot water flowing through them.

In addition to triplex glass, $U_g \leq 0.70$ W/(m²K) with a psi value of less than 0.05 W/(mK) – which can be achieved using two warm-edge spacer bars – the main modification is a double cross-linked foam strip in the glazing rebate and an interior gasket with a height of 20 mm *(see figure 04)*.

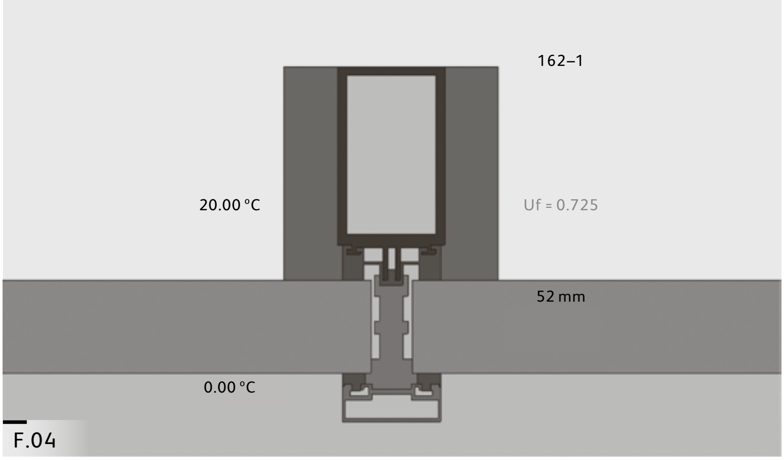
This type of design reduces heat losses in the area of the heated profile even more significantly. In the example examined, with a flow temperature of 40 °C (= average over the heating period), the temperature differ-



F.03

F.03
Construction cross-section of heated façade system – current principle

F.04
Basic design of a heated façade suitable for passive houses



F.04

ence between the external profile surface temperature and the outside air temperature is reduced to 1.24 K – slightly above a profile that does not have hot water flowing through with 0.86 K.

However, the glass and frame by themselves are not sufficient. That applies most notably to the area of high thermal insulation technology – a suitable panel with Up values ≤ 0.20 W/(m²K) must be added.

To date, two solutions have been used to address this:
Solution 1: standard panels with insulating boards and filling thicknesses of between 200 and 300 mm;
Solution 2: vacuum insulation panels with a thickness of approx. 30 mm or higher if necessary.

Both solutions create considerable technical problems for passive house façades. A standard panel with a filling thickness of 200 mm and higher can only be integrated using expensive edging systems which, at the same time, have a very adverse effect on the thermal insulation.

With VI panels, the thickness of the adjacent insulating glass pane and the barrier film temperatures of the VI panels (often in the range of 100 °C and higher in the summer, below the dew point temperature in the winter) are problematic. An additional limitation that needs to be mentioned is the high edge psi values in the range of 0.10 W/mK, which can double or triple the total U value of this type of panel.

Panels with combined insulation comprising mineral wool in front and a VI panel positioned behind it provide the solution: a vacuum panel facing towards the interior and a standard mineral wool panel facing towards the exterior are integrated into a standard panel design *(Figure 06)*.

This produces very simple panels with adjustable thicknesses. Proven components made of pressure-resistant foam can be used as the edge seal. The edge psi values are hence in the range of ≤ 0.03 W/(m²K).

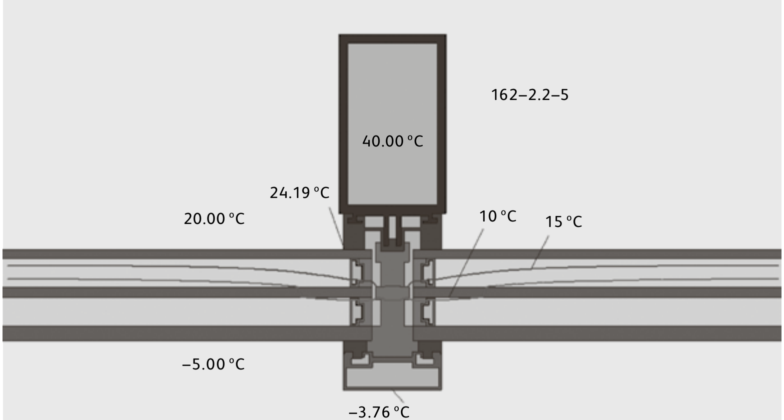
Only this panel design facilitates a complete solution for a homogeneous design for the glass and panel area of a heated passive house façade *(Figure 07)*.

And heat losses are further reduced, as shown by the isothermal calculation *(Figure 08)*. The temperature gradient is now 0.54 K – compared to 0.44 K of a non-heated façade.

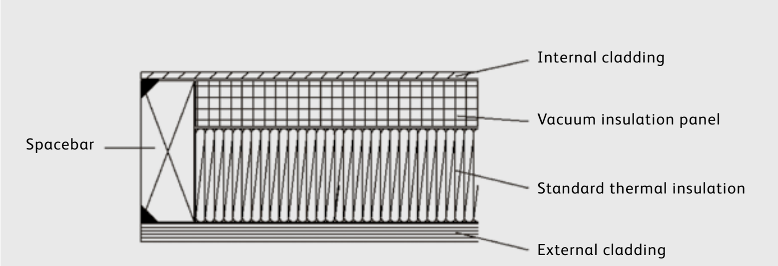
And, in addition – almost as a by-product of this concept – very low values for the total heat transmission coefficient of the façade are achieved.

Using standard dimensions for the façade elements, the UCW values are 0.67/0.55 W/(m²K) if the dimension between axes is 1 m and 0.63/0.50 W/(m²K) if the dimension between axes is 2 m, i. e. in any case values significantly below the limit for the passive house concept.

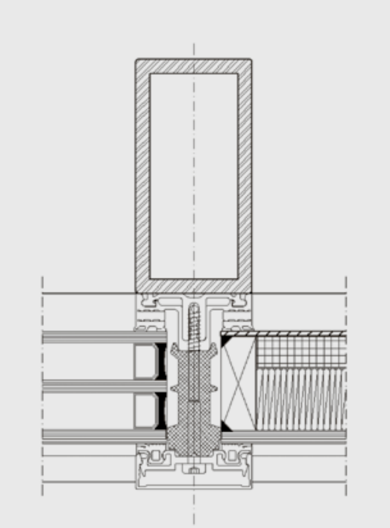
The level that has now been reached creates completely new prospects, such as the possibility of further reducing the flow temperatures of the profiles that have hot water flowing through them and/or reducing the number of heated profiles, thereby further lowering costs.



F.05



F.06



F.07

F.05
Isothermal flow and surface temperatures in a heated façade suitable for passive houses, with triple thermal insulation glass and warm-edge spacer bars.

F.06
Design of the VI panel

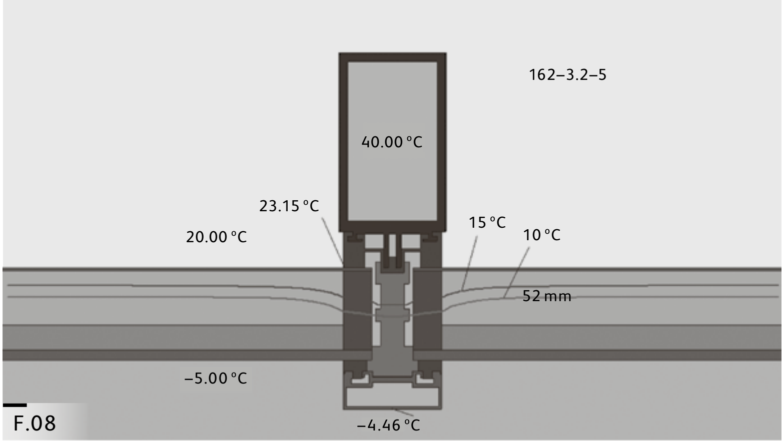
F.07
Heated façade suitable for passive houses – complete solution

Summary

For more than 40 years, heated façades have had their place as high-quality glass/metal façades with particular advantages in terms of utilisation of interior space and comfort.

The development of the thermoblock-free system has significantly expanded their potential uses (simplified construction – better design).

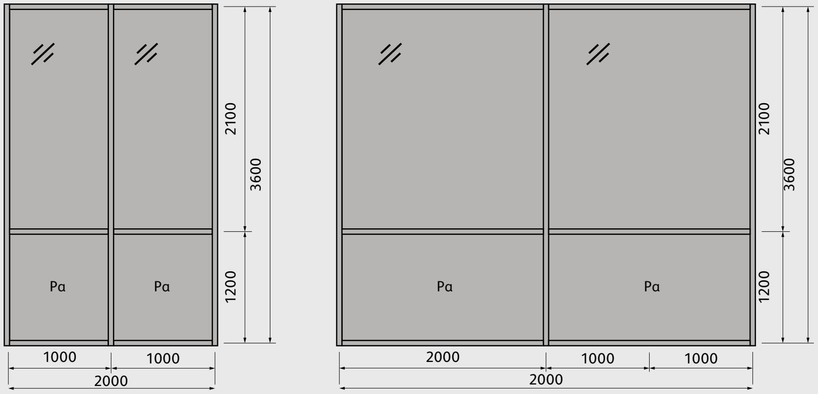
The concept of the heated façade suitable for passive houses enables other signifi-cant improvements to be achieved: thermal insulation of the frame, glass and panel at passive house level with further reduced heat losses in the range of 40 % and higher.



F.08

F.08
Isothermal flow and surface temperatures in a heated façade suitable for passive houses, with a VI-plus panel

U-Top



Dimension between axes	*Uf*		*Glass*			*Panel*		*Ucw*
		Ug	*Ψg*		*Up*	*Ψp*		
1000	0.92	0.7/0.5	0.04	triple	0.2	0.02	VI-plus	0.67/0.55
2000	0.92	0.7/0.5	0.04	triple	0.2	0.02	VI-plus	0.63/0.50

F.09

INTELLIGENT FAÇADES: STATE OF THE ART

Andrea Compagno
FASSADENPLANUNG UND -BERATUNG, ZÜRICH (CH)

The discussion on the sustainability of buildings led many architects to consider the building envelope as a responsive system, which interacts between the environment and building's services systems in order to reduce the energy consumption of the building.

In the early 90's high performance façade constructions as double skin façades were developed and promoted as the ultimative solution to energy consumption. Energy efficient façades can be considered intelligent façades. However energy efficient façades are not a recent invention; rather, they have always existed everywhere in the world where buildings are constructed in accordance with the climatic conditions of their location.

Therefore double skin façades are only one step in an evolution which can be seen as a steady process, in which the basic conditions are changing perpetually due to the development of new technologies.

In the years following the Second World War, the leading examples of modern glass architecture were realized in the US, for example the skyscrapers «Lever Building», 1951–52, by the architectural office SOM, and the «Seagram Building», 1954–58 by Mies van der Rohe, both in New York, and later on the «Hancock Tower» in Boston, 1967–76 by I. M. Pei and Partners in collaboration with H. N. Cobb.

At that time energy loss in winter and overheating in summer were overcome with energy intensive mechanical air conditioning systems for heating and cooling.

After the energy crisis of the 70's double glazing against energy loss and solar shading against overheating were increasingly employed. Due to wind forces the allocation of external shading devices is problematic, especially in the case of high buildings.

Double façade overview

Double skin façades are a possible solution to this problem, because the solar shading device is located in the cavity between the two glazing skin and therefore protected from the wind.

F.01
Richtiareal, 2008–13,
Wallisellen by Zuerich,
Wiel Arets Architects

By externally ventilated systems the cavity is connected with the external air, which enables the users to ventilate naturally the space simply by opening windows or flaps, thereby reducing the running costs of the mechanical ventilation system.

This advantage led to various concepts for naturally ventilated double skin façades, which can be distinguished primarily by the geometry of the cavity, the arrangement and the size of the ventilation openings and the resulting air flows.

For efficient natural ventilation it is essential to prevent overheating of the cavity. Many factors influence this, as the building location and design, air flows inside the cavity as well as the impact of solar shading devices.

Well known example are the Commerzbank Headquarters in Frankfurt, realized by Foster and Partners in 1991–97, the RWE Headquarters in Essen, 1991–97, by the architects Ingenhoven Overdiek and Partners and the GSW Headquarters in Berlin, 1995–98 by Sauerbruch Hutton Architects.

In order to adapt easier to the changing climatic conditions some double skin façades are fitted with adjustable openings.

The architects Petzinka Pink and Partner designed ventilation units for the «Düsseldorfer Stadttor» in Düsseldorf, 1991–97. They are situated in front of the floor slab and are fitted with adaptable flap, which regulate the air flow in the cavity.

Façades which allow for the opening of the exterior glazing itself are a further development.

At the Debis Headquarters in Berlin, 1991–97, the architects Renzo Piano Building Workshop and Christoph Kohlbecker devided the exterior glazing in pivoting glass louvres.

The architects Schneider + Schumacher radically simplified this idea at the Braun administrative building in Kronberg, 1996–2000; the storey height panes of the exterior glazing can be opened like glass doors.

Hybrid façades

One of the most important arguments for the use of double skin façades is that natural ventilation throughout the year is made possible. However, this function is considerably compromised by the fact that the cavity air heats up as soon as the sun shines and so prevents to open the windows. Depending on the location and type of façade construction natural ventilation may be possible only 50 % of the year. In order to deal with this disadvantage hybrid façades were developed, where a double skin façade is combined with a separate façade module for natural ventilation.

F.02

F.03

F.02
Commerzbank Headquarters, 1991–97, Frankfurt, Foster and Partners

F.03
Debis Headquarters, 1991–97, Berlin, Renzo Piano Building Workshop and Christoph Kohlbecker

Example of this type are the high rise building of the new Debitel headquarters in Stuttgart-Waihingen, designed by the architects Rhode, Kellermann, Wawrowski RKW in 1996–2002 or the office building Westend-Duo in Frankfurt a. M., completed by Engel + Zimmermann Architects in 2006. The double skin façades are fitted with small vertical ventilation modules which enable individual ventilation by opening manually an internally located vent with fixed louvres for sun and rain protection on the exterior.

Decentralized ventilation

A further possibility to reduce the costs for central ventilation system is to use decentralized ventilation units. They are displaced along the façade and are fitted with a fresh air intake, which allows to supply fresh air directly to the rooms. The units can regulate the temperature of the fresh air by heating or cooling it and, depending on the model, they can even function as heat exchangers between the exhaust air and the supply air.

Depending the design, maintenance is easy.

Another advantage is the individual possibility for control and the adjustability to different situations of room occupancy.

In addition, the space required for complex and costly ductwork of a centralized air system and the dimensions of the services central plant itself are reduced.

Examples of façades with decentralized ventilation units are the office building «Capricorn-Haus» in Düsseldorf, completed by the architects Gatermann + Schossig in 2006. The ventilation units are located inside the façade parapet. The fresh air from outside is heated or cooled by the ventilation units and flows into the offices through slots at the edge of the floor. The exaust air is drawn through the unit for heat recovery and then exausted.

The Deutsche Post Headquarters in Bonn, completed in 2003 by the architects Murphy/Jahn, is a further example for the use of decentralized ventilation units in a double skin façade.

The exterior glazing of the south façade is shingled and the steps are closed by ventilation flaps. When the flaps are open, fresh air enters the façade cavity. The decentralized ventilation units are located in the double floor at every other axis of the façade. The fresh air from outside flows from the façade cavity into the offices via ventilation units, which either heat or cool it. The exhaust air is drawn along the corridors to the central atrium and exhausted through ventilation flaps in the glazed end façades.

F.04
Debitel headquarters, 1996–2002, Stuttgart-Waihingen, Rhode, Kellermann, Wawrowski RKW

F.05
Westend-Duo, completed in 2006, Frankfurt a. M., Engel + Zimmermann Architects


F.05


F.04


F.07


F.06

F.06
«Capricorn-Haus», completed in 2006, Düsseldorf, Gatermann + Schossig Architects.

F.07
Deutsche Post Headquarters, completed in, 2003, Bonn, Murphy/Jahn Architects

The north façade functions in the same way as the south façade. However, it has a smooth exterior skin and the ventilation flaps are flush within the façade.

New developments

Since the introduction of natural ventilation concepts in the 90's, more and more office building in Europe are fitted with windows or vents, to allow the users to ventilate naturally the working spaces. On the other hand, office building in USA are only ventilated by central air handling systems.

In Europe the trend of natural ventilation is supported by the mild climate and high quality of external fresh air and seems to make a positive impact on occupants comfort. The design must take account to minimize the heat loss in winter by opening windows or vents, and to avoid draft through the building caused by wind pressure and depression.

Example of single façade with openable windows or vents are the Deutsche Bank Headquarter in Frankfurt and the Elbe Philharmonic Hall in Hamburg.

At the Deutsche Bank, the existing window were not openable and functioned as internally ventilated double skin. Since the refurbishment completed by Mario Bellini Associati in 2011, the window are now parallel moving out sash and allows the users natural ventilation.

The Elbe Philharmonic Hall in Hamburg, designed by Herzog de Meuron, under construction, is a mixed use building with offices, hotel, concert hall and apartments. The façade is fitted with oval, openable vents, which are integrated in the curved central posts between the flat and the concave or convex glazing units. They allow on one side the natural ventilation and on the other the acoustic contact to the external harbor activity. In the apartments and hotel rooms, the vents are operated manually, in the main foyer they are motor driven and are part of the smoke exhaust concept.

A recent example of double skin with openable vents is the ADAC Headquarters in Munich, 2004–11, designed by Sauerbruch Hutton. The variously colored façade is composed by double skin modules. The internal skin presents two glazed windows and an opaque vertical vent. The windows can be opened for maintenance. The vents enable the natural ventilation. They are fitted with a constant volume-flow control system, which ensure a constant air exchange rate between outside and inside and avoids that difference pressures cause draft effects inside the building. The unit operates mechanically by itself and it requires no auxiliary energy.


F.09


F.08

F.08
Elbe Philharmonic Hall,
under construction,
Hamburg,
Herzog de Meuron,

F.09
ADAC Headquarters,
2004–11, Munich,
Sauerbruch Hutton

Closed Cavity Façade

A further development of double skin concept is the closed-cavity façade, so called CCF. The cavity between the two skin is completely sealed from external influences and is supplied with clean dry air via a compressed air system. The tubes are only few millimeters diameter thick and are fed by a compressor located in the buiding service central. The dry air prevents the formation of condensation in the cavity and on the internal surface of the single glazing. The advantage of this type is to reduce considerably the cleaning costs and to achieve a higher insulation performance.

An example of the closed-cavity façade is the administrative building for Roche Diagnostics AG, Rotkreuz, 2008–11, designed by Architect Andreas Hell, Burckhardt Partner (Basle). The double skin façade is equipped with triple glazing on the internal skin, high reflective louvers for solar protection in the cavity and laminated glazing on the external skin. To provide the ventilation of the building 600 decentralized ventilation units with a heating and cooling component are placed in the double floor along the façade.

Another example of CCF are the office buildings «Richtiareal» in Wallisellen by Zuerich, designed by the Wiel Arets Architects in 2008 and to be completed in 2013. The modules are fitted with triple glazing inside, textile tends for solar shading and a fritted laminated glazing on the outside; the rooms will be ventilated mechanically.

An example of CCF with openable windows is the refurbishment of the «Poseidon Haus» in Frankfurt, to be completed in 2013 by the Architects Schneider+Schumacher. Every second glazing units is a parallel moving out window, which allow a natural ventilation of the working spaces.

Summary

The different examples show that doesn’t exists an intelligent façade but rather that different parameters have to be considered depending on the case, in order to find an individual solution according to the local climate and the function of the building. This is a prerequisite for the development of holistic energy concepts, which can only be realized through integrated planning, that is through an intensive, interdisciplinary collaboration between architects, façade and environmental engineers.

Double skin glass façades are technically intricate and therefore expensive. Hybrid façades are an alternative. Both enable natural ventilation over a certain period of time, but require the support of a central mechanical air system at low or high exterior air temperatures.

F.10
Administrative building
for Roche Diagnostics AG,
2008–11, Rotkreuz,
Burckhardt Partners

Façades equipped with decentralized ventilation units require a central mechanical air system for heat recovery purposes in so far as they are not equipped for it.

Closed cavity façades allow to reduce drastically the maintenance costs and enable the use of decentralized ventilation units or to open windows for natural ventilation.

The examples listed also show that new ideas and experiments are continuously leading to improvements. The objective of realizing intelligent façades for environmentally sustainable buildings with minimal energy consumption and reduced investment of capital will continue to be a challenge in architecture and technology.

EMBODIED ENERGY IN FAÇADE DESIGN

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This article gives a short introduction to the recent development of sustainability in the built environment and shows the potential of embodied energy to reduce the impact this sector has on nature. The applications of ecological information are introduced and commented on according to their potential. An excerpt of strategies is given at the end.

Sustainability in the built environment

In the last millennia mankind has learned to cultivate the broad variety of resources nature offers. The dimension of consumption increased with the industrialization and interfered with a stable system, thus causing change, which is unpredictable, irreversible and potentially constrains the living standard society has reached. While the massive influence on nature took place in the last three hundred years, consciousness about that effect developed in the second half of last century. In the past fifty years, politically and socially motivated environmentalism has become a new focus.

The growing respect for nature and its integration into decision-making processes on different levels (individual, industrial, political) are stimulated by various aspects. Extreme weather conditions, increasing energy prices and the subsequent energy revolution have raised a new awareness for nature, which shows the dependence on a well-functioning ecosystem. The social pressure has now reached a level at which the industry has to react with ecologically friendly products. Transported by media, the topic of environmental protection has been widely discussed. Today’s society is well informed about the reciprocal effect of consumption and environmental impact. Hence, environmentalism has become a marketing topic.

Today this increased sensitivity for nature is evident in everyday life. The building industry is affected in a special way since it deals with half the global resources and is responsible for more than the half of the global waste. Additionally, the emission and land use contribute essentially immensely to the impact mankind has on nature. Three groups of parameters navigate the amount of environmental impact in the constructive context. The energy and emissions used for transportation, operational energy and the energy bound in the building substance, the so-called embodied energy.

Legal regulations in the building sector define minimum standards for operating energy consumption, and thereby control the use of natural resources. The building industry became increasingly aware of this correlation in the last 50 years and reacted on different levels. The respect for nature originates from a political left oriented group, while the oil crisis made it tangible for the broader population, and the IPCC report illustrated the urgency of reducing emissions. The building sector reacted with regulation on passive heat loss und limited the amount of energy to operate a building. Beginning in the 70s, the regulation became stricter over time so that now architects and planners are facing the introduction of the 2010/31/EU directive in 2020, which requires all new constructions to be nearly zero energy buildings. While today 30 years of operational energy equal the energy for the construction and demolition (assuming EnEV 2007 standard and massive construction method), this ratio will drastically change when nearly zero energy is used to operate the building. Including the ecological performance of the building substance is increasingly becoming a part of common practise. The green building certificates consider embodied energy and support its application. This tendency will develop substantially in the next decades. When a building regularly generates a high level of comfort with nearly zero energy, the building material will define the ecological quality of buildings!

Embodied energy as a potential to optimize the relation of built and natural environment

Apart from turning resources into energy carriers, processing resources into building components offers a hitherto mostly ignored potential for climate protection. Since energy is needed for every step of the production chain, (for example to make bricks from clay,) this energy must flow into a holistic consideration. The sum of all amounts of energy used in the production process yields the ecological footprint of a product. While operating energy exclusively relates to the utilizations phase, embodied energy includes the energy needed for the production and deconstruction phases. Linking both amounts of energy allows for a holistic examination of the ecological potential in the building sector.

Calculating embodied energy is done on the basis of a Life Cycle Analysis (LCA). This method is based on ISO 14040 and ISO 14044, which regulate the framework, define terms and the calculation procedure. The goal of a LCA is to identify and analyze the environmental impact resulting from the production all the way to the disposal of a particular product. It consists of a compilation and assessment of the input and output influences, and potential environmental impact of a product system throughout its entire life cycle. Depending on the life cycle impact assessment model, the indicators vary. In the building industry the factors most frequently considered are embodied energy in mega joule and global warming potential in kilogram CO_2 equivalent. This quantification serves to indicate the environmental impact. The use of embodied energy aims at the comparison of solutions in order to identify a more or less ecologically beneficial solution. It does not serve to define absolute judgement.

The instrument LCA can identify potential by comparing different variations against each other and determine the one with the most beneficial qualities. This helps to understand the relation between planning decisions and environmental impact. Naming solutions with the lowest amount of embodied energy helps to optimize the usage of resources and to limit the amount of emission as often resource consumption and emission pollution correlate. The design, the construction method and the materialization influence the amount of embodied energy spent for a building and each phase offers a potential to optimize this. In order to exploit the building substance's potential, embodied energy has become a relevant parameter in the architectural planning process.

The relevance of the facade

A building requires resources and emits gases during all life stages. The erection includes the materials, which form the building substance. The operational energy uses resources as energy carrier to generate heat and electricity for a high level of comfort. Additionally, in this phase materials are exchanged or repaired, which is part of the building's maintenance. The demolition process requires effort to deconstruct and demolish the building substance. Some of the materials can be reused or recycled. This can have a positive effect on the consumption of primary resources of the next material cycle and helps to reduce the waste amount.

The distribution of embodied energy for building elements differs with each building. Generally speaking, the structure bounds most of the energy, as it is the heaviest building element. LCA works mass-related. Hence, with mass the embodied energy increases. The difference between a concrete and steel structure is not significant and so the optimization potential is limited. The façade contributes around one third of the amount of embodied energy (again generally speaking). The essential difference to the other building elements lies in its variety. The broad possibilities of massive, skeleton, rear or modular façade and the materialization with natural stone, wood elements, metal sheets or synthetic materials influence the embodied energy essentially. Here lies a significant potential that when utilised strategically, contributes not only to a contemporary perception of architecture, but can reduce the environmental load the building sector bears today.

Following this thought, it is not only a duty to reduce the natural impairment but an architectural challenge to generate a high level of quality with what is withdrawn from nature. This relation between expended energy and generated quality defines sustainable solutions. It imperatively emphasises the exploitation of the qualitative potential, which is the drive of architects and is filled with content by each planner individually.

LCA application in the building industry

For non-LCA professionals, information on embodied energy for construction material is available in different formats. The information can be accessed on material-basis for example in Environmental Product Declaration EPDs or in a compilation of LCA results in form of a database. It can be part of interactive database or Building information modelling BIM.

Single material-based LCA information – Environmental product declaration according to ISO 14025: Material-based LCA express ecological information related to one kilogram, one cubic metre or one square metre of material. Generally, one document contains information about one product or product group. For the material-based LCA information the Type III label *Environmental Product Declaration* EPD is of special relevance as it presents ecological information on a reliable and readable basis. (The definition Type III follows the ISO 14025.)

LCA is designed to compare different solutions against each other and to identify the one with the least ecological impact. In order to do so, the investigation of the ecological impact has to have the same basis. The same phases have to be assessed, the same system boarders have to be chosen and the same processes need to be in- or excluded. In order to generate a fair comparison, *Product Category Rules* (PCR) regulate these parameters for each product category group. The structure and content is regulated in ISO 14025. The PCRs are developed by the institutes, which issue the certification in cooperation with industry partners. The content of a PCR is displayed in the box below. *(Figure 01)* The application of the PCRs helps increase the comparability and, as a result, has supported the acceptance of LCA data.

EPD was introduced by the Swedish *environdec*, after which several European institutes followed (Marino 2012). The *German Institute Construction and Environment e. V.* (IBU) published EPDs in over 20 categories relating to the building sector (Peters 2012). Companies can approach an institute like IBU or environdec. The IBU requires an LCA conducted with the Software GaBi or Simapro. If a PCR is available, the LCA will be conducted according to that, if not, a PCR will be developed. The institute itself does not carry out the LCA itself but is the holder of the certificate. An external reviewer is required to check the compliance the ISO 14040 and the PCR. By doing so, the ISO 14025 criteria third party review is fulfilled. Currently in the Netherlands the MRPI, along with others, is developing guidelines according to the ISO 14025 and prEN15804 (introduced in the following) standards for conduction an EPD.

The aim of an EPD is described as the following: *«present quantified environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function».* (Labelling" 2006) With EPD based on the ISO 14025 a format was introduced that communicates the amount of resource and energy used in the production of a product. The main element is the presentation of LCA results for products in a condensed and readable format.

A product is assessed by volume, mass or area. LCA results for products are displayed along with other physical properties. The EPD has a descriptive character and does neither judge the results nor translate them into a benchmark system. In the last two decades the demand for EPD increased significantly because EPDs deliver a relevant input for material criteria the Type I building certificates.

Even more reliability is achieved with the EN 15804:2012 *Sustainability of construction works-environmental product declaration- core rules for the production category rules of construction products.* It regulates PCR for products in the building context. It defines more precisely the parameter of the rules. An essential part is the adoption to the phases of a building product's life cycle. The norm considers production, construction, usage, end of life stage as well the benefits and loads for the next product system *(Figure 02)*.

PCR content
1 Product definition
2 Base materials
3 Manufacturing of the product
4 Product processing
5 Condition when in use
6 Singular effects
7 End of life phase
8 Life cycle assessment
9 Evidence

F.01

F.01
Paragraphs of PCR

F.02
LCA phases according to EN 15804

PCR phases according to EN 15804:2012

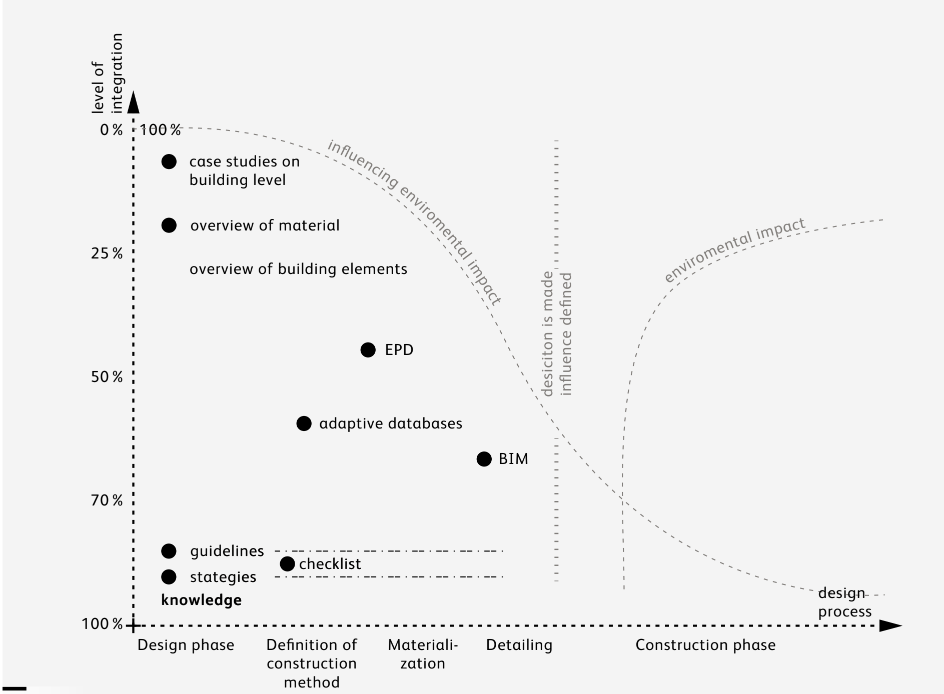
			cradle to gate	cradle to grave
Production stage	A1	raw material supply	mandatory	mandatory
	A2	transport		
	A3	manufacturing		
Construction stage	A4	transport	optional	
	A5	construction/installation process		
Usage stage	B1	use		
	B2	maintanence including transport		
	B3	repair and transport		
	B4	replacement including transport		
	B5	refurbishment including transport		
	B6	operational energy use		
	B7	operational water use		
End of life stage	C1	de-construction demolition		
	C2	transport		
	C3	re-use recycling		
	C4	final disposal		
Benefits and loads for the next product system	D	re-use recovery and recycling potential		optional

