Design Considerations For Double-Skin Façades in Hot and Humid Climates

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Abstract: Thermal building simulations (TRNSYS) were linked to nodal airflow network simulations (COMIS) for a ventilated double-skin facade performance calculation and overall energy consumption for office building facades. Simulation results show good agreement with measured data. Especially interesting was the attempt to reduce the high peak cooling loads during the summer period by controlling the exhaust airflