The façade is only one half of the story

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Abstract

New façade developments consider the thermodynamic, optical and acoustic properties of the applied materials to regulate comfort parameters. Building and façade design is developed from the 'inside out', with a focus on high autonomy for building operation, creating good conditions for thermal comfort, high daylight availability and an excellent fresh air supply. Façades can be designed to manage external loads, reducing the burden on mechanical systems. Combined dynamic thermal and daylight simulations consider user requirements (thermal, radiant comfort, glare, daylight, fresh air, natural ventilation, etc.) material properties and complex 3D geometries to inform design decisions. Two projects, one in Singapore and one in Basel, show the value high performing facades developed in an integrated design process.

Keywords: performing façade, integral design, thermal comfort, low energy, low-e hard coating

1. The role of high performing facades

In the last decade, façade performance regarding energy and heat protection has made substantial progress. Today, high quality glazing products for heat and solar protection, kinetic shading, intelligently controlled automatic openings, etc. are available and widely used. These façade improvements should impact technical systems for heating, cooling, ventilation, artificial light. They can result in a reduction of system capacity and operation hours, ultimately reducing energy consumption.

1.1 The wish for transparency in facade design

In current building design practice, we notice a trend that responsibility for building performance is shifted from architectural and façade design towards so called innovative mechanical systems. This is most noticeable for highly glazed buildings where the budget for mechanical systems can range up to 40%.

Are architects and façade designers missing the opportunity to take (back) ownership of the design and performance of their buildings? New façades can be designed to manage the external loads of the local climate, reduce the reliance on and investment in mechanical systems and minimize operational energy demand.

1.2 Design for People – Design for Comfort

People are not interested in energy or building technology, people are interested in how a place feels. People are interested in the quality of the indoor air, thermal comfort, daylight, good acoustic conditions, spatial qualities, etc. If all this can be achieved with low tech and low energy intensity then all the better. When it comes to highly comfortable building design, priority is typically given to mechanical systems and technologies specifically aimed at a conventional understanding of thermal comfort which focuses on providing air at low temperatures. So re-thinking how to deliver comfort and develop building and façade designs from the inside out with a focus on high autonomy for building operation, good conditions for thermal comfort, high daylight availability, excellent fresh air supply, etc. is key.

This paper shows two examples of highly glazed buildings designed for high comfort and low energy. The buildings are of very different purpose and in very different climates; one is a conservatory in the tropics and the other an office building in Switzerland. For both buildings, the façade was optimized to manage external loads and reduce HVAC systems and loads.

2. High performing facade and climate concept for greenhouses in the tropics

Set in the heart of the new downtown in Singapore, the Gardens by the Bay comprise a total of about 100 hectares of land surrounding the Marina Bay area. Two cooled conservatories – approximately two hectares of plants from the Mediterranean type and Tropical Highland climates – are the key attractions of the Garden at the Marina South. The challenge of designing these conservatories is that their indoor conditions must meet horticultural requirements for plant growth and flowering while simultaneously achieving thermal comfort for visitors. The Conservatories replicate cool conditions for the display of plants from the Mediterranean (cool dry) and Tropical Montane (cool moist) regions of the world. They are temperature and humidity controlled environments that cater to both optimal growing conditions for plants and human comfort.

To inform the design of the two large conservatories, the Singapore National Parks Board commissioned the development of 6 prototype greenhouses to test different architectural and engineering strategies, particularly focusing on the façade and cooling systems. These design strategies focused on the facade elements – highly selective glazing, low-e coating, internal shading and automated openings for cross ventilation - and active cooling elements - floor cooling, displacement ventilation, return air cooling and dehumidification and fog system.

The façade elements are key to achieving maximum solar heat load reduction, while the active cooling elements are critical to controlling the environment to the design conditions in an energy-efficient way.