F.02

Databases: A compilation of LCA data can be found in databases. A range of databases are available, some of them freely accessible. Several databases were published in XML-format, which offers the advantage of easy access without the necessity of software and a quick and sufficient overview. Material comparison on the bases of mass and volume can easily be made based on this type of information. Some databases contain LCA information from literature (for example the Inventory of Carbon & Energy conducted by Bath University or Econum, a compendium of Swiss data published by Econum GmbH) and others display assessment results. Researched databases have to be used with care since the background information is not always available and the calculation conditions might vary. Databases published by LCA conducting companies tend to give more information about the assessment, which makes the application more easily. The German Government offers several free databases available under *www.nachhaltigesbauen.de*, like *Wecobis* or *Ökobau.dat* (Kerz 2012). The Ökobau.dat was compiled by the LCA company *PE International* and published by the German Government in 2008. It is available as xml format and in so-called ILCD format, which the European Commission, Joint Research Centre defined. Both formats do no require professional software. While the database gives quick information, the ILCD file informs on included life phases, end of life scenarios and validity. This information is necessary to understand the origin and scope of the LCA data and helps the sufficient implementation.

Interactive databases: Interactive databases contain a database and a simple calculation web-based tool (with no software installation required.) The ecological impact of for example 1 m² façade can be calculate by the thickness of each layer. Different material for layers is provided. With very little effort different solutions can be compared with each other. The simple way of operating the interactive databases makes them interesting for a quick material comparison but the background information (data quality) needs to be transparent.

Building information model BIM: The software-based *Building information modelling* (BIM) organizes physical or financial information and relates its to the building substance. CAD developer like Autodesk included BIM in the software product Revit as well Computerwork in Vectorworks. The idea behind BIM is to save all the calculation but have them within the program. By this, changes can be implemented more easily. LCA data is



F.03

available as mass related so the software can easily include LCA information. BIM is a relatively young product and it has to overcome some beginner's obstacles like organisation of building elements in groups. While the concept sounds rather simple, the implementation of LCA data in BIM is not common yet.

A similar concept can be found in the planning software for façade construction. For example Wicona and Schüco use tools with integrated LCA of a façade product. BIM is very close to the planning process and requires a lot of planning information. Corrective planning follows the identification of critical planning decision. This iterative process can involve high effort.

Overview: From the architect's perspective ecological information about building materials is accessible but quite complex. The characteristics of the architectural planning process do not easily allow for the integration of additional information due to its permanent tight time schedule. Added parameters need to be very efficient in order to become part of the planning routine.

Ecological information is available on single material level, in the format of databases or integrated in CAD software. Like described earlier, they

F.03
Administrative building for Roche Diagnostics AG, 2008–11, Rotkreuz, Burckhardt Partners

impact the grade of environmental performance to different extent. *Figure 03* shows these various formats of LCA information and indicates the level of influence planning has on the actual environmental impact. Decisions in the early design phase are the most important ones. This decreases with proceeding planning phases since the steering possibilities become more limited. While general information, like published in case studies, is very interesting, practical information on ecological impact and sufficient planning advice is needed to become relevant for the planning process for example given in the guidelines and strategies.

Consequences for facade design

The potential for the reduction of the environmental impact of the building sectors is evident when considering the resource flows which are controlled by the planning of the erection, opera tion and demolition of a building. Though information is available, it lacks integration into the architectural planning process. The architect and planner have to have the ecological parameter in the right planning phase in the appropriate form. Single information on material is not sufficient to become part of the planning routine. BIM includes an iterative process, which requires detailed planning for a corrective solution and by that a high planning effort. Architects and planners need to understand the embodied energy's mode of action. This contains different parameter for each planning phase. While the design phase defines the cubature and by that the façade area, the construction method determines the amount of material that will be installed. Additionally, the way of jointing is decided and by doing so, the possible end of life scenario. The environmental burden will increase with extensive material use. In the materialization phase the choice of material finalizes the amount of embodied energy.

Strategies and guidelines contain comprehensive knowledge in a simple format. The general character is appropriate for the uncertainties, which are typical for the design phase. Various interdependencies can be identified from the evaluation of LCA on product-, building element and building level. Here three important ones of mentioned.

1. The grade of sustainability is a relation which can be optimized in two direction: quality and environmental impact
2. LCA is mass based. With less material consumption the embodied energy figures decrease.
3. All phases of a material are relevant to address all environmental dimensions (resource consumption, emission and waste production)

F.04
In the design phase the cubature is defined and with this the amount of embodied energy in the building skin.


F.04

Especially for facade design the determined duration of a building should be reflected in the construction method. The shorter a façade will be used for, the less energy it should bind. In the planning process the end of life should be considered and functional advantages should be weighed against the potential reuse or recycling capabilities. The format of LCA data needs to be suitable for the architectural planning process in order to exploit the potential in optimizing resource consumption and limiting emission and waste production.

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F.05
The broad variety of construction method and the materialization bear potential to realize high quality architecture with low embodied energy (Academy Mont-Cenis)

USING BIM TO DEVELOP BUILDABLE FAÇADES

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Abstract

The increasing use of Building Information Modelling (BIM) across the construction industry opens new opportunities for interdisciplinary working. For the façade industry, BIM offers improved communication with members of the design and construction team, and fast access to increasingly complicated design information in a consistent digital format.

Modern façade design projects involve a wide range of materials whose manufacturing and installation impose many different constraints on the design. The façade engineer's role is to manage and apply these constraints to achieve an optimal design. This task is complicated by the increasing geometric complexity and diversity of elements required by architects. In other information rich industries, technologies similar to BIM are used to facilitate the design process.

The research project proposes a tool to assist façade engineers in the capture, storage and use of «downstream» design constraints. The tool captures and codifies expert knowledge of the geometric constraints placed on façade panels due to the manufacturing processes required to meet the design specification. Using the data stored in project BIM databases, the tool evaluates façade designs against constraints stored in the reusable expert knowledge database. The prototype tool facilitates the use of expert knowledge to perform manufacturability analysis of façades.

As a demonstration, the tool is applied to real-world façade projects taken from the portfolio of the project industrial partner, Ramboll. The manufacturability of the design is assessed, assisting the façade engineer in the iterative development of the panelisation scheme by proving fast feedback on the implications of any modifications.

Introduction

The façade sector is information intensive, and the development of a good façade design relies on the façade consultant's ability to gather and assimilate large quantities of information regarding the constraints on the design. Using this information, the consultant must identify and communicate the impact of these constraints to the design team. The task is made more challenging by the increasing complexity of façade designs. This complexity arises both from the geometry and from the materials and processes required to produce façade panels to increasingly high-performance specifications.

The primary benefits of Building Information Modelling (BIM) include the efficient storage, access and transfer of design information, and increased collaborative working.[1] As a result BIM has been proposed as a tool to manage and communicate design information.[1] In recent years the construction industry as a whole has increased its use of BIM. However, BIM can be used to improve the end product as well as the design process. The availability of semantic digital design information provides the construction industry with the opportunity to employ knowledge-based engineering techniques.[2]

Knowledge-based engineering techniques have previously been used successfully in manufacturing industries to improve manufacturability using Design for Manufacture (DFM) strategies.[3] This has relied partly on the availability of semantically rich digital design information. Fox et al.'s[4] review of DFM and its applicability to the construction industry places the façade sector in the group of sectors to with the potential to benefit most from cost reductions through DFM.

Mapping Façade Design Processes

As part of previous work undertaken by the author[5], a full map of the façade design and construction process has been developed. For the research presented in this paper, the map was used to identify patterns of use of specific information or knowledge objects. For example, by identifying the repeated use of packets of knowledge that are not project-specific a system can be developed to capture, store, and make accessible these elements for re-use in subsequent projects. In addition, by assessing when these information objects are re-used, the tool can been developed to encourage users to update the recycled information.

Figure 01: Activity A1.5.1: Activity A1.5.1 *(Figure 01)* requires knowledge on size restrictions of facade panels to assess the panelisation scheme proposed by the project architect. This knowledge is owned by the consultant and not specific to the project. Activity A1.5.3 uses the same information for a development rather than a review task. The consultant has the opportunity to update the knowledge during activity A4.6.1, when the same type of information, this time owned by the contractor, is used to review the design.

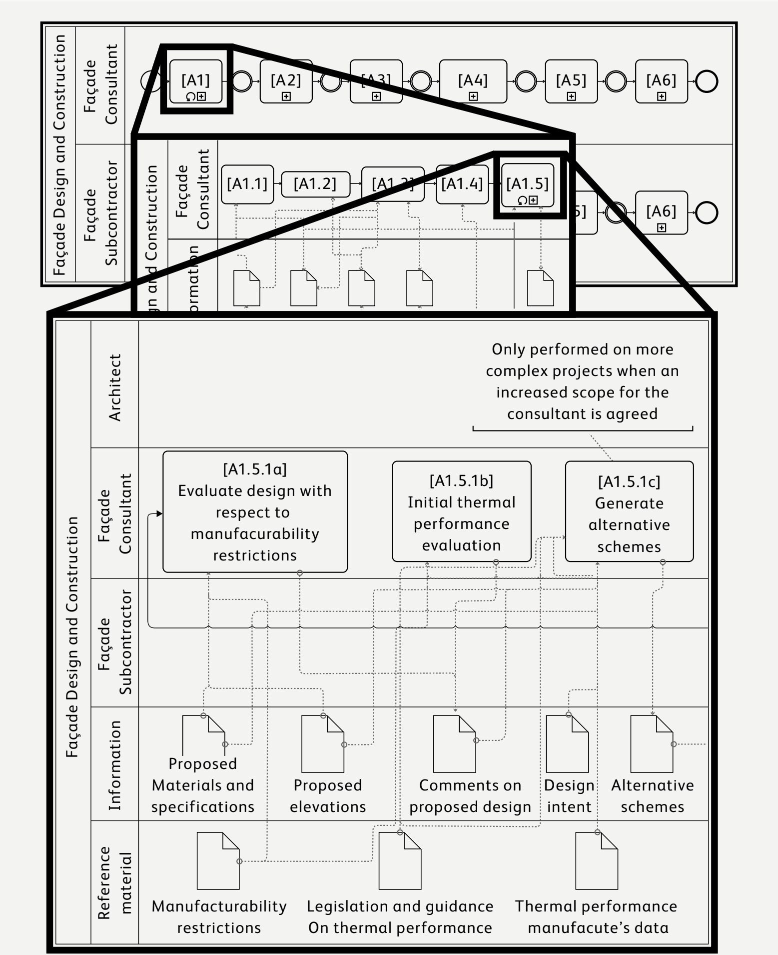
Proposed Tool

Building on work discussed briefly above and presented in[6] the tool presented in this section has been developed to capture, store, use and re-use knowledge. The tool focuses on knowledge of the constraints manufacture imposes on the façade panelisation scheme.

The proposed system is in prototype form and consists of a series of modules. Geometric design information is stored in the Building Information Model (BIM) in IFC format (element (A) in *figure 03*). Details of the extraction and analysis of design information from the IFC database are provided in.[7]

Figure 02: Diagram of the proposed tool: The IFC schema (a digital BIM neutral format) is unable to store details of the materials and processes that make up the façade panels in a sufficiently structured manner. Therefore the panel materials are specified by the user using a spreadsheet-based tool developed for the project (element B on *figure 01*). The two types of design data (geometric and material) are linked through a labelling system. The specification options are stored in the re-useable database (element (D) on *figure 03*). This part of the database has been populated by extracting information from specifications for 30 real-world projects.

Several different checks on the geometry may be required for each panel. For example, dimension, curvature and aspect ratio checks may all be performed. To aid this, the re-useable database (element (D) on *figure 01*) stores a set of constraints for each possible specification option. The constraints stored in the prototype tool have been gathered from interviews with industry members. When the user selects the materials and processes to be used to make the panel, the tool identifies the correct set of geometrical constraints.



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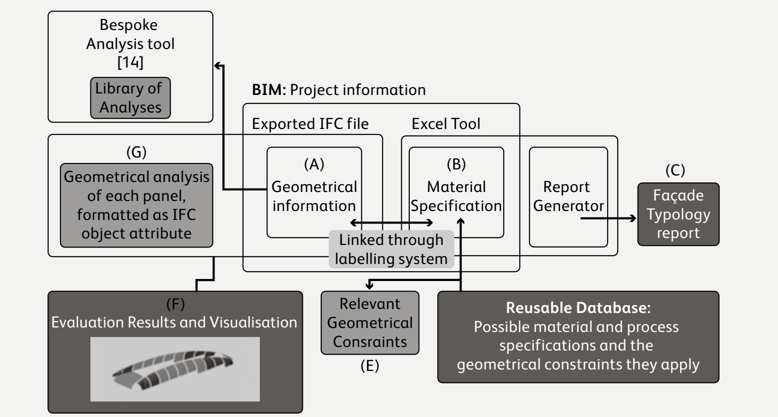
F.01
Activity A1.5.1



F.02

F.02
Diagram of the proposed tool

In addition to the identification of constraints, the tool provides the user with a knowledge storage facility that can be updated or expanded in parallel with a project. This encourages and enables live knowledge capture by facilitating the use of the knowledge on the current project; capture of knowledge as it is identified; and involvement of the supply chain.

The design is evaluated by comparing the constraints to the results of the corresponding geometrical analysis performed on the design data extracted from the BIM database (element (G) on *figure 01*). The results of the evaluation can be provided visually, so as to ease communication of the design issue to the rest of the design team (element (F) on *figure 01*).

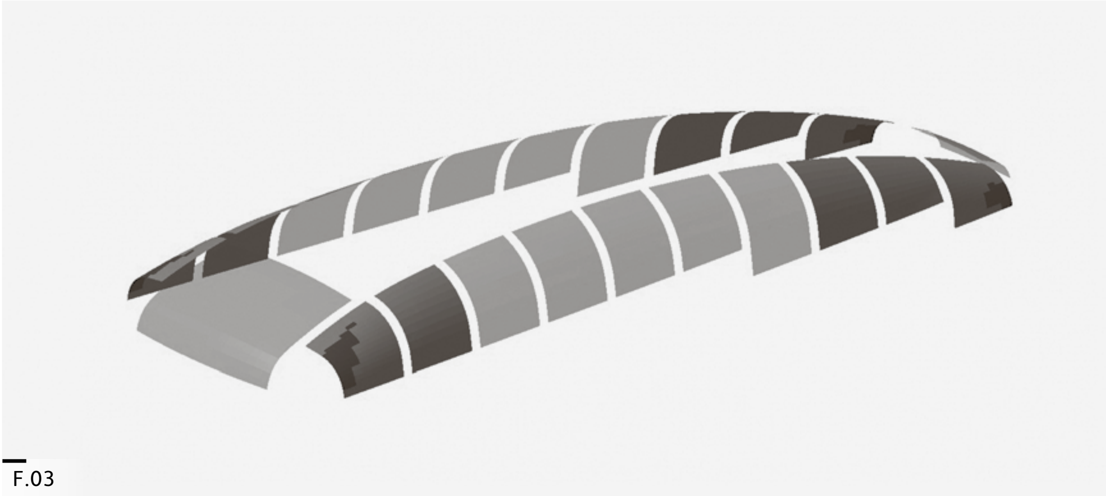
Case Studies

These case studies aim to identify whether the proposed tool can assist the façade consultant to identifying panels in proposed panelisation schemes that are shaped or sized in such a way that they either cannot be manufactured, or cannot be manufactured at a reasonable cost.

Park House, Oxford Street: Park House is a large, high-specification combined commercial and residential development in the center of London. The roof panels are glazed using a variety of high-specification treatments and glass coatings.

A key design issue for this project was manufacturing the curved panels. The cold bending technique of forcing the glass into shape without heating is considerably cheaper than hot bending, which requires heating the glass to allow it to sag under its own weight. Therefore it was important to understand the extent of hot bending required, and the zones in which it would be necessary. This information could be used to focus the design development, and to evaluate design iterations.

Figure 03: Park House roof; visualisation of Manufacturability analysis results: A comparison of the result from the proposed tool and the subcontractor’s design information shows a close match. The tool underestimated the extent of the panels requiring hot bending by 30 % but accurately identified the area of the roof that would require further design development if hot bending was to be avoided. It is possible that the design heuristic should be adjusted if limited design information is available.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Presidential Library, Astana: The Presidential Library building in Astana, Kazakhstan is a geometrically complex building, based on a Mobius Strip. The building is particularly large, with over 40,000 panels. Ramboll's scope of works included providing advice to the design team and assisting in generating the panelisation scheme.

The tool was used to assess the extent to which the problem of highly acute panel corner angles occurred in the triangular panels. Acute corners are easily damaged during transportation and installation, increasing build and causing delays.

F.03
Park House roof; visualisation of Manufacturability analysis results

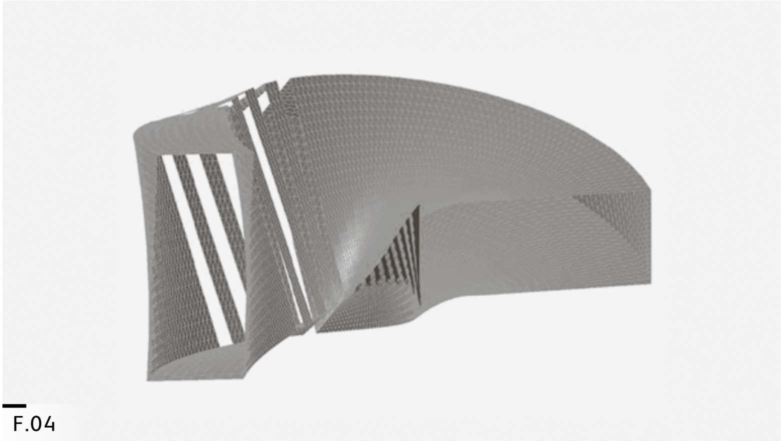
Figure 04: Visualisation of the result of the acute-angle analysis: The visualisation of the results clearly shows an area of the building where the smallest angle of the panel is less than that recommended by facade engineers (12.5° [8]) Since the model is constructed parametrically, the parameters can be adjusted and the model re-analysed to rapidly develop the design. In addition, the visualisation and the BIM can be used to communicate this design issue to the rest of the design team.

Conclusion

This research proposes a rule based, semi-automated manufacturability assessment of façade panelisation schemes using the project BIM. The rule based knowledge management technique is found to be appropriate to manufacturability assessments. Interviews with industry members identified heuristic rules (or «rules of thumb») that are used by consultants and contractors to highlight manufacturing issues for façades. This makes it possible to capture, in the form of a rule, the required knowledge for the manufacturability assessments.

The proposed modular tool has been tested on real world projects and was able to identify panels with possible manufacturability challenges. The results from the tool matched those generated by industry members. A key capability of the tool is to enable the live capture and use of expert knowledge. The tool automates the identification of manufacturability constraints using the material specification process undertaken by the façade consultant and the project BIM. In addition the tool stores and supplies these constraints in a computer interpretable form to semi-automate evaluation of the proposed panelisation scheme.

Further Testing of the system is planned on a new selection of real-world case studies. The tests will aim to build an improved understanding of the system's performance compared to the current industry processes.



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F.04
Visualisation of the result of the acute-angle analysis

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FORM FOLLOWS ENVIRONMENT – DESIGN PROCESS OF ZERO ENERGY BUILDINGS IN NORDIC COUNTRIES

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Insights and experiences with designing Zero energy Buildings in Nordic countries. Interaction and consequences for appropriate envelope solutions.

Introduction

Zero Energy Buildings and Energy Plus Buildings are architectural concepts which experience a growing concern in an international scale. Innovations in this market segment are also driven by the plan of the European Union to make «nearly zero energy buildings» a general building standard from 2020 on.

Whilst discussions are still ongoing about the definitions, the objectives and the limits of balances, the required calculations and the modes of attestations, first projects of this kind are already emerging.

Practical experience shows that engineers, specifiers and stakeholders involved in the development and decision processes are reaching the limits of existing methodologies for the cooperation in construction and have to cope with a growing complexity of the engineering contents.

By means of «Powerhouse», a project in Norway, we want to illustrate how the approach «form follows environment» can lead to a commercial solution for an energy plus building.

Objective

The Powerhouse alliance, consisting of developers Entra Eiendom, construction group Skanska, architects Snøhetta, environmental group ZERO and aluminium company Hydro decided to build Norway's first – and the world's northern-most – energy-positive commercial building, in Trondheim. Cold winters and great variations in solar energy potential, combined with warm summer days, mean climate challenges found in few other parts of the world. The project is therefore especially challenging and technologically groundbreaking.

