Environmental impacts of ventilation and solar control systems in double skin façade office buildings

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Abstract: Buildings are one of the important energy consuming sectors. The increasing environmental awareness has triggered a great emphasis on sustainable design in the current global building industry. Since the past century, there has been a distinct growing trend in the use of fully glazed façade in office buildings. This paper discussed and analysed how solar control and natural ventilation systems can be integrated into double skin façade systems to minimise the environmental impacts. Sun shading should be considered as an integral part of fenestration system design that is adapted into the façade design of office buildings. The technology of façade systems that integrate solar control and ventilation systems encompasses a wide range of strategies and options resulting in energy efficient building design. Such façade systems minimise overheating and excessive solar gains during summer whilst increasing direct solar gains during winter to minimise the use of mechanical heating. Through case studies, this paper examines the performances of different double skin façades systems. Evaluations and recommendations are made to enhance the future designs of glass façade systems.

Conference theme: Construction and materials.
Keywords: Double skin façades systems; Sustainable design; and office buildings.

1. INTRODUCTION

The last few decades have shown significant advancements in the nature of glazing systems in the building industry. The increasing use of fully glazed façade in office buildings is due to this technological advancement. On one hand, the façade of a building is particularly important as an expression of the designer's creativity. Fully glazed building façades give the impression of light and transparency with maximum exposure to daylight as compared to traditional buildings. On the other hand, the technology of ventilation, solar control and daylighting were used to improve the indoor air quality, energy efficiency of the building consumption and thermal comfort thus, increasing the occupant performance (Tzempelikos, Athienitis, 2006).

On its own the fully glazed façade of a building may appear to be slick and elegant but it is not an effective design in terms of energy efficiency (Sala, 1997). The application of the glass façade in office building designs has evolved to the extent where the appearance of the building is more significant than the functionality of the glass facade. Meanwhile, innovative new buildings have been constructed with fully glazed façades that claim to include energy efficiency, sustainability and other environmental considerations. The variety of technological solutions used to produce high performance building façades are based on basic fundamentals of building physics for day lighting, solar heat gain control, ventilation and space conditioning. Through case studies, this paper critically assesses and compares the performance requirements of various fully glazed façade systems in office buildings that consider environmental impacts. The paper will

- examine the different types of glass façade systems, in particular double skin façade systems that incorporate environmental performance;
- identify and evaluate each parameter that influences the environmental performance of the glass façade.

By studying the environmental performances of different glass façade systems, this paper will contribute to the development of related technologies that help to minimise the environmental impacts of fully glazed office buildings. The study will also raise the awareness of the importance of the glass facade systems being not purely aesthetically driven. The underlying functionality of the systems such as the environmental performances should also be considered.

2. GLASS FAÇADE SYSTEMS

2.1 Glass as a building material

Glass is a remarkable material. It allows natural light into interior spaces. Its multiple functions to reflect, transform and enclose spaces without appearing to do so has made it a material that is a must have in almost all contemporary buildings. The evolution of glass has a long history in architecture from fixed, plain, stained, light permeable to the modern glazing system. Glass as a building material led to the significance of windows in the design of any building. The traditional purpose of windows was to provide light, view and fresh air for the occupants. Windows are a dominant feature of a building that provides opportunities for natural ventilation. Nowadays, windows have become a component of the building that is completely sealed, mechanically ventilated and electrically lit. The role in addressing occupant's needs have declined. However with technological advancement, environmental concerns are becoming a growing recognition. Nowadays these concerns are highly valued and contribute to the satisfaction, health and productivity of building occupants (Carmody et al., 2004).

In the late 19*th* century 15% of window-surface areas were typical for the architecture during that period. The window surface gradually increased to 80% by the beginning of the 1970s. This change had resulted in the increase of winter heat-loss and summer heat-gain as well as the increasing heat stress on the external surface materials. In order to prevent further damage, an entire line of construction measures were necessary (Szell, 2002). As the technology developed it allowed the advancement of glazing to be used in buildings.

This led to the invention of the curtain glass wall that evolved through the growing need for buildings to appear sleek and transparent. Architects began to design buildings that were fully glazed and appeared to have a floating façade. The curtain glass wall opened a new window for architectural expression where the use of glass as a building envelope material in commercial buildings kicked started the development of fully glazed façades. One of the factors of the curtain glass wall that led unavoidably to a further step in the successful march of glass as a building envelope was its very poor thermal performance (Butera, 2005).

Presently, sustainable design and ecological considerations have become fashionable words in the building industry. Technological advancement has made it such where the popularity of glass as a building material has grown. The architectural language has given more and more emphasis to the lightness and transparency of the building gradually becoming fully glazed envelopes. The increase popularity of applying fully glazed facades into building design has grown to the extent where it has become an environmental concern (Butera, 2005).

2.2 Environmental awareness of the glass façade systems

The increase in use of fully glazed façade's is due to the developments of heating and cooling systems, otherwise the buildings would be uninhabitable. This has led to the enhancement of the functionality in glass facades that have been altered to provide added intrinsic capabilities (Carmondy, 2003). The overall performance of glass as a building component can be further developed when it is designed to an integrated part of the building as a complete façade system. Through the past decade sustainability and environmental concerns has become a predominant issue globally in the architectural discipline.

In recent years there has been a growing awareness of the impact of buildings on its environment. According to the World Watch Institute, "as much as a tenth of the global economy is dedicated to buildings: to construction, operating and equipping our built environment. Blame for much of the environmental damage occurring today, from destruction of forests and rivers to air and water pollution and climate destabilisation, must be laced squarely at the doorsteps of modern buildings. Many buildings do harm on the inside as well: they subject us to unhealthy air or alienating physical environments, making occupants both less healthy and less productive" (Roodman and Lesson, 1995).

The functional aspect of windows meeting the goals of energy efficiency while providing daylight, views and other amenities of windows has traditionally been a problem. Single pane windows are a great source of unwanted heat loss and heat gain. In the last 20 years, the energy efficient properties of windows have been improved by innovations in glass coatings, gas fill, low conductance spacers and frames and suspended plastic films that result in multiple glazing layers (Schittich, 1999). These improvements to standard windows are only one aspect of developments that has transformed windows into dynamic elements that provide a filter for light, heat, air, view and sound

The development of curtain walls in office buildings is without a doubt a phenomenon hardly reversible, in a sense that these building practices belong to natural evolution in the use of materials and to expectation of users who consider normal the present standards of natural lighting and transparency of the building envelope. The application to the curtain walls of the exploitation of solar energy and of ventilation is a natural development of this technology. On the one hand the presence of extended glass surfaces allows the use of thermal solar energy in winter or to the introduction of photovoltaic panels. On the other hand the ever increasing pollution of the most central urban areas forces the designers to a consideration of the ventilation system avoiding the direct relationship with the outside (Sala, 1994).

New technologies such as motorised shading systems and electrochromic glazing make it possible for windows to optimise energy use and interior environmental conditions. The past decade has seen a lot of improvement in the building façade system. There has been a wave of innovation by architects and manufacturers exploring advanced façade systems. These systems are designed to manage energy flows, view and comfort. One type of advanced façade of current interest is the double envelope system. Windows and façades are at the cutting edge of new technologies in buildings.

3. Double skin façade

Double skin façades was developed to increase the transparency of buildings integrating a combination of systems that provides a comfortable indoor environment that attempts to reduce energy use. The double skin façade is a trend that began in Europe. There are a few design aspects that drove the development of this advance system:

- the aesthetic desire for an all glass façade that leads to the increase transparency appearance of a building

- the need to improve indoor environment qualities
- the need for improving the acoustics in buildings located at noise polluted areas
- the reduction of energy used due to environmental concerns

Double skin façades are composed of two façade layers separated by a cavity. The configuration of the façade can vary in the depth of the cavity, materials used on each façade layer, the window to wall ration, the division of the air cavity and shading materials used in the cavity. The exterior façade is usually glazed and can be fully glazed. The interior façade is an insulated double glazed unit and is usually not fully glazed. The air cavity between the two panes can be natural, fan supported or mechanically ventilated. The width of the cavity can influence the way that the façade is maintained (Hamza, 2006).

The interior window is usually operable by the user. There are more advanced façade technologies that have automated ventilating systems that regulate the natural air flow into the building. Some double skin façade systems integrate automatically controlled solar shading inside the air cavity. Although the double skin façade is not a new technology there is still a growing need understand the function of this façade type (Poirazis, 2004).

Heat extraction double skin façade rely on sun shading located in the interstitial space between the exterior glass façade and interior façade to control solar loads. The concept is similar to exterior shading; solar radiation loads are blocked before entering the building. Heat absorbed by the shading system is released within the intermediate space and is drawn off through the exterior skin by natural or mechanical ventilative means (Carmondy…et al., 2003).

The effectiveness of ventilation driven by thermal buoyancy or stack effect is determined by the inlet air temperature, height between inlet and outlet, openings size, degree of flow resistance, temperature or the louvers and interfacial mixing that may occur if there is no wind. Box windows are single story double skin facades that are divided by structural bay widths or on a room by room basis. Shaft box facades couple single story box windows to multi story vertical glass chimneys via a bypass opening at the top of the box window. Corridor facades are single story facades that have no vertical divisions except those required at the corners of the building for structural, acoustic or fire protection reasons (Poirazis, 2004).

The position of the Venetian blind within the air cavity affects the rate of the heat transfer to the interior and amount of thermal stress on the glazing layers. The blind should be placed toward the exterior pane with adequate room for air circulation on both sides. Heat recovery strategies can be implemented using the same construction to reduce heating load requirements during the winter.

3.1 Solar control façade

Spectrally selective glazing is a type of glass that permits some portion of solar spectrum to enter a building while blocking others. This glazing admits as much daylight as possible while preventing transmission of as much solar heat as possible. It functions by controlling solar heat gains in summer and prevents loss of interior heat in winter (Ralegaonkar, 2004).

Angular selective façades provide solar control based on the sun's angle of incidence on the façade. The main objective is to block or reflect direct sun and solar heat gains during summer. It also admits diffuse sky light for daylighting. There are a few variations that include between pane louvers, or blinds with mirrored upper surface where the upper surface is treated with reflective coating. These systems fully or partially block direct sun and redirect sunlight towards the interior ceiling plane. Conventional louvered or Venetian blind systems enable users to adjust the angle of blockage according to solar position, daylight availability and glare (Poirazis, 2004).

Exterior solar control as mentioned before in the sun shading section can be provided by overhang, fin or fully window screen geometries. The shape and the material will define the architectural character of the building. The main concept is to intercept direct sun before it enters the building. Operable systems can be used to control thermal gain, reduce glare and redirect sunlight. Operable systems provide more flexibility responding to outdoor conditions. I hot climates the system can be used to provide more daylight and absorb solar radiation before it penetrates into the building.

Conventional side lighting concepts distribute flux principally 0-15 feet from the window wall causing glare, high contrast and excessive brightness, leaving the remainder of the perimeter zone and the core in the dark. We live in a computer orientated society and glare on the computer screen can cause severe eye sight problems therefore indirect lighting is much preferred in office buildings. Systems using direct sunlight are most effective on the south façade and for practical geometric simplicity and efficiency are designed based on seasonal variations in solar altitude.

Light shelves are typically a horizontal exterior projection that uses a high reflectance, diffuse or semi-secular upper surface to reflect incident sunlight to a given interior depth from the window wall. Between panes light shelves employ many of the same principles of their larger counter parts but can be fabricated in volume and protected from dirt and dust between two panes of glass. Optical efficiency with respect to redirection may be poor since the primary design intent is to diffuse incoming daylight. In most systems, view is distorted or impaired so placement of such a system above standing view height is typically recommended. With many of the transparent systems glare is not controlled since the direct sun increases the luminance of the panels well above acceptable limits for most office tasks.

3.2 Active façade

Smart windows and shading systems have optical and thermal properties that can be changed in response to climate, occupant preference and building energy management control system requirements. These include motorised shades, switchable electrochromic or gasochromic window coatings and double envelope macroscopic window wall systems. User choice and options will be further enhanced if they have the flexibility to dynamically control envelope driven cooling and lighting loads (Lee….et al, 2002).

Many people recognise that control of solar heat gains during peak periods can be accomplished by simply blocking all solar radiation before or just after it enter the windows. It is also recognise that admitting daylight reduces the need for electric lighting. Determining the optimum energy balance between solar heat gains and daylight is a critical issue and is the key to optimising window and lighting peak demand reductions during the summer. Other long term opportunities not normally associated with window systems are those that allow windows to become part of the space conditioning solution. Natural ventilation, heat extraction and night time cooling strategies using operable windows reduce a building's dependence on mechanical cooling or shift the load to off peak hours.

4 METHODOLOGY

Research on office building designs has developed over the years. It looks to improve the quality of the environment through the introduction of more natural technologies in the lighting, heating and ventilation of the spaces. The main objectives of researchers are to investigate and test façade systems that are being used in buildings and determine ways of how it could produce reliable environmental performance, low coast, high efficient solar components which can be integrated in a wide range of building typologies (Sala,1994).

In this research, five case studies have been selected each based on office building types that is fully glazed and have different approaches on the use of its façade treatment. Examining individual buildings and analysing the functionality of the façade system, each case study looks into the selected performance criteria that are solar control, daylighting and ventilation.

The scope of this research is based on current research and practice on the theoretical principles of the standard types of double skin façade system in terms of solar control, daylighting and thermal comfort. The selected study on innovative façade systems intends to explore the possible design parameters of the façade system used in modern high-rise buildings. The recommendation of improvements to the façade system excludes the consideration of thermal massing, energy consumption, and user comfort.

The limitation of this research is that the case studies available to the study and selected are based on northern hemisphere locations. External pollution factors therefore are not considered in this research. The issue of maintenance with external shading devices is also not part of the scope of this paper. Nevertheless, the findings of the study, especially the technical aspects are relevant and applicable to the global context.

5 RESULT

The case studies were analysed base on the performance of the façade in relation to the orientation, design and environmental performance. Each case study has a façade system that provides examples that attempts to achieve an integrated active façade system. The design of each façade system integrates ventilation and solar control with the aid of an automated and manual operation mode. The results are divided into three sections: ventilation, solar control and façade glazing. The selected buildings for the case studies:

1. Helicon, United Kingdom, 1996.
2. Building Research Establishment, United Kingdom, 1997.
3. Debis Headquarters, Germany, 1997.
4. Stadttor, Germany, 1997.
5. GSW Headquarters, Germany, 1999.

5.1 Ventilation of façade system

Ventilation considerations	1	2	3	4	5
External air intake	●	●	●	●	●
Integrated system (natural and mechanical)	●		●	●	●
Cross ventilation		●			●
Stack effect	●	●		●	●
Openable internal windows		●		●	●
Ventilation box				●	
Mechanical extractor	●		●		●

Table 1 Types of ventilation performance used

Common parameters
The comparison of the ventilation performance used in each building show a common similarity. It is a popular method to integrate natural and mechanical ventilation systems. This consideration is due to the enhancement of air quality in the building and minimising air conditioning cost. Each case study tries to achieve this by allowing external or natural air intake into the cavity to assist with the filtration of interior air. This combined system shows that it is possible to enhance the air quality within the working areas and to create a more comfortable and productive environment for the users.

Suggestions
Openable window that are integrated into the building's façade system is a good design to adopt. However, this may lead to the loss of too much interior air being dispersed to the outside. Noise penetration may be another issue where if the building is located at a busy or noisy district the noised from the outside may be heard from the inside. This will cause a lot of discomfort to the users of the building

5.2 Solar control of façade system

Solar control considerations	**1**	**2**	**3**	**4**	**5**
External sun shading		●	●		
Internal sun shading within cavity	●		●	●	●
Wider depth of cavity				●	
Interior blinds		●	●		●
Fully glazed	●		●	●	●
Integrated artificial lighting	●	●	●	●	●

Table 2 Types of solar control system

Common parameters
Solar control for each building shows that most façade systems have solar control within the cavity. All the systems have an automated and manual function where the solar control can be adjusted by the user or according to internal lighting conditions that are picked up by sensors. Integrating artificial lighting to responds with the amount of natural lighting that light up a space is an economical way to increase energy efficiency. This type of system is mainly a monitored system that is done by computers picking up light levels through sensors that a place within the office space. Interior blinds within the work area are so that users can minimise the amount of glare that gets into the work space.

Suggestions
Most solar controls in the buildings are designed in a way to deflect the solar radiation from penetrating into the interior space. However the most effective way would be to have the solar controls on the exterior of the building where it deflects the rays before it penetrates into the cavity. The amount of solar rays that penetrate into the interior office space would be minimised.

This proves that the need to have a sleek and smooth appearance drives most of the façade design. The solar control within the cavity is an effective way to block out solar rays whilst still maintaining a smooth and light façade. However, by having the solar controls within the cavity does increase the temperature within the cavity and this may cause over heating.

5.3 Façade glazing
Consideration for façade design
Transparency levels on each façade depend on the amount of glazing used on the façade. The result shows that each façade should be treated differently and the consideration of the orientation of the building is very important. Strong levels of sun light come from the eastern and western side of the buildings. Therefore it is more suitable if both sides of the façade are less transparent or has more sun shading as to filter and disperse the direct sunrays.