Figure 1: Cooled Conservatories at the Gardens by the Bay, Singapore designed by Wilkinson Eyre, London Client: National Parks Singapore. Design Team: Architect: Wilkinson Eyre and CPG; VAC: atelier ten and CPG; Structure: atelier one and CPG; Landscape: Grant Associates.

Figure 2: 6 Prototypes to test façade, envelope and mechanical strategies. 2 high prototypes to test stratification and removal of solar gains by cross ventilation. 4 prototypes with different high selective glazing and ventilation systems. Client: National Parks Singapore. Design Team: Architect: Nirmal Kishnani and CPG; MEP: CPG; Structure: CPG.

2.1 Operative temperature for human comfort

In any greenhouse, the radiant temperature, due to solar and long-wave radiation, tends to dominate in the day. The thermal condition that occupants experience is therefore not just the ambient temperature, but the combined effect of the mean radiant temperature and ambient temperature. This is known as the operative temperature. In the design of the Conservatories, the shading effect of plants, particularly that of trees, was especially considered for thermal comfort. In the shade, the mean radiant temperature will be about the same or slightly higher than that of the ambient temperature.

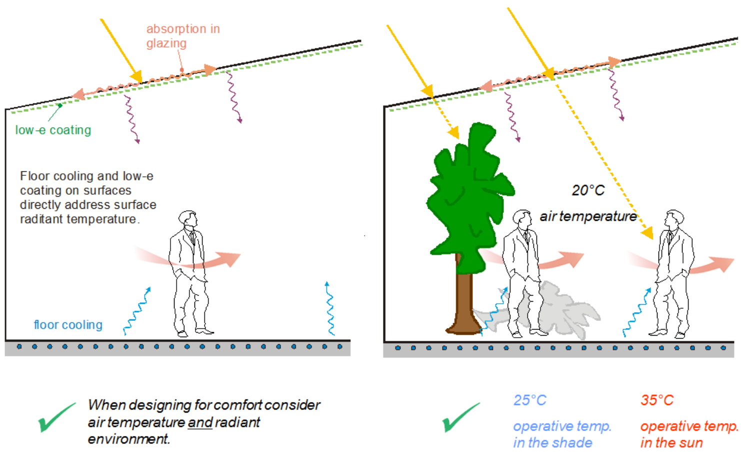

Figure 3: Left: schematic of floor cooling in combination with low-e coating in glass. Right: mimicking user behavior in sunny environments, best comfort is provided in the shade.

2.2 Façade and climate engineering strategies for load reduction

From a horticultural standpoint, maximum natural light is desirable; from the standpoint of human comfort, controlling solar heat gain is crucial to reducing cooling energy. In the fully glazed conservatories, identified optimal internal natural light conditions must be balanced against solar heat gain.

2.2.1 High selective glazing

For the conservatories, 70% daylight transmittance was called for. With glazing of the highest selectivity, the solar heat gain is reduced to about 35% without compromising optimal PAR spectrum for growing conditions and light for display. With double-glazing, transmission losses and risk of condensation are reduced.

2.2.2 Internal shading and natural ventilation to remove solar loads

An internal shading strategy was developed to allow solar gains to be reduced by natural ventilation. In combination with displacement ventilation and well-developed stratification, the occupied zone can be air conditioned and the upper volume of the glass houses can be naturally ventilated. The heat absorbed at the glazing and the internal shading can be removed by natural ventilation even in the warm and humid climate of Singapore.

2.2.3 Low-e coating and floor cooling

To deal with the radiant condition in the greenhouses, a low emissivity coating (low-e coating) was applied to the internal shading material and to the roof on the side of the glass facing the interior, position 4. This coating reflects long wave radiation similar to how a mirror reflects light. Occupants inside the greenhouses cannot sense the radiant temperature of the glass behind the coating; they sense instead a reflection of the environment that the coating ‘sees’ in front of it. Even if the roof glass reaches a temperature of about 60 °C, the coating reflects the radiant temperature of the cooled floor and plants it ‘sees’, which could be in this case 29.9 °C. Radiant flux – a measure of amount of radiation flowing from point to point – is only about 65 W/m² (Figure 4, left side). Had the low-e coating been applied on the external side of the glazing (i.e. the exterior face of the roof) the radiant flux would have increased by more than 115 W/m², which would have substantially increased the cooling load for the floor cooling and air conditioning system.

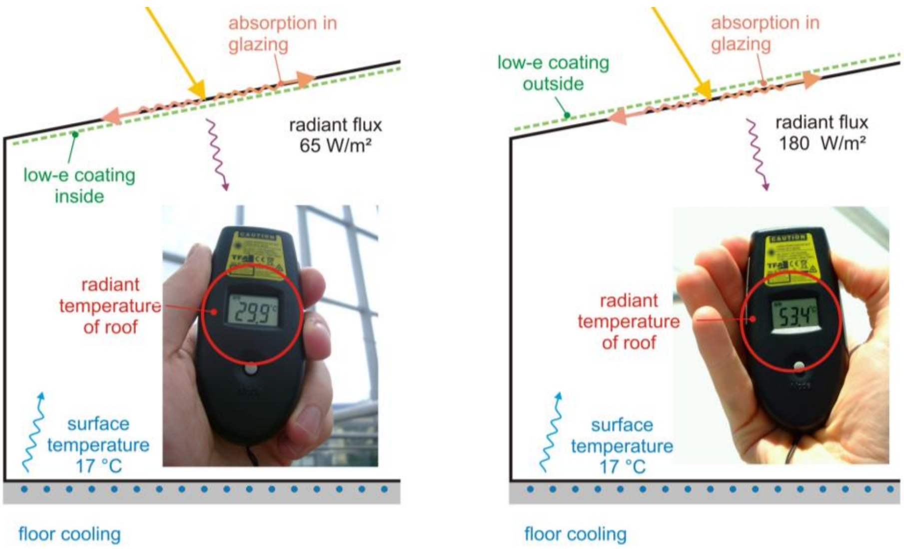

Figure 4: Right: During construction, the roof glazing was installed upside down and the radiant temperatures are high. Left: Reduction of radiant temperature with low-e coating on position 4 and the radiant flux is reduced by 115 W/m².

2.2.4 Energy

The impact of the different combined architectural and climate engineering strategies on the cooling load have been studied with dynamical multi-zone energy modeling utilizing TRNSYS 16. In Figure 5, an example for 5 variants is given. With the energy modeling of the greenhouses, the combined effect of all proposed passive measures was estimated to reduce cooling energy to about 45% of the reference scenario. Measurements in the prototype greenhouses as well in the conservatories confirmed the approach.

NParks is responsible for some million trees in Singapore generating plenty of timber clippings. In addition to the advanced envelope and cooling concept, Transsolar initiated zero-carbon operation of the Conservatory cooling by utilizing this renewable energy source in a steam biomass boiler as part of a combined heating, cooling, liquid desiccant dehumidification and electricity plant.

2.3 Innovative façade and climate engineering strategies for green houses in the tropics

The large conservatories have been in successful operation since 2011 and became a world attraction in Singapore. The achieved light conditions support a vast variety of species. The visitor comfort and fresh air conditions are rated as excellent. The façade development and integration with the climate concept was key to reduce ventilation and air conditioning systems and to allow a net zero carbon operation of green houses in tropical conditions.

Similar design strategies were applied to the refurbishment of the cool house at the National Orchid Garden at Singapore Botanical Gardens which is currently under construction (2017 – 2019).