How to plan such a building that produces energy to cover its own demand for heating, cooling, atrifical light and compensates for the embodied energy of its construction materials (production, construction, renovation, operation and demolition).

This energy goal needs to be reached meeting the cost requirements of the developer and delivering high comfort to the building occupants at the same time.

Methodology and working process

The construction culture in Norway is based on a very sequential planning process. Integrated planning is partly covered by large-size engineering firms, offering such service from one source comprising the classic disciplines statics, solid structure and building physics.

Right from the first workshop it became apparent to the project participants that besides the processing of factual contents a new culture of cooperation should be installed, in order to facilitate the integration of further specific disciplines from the beginning.

The only basis for the criteria of selection and the assessment of requirements was the content of the so called «appraisal phase» defined in BREEAM. A working group was installed taking care of a comprehensive assessment of requirements from an owner or user point of view. As a potential user did not exist in this early phase of the project the working group defined presumptions on the basis of market data and corporate structures in the surroundings of Trondheim, and used those for further decisions.

In the course of planning of a ZEB or an Energy Plus building it becomes apparent that energy production and energy need have to be taken into consideration simultaneously. This also applied to this precise case where besides the maximum number of storeys, building volume and desired gross office space no additional marginal conditions like shape, alignment of dimensions were given.

A particular challenge was to make available a permanent access to any new findings to each member of the working groups, so that they could imply these into their considerations and specific disciplines. A fundamental tool proved to be the central project server with a workflow that gave notice to all members by email as soon as new information was available.

At the same time information was defined as «obligation to collect». Each member of the working groups was bound to verify if any new information that could have an influence on his decisions had come up in the meantime. This type of working culture caused an increased empathy of each individual for the work of the others. Synergy effects became apparent much faster and the planning progress received an enormous dynamics.

At a very early stage a matrix was installed in order to determine all the competences and responsibilities of the members and to define working groups. These groups consisted of decision makers, experts and supporters each. Especially the supporters often had a secondary competence in a different working group, supporting at the same time the networking within the various working groups.

Design

The most challenging aspect turned out to be the ambition of an «On site energy production». After intensive verification of all possibilities only wind and solar energy remained.

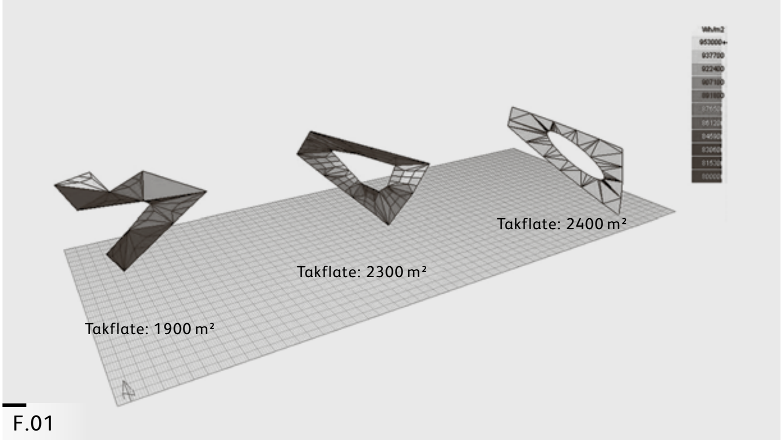
Contrary to the primordial expectations even at the location at a latitude of N 63.6° the solar radiation proved to be sufficient.

The final benchmark and risk assessment for a building integrated wind energy system concluded that the investment in and the consequences for the embodied energy (necessary constructive measures for vibration absorption and others) could not be brought into accordance with the set objectives. As a result the decision for a so called solar energy building was taken. High efficiency photovoltaic modules are integrated both in the roof area which is inclined towards the south and in the balustrades of the vertical main façades.

The ratio between transparent and opaque building skin follows the experience with passive buildings in Norway and was determined as 40/60. It should be emphasized that the windows are not placed in a regular order around the building but vary according to the height of the building and to the natural light offer, which is also influenced by neighbouring buildings.

As a result there are less windows in the upper floors but at the same time more opaque areas with integrated photovoltaic, leading to an ideal balance between utilisation of natural light intensity and the solar radiation for energy production

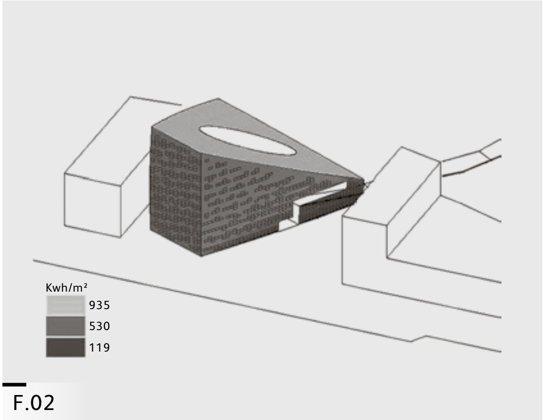
The thermal insulation of the façade fulfils as a minimum passive house standard, in some areas it even achieves values below. The final decision for the façade concept was a variation of a punched window, accomplished in a double skin technology with a cavity which was optimised for the climate in Trondheim. The air inlet and air outlet could be limited to an opening height of only 5 cm due to the moderate average temperatures in



F.01

F.01
Design studies for an optimisation of the solar aperture surface of the roof and for the natural light supply of the patio

F.02
Pixel facade, solar radiation intensity on partial areas of the facade



F.02

summer and winter. This dimension can not be explicitly distinguished in this building skin with its so-called «pixel design».

The so-called pixel facade assumes an exactly identical horizontal and vertical grid of the transparent and the opaque partial areas. For the assembly of the façade a variation of a modular concept taking into consideration the basic principles of a unitised curtain wall is stipulated. A special challenge in this aspect was the interaction with the high insulation wall structures in wood frame construction. The parapet glazing with integrated photovoltaic (BIPV) in front of the opaque façade areas of the wood construction also have to comply with the criteria of the pixel façade.

In Norway facade units in wood frame or wood panel construction are traditionally fabricated and assembled directly on the building site. The concept for the Powerhouse Trondheim however envisaged a pre-fabrication of units in the workshop and their consequent assembly on the building site.

Results

Using renewable energy: During the appraisal phase various on site energy sources have been evaluated e. g. tidal energy, wind energy, geothermal energy and interaction to a nearby waste burning driven district heating system.

With reference to the given definition of an on site energy production, characteristics of supply and demand and finally the economical investment frame priority was given to a building integrated photovoltaic installation (BIPV).

So solar cells, heat exchangers and heat pumps will help to produce electricity and heat for the building. Sea water contributes to both heating and cooling.

The building rises from the fjord toward the north and is lower toward the city in the south. The south-facing sloping roof provides optimal conditions for solar energy production. The placement of the solar cells and windows in the façade takes compass direction and sunshine intensity into account to ensure optimal daylight conditions for the building's tenants with minimal energy consumption. Where the sunshine is strongest, the window openings are reduced to minimize solar heating of the building, while the dense construction of the façade maximizes use of solar energy.

Good indoor air quality

The technical systems in the building ensure low energy consumption without compromising indoor air quality. A displacement ventilation system will supply fresh air at a very low pressure of round about 15Pa via a raised floor installation. Installation of air handling units and ventilation shafts are designed for low pressure losses and result in a specific fan power of far below 1 KWh/m^3 sec.

Daylight sensors and motion detectors will ensure proper illumination without unnecessary energy waste while thermostats and CO_2 sensors will contribute to a stable indoor climate under all weather conditions. The building will utilize natural ventilation when outdoor temperature and wind conditions make it possible.

F.03
South facing roof sloped with 26° as main energy gaining surface, BIPV installation


F.03

Energy efficient

In addition to producing energy, it is essential that the building is as energy efficient as possible. The technical systems are designed for optimal interaction under all climatic conditions. This means that it requires minimal energy to heat up and operate the building. Compared with a normal office building of similar size, the annual energy saving will be approximately three million kWh, equivalent to the energy consumption of over 100 houses.

Powerhouse at Brattørkaia

- Brattørkaia is located by the sea in downtown Trondheim and is the planned site of Norway's first energy-positive office building.
- Excess energy produced during the building's operational lifetime will exceed the energy used to create the building.
- The planned size of the building is approximately 16,000 square meters spread over four to 12 stories, with space for approximately 750 workplaces.
- A major upgrade of the waterfront and other outdoor areas is planned, making the whole area attractive for everyone living in Trondheim. At street level in the building itself, plans include cafés and cultural and retail activities.
- The building's estimated energy needs are only 21 kWh/m²/year and estimated energy production is 49 kWh/m²/år. Embodied energy is estimated at 22 kWh/m² per year.
- The building's total environmental impact will be assessed using a life cycle perspective. The building's expected lifespan is 60 years.
- The building will have a 26 degree sloped south-facing roof to best utilize solar energy. Thus main energy production area is the 2100 m² roof with a 429 KWp BIPV installation. BIPV in the opaque vertical facade areas contribute in addition to an overall annual calculated electrical yield of 715 MWh/year.
- Seawater will contribute to cooling and heating of the building as needed.
- The goal is to achieve the environmental classification «Outstanding» according to BREEAM NOR.

F.04
Rendering visual indoor comfort

Acknowlegdments

Powerhouse is a collaboration between property management firm Entra Eiendom, the aluminium system house company Hydro Building Systems, the construction company Skanska, the environmental organisation Zero and the architect firm Snøhetta with the goal to build Norway's first energy positive office building.

Powerhouse #1 on Brattørkaia in Trondheim is an office building of approximately 16400 m^2 that in the course of a 60-year lifetime is to achieve a plus energy balance, i. e. the building produces more local renewable energy in the operational phase, than the building is calculated to consume for production of building materials, construction-, operation- and disposal of the building. The project is expected to be completed in December 2014.

