International Journal of Architectural Engineering & Urban Planning

Architectural

Double skin glass façade and its effect on saving energy

M. Farrokhzad[1],*, Z. Nayebi[2]

Received: November 2012, Revised: June 2014, Accepted: August 2014

Abstract

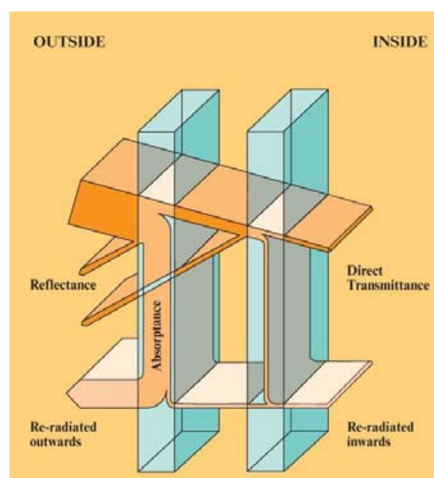
One of the most important methods of saving energy and providing indoor comfort conditions of buildings is the careful design of the façades. A "double skin glass façade" is optimally one of the best options that control the heat interaction between indoor and outdoor spaces. Two kinds of heating energy is usually transmitted through exterior envelope; "conduction" and "radiation". Double skin glass façades (DSFg) are designed to manage these energies and in some special conditions, can prepare determined convection. The total solar radiation energy that can be received into the interior space, is one of the most important parameters for estimating the cooling load of the building and its occupants' thermal comfort. DSFg also provides flexibility in architectural design. Recently, it has been more attention to double skin glass façades opposed to the most typically curtain walls for its ability to efficiently reduce energy consumption and therefore save cost. The design of the double skin glass façade involves decisions of geometric parameters, glass selection, ventilation strategy, shading, daylighting, wind loads, and maintenance and cleaning cost expectations. In this article, the authors intend to investigate features of double skin glass facade in reducing air pollution, air conditioning, fire safety and in the optimal use of sunlight within the building. In another part, this article will pay attention to the effect of wind, shading, type of glass and ventilation in the space between skins on the performance of double skin glass façade and their effect on energy saving. Finally, the authors analyze the rate of energy transfer from the double skin glass facade and provide four case studies. In addition, this paper shall review previous studies done on DSFg systems in building for saving energy.

Keywords: *Double skin glass façade, Saving energy, Air conditioning, Indoor, Comfort conditions.*

1. Introduction

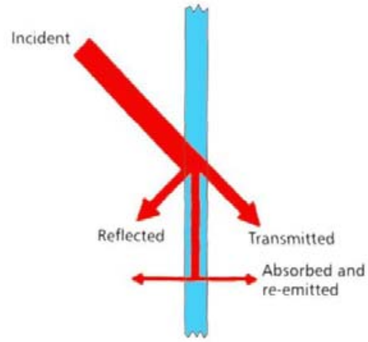
Conventional building skin facades are known to have numerous problems such as thermal comfort, natural ventilation and glare especially in buildings with high glazing skin, which are located in hot temperature regions. One of the most important problems in such buildings is the heat loss between indoor and outdoor by the conduction of thermal transmittance. These problems encourage the engineers to seek ways that improve the problems by utilization of new techniques and methods such as shading devices, color glass and tint glass. The usage of these techniques have shown a reduction in natural lighting, and the increase in the use of artificial light; which inevitably led to the increase in the interior heat gain besides the utilization of other electric devices and office equipments that retrieve the lack of penetration of external illumination. This interior heat gained is coupled with the external heat gained by solar radiation that is usually caused in some cases by poorly shaded buildings.

To resist this situation, air-conditioning is used to cool down the heat effect. This results for increasing energy consumption lead to increasing the cost [1, 2].



(a)

* *Corresponding author: m.farrokhzad@gu.ac.ir*
1 Academic Member of Golestan University, Gorgan, Iran
2Graduate student of architecture, Noor Islamic Azad University, Iran



(b)

Fig. 1 Thermal transmittance across the building glazing layer; (A) ouble Glazed Window, (B) Single Glazed Window [3, 4]

In 1990s, the concern pertaining to global warming and the increasing demand for high-quality office building encourages the engineers and developers (who are interested in natural cooling strategies) to look for new techniques, which together with clear and environmental friendly energy used as an alternative source of energy for artificial lighting of buildings, ventilation and Air-conditioning, can be the solutions for this problem [5].

Nowadays, double skin facade—DSF is used for better thermal energy performance of facades of buildings with high glazing fractions. It is made of an external glazing offset from an internal glazing integrated into a curtain wall. It commonly features a controllable shading system located in the cavity between the two glazing systems [5, 6]. DSF has gained much popularity in prevalent time for its ability to reduce solar heat gain or losses in buildings [7, 8]. In fact, it has become highly significant worldwide modern building practice especially in cool/hot climate regions.

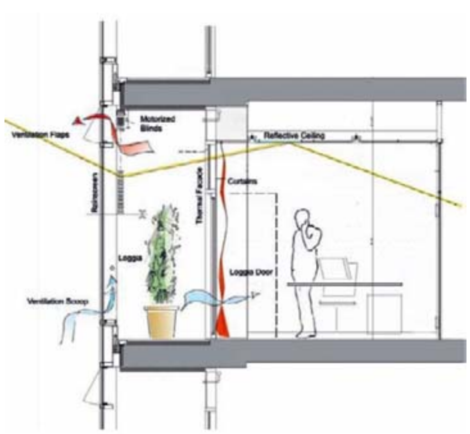


Fig. 2 Section through the Genzyme Center in Cambridge, Massachusetts, illustrating the corridor facade configuration of a double skin façade [9]

The main architectural reason for using DSF is in its transparency properties Which allows close contact with the surroundings of the building, and of the fact that it admits a large amount of daylight coming into building without glare. Finally, it has attractive aesthetic value that is much desired by architects, developers and owners [10, 11]. On the other hand, there are several disadvantages of using DSF; one of them is the investment cost that is considerably much higher than a traditional single-facade. Furthermore, the risk of overheating on warm sunny days is evident and may lead to a higher cooling demand [12, 13].