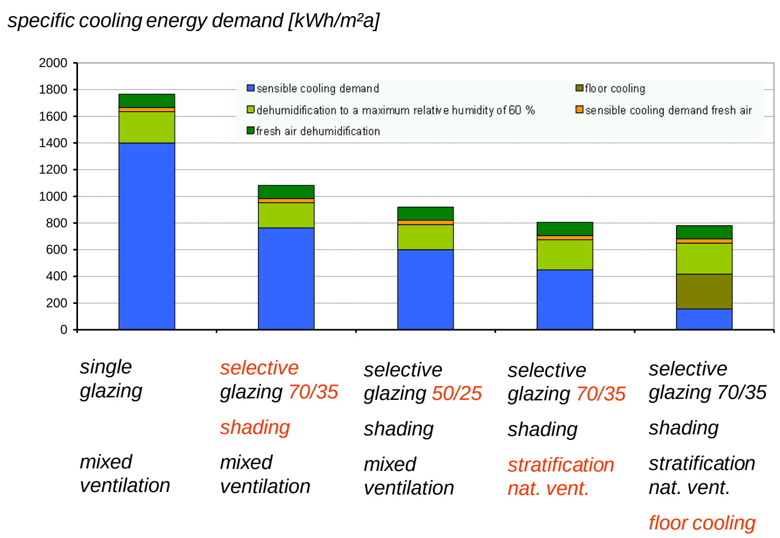

Figure 5: Reduction of energy demand for different combined envelope and climate strategies

3. Fully integrated climate and envelope concept

Figure 6: The Novartis Campus Human Resource Headquarter Building, Basel, Switzerland designed by Gehry Partners LLP
Client: Novartis. Design Team: Architect: Gehry Partners; General Planner: Arcoplan Nissen Wentzlaff, Structure: Schlaich Bergermann und Partner; MEP: Aicher De Martin Zweng; Fassade: Emmer Pfenninger Partner.

The Novartis Campus Human Resource Headquarter Building designed by Gehry Partners LLP offers open plan office areas for about 630 people, a restaurant, a library and a large underground auditorium with 600 seats. The sculptural from is made of fully glazed 5-sided building elements which enclose one large connected air volume. The open plan office areas are grouped around a large atrium like terraces.

The fully glazed building skin is largely made of curved and shingled surfaces and encloses the main building by forming an open façade volume spanning the open floor office levels. Together with an inner atrium connecting all levels, a single air space is formed over the entire building volume. The challenge to create a comfortable and sustainable building was to optimize the passive façade qualities to manage the external loads, reduce draft in winter and control solar gains and glare.

3.1 Climate and façade concept

The climate concept is developed as a shell and core concept. The fully air-conditioned office areas in the core are designed for operative temperatures of 22 to 26 °C. Fresh air is supplied via the raised floor and exhausted via the atrium to the heat recovery system. The façade volume is used a buffer to compensate for cold draft and to control solar gains.

For the envelope, sun protection triple glazing with fritting has been designed. The façade accommodates about 275 specially designed sun shades, each reflecting the geometry of the individual façade section stretching across its total height. For the textile material, appropriate low-e coatings have been specifically designed and developed in cooperation with manufacturers and they are now available as of the shelf products. The function of the low-e coating is to reduce radiant heat flow from the façade to the core areas enhancing thermal comfort by reducing the operative temperature for the people.

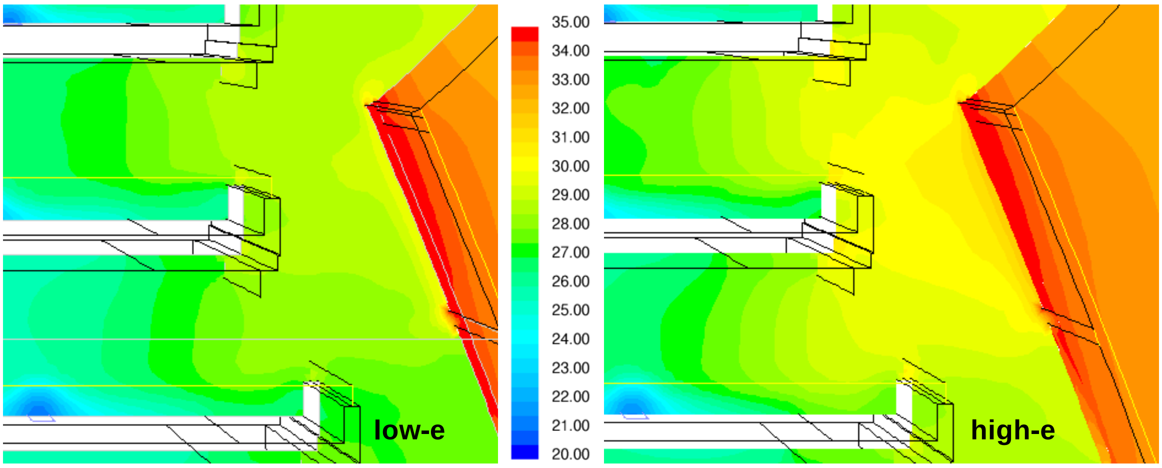

Figure 7: Operative temperature in °C in occupied areas with and without low-e-coating on shading material

Motorized façade openings allow the use naturally ventilation to remove solar heat gains from the shading to outside, keeping the façade air volume at a temperature between 18 and 28 °C. The sun shades are automatically controlled per façade section and orientation.

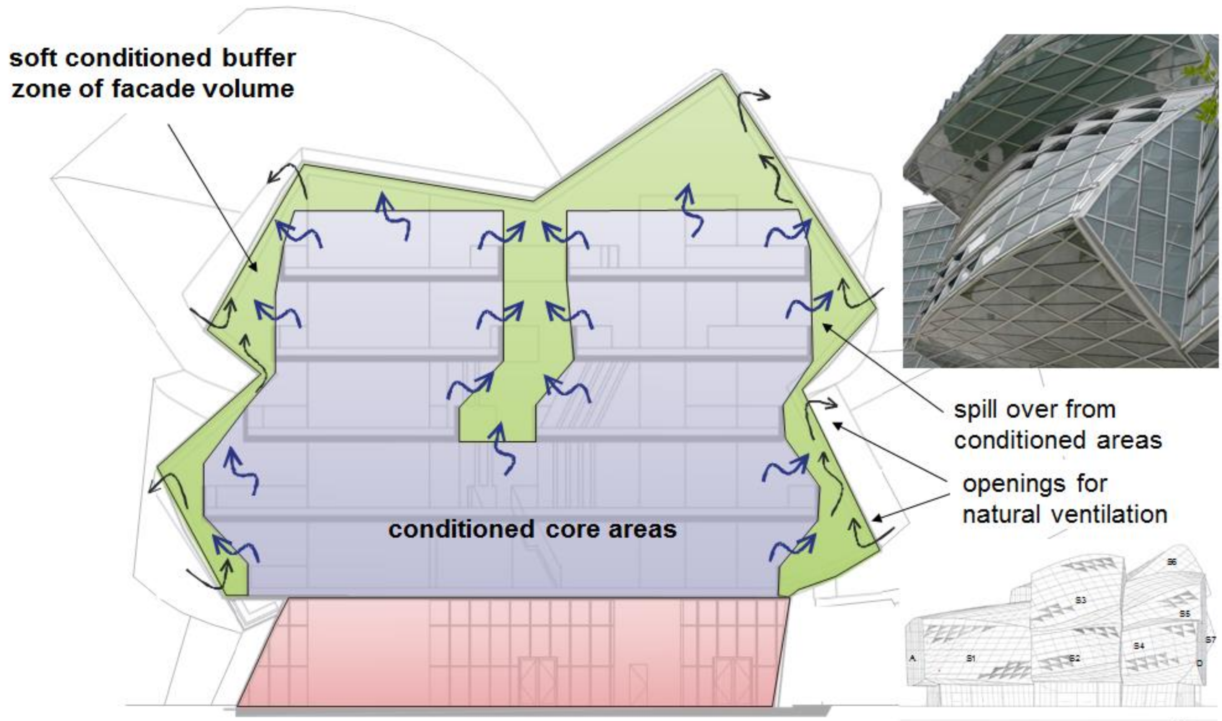

Figure 8: Shell and core climate concept. The buffer zone of the façade can be natural ventilated to remove solar gains.