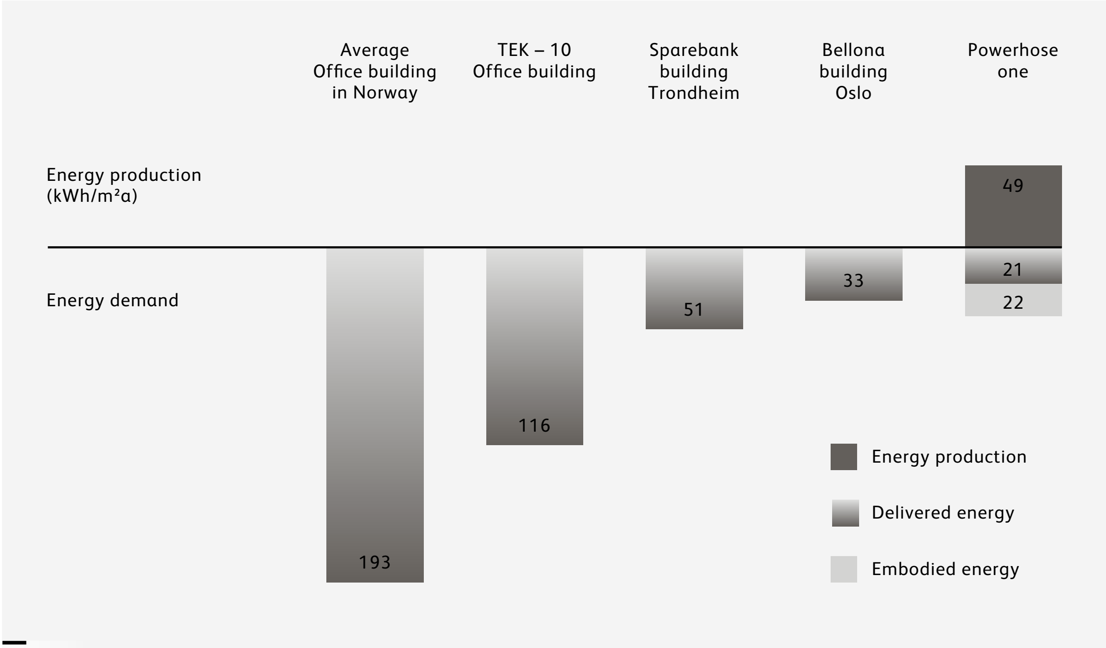
The building is aiming to be certified by BREEAM «Outstanding» and designed with a focus on good indoor climate with minimal consumption of energy.

Close cooperation between industry and research is required in order to translate the high ambitions of the project into a building that is to be built on commercial terms and conditions.

Power House #1 is one of six pilot projects for the Centre on Zero Emission Buildings and an important project for the building industry towards a Zero Emission Building standard.

The Powerhouse alliance wants to develop commercial buildings that in the course of the buildings' life produce more renewable energy than consumed during the production of building materials, construction, operation and ultimate disposal of the buildings' components. A definition which is quite new for Scandinavian countries.

F.05
Evolution delivered energy demand of realised buildings compared to Powerhouse Trondheim



F.05

DESIGN AND PERFORMANCE OF FAÇADES IN VARYING CONDITIONS AROUND THE WORLS

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Abstract

This paper will discuss the research and development that Inhabit Group are implementing into projects around the world. According to Inhabits integrated design philosophy, the projects will be discussed with regards to environmental performance, structure, aesthetics and local conditions. It will show how the design is influenced by these conditions in different parts of the world and what limitations and opportunities are given to further develop current state-of-the-art technologies, leading to innovative designs of enhanced performance characteristics.

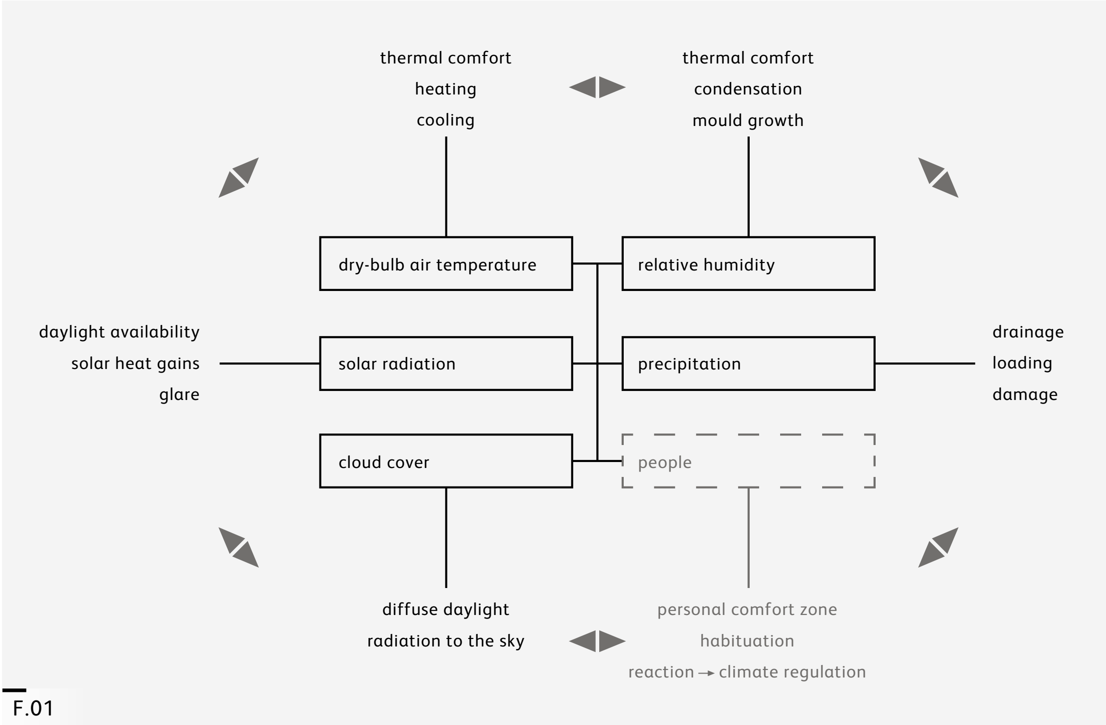
Energy efficient design

Reducing the consumption of primary energy is nowadays one of the most important issues for architects and engineers. Heating, cooling, lighting and ventilating a building requires large amounts of energy. In cases where this energy cannot be produced by the building itself, it is important to use the available energy more efficiently. Energy efficiency can basically be described as the ability to use less energy in a more effective way providing the same output. A possibility to reduce the amount of energy required is to design buildings and façades which are responsive to their particular environment.

Façades can be described as responsive or adaptive when they are able to respond to different surrounding climate conditions, weather related changes and varying day/night and summer/winter conditions or resist external impacts. The main impacts a building skin has to react to can be named as dry bulb air temperature, relative humidity, solar radiation, precipitation, cloud cover and people although human impact is to be considered severally *(Figure 01)*.

A fundamental principle to be followed is to use passive strategies before considering active ones and to design façades preferably «low tech» instead of highly complicated.

It is commonly known that the largest amount of energy is used by technical installations to cool the interior space of the building. Fully glazed façades, exposed to a large



F.01
Influences a building skin has to respond/adapt to

amount of solar radiation especially in hot climates lead to solar overheating causing a frequent use of mechanical conditioning systems.

Looking back to the time where air conditioning systems where not commonly used, buildings frequently show passive design principles like optimised orientation, external sun shading devices, evaporative cooling via water areas within the landscaping of the surrounding, etc. One important task for designers and engineers today is to carefully analyse the location of the building and to make use of it for passive conditioning strategies. But it is not only climate control which makes façades energy efficient or sustainable; efficient use of material is a very important factor within the design of façades especially for large projects where systems are often overdesigned in areas where the maximal loading is not equivalent to the overall maximal loading.

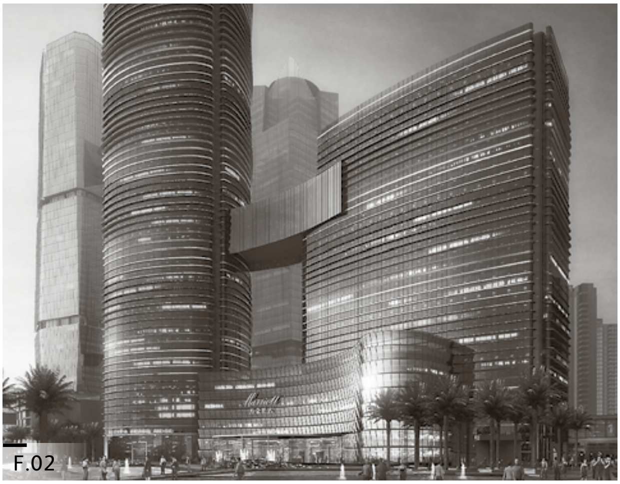
Project: Avic Plaza, Xiamen

Located in Xiamen, this project consists of three buildings; a 194 m office tower, a hotel tower and a commercial building. Designed by the London based architectural studio Vx3 the façade shows a wave movement running up the elevations. This was achieved by utilising shading fins, which are set out in different angles throughout the height of the building *(Figure 03)*. These extruded aluminium fins are curved around the perimeter of the building enhancing the inflected appearance of the façade. Where two curved surfaces meet each other, the arched building design features particularly articulated areas. These are designed to converge to semicircles forming a shadow gap between the two façades *(Figure 04)*.

To build this building as efficiently as possible, the main focus lay on the material efficiency. Due to the size of the building with 46 storeys and nearly 200 m in height, there are great saving opportunities in material when optimised to requirements. To adapt the size of the curtain wall structure to the exact conditions, a detailed wind and orientation analysis was carried out. As varying wind pressures occur in different heights and on the different elevations due to the orientation, it has been possible to adapt mullion sizes to the exact requirements *(Figure 05/06)*.

Project: Hongqiao, Shanghai

This project is a commercial development located in the Hongqiao district of Shanghai, and is near Hongqiao airport. The low-rise office and retail space is designed with comfort levels and energy efficiency as a high priority since the building is part of a sustainable development. Large horizon-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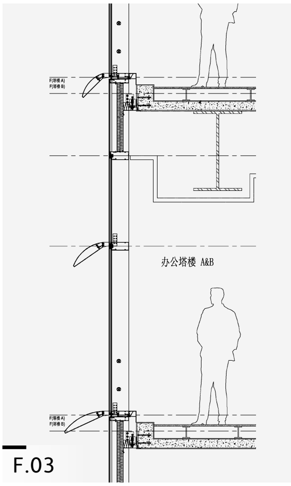

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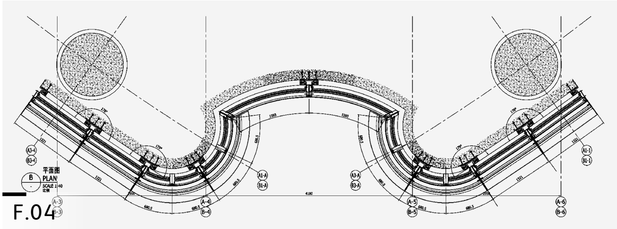

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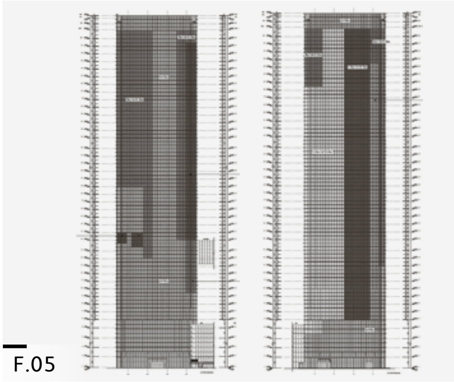
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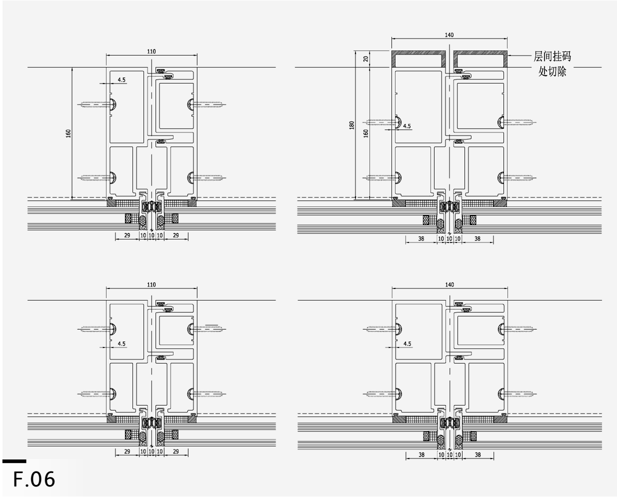


F.06

F.02
Building design

F.03
Rotating fin angle

F.04
Shadow gap articulation

F.05
Wind pressure analysis

F.06
Mullion dimensions adapted to varying wind load areas

tal fins are used for solar glare and heat gain control around the perimeter of the façades. Inhabit has been involved in this project during the early concept stages which was crucial to the integral façade concept.