The design of the DSF involves decisions on geometric parameters of glass selection, ventilation strategy, shading, daylighting, aesthetics, wind loads, and maintenance and cleaning cost expectations [14]. Unfortunately, to date, still relatively few buildings actually use DSF. Usually, it is used in cases such as important official buildings and sometimes urban tall buildings. Furthermore, there is too little information on DSF operational behavior. Thus, it is said that it is quite difficult to find any objective data on the actual performance of buildings mobilized with DSF [1, 12, 13]. Therefor in this article, some of the configurations issues in designing a DSF will be discussed, where the aims of this study is to give a broad overview of double skin facade for different climate and regions.

2. Characteristics of Double Skin Glass Facade on Saving Energy

2.1. Ventilation in DSFg systems

Ventilation is used for different purposes. Its principal purpose is to exchange contaminated air with fresh air. It is also important to create an indoor climate without draught problems and only slight temperature changes in the occupied zone [15]. DSFg is categorized according to its function (i.e. ventilation type of the cavity). They are the natural, mechanical and hybrid ventilation. In order to provide fresh air before and during the working hours, different types of DSFg ventilation can be applied in different climates, orientations, locations and building types to minimize the energy consumption and improve the comfort of the occupants [8]. Furthermore, Ding et al. 2005 [10] suggested adding a thermal storage space called a solar chimney above the double-skin space to improve the stack effect in the double skin. Reduced-scale-model experiments and computational fluid-dynamic analyses were carried out to evaluate the performance of the natural ventilation in prototype building. Suffice to say, the system improved the chimney effect of the double skin despite necessitating a chimney reaching at least 11 meters above the building. However, this is no doubt a significant aesthetic constraint.

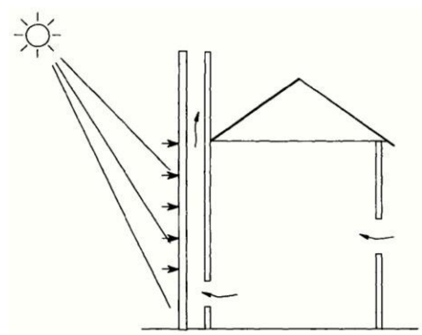


Fig. 3 Solar chimney designed for DSFg [16]

Gartia and Herde 2007c also did further researches and studies on DSFg [10] and examined how natural ventilation can be achieved during a sunny summer day in an office building with a double-skin glass facade. They concentrated on the possibility of natural ventilation during the daytime in relation to the orientation of the double skin and the speed and orientation of the wind.

It determined the way in which the DSFg should be opened, and the size of the openings necessary, to achieve a ventilation rate of four ach in each office under various wind conditions. However, these results cannot be generalized to other configurations of DSFg, and are insufficient for the technical design of a double skin glass facade as it is only the initial step towards a better understanding efficient of DSFg design. Ensuing with the endings by Gartia and Herde 2007c, the researchers bring to attention the study done by Kim and Song 2007 [13] who examined the contribution of a Double Skin Envelope (DSE) to the heating energy savings brought by natural ventilation in office buildings.

A DSE was applied to the east and west facing walls on an actual three-floor building. Field measurements and computer simulations were performed in winter. The results implied that the DSE on the west-facing wall contributed to energy savings when natural ventilation was supplied from the cavity to the indoor space. The DSE facing east was not recommended for energy savings by natural ventilation because of its smaller exposure to solar irradiance.

Other related studies include a study done by Manz et al. 2004 [14] who implemented numerical simulations on the natural and mechanical ventilation for glass double facades. It was found that air-flow patterns depend on boundary conditions and it is much more complex than postulated by the piston-flow assumption in simple analytical models. Finally, it demonstrated that a change in the orientation of the facade flow can influence the total solar energy gain.

In addition, Xu and Yang 2008 [17] made a detailed analysis of the thermal process in glass double facade with venetian blind. Governing equations were solved by using CFD, optical and heat balance model for multi-layered transparent system. It was found that a more complex natural ventilation exists in the two air gaps divided by the venetian blind, which cannot be reflected with the simplified model. It can be used as a reliable tool to analyze the ventilation in double skin facade with ventilation blind.

The results show that there is good agreement achieved between the simulation and experimental results for the maximal and minimal errors, which are 12% and 2.5% respectively. The reliability of the simulation model is thus verified.

Double-skin glass facades (DSFg) are a technique developed for colder climates, so few people think about whether or not it can also be used for hot-summer. Zhou et al. 2009 [18] studied it for hot summer and cold-winter zone in china. It was found that the ventilated DSFg with controlled shading devices could be used even in hot summer in China.

Fig. 4 The idea of DSFg system with vertical ventilation to decrease the greenhouse effect in summer [9]

2.2. Usage of shading device in DSFg systems

The main goal in designing a building from an engineer's point of view is to compute the total heat transfer through the cavity. This requires an adequate knowledge concerning the use of correctly sided inlet and outlet openings, well-positioned shading device, as well as an optimized space between the facade and proper working conditions of fans located in the facade itself [19].

In one experiment, blinds and shading devices were placed inside a cavity between the two skins to provide protection against intrusion, glare and direct sunlight. It is to be noted that external or mid-pane types provide reductions in solar heat gains. In addition, the use of blinds can lead to considerable energy savings if controlled and adjusted correctly [20].

Concerning shading device and DSFg, Baldineli 2009 [21] presented the double skin glass facade equipped with integrated movable shading device. Energy performance was determined by measuring the optical properties of materials and by implementing a computational fluid dynamics analysis. Validation was made by comparing with data of similar experimental apparatus. The façade performance was then compared with traditional enclosures such as glazed and opaque walls. The result showed that the facade significantly improves the building energy behavior, especially when the configurations with winter-farced convection is considered. A comparison with opaque walls showed an energy saving of up to 60 kWh per year per square meter.

Furthermore, it was found that correct position of the blinds makes it possible to reduce heat consumption of the building. In addition, it was found that light colored blind tends to invite more light into the office buildings.

Gratia and Herde 2007d [22] illustrated how the position and the color of blinds affect the cooling consumption in a building with a double skin glass facade wall. They also highlighted the importance of the opening of the double-skin glass facade. Other interesting factor to note is the impact of the blinds characteristics on human comfort and ergonomics. The result showed that the position and the color of the blinds have an influence on the temperature of the inner skin windows. Logically and practically, the correct setting of blinds can filter the hot radiation coming from the windows to the occupants.

All of these design options are for conventionally located shading devices such as roller shades, louvered blinds, fixed versus manually or automatically controlled, horizontal versus vertical fins, etc. The designer should consider how the device will affect air-flow within the cavity, and how solar gains absorbed by the shade will be radiated relative to the interior facade [23]. Furthermore, the types, sizes and positioning of any shading devices depend on the climate and function of buildings. Furthermore, the source of the light may be excluded; whether at a high or a low angle of direct sunlight, diffuse sky light, or perhaps reflected light from the exterior pavement on the street outside [24].

It is no doubt that providing the shading devices, usually is suitable for hot and tropical climates. These shades can be used in hot climate for the majority time of the year; while in tropical and moderate climates, it can be used for summer times and their geometry is designed in a way to allow the entrance of direct solar irradiance into spaces at winter times.

2.3. Fire safety of DSFg

Extensive use of glass sheets in glazing might cause fire problems. There is a public concern on the safety of buildings that have high window to wall ratio with large glass panels. Experiments with physical scale models were carried out to investigate the fire hazard of DSFg. Many new construction projects with DSFg failed to comply with the fire safety codes. The temperature gradient inside the glazing could be observed by increasing the risk of thermal that breaks the glaze.

In relation to this, Chow and Hung 2006 [25], Chow et al. 2007 [26], studied the spreading of smoke and flame into the cavity of DSFg. The main fire safety concern for DSFg is that smoke might spread to other levels through air cavity when a glass panel of DSFg is destroyed by fire.

The depth of cavity was identified as the main agent in fire eruptions in building with DSFg. When fire erupts, smoke would move at the center of the cavity rather than along the wall. Hot smoke will then be forced towards the outer panel at the beginning and bounced back to inner panel. The upper glass panel would be affected if the hot gas moves upward to upper inner skin by the induced air flow. Thus, it is suggested that using different types of glass for inner and outer skins might provide more desirable fire safety.

In addition, Ding and Hasemi 2006 [12] examined the possibility of using natural ventilation system of a double-skin glass facade for smoke control. They conducted reduced-scale model experiments and CFD analysis. It was found that smoke from a fire room escaping through the inner facade into the intermediate space between the two

skins may accumulate and spread horizontally or vertically to other rooms that have openings connected to the intermediate space. The result showed that smoke spread could be prevented with suitable arrangement of openings.

2.4. Cavity depth of DSFg

When considering double skin glass facades (DSFs), consideration of the cavity that lies sandwiched between the two walls (internal and external wall) is inevitable. According to Sinclair et al. 2009 [27], the depth of the cavity is determined by a number of parameters including the aesthetics, types of shading devices/blinds, access to the cavity for cleaning, and the ventilation strategy that include arrangement and flow rates.

When the cavity of DSFg become larger, the vertical ventilation will increase, but it does not affect on thermal conduction. Chen et al. 2009 [28] carried out experiments using a solar chimney model with uniform heat flux on a low wall. The inducing air-flow rates were obtained by changing the gap-to-height ratio between 1:15 and 2:5 at different heat fluxes and inclination angles. The optimal gap width or optimal gap-to-height ratio is the gap size or ratio when a maximum ventilation flow rate was achieved. Regardless of the results, the obtained optimal spacing from these studies lack consistency. From heat transfer point of view, the optimal spacing should be the gap size when the vented heat is high, or when the heat is blocked by roof structure.

Some architects employ the larger cavities as a corridor to approach the interior spaces –called “Corridor Facade” [9] – or a closed terrace for users to retire (Fig 5). It should be mentioned that if these cavity spaces are not used suitably, not only it would increase the cost but also the useful area would decrease.

Fig. 5 View of double skin façade of Duesseldorf City Gate [26]

In studies that were done by Bay (2004) the parameters of designing these spaces were investigated [29, 30]. Wang (2005) used the observations of Bay (2004) of the activities of the forecourts at Bedok Court and the corresponding thermal performance as a basis to simulate the quality of smaller forecourt cavities [31]. The quality of smaller size forecourts for facilitating social activities was determined by the ergonomics and space standards. Down to a certain size, the forecourt would fail to satisfactorily support a similar set of activities as observed in Bedok Court. The quality of thermal performance of smaller size forecourts were simulated and plotted against the degree of reduction of solar radiation by shading. As the forecourt size narrows down to a threshold point, the thermal comfort condition deteriorates drastically, rendering the space not conducive for various social activities. The observations of the study are summarized as a set of design guidelines.

Table 1 Summary of the guideline, morphology corresponding to social benefits and how each works. [32]

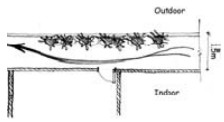
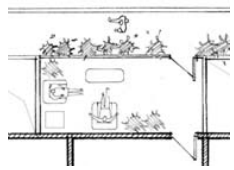
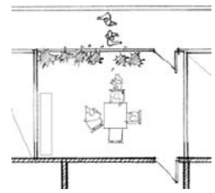
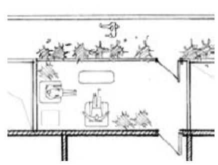
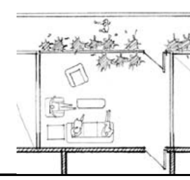
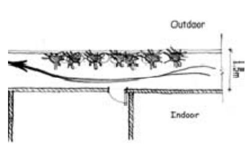
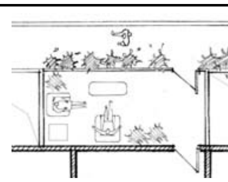
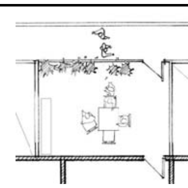
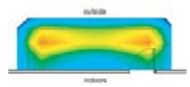
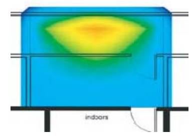
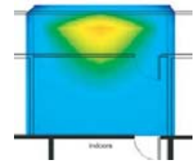
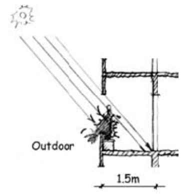
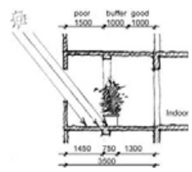
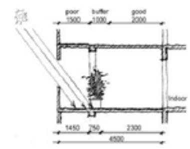
	Unacceptable design size	Acceptable design size	
	Poor	Threshold	Good
	Possible design configuration (Morphology)		
	0-2m depth of veranda from 1.4m corridor	2m depth of veranda from 1.4m corridor	Bigger than 2m depth of veranda from 1.4m corridor
			
	Social aspect		
Possible social activities (Social Performance)	Saying hello to neighbors Gardening	Saying hello to neighbors Gardening Sitting Reading Chatting	Saying hello to neighbors Gardening Sitting Reading Chatting Children's playing Exercising Housework Party, etc.
How it works (Operation)	• Only several pots of plants can be placed at the corridor. And they will make the semi-open space more crowded. • Residents have little chance to communicate with their neighbors at the semi-open space.	• The maximum number of persons allowed having activities at the veranda at the same time is two. • Residents have some chances to see and communicate with their neighbors at the veranda.	• The number of persons allowed having activities at the veranda at the same time is more than 2. • Residents have many chances to see, say hello to or communicate with their neighbors at the veranda.
			

Table 2 Summary of the guideline, morphology corresponding to environmental benefits and how each works. [32]

	Unacceptable design size	Acceptable design size	
	Poor	Threshold	Good
	Possible design configuration (Morphology)		
	0-2m depth of veranda from 1.4m corridor	2m depth of veranda from 1.4m corridor	Bigger than 2m depth of veranda from 1.4m corridor
			
	Environmental aspect		

Desired environmental effect (Environmental Performance)			
How it works (Operation)			
	• Semi-open space is totally exposed to solar radiation. • Temperature is high for outdoor activities.	• 57.1% of the veranda is shaded even without plants. • Plants can be arranged between the corridor and veranda. They help block the solar radiation and reduce the temperature of the veranda.	• More than 57.1% of the veranda is shaded even without plants. • Plants can be arranged between the corridor and veranda. They help block the solar radiation and reduce the temperature of the veranda.

2.5. The relation between wind pressure and DSFg

Wind pressure in one of the most important parameters affecting the glass. For DSFg checking wind pressure is very important because DSFg have three surfaces subjected to wind pressure due to the air-flow between the double facades; those are the outside and inside surfaces of the external skin facade and the outside surfaces of the internal skin facade [33].

According to Grabe 2002 [34], the wind creates differences of pressure that stimulates the air-flow in the building. He suggested that values of pressure differences on the facade of the building depend on the direction of the wind, shape and height of the building. In particular, value of the wind pressure coefficient depend first on the direction of wind and for different building construction, different formulas are given.

In addition, Luo et al. 2005 [33] studied the wind pressure distribution on each surface of the double-skin glass facades using wind tunnel tests. Furthermore, the characteristic of the wind pressure distribution on the long-span canopy was also obtained from the tests. Results showed that the effect of wind load appears when it is blowing in front of the canopy and it is almost the same when the wind load is acting on the upper and lower surfaces of it.

Other related studies include a study by Zhang et al. 2008 [35] which analyzed the wind pressure and gust factor distribution on DSFg and comparison of wind load between internal and external facade in different air-flow zone by using model tests in wind tunnel and synchronous monomeric method on internal and external facades. Results showed that one aroused by vortex shading mostly acts on external facade, while compression force aroused by air-flow adhesion and collision mostly acts on internal facades.

In addition, DSFg gust factor changes largely depending on the variation of facade's region or wind direction.

Moreover Luo et al. 2009 [36] studied mean wind pressure distribution on DSFg by using wind tunnel tests. Results showed that mean wind pressure mostly acts on external façade and is larger than that on the internal faced.

On the other hand, in order to determine the wind load on DSFg and predict the load difference between single skin glass facade and double skin glass facade Luo et al. 2008 [36] used wind tunnel tests to study tall buildings with arc-shape and L-shape double-skin glass facade. This study indicated that pressure in the draught corridor acting on the external and internal facade at any point is the same. The wind load carried by internal facade can be also stated the same as that of single-skin glass facade. However the wind load carried by external facade can be discounted when the facade is located at the middle of the arc-shape or the long side of the L-shape corridor, and should be amplified when the facade is located at the end of the arc-shape or the short side and the turning point of L-shape corridor.

Furthermore, in another study done by Luo and Zhang 2009 [37], they studied on the characteristics of the wind loads on the arc DSFg with different central angles using wind tunnel tests were carried out. Results showed that the wind load of the internal skin facade are even and increase with the central angle decreasing .The wind loads acting on the end of the external skin facade are larger than that on the center of the external facade and much larger than the single skin glass facade.

Sometimes, well-known selection of orientation for buildings that use DSFg systems could play an important role for ventilating indoor spaces. Architects supply suitable comfort conditions for residents by leading the prevailing wind to the cavity of DSFg and combined it with horizontal and vertical ventilation. (Fig 6).

Fig. 6 Natural ventilation concept for the Sekisui Building office tower in Tokyo Japan; combined the wind and ventilation across DSFg [26]

3. Investigate Case Studies

Case Study 1

The facade of the office levels has mechanically ventilated windows. The warm air in the room is extracted above the lighting units, so that the air also takes up their additional heat. Then this air is fed via specially shaped ducts at the level of the topmost transoms into the narrow cavity of the story-height ventilated windows. Here the air is warmed further by taking up heat from radiation of the glass; it is then taken out at the bottom of the window and drawn forward to the air conditioning system of the building. The aim in extracting the air via the lighting and then down from the top to the bottom of the cavity, is to utilize the internal heating loads as much as possible in achieving higher temperatures on the surface of the window during colder periods; this improves the thermal comfort in the office space near the windows. (Fig 7).

The integration with the AC system achieves preferred temperatures on the surface of the window. In the proposed addition to Cowgill Hall, heat absorbing glass is proposed to achieve high temperature in the cavity without blocking views.

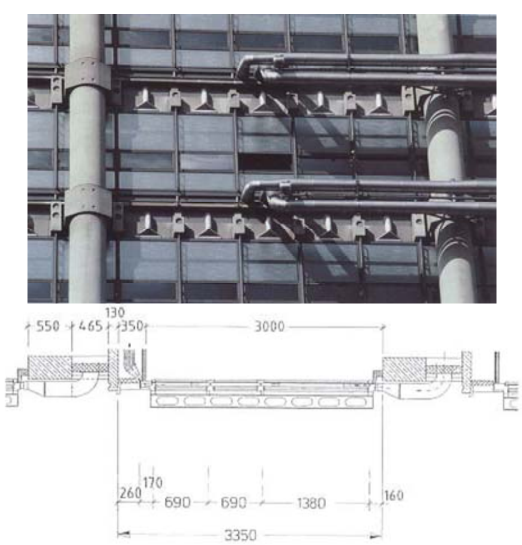


Fig. 7 Headquarters of the Lloyd's Insurance Company, London by the Richard Rogers Partnership

Case Study 2

In this project, the street facade is composed of load bearing sandstone piers and glazed bay windows. As these windows are not intended to be opened, for reasons of safety and acoustic insulation, a ventilated cavity façade was proposed. The window construction is composed of an external insulating unit (an external clear laminated glass, an argon gas filling in the cavity, and an internal float glass with a low-E coating), and internally an opening sheet of toughened glass. Solar shading is taken care of by adjustable Louvre blinds integrated in the 75 mm wide cavity between the outer and inner skins, and by light shelves positioned above the bays; these shelves shade the area immediately next to the window, and they are designed to reflect daylight into the back of the room. (Fig. 8).

It is important to integrate lighting devices with the double glass facade to maximize the benefit of the double glass facade in buildings which do not have an all-glass surface. In case of the proposed addition to Cowgill Hall, the all glass facade is sufficient for natural lighting.

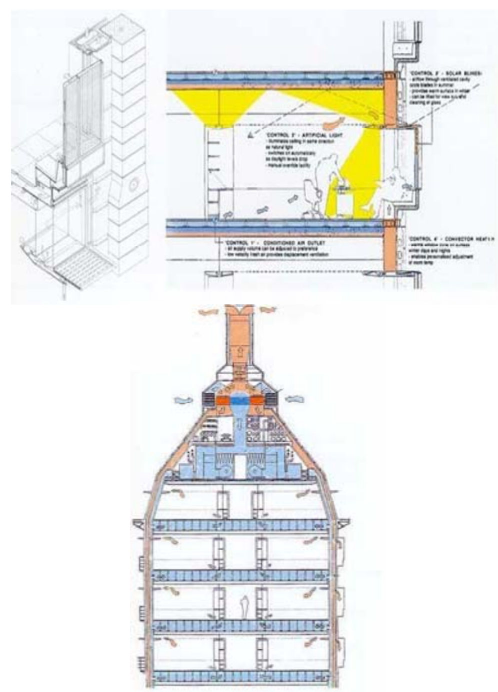


Fig. 8 New Parliamentary Building, Westminster, London by Michael Hopkins and Partners

Case Study 3

The glass skin gives an overall unity to the existing building with its stone facade and its new extension. At each story level, the mullion and transom frame has triple horizontal banding with top-hung windows. The glazing band at window level is of clear insulating glass; the rooms' occupants can open these sections manually for ventilation. The upper band consists of insulating glass with integrated prismatic panels. These glazing are computer- controlled to track the sun across the sky and thus protect the interior of the offices from direct sunlight. The top-hung windows in the lower band at each floor level, however, fulfill a different function in the energy system of the building. In winter, they remain generally closed and create a buffer air zone in front of the parapet. In summer they are open, to prevent the stone façade of the old part of the building from overheating and to ensure night cooling of this facade. This possibility of adjusting the glass panels permits a differentiated approach to respond to changing the weather and climatic conditions and shows how other aspects such as natural ventilation, light deflection, etc., are becoming increasingly important components of façade planning. The increasing complexity in facade requirements high lights the need for new working methods to guarantee optimum interaction of façade and building services. (Fig. 9)

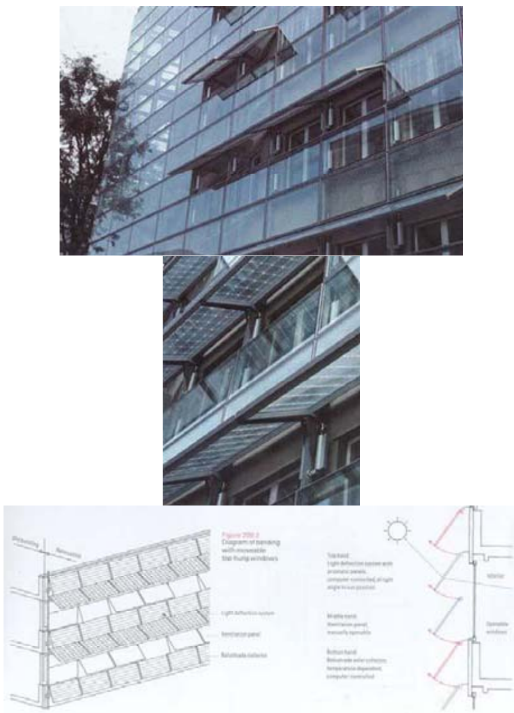


Fig. 9 Headquarters of the Swiss -Insurance Company, Basel by Herzog and de Meuron

Case Study 4

One of the most recent recipients of the highest, six-star rating from Australia's Green Star building assessment system is 1 Bligh Street in Sydney, Australia, co-owned by DEXUS Property Group, DWPF, and Cbus Property (Fig 10). The 28-story building is Australia's first high-rise with a double-skin façade, and it has a full-building-height, naturally ventilated atrium that helps maximize daylighting at each office floor level. The double-skin façade has internal blinds and external louvers that are automatically adjusted depending on their orientation to the sun (Fig 10). This system conserves energy, eliminates sky glare, and optimizes user comfort. The unique full-height atrium and elliptical-shaped floor plates enable 74 percent of the building to be within 8 meters of either the façade or the atrium, providing large amounts of natural light into the building and spectacular views in all directions. Its energy performance is outstanding, with a 42 percent CO_2 reduction when compared to a similar-sized conventional office tower. On top of the building, 500 square meters of roof-mounted solar panels capture solar energy to directly power an absorption chiller to drive the cooling systems, an advanced hybrid of variable air volume (VAV) and chilled-beam air-conditioning technology.

Water is a crucial resource everywhere, but nowhere is it more precious than in Australia, which is in the grip of a decade-long severe drought. New projects, such as 1 Bligh Street, provide an opportunity to demonstrate how to truly minimize potable water consumption. It has the first blackwater recycling system in a high-rise office building in Australia, and it will save 100,000 liters of drinking water a day, equivalent to filling an Olympic-size swimming pool every two weeks. Wastewater is mined from the building and nearby sewers, processed, and then distributed around the building for nondrinking purposes, with 75,000 liters used for cooling towers and 25,000 liters used for flushing toilets. The system provides 100 percent recycled water for toilet flushing, as well as 90 percent of cooling tower makeup water. Sydney's goal is to have recycled water provide at least 15 percent of its water supply by 2015, and 1 Bligh Street is an important example because it employs new blackwater recycling technology.

Fig. 10 (A and B) The double-skin façade of 1 Bligh Street has a system of internal blinds that automatically deploy or adjust to optimize the combination of daylighting and energy transmission while protecting the occupants from glare. (C) Detail of air movement through the façade. [38]

The use of specially formulated high-strength concrete reduces the number of columns and therefore minimizes the amount of concrete used. Timber and plywood used in the structure is recycled or from FSC accredited sources. The steel used in the project comprises more than 50 percent-recycled content. Over 80 percent of all PVC-type products have been replaced with non-PVC materials. Over 37,000 metric tons, amounting to 94 percent of all construction waste produced on the project, was recycled.

4. A Closer Look at Double Skin Glass Facades, Physical Characteristics

Assuming that fresh air enters a building through the cavity between a double-leaf façade, it's very important, especially during transition periods and when individual occupants want natural ventilation that no extreme temperature increase occurs in the cavity between the window panes, because the heated outside air would then overload the room temperature. The Figure series compares the temperature in this transition space for different types of shading (reflection quotient). In this example, fresh air enters into the window-pane configuration at a temperature of 25 centigrade and is already heated in the boundary layer region in the outer pane. On this path through the cavity between panes, the temperature rises further. The rise in temperature in this space due to reflection and especially due to light absorption may vary greatly and reach maximum temperature of 70 centigrade.

Temperatures in different cavities vary considerably. The question of how to remove the heat from the cavity is important. Very little inlet and outlet design has been done. The idea of accelerating ventilation by designing the inlet and outlet seems promising.

The chart presents a calculation of the change in total solar energy transmission per changing reflection quotient. When the reflection quotient diminishes (pollution), the total solar energy transmission does too, because there is less radiation transmission, which is usually positive in terms of heat for the adjoining rooms. On the other hand, the light quality may suffer. The quality of the Louvre, for e.g., reflection quotient, is worth studying.

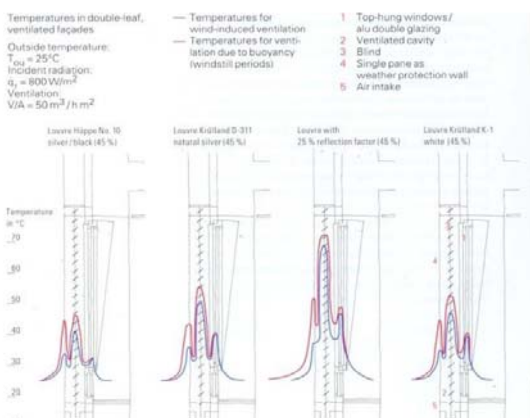


Chart 1 of Temperature in transition space for different types of louvre

While the surface of the Louvre is most important, the angle at which it is placed has an influence as well and changes the total solar energy transmission. The chart shows an example of two different louvers and how the total solar energy transmission changes, depending on the angle. Hence, the correct form of angle control (computer-aided) is key to the optimization of a facade, since direct radiation of office areas should be avoided for lengthy periods of the year while maintaining high daylight utilization (radiation transmission). Depending upon the season and the time of day, the angle control of louvers achieves optimal daylight incidence in combination with minimal heat gain. 'Intelligent facades' operate with automated angle control regulated by incident radiation and outside air temperature. During periods of unwanted thermal gain, the louvers are positioned at a steeper angle than during periods when passive solar gain reduces the energy costs for heating the room. Angle control is thus clearly an important factor with regard to total solar energy transmission. Another is the type of glazing used between the indoor space and the air cavity.

Since direct radiation of office areas should be avoided for lengthy periods of the year while maintaining high daylight utilization, the question is, "how much energy can computer-aided control save and is it a sufficient method to achieve cost efficiency?"

5. Conclusion

The main deductions, which can be concluded from the results of the present studies, are summarized as follows:

1) The idea of DSFg has been a source of numerous studies conducted on different areas since the 1990s.

2) Ventilation is the most important part studied by most of the researchers while the researchers highlights the inadequate past researches done on daylighting.

3) It was found from past researches that shading devices can reduce the external hot gain if it is placed correctly in the DSFg cavity.

4) However, it was discovered that DSFg pose a high fire hazard risk.

5) The researches done on DSFg need further exploration.

6) Users of the DSFg (especially in hot and humid climate) are still in the early stages of development. Therefore, urgent theoretical and experimental research works is needed in order to clearly understand the challenges, effects and implications of DSFg.

In conclusion, double skin glass facade (DSFg) has been proven to be highly useful and significant in current building developments. The only downside of double skin glass facade is that it is said to be more expensive than the traditional single glass facade. However, it is widely agreed by many experts that double skin glass facade (DSFg) is more cost-effective in the long run. This is because it is long lasting and more durable as compared to the single glass facade. In addition, it provides other benefits that cannot be found in single glass facade. One of these benefits is that double skin facade helps create a more comfortable and eco-friendly office environment which in turn, further reduces maintenance costs as it saves the building's energy resources.

Finally, DSFg systems have great potential for decreasing energy consumption in wide ranges of research areas. The systems based on the ideal can find significant opportunities to be used in some innovative and prospective studies with multi-disciplinary research structure.

Thus, the researchers of this study propose future works and more studies to be done on DSFg designs, on the problems in DSFg designs and its impact on the environment, building ergonomics and human psychology, and comfort. Innovations in DSFg designs should be further pursued and DSFg applications in buildings should seriously be considered as an element in addressing climatic changes and environmental hazards, as it is cost and energy efficient.

References

[1] Baker N, Steemers K. Energy and Environment in Architecture; A Technical Design Guide, Routledge, New York, 2000.

[2] Boake et al. (ND). The Tectonics of the Double Skin: What are double facades and how do they work? University of Waterloo.

[3] The Glass Range for Architects and Specifiers, Technical Report, Pilkington Building Products, UK, June 2006.

[4] Environmental performance toolkit for glazed facades, CIBSE TM35, The Chartered Institute of Building Services Engineers, London, 2004.

[5] Boyce P, et al. The Benefits of Daylight through Windows, Lightning Research Center Rensselaer Polytechnic Institute, 2003.

[6] Heiselberg P, et al. Modeling a Naturally Ventilated Double Skin Façade with a Building Thermal Simulation Program, 2008.

[7] Loncour et al. Ventilated double Facades, Classification and Illustration of Façade Concepts, 2004.

[8] Till Pasquay. Natural ventilation in high-rise buildings with double facades, saving or waste of energy, Energy and Buildings, 2004.

[9] Kwok AG, Grondzik WT. The Green Studio Handbook, Environmental Strategies for Schematic Design, Elsevier, Architectural Press, 2007.

[10] Wenting Ding, Yuji Hasemi, Tokiyoshi Yamada. Natural ventilation performance of a double-skin facade with a solar chimney, Energy and Buildings, 2005, pp. 411-418.

[11] Giuseppe Ballestini, Michele De Carli, Nicola Masiero, Giovanni Tombola. Possibilities and limitations of natural ventilation in restored industrial archaeology buildings with a double-skin facade in Mediterranean climates, Building and Environment, 2005, pp. 40-95.

[12] Wenting Ding, Yuji Hasemi. Smoke control through a double-skin facade used for natural ventilation, Ashrae Journal, 2006; Part 1, Vol. 112, 181 p.

[13] Kim SY, Song KD. Determining photo sensor conditions of a daylight dimming control system using different double-skin envelope configurations .Indoor and Built Environment 2007.

[14] Manz H, Schaelin A, Simmler H. Air flow patterns and thermal behavior of mechanically ventilated glass double facades, Building and Environment, 2004, pp. 1023-1033.

[15] Harris Poirazis. Introductory Report for the Glazed Office Buildings Project, Internal Report, Report EBD-R–5/10, Division of Energy and Building Design, Department of Construction and Architecture, Lund Institute of Technology, Lund University, 2005.

[16] Awbi HB. Chapter 7- Ventilation, Renewable and Sustainable Energy Reviews, 1998, No 2, pp. 157-188.

[17] Lei Xu, Toshio Ojima. Field experiments on natural energy utilization in a res- idential house with a double skin facade system, Building and Environment, 2007, pp. 14-23.

[18] Zhou J, Chen YM, Fang SS. Ventilated double skin facades in hot summer and cold-winter zones in China, Journal of Hunan University Natural Sciences, Part SUPPL, 2009, pp. 160-162.

[19] Carla Balocco, Massimo Colombari. Thermal behavior of interactive mechanically ventilated double glazed facade: non-dimensional analysis, Energy and Buildings, 2006, pp. 1-7.

[20] Matthias Haase. Double-skin facades for Hong Kong, PhD Thesis, University of Hong Kong, July 2008.

[21] Baldinelli G. Double skin facades for warm climate regions: analysis of a solution with an integrated movable shading system, Building and Environment, 2009, Issue 6, Vol. 44, pp. 1107-1118.

[22] Elisabeth Gratia, Andre De Herde. The most efficient position of shading devices in a double-skin façade, Energy and Buildings, 2007, Vol. 39, pp. 364-373.

[23] Remi Charron, Athienitis Andreas K. Optimization of the performance of double-facades with integrated photovoltaic panels and motorized blinds, Solar Energy 2006, pp. 80-91.

[24] Daylighting in building, Thermie program me, (UCD-OPET) European Commission, Directorate-General of Energy (DGXV11) Thermie Daylighting Workshop, Dublin, 3-4 February 1994 Energy Research Group, School of Architecture, University College Dublin, Rich view, Clonskeagh, Dublin 14, Ireland, 2006.

[25] Chow WK, Hung WY, Gao Y, Zou G, Dong H. Experimental study on smoke movement leading to glass damages in double-skinned façade, Construction and Building Materials, 2007, Vol. 21, pp. 556-66.

[26] Bauer M, Mosle P, Schwarz M. Green Building-Guidebook for Sustainable Architecture, Springer, 2007.

[27] Sinclair, Duncan Phillips, Associate, Vadim Mezhibovski. ventilation facades, Ashrae, April 2009.

[28] Chan ALS, Chow TT, Fong KF, Lin Z. Investigation on energy performance of double skin facade in Hong Kong, Energy and Buildings, 2009, pp. 41-42.

[29] Bay JH. Socio-climatic design in the sky, in Proceedings of PLEA 2004, The 21st Conference on Passive and Low Energy Architecture, Eindhoven University, The Netherlands, September 2004.

[30] Bay JH. Research Report: Towards More Robust and Holistic Precedent Knowledge for Tropical Design: Semi- open Spaces in High-rise Residential Development, Research in collaboration with Khee-Poh Lam, Reference Number: R 295-000-034-112, Department of Architecture, National University of Singapore, 2003-2004.

[31] Wang N. Guidelines for Socio-Climatic Design of Semi-Open Entrance Spaces of Tropical High-Rise Apartments, Masters of Arts (Architecture) thesis, supervised by JH Bay, National University of Singapore, 2005.

[32] Bay JH, Ong BL. Tropical sustainable architecture, social and environmental dimensions, Elsevier, Architectural Press, 2006.

[33] Lou W, Jin H, Chen Y, Cao L, Yao J. Wind tunnel test study on wind load characteristics for double-skin facade building with rectangular shape, Journal of Building Structures, 2005, Part 1, Vol. 26, pp. 65-70.

[34] Jorn von Grabe. A prediction tool for the temperature field of double facades, Energy and Buildings 2002, Vol. 34, pp. 891-899.

[35] Zhng M, Lou WJ, Chen Y. Wind pressure distribution and gust factor on double skin facades of high-rise building with rectangular shape, Journal of Zheliang University (Engineering Science), 2008, Part 1, Vol. 42, pp. 54-59.

[36] Lou W, Zhang M, Shen G. Wind tunnel test study on mean wind pressure distribution for double-skin façade, Journal of building Structures, 2009, Part 1, Vol. 30, pp. 120-125.

[37] Lou W, Zhang M. Test of wind load characteristics of cylindrical building with double-skin façade, Journal of Huazhong University of Science and Technology, 2009, Part 5.

[38] Kibert CJ. Sustainable Construction, Green Building Design and Delivery, 3rd Edition, John Wiley & Sons, Inc, 2013.