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Integrating Ventilated Façades in Hot and Humid Climates

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ABSTRACT

There is a need for sustainable building design in Hong Kong. The Hong Kong climate is sub-tropical with hot and humid weather from May to September and temperate climate for the remaining 7 months period. A mechanical ventilation and air conditioning (MVAC) system is usually operated to get rid of the high peak cooling loads. One of the most significant technologies for energy savings in an office building is the façade. This work evaluates different ventilated façade designs in respect to energy consumption savings. It further proposes a new type of airflow window with a solar chimney to control the exhaust airflow. It could be demonstrated that this façade design can play an important role in highly glazed buildings. An important factor was the development of a climate sensitive regulator that helps to take advantage of the hot and humid climate.

Keywords: **Double Skin Facade, Hot-and Humid Climate, Building Simulation**.

1. INTRODUCTION

There is a world-wide need for a sustainable development (Behling c1996.). 52% of the total energy in Hong Kong is used by buildings. Office and commercial buildings are using 37% total energy (emsd 2003). Several ways of reducing energy consumption by applying energy efficient technology in the built environment have been identified (Baker c2002.; CEC 2002; Goulding et al. 1992; Krishan c2001.; Lee et al. 1998). Thus it is important to develop buildings that consume less operational energy during its life cycle. Especially in moderate to cold climate like Europe new building concepts were tested. They took into account the outdoor conditions and tried to create a climatic responsive building (Givoni 1992; Szokolay 1980; Wigginton 1996). Especially for the top-end market sector of office buildings advanced façade technologies were developed (Wigginton and Harris 2002). They tried to integrate more and more building services into the façade system. This has the advantage of reducing the space needed inside the building and reducing initial overall costs. However, little work has been done on the behaviour of double-skin façades (DSF) in hot and humid climates (Ding et al. 2005; Haase and Amato 2005b).One of the reasons might be that building types and climate are different in Hong Kong (Lam 1995; Lam 1999; Li and Lam 2000) with an urban environment that is dense and high-rise with usually 40 floors and above (Close 1996).

The seasonal and daily climate in respect to mean temperature, humidity and wind speed distribution in Hong Kong is different to the moderate climate in Europe (Lam and Li 1996; Li and Lam 2000; Li et al. 2004). A new approach for DSF design has to take the climatic factors into account to reduce the energy consumption in office buildings in a hot and humid climate.

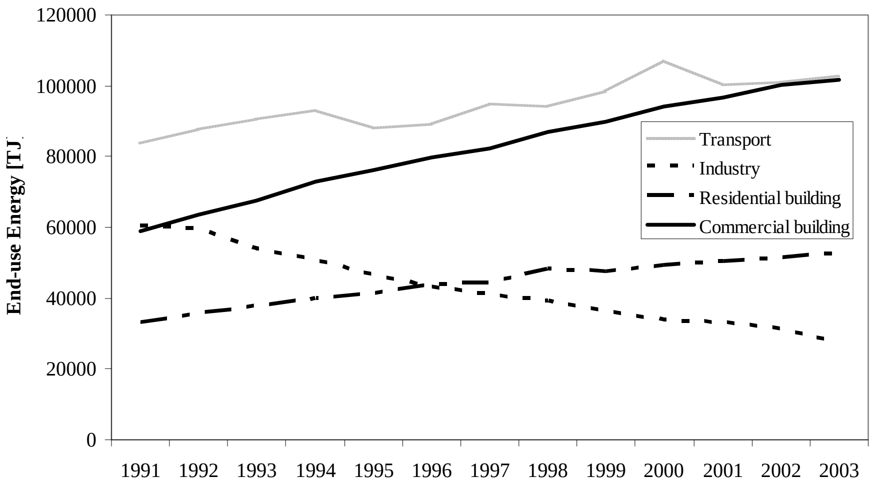

Figure 1.1 Energy consumption in Hong Kong

1.1 ADVANCED FACADES

One promising development of advanced façade systems is the double-skin façade (DSF). Conduction through the window system can be significantly reduced by making use of the air gap. The complexity of the new concept and technology requires a careful and responsible planning.

Heat transfer due to convection is the most complex one depending on the temperature distribution in the gap, the air velocity and pressure field. To predict the performance of a DSF is thus not trivial. The temperatures and airflows result from many simultaneous thermal, optical and fluid flow processes which interact and are highly dynamic (Chen and Van Der Kooi 1990; Garde-Bentaleb et al. 2002; Prianto and Depecker 2002; Qingyan and Weiran 1998; Xu and Chen 2001; Zhang and Chen 2000). These processes depend on geometric, thermophysical, optical, and aerodynamic properties of the various components of the double-skin façade structure and of the building itself (Hensen 2002). The temperature inside the offices, the ambient temperature, wind speed, wind direction, transmitted and absorbed solar radiation and angles of incidence govern the main driving forces (Manz 2003; Reichrath and Davies 2002; Zhai et al. 2002). Many types of DSFs have been developed since the first double layer was used in the building envelope (Parkin 2004). Figure 3 gives an overview of the main characteristics often used when describing the various features of DSFs.

1.2 DOUBLE-SKIN FAÇADE CONCEPT

When looking at the various airflow concepts it is important to note that all main types of DSFs can be combined with both types of ventilation and all types of airflow concepts. This produces a great variety of DSFs. Figure 4 shows the different airflow concepts that can be applied to DSFs. More recently, DSF have been developed that act as climate responsive elements with hybrid ventilation (natural and mechanical) concepts with a possibility to change the airflow concept due to different weather conditions in different seasons (Heiselberg et al. 2001).

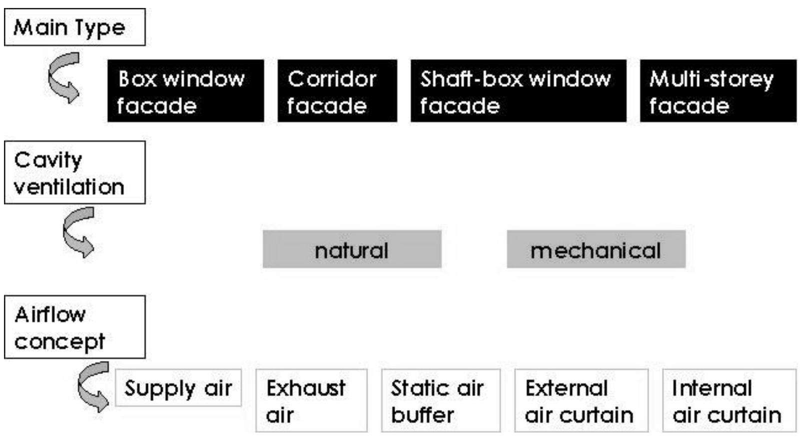

Figure 1.2 Classification of DSFs

1.3 DSF PERFORMANCE

The development of DSF technology involves several advantages by improving the thermal, visual and acoustic comfort (Oesterle et al. 2001). In moderate climates the air layer helps to insulate the building and thus reduce the energy consumption for heating. This is more significant in cool climates with strong winter periods (Balocco 2002; Park 2003). Furthermore the buoyancy flow in the cavity itself may reduce solar heat gain and additionally it can support the HVAC-system (heating, ventilation and air-conditioning) and it can help to minimize the size of the system and consequently the energy consumption of the building (Allocca et al. 2003; Andersen 2003; Gratia and De Herde 2004a; Gratia and De Herde 2004b; Gratia and De Herde 2004c; Gratia and De Herde 2004d; Saelens et al. 2003; Stec 2001; Stec and Paassen 2004).

Then, it creates a space for advanced sunshading devices. Positioned into the cavity of the DSF it seems to reduce heat gain (von Grabe 2002). In addition, natural daylight filtered into a building for lighting appears to reduce the heat load for artificial lighting on air conditioning (Garcia-Hansen et al. 2002; Grimme 1999). Thus, it is important to enhance the use of natural daylighting in office buildings (Bodart and De Herde 2002; Lam and Li 1998; Lam and Li 1999). This provides not only energy saving potential but also acknowledges the growing awareness for natural daylight and its effects on a healthy environment (Li and Lam 2001).

2. OBJECTIVES

The concentration of heat gain in the cavity might result in an increase of thermal comfort next to the window area. Since a part of the cooling ventilation is directed through the airflow window cavity a detailed analysis is needed that will help to improve airflow rates and ventilation efficiency (Haase and Amato 2005a). Finally, DSFs provide an additional layer that helps to reduce the acoustic impact into the building (Oesterle et al. 2001).

This study tried to find out if is possible to design an energy efficient DSF system for warm and humid climate. First, the amount of heat gain through the buildings envelope should be reduced by designing a ventilated DSF. Then, are several control strategies in respect to DSFs. The first is to control the shading system. The second strategy is to control the airflow direction. The third strategy is to control the HVAC system. Thus, the DSF should be optimised in respect to its control strategy.

3. DSF SIMULATION

The heat transfer through the buildings envelope depends on solar radiation, conduction and convection on the airflow through the double-skin gap. The convection in the cavity depends on the airflow. Several possible calculation models have been developed to simulate the thermal behaviour of DSF (Manz 2003; Saelens et al. 2003; Stec and Paassen 2004). One problem is to use dynamic building simulation with hourly weather data on the one hand but also to take the effects of airflow in the cavity into account. The airflow affects the heat transfer but is also influenced by external wind conditions (and the pressure it creates on the building envelope).

Three models were used to compare their performance. The first model is a curtain wall system which acts as a base case for comparison. The second model is a natural ventilated external air curtain. A cavity depth of 600mm was chosen. Both glass layers were selected as single clear glass (8mm). An internal shading device was positioned in the cavity. The third model is a mechanical ventilated internal air curtain with a cavity depth of 240mm.

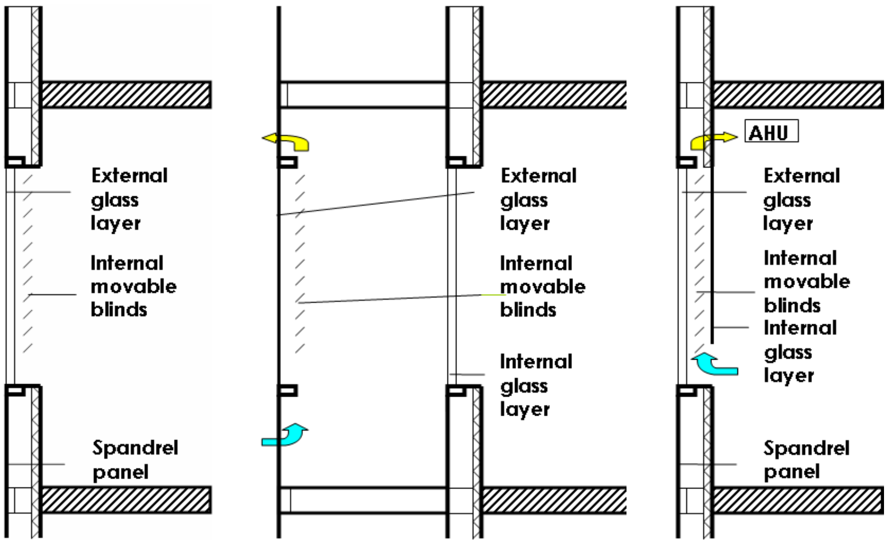

Figure 1.3 Three facade systems

3.1 BASE CASE MODEL

The model room was simulated with 6.6m width and 8m deep. The façade was facing South and a schedule was used to simulate the office use (working hours from 8am to 8pm). The model consists of a single glazed curtain wall (CW) system. The window to wall ratio is WWR=44%. A section is shown in Figure 5.

For this study a combined thermal and airflow simulation was chosen. TRNSYS and TRNFLOW (coupled with COMIS) were used to model an office room with DSF.

A simple DSF can be described as naturally ventilated external (EAC) which does require a control strategy for solar control and HVAC. The other possibility which is used in HK is a mechanically ventilated internal air curtains (IAC). For simulation purposes the two DSF were simulated and then a switch has been tested by opening windows to allow for supply air and exhaust air.

The switch is controlled by measuring enthalpy in the cavity which allows controlling the exhaust airflow.
The aim of both control strategies was together with the optimisation of the shading device to reduce solar heat gain and thus reducing the peak cooling load of the building.

3.2 EXTERNAL AIR CURTAIN

The design proposal includes a double-skin façade with 600mm cavity with one-storey double-skin façade. The double-skin façade is open on bottom and top to the outside allowing a naturally ventilated cavity as shown in Figure 6. A shading device is positioned in the cavity and solar controlled (DSF1). The internal window is closed. The second case is with an open able internal window and controlled by enthalpy difference between room and cavity. A regulator indicates the times of the year when the enthalpy of the air in the room is exceeding the enthalpy of the air in the cavity (DSF2) and the window opened.

3.2 INTERNAL AIR CURTAIN

The windows are connected to an additional second layer of glazing placed on the inside of the window to create a DSF. A section is shown in Figure 7. The mullion’s depth of around 240mm is needed for structural purposes and leaves space for the shading device which can be opened and closed automatically. At the same time the mullion can be used to introduce a second glass layer on the inside. It is open to the room at the bottom and has a ventilation slot on the top of the window. Air is vented through the airflow window from the room back to the MVAC system (AFW1).

The cavity of the double-skin is connected to the interior, air handling unit respectively allowing used air from the room to be forced through the gap and back to the air handling unit. Solar heat gain through the external glass layer is counting towards the total cooling load of the room. A regulator indicates the times of the year when the enthalpy of the air in the window gap is exceeding the enthalpy of the outside air (AFW2). The regulator will then exhaust the air which is expected to result in reduction of cooling load.

3.3 CONTROL STRATEGY

There are several control strategies in respect to DSFs which are summarized in Table 2. The first is to control the shading system. The second strategy is to control the airflow direction (from internal to external or vice versa). Both strategies involve climatic indicators. In the first case a sensor is used to detect the amount of solar radiation on the façade and to shade the window accordingly. It was switched down when the amount of incident solar radiation on the vertical façade exceeded 200W/sqm (switched up below 150W/sqm).

The second strategy is more complex. In temperate climates where natural ventilation is a cooling strategy the internal façade consists of open able windows. This allows the occupant to control airflow according to individual comfort (Saelens et al. 2003).

Table 1.1 List of control strategies.

Case	control Airflow		Solar Strategy		HVAC strategy	strategy
BC0	no	-	no	-	yes	cooling above 24°C
BC1	no	-	yes	200 – 150	yes	cooling above 24°C
BC2	no	-	yes	200 – 150	yes	cooling above 26°C
BC3	no	-	yes	150 – 100	yes	cooling above 24°C
BC4	no	-	yes	100 – 50	yes	cooling above 24°C
BC5	no	-	yes	50 – 0	yes	cooling above 24°C
DSF0	no	-	no	-	yes	cooling above 24°C
DSF1	no	-	yes	200 – 150	yes	cooling above 24°C
DSF2	no	-	yes	200 – 150	yes	cooling above 26°C
DSF3	no	-	yes	150 – 100	yes	cooling above 24°C
DSF4	no	-	yes	100 –50	yes	cooling above 24°C
DSF5	no	-	yes	50 – 0	yes	cooling above 24°C
DSF6	yes	hr > hc	no	-	yes	cooling above 24°C
DSF7	yes	hr > hc	yes	200 – 150	yes	cooling above 24°C
DSF8	yes	hr > hc	yes	200 – 150	yes	cooling above 26°C
DSF9	yes	hr > hc	yes	150 – 100	yes	cooling above 24°C
DSF10	yes	hr > hc	yes	100 – 50	yes	cooling above 24°C
DSF11	yes	hr > hc	yes	50 – 0	yes	cooling above 24°C
AFW1	no	-	yes	200 – 150	yes	cooling above 24°C
AFW2	yes	hc > he	yes	200 – 150	yes	cooling above 24°C

The third strategy is to control the HVAC system. The set point temperature determines the room temperature at which the HVAC system starts cooling and is very sensitive to changes (Lam and Hui 1996). Here, different set point temperatures were chosen with infinite cooling power. A heating system was not used.

In hot and humid climates natural ventilation can be applied to increase thermal comfort throughout the year. But especially in sub-tropical climates this effect is rather small. For Hong Kong thermal comfort improvements of natural ventilation are 20% for the whole year and during the three hottest months (June, July, and August) 10% (Haase and Amato 2005c).

For the DSF with EAC a comparison between room enthalpy and cavity enthalpy was done. The window was opened when the room enthalpy was higher then in the cavity. For the DSF with IAC the window was opened when the cavity enthalpy was higher then outside in order to exhaust the air.

4. RESULTS

Simulations were done for the whole year. The results shown in Figure 8 give the annual cooling load per area for the different control strategies.

It can be seen from Figure 8 that the base case uses between 128 and 155kWh/sqm. This is an improvement between BC2 and BC0 of 18% due to the increase in set point temperature (from 24 to 26°C) and the introduction of a solar control that lowers the shading device when the solar radiation is more than 200W/sqm and lifts it when solar radiation is falling below 150W/sqm. Further reductions in cooling load are possible by further reducing the amount of solar radiation on the façade before the shading device is lowered (BC3, BC4). Interestingly, a further reduction to 50W/sqm (BC5) increases the cooling load slightly (from 145kWh/sqm for BC4 to 146kWh/sqm for BC5, or 0.53%).

The EAC uses between 81 and 120kWh/sqm cooling load which is less than all base cases. Again, there is an improvement between DSF0 and DSF2 of 30% due to the increase in set point temperature (from 24 to 26°C) and the introduction of that solar control. Further reductions in cooling load are possible by further reducing the amount of solar radiation on the façade to 100W/sqm (DSF3, DSF4). Interestingly, a further reduction to 50W/sqm (DSF5) increases the cooling load slightly (from 114kWh/sqm for DSF4 to 115kWh/sqm for DSF5, or 0.92%).

The DSF with additional airflow control (DSF6 to DSF11) are significantly reducing cooling load compared to DSF without this control. There is an improvement between DSF6 and DSF8 of 31% due to the increase in set point temperature (from 24 to 26°C) and the introduction of that solar control. Further reductions in cooling load are possible by further reducing the amount of solar radiation on the façade to 100W/sqm (DSF9, DSF10). Interestingly, a further reduction to 50W/sqm (DSF11) increases the cooling load slightly (from 95.7kWh/sqm for DSF10 to 96.8kWh/sqm for DSF11, or 1.17%).

The IAC without airflow control increases the cooling load to 161kWh/sqm (AFW1). Only the introduction of an airflow control ensures that cooling load can be reduced to 99.5kWh/sqm (AFW2) which is 38% compared to AFW1.

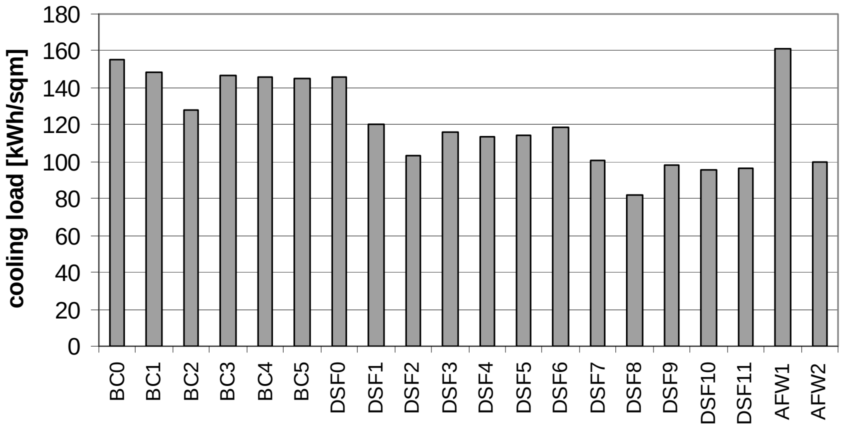

Figure 1.3 Cooling energy for different facade systems and different control strategies (as described in Table 1.1).

5. CONCLUSIONS

It is possible to design an energy efficient DSF system. The amount of heat gain through the buildings envelope can be reduced by designing a ventilated DSF that is optimised in respect to its control strategy.

For the base case curtain wall system solar control and HVAC control can be applied. The results for BC0, BC1 and BC3 show the effectiveness of the applied control strategy.

The DSF uses natural ventilation in the cavity to reject heat gain. The system provides a possibility to reduce annual cooling loads of an office room. The performance of the EAC can further be optimized by using the appropriate control strategy.

The IAC does not reduce the cooling load of the office room unless an enthalpy based control is used that extracts air in order reduce the cooling load of an office room. This system is giving the best results for the solar control strategy of lowering the shading device at 200W/sqm and lifting it at 150W/sqm. Further reductions are possible if the solar control strategy is more stringent and uses 100W/sqm for lowering the shading device. Further reducing the amount of solar radiation to control the shading device does not reduce cooling load.

While a reduction of radiation is met by using controlled solar shading devices, there are constraints from maximizing the use of daylight. Further research is planned to optimize the amount of daylight and thus reduce internal heat gain.

An EAC system has the potential of reducing cooling load even without applying control strategies (comparing DSF0 with BC0 provides 6% reduction in annual cooling load). For IAC the importance of an airflow control based on enthalpy of the air became obvious.

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