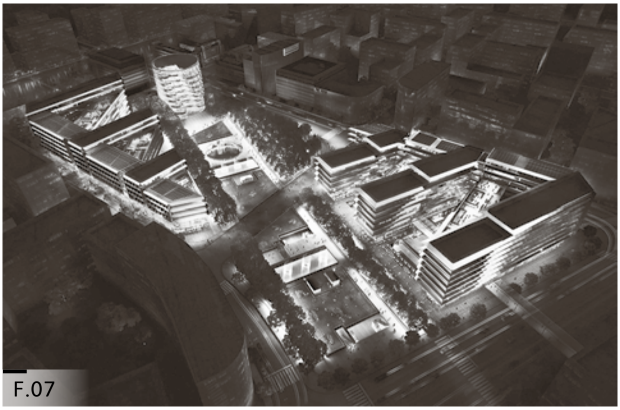
The initial idea of horizontal fins wrapping around the perimeter of the building, adapting in depth to the amount of solar impact they are exposed to was studied and further developed with architectural and environmental engineering input. A detailed sun path analysis was carried out showing clearly, which part of the building required what amount of shading provided by the fins. The output was a required shading depth for every meter of the façade. Each depth resulted in a different angle of one side of the triangular while the base side was fixed. The remaining side was just adapted in length with a fixed inclination. This was then rationalised to several angles the fin could be adjusted to and in a later stage further simplified to three main fin positions.

Additional to the shading and lighting control, the fins allow for a natural ventilation option with a cold air intake in the up-stand part and a hot air outtake underneath *(Figure 08)*. The shape of the fins is designed to provide sufficient distance between intake and outtake. Furthermore the shape of the fin was adjusted to optimum light gain especially in the courtyard areas where over-shading is an issue. Detailed studies of the fin shape and angle have been undertaken to achieve the most sufficient shading, glare protection, daylight reflection and natural ventilation results.

Enhanced by the fins, the façade design is orientated horizontally, while the vertical structure shall appear as minimal as possible. The basic façade grid is based on 3 m centres whereas the cladding structure is positioned at 6 m centres with a glass-to-glass joint every 3 m. Dealing with 6 m mullion centres and 3 m wide glass panes was one of the challenges during the design phase. The slab deflections led to relatively large movements at the glass joints so they had to be designed to take these movements while providing weatherproofing and a clean, neat appearance. *(Figure 09/10)*

The initial design showed a flush plate on the inside integrated in the stepped glazing and clamped with a steel plate on the outside. Different module sizes and glass thicknesses were calculated to visualise joint movements and appearance *(Figure 11/12)*. A special extruded gasket has been designed which is able to adapt to joint movements with little expandable wings working like an accordion *(Figure 13)*.

During the design process a new building regulation was introduced in Shanghai, limiting glass sizes above the first floor of new buildings to a maximum area of 4.5 m². This led to an additional transom been inte-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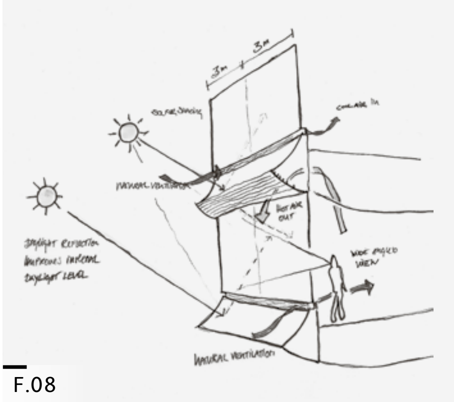

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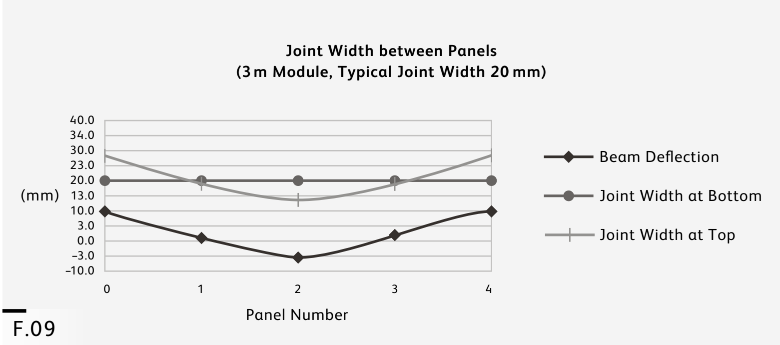

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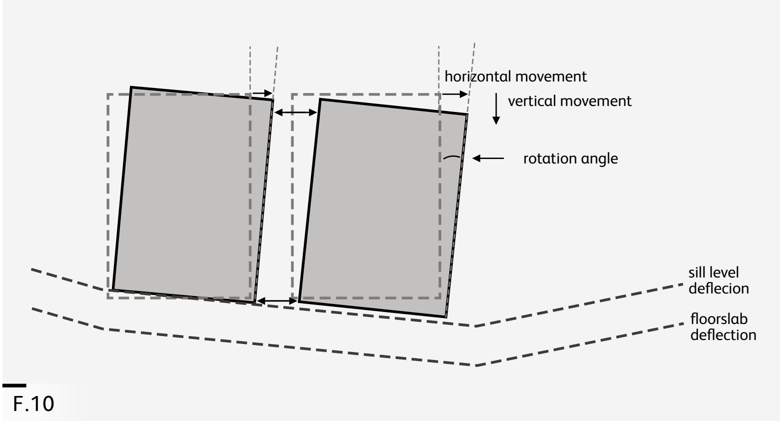

F.10

F.07
Building design

F.08
Fin design and functions

F.09/10
Joint analysis due to slab deflections

grated horizontally enabling the verticals size to be kept to a minimum as per the design intent. The design of this additional member was again studied with regards to optimisation of energy consumption. The cover cap forms an additional light shelf providing glare protection to direct sunlight entering the interior space yet enhancing light reflection to the ceiling. This leads to a larger amount of indirect lighting and increases the comfort for the user. The glass joint design was adapted to the reduced panel sizes and in the end it was possible to achieve a very slim butt joint, using the expandable gasket on the inside and a wet sealing with an antistatic nylon inlay on the outside preventing dust settling *(Figure 13)*.

Conclusion

The discussed projects show different approaches of integral façade engineering, gaining to achieve façade designs that are optimised to the specific conditions their environment presets. One approach shows how the structure can be optimised to use material efficiently within a façade concept that has been determined before Inhabit was involved. The other approach shows how efficient passive functions can be integrated into an envelope and into the design intent when the façade engineer is involved in an early stage of the design. Close cooperation between design architects, climate- and façade engineers led to a façade design that takes local condition into account using simple passive strategies for the conditioning of the interior space, maximising performance and feasibility.

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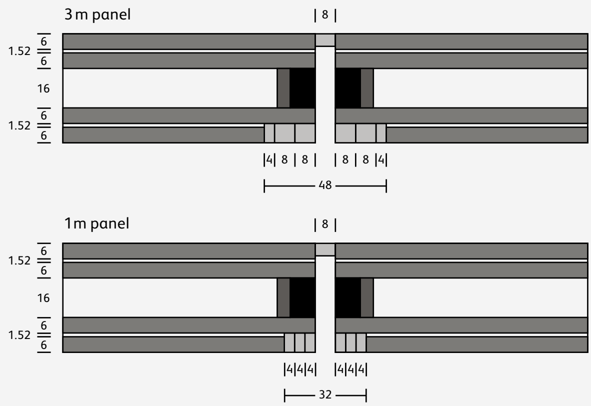
Joint sizes with different module options



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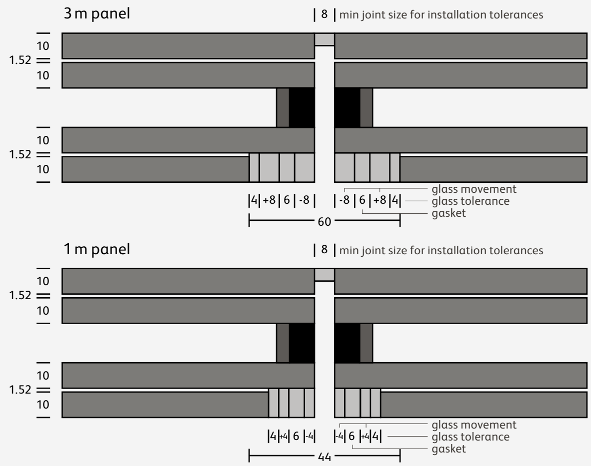
Joint sizes with different module options



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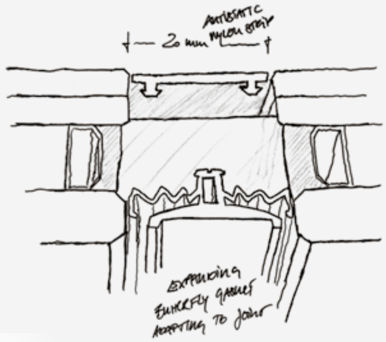

F.13

F.11/12
Glass joint design comparing several panel sizes and glass thicknesses

F.13
Glass-to-glass joint with expandable gasket