3.2 Photovoltaic and daylight

The entire roof glazing – the fifth building façade - has been equipped with semitransparent photovoltaic (PV) modules integrated directly into the glazing buildup. The electricity yield from the PV system compensates for the entire energy demand of the artificial lighting. Thus, full artificial and daylight autonomy is achieved through the façade. High daylight autonomy is provided by the vertical facades and the remaining demand for artificial light is supplied via the BIPV in the fifth façade. PV cells and modules are custom made to have a punched pattern and special color and were developed in cooperation with the architect and manufacturer.

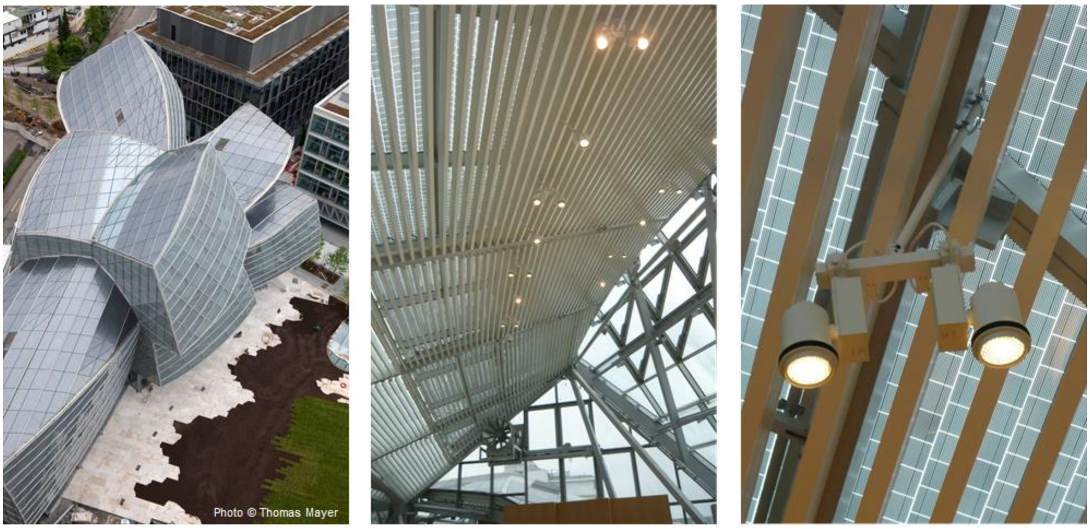

Figure 9: View from outside and inside on the roof with Building Integrated PV

3.3 High performance facades for low energy design

The developed concept satisfies both exceptional comfort requirements of the user as well as the low primary energy target of 83 kWh/m²a including heating, cooling and the total electricity consumption for building operation and use. The building is successfully in operation since 2009.

4. Conclusions

The examples show that for highly transparent architecture, the façade design needs to be integrated into the overall building climate concept. Façades can be designed to manage the external loads of the local climate and sun, therefore reducing the reliance on and investment in mechanical systems and reducing energy demand for operation.

The examples also show that in fully glazed environments, aspects of solar and long wave radiation need special consideration. For occupants' comfort, the operative temperature is important. To achieve a comfortable environment the exposure to direct and diffused solar radiation needs to be reduced.

With highly selective glazing, optimal natural daylight supply can be achieved with a minimum of solar heat gain. Direct solar gains can be further reduced by operable internal shading devices. Integrated into an overall climate and comfort engineering strategy, the absorbed solar heat can be removed by natural ventilation even in the tropical climate of Singapore.

Solar heat gain and long wave radiation can be controlled by a combination of active floor cooling and low-e coating applied to glazing and internal shading textiles. In highly glazed environments the active cooling systems need to be controlled to achieve the design operative temperatures.