The southern façade needs horizontal sun shading to deflect solar rays from penetrating the interior. On the northern façade it is the façade that least needs sun shading. The northern façade is usually the façade that permits diffused light into the building and provides a good amount of light.

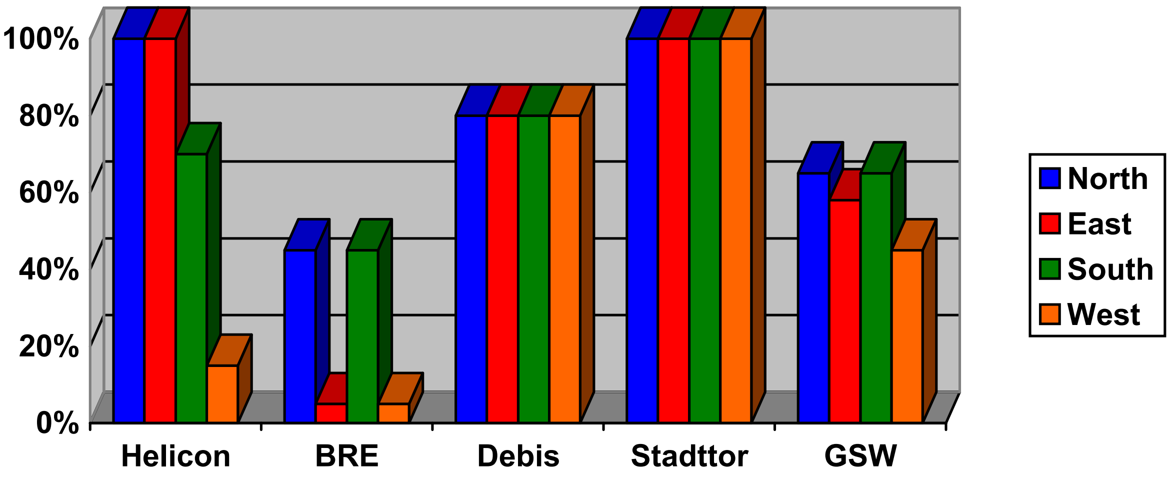

Chart 1 Façade transparency

6 DISCUSSION

6.1 Façade design strategies

All five buildings were selected because they have been widely considered as good examples of façade systems with solar control and natural ventilation for office buildings. Base on the results from the case studies, double skin façade systems have been identified as effective common glass façade types. Integrating solar control and ventilation systems within the façade cavity seams to be the most common parameter for the double skin façade system. The performance and type of integration methods vary according to the different building criteria.

The most important issue that should be considered for façade design is the orientation of the building. The buildings from the case studies were all located in the same region and all had similar weather conditions. The treatment to each building facades should vary from one to the other and reflect the geographical context. The northern façade can be fully glazed without any solar control as it is the façade that get diffused light from the north. For the eastern and western façade vertical solar controls are more appropriate for minimising solar radiation as it blocks direct sunlight at different angles throughout the day.

6.2 Solar control strategy

Climatic conditions and daylighting play a major role in the design and control of a shading system. The location, properties and control of the shading devices have a significant impact on daylighting and the prevention of glare within the parameter of the office space.

A shaded façade will only have to sustain the diffuse and reflected radiations. The diffuse solar radiation depends on the surrounding environment and can be reduced with use of vegetation, colour and material texture. Other distinct parameters that should be considered when deciding on solar control devices are the orientation of the building, glass transparency, position of sun shading and the materiality.

Maximization of daylight usage is desired because visual quality within an office increases user productivity and artificial lighting consumption is reduced significantly. The consideration of placing solar control on the exterior of the façade is so that the sun shading is able to minimise the amount of solar radiation that penetrates into the cavity thus minimising the need for using internal blinds. Although some of the case studies were able to minimise or control the amount of lighting needed in the interior space the shading devices were still unable to cope with blocking out glare externally. This is noted as a major concern as glare is harmful to the user especially when it affects the visibility of computer screens.

The integration of the automated control system is a good technology but user controlled of movable shading devices is not reliable and may cause a constant disruption for other occupants. Dynamic control of automated shading devices, fenestration systems, electric lighting and HVAC system components could lead to minimization of energy consumption for lighting, heating and cooling while offering a comfortable indoor environment under continuously changing outside conditions (Tzempelikos and Athienitis,2007)

6.3 Integration of natural and mechanical ventilation

The integration of natural and mechanical ventilation is known as a hybrid system. When natural ventilation is employed, cool outside air is drawn into the building to provide free cooling. It reduces the energy that is consumed by fans to circulate air within the building. The fresh air that is naturally vented into the building improves the air quality.

Base on the results of the case studies there are two ways that the buildings can be ventilated by stack effect or cross ventilation. The cross ventilation method works best when the depth of the floor plan is slim and does not have any obstructions. As for the stack effect method is where the external air intake is done within the cavity of the double skin façade. The cavity can be used as a stack, where recycled internal hot air can be exhausted into the cavity and is extracted up and out. The natural air intake can then be mixed with the internal air that is circulated and dispersed through air vents. This creates a more comfortable environment for the users within the building and thus increases productivity.

6.4 Relationship between the functionality of the façade and aesthetics

Shading is the interactive concept between aesthetics and solar control. An optimal façade design is determined by the consideration of a smooth exterior façade and incorporating all the functionality of façade performances within the cavity of the double skin. When the applications of façade systems are integrated into the design it presents more design opportunities for the designer to develop an interesting and exciting façade. This will allow the functionality of the façade to be enhanced by the architectural quality of the façade design.

6.5 Summary

Based on the above results and discussions, it is evident that the double skin façade system with solar control and ventilation is an ideal façade system that can be further developed and optimised to minimise environmental impacts. It considers the fundamental design parameters of how a building should be ventilated and integrates the normal air conditioning system with a hybrid system. The façade design can create an appealing building envelope that would efficiently control solar gains, contribute to reduction in energy demand and maintain comfortable indoor conditions.

The impact of shading design and control is critical for the daylighting performance in an office spaces. Translucent glazing is recommended to help minimise glare. The consideration of using external solar control would be a more effective method but if other requirements need to be accommodated, the use of automated integral Venetian blinds within the cavity of the double skin façade proves to be sufficient.

Horizontal solar controls are effective for blocking sunlight and improve the uniformity of the light in the interior space. The problem of eliminating glare is still yet to be developed. The current solution is the use of a more translucent glazing material or the use of manually controlled roller shades. This provides the users with some control over the visual environment that suits their needs. However with internal shading within the cavity it does contributes to the over heating of the cavity. Over heating of the cavity especially during summer proves to be a major problem with the double skin façade system. By having the sun controls within the cavity does contributes to the increase in temperature.

With the ventilation system it provides many good opportunities to further develop the integration of natural ventilation system with mechanical assistance. The results from the case study presents the same aims that is seeks to be achieved but is done through different façade systems. The most suitable ventilation method would be through stack effect. Where the air is filtered or circulated within the cavity of the double skin façade. This then allows the extracted interior air to be released and exhausted out of the building through the stack effect process.

The cavity within the façade can be divided up into zones or by floor. Where the temperature within the building can be regulated with an automated system and the users on each floor level can adjust the temperature and ventilation mode to suit their needs. There are a few other issues that have yet to be addressed like air pollutions in the urban environment. This would be a major consideration in selecting the type of ventilation system that would be appropriate for the type of environment. The recommended strategies can be considered as the principles to apply to different façade systems. Although the examples presented in this paper are based on northern hemisphere context, the principles and performance criteria are the same if applied to southern hemisphere.

7 CONCLUSION

This paper provides an insightful analysis of different double skin façade system used in office buildings with recommendations made to the solar control and ventilation of the façade system design.

The emphasis on environmental considerations and sustainable designs can be seen in the attempts of buildings to maximise natural resources and minimise energy use. Glass façade systems can be integrated with many different parameters that will assist with the building performance. Solar control and Ventilation is the most primary function that needs to be considered in the design of the façade system. Although the emphasis on having a light and transparent façade may still be one of the driving factors in designing façade systems, this paper argues that the functionality in relation to the environmental performance of the façade is as important and can be integrated in enhancing the aesthetics of the façade. Although the examples presented in this paper are based on northern hemisphere context, the principles and performance criteria are the same if applied to southern hemisphere.

This research stresses on the need to develop the double skin façade technology further to fully realise its potential in minimising energy usage within a building and creating a better and more adaptable interior environment. The design of solar controls on the exterior of the façade will pose a further challenge to architects. With the continuous trend of achieving visual transparency, integrating solar controls on the exterior will create new design topics and opportunities in future office building design. The use of façade systems does have a greater purpose beyond aesthetics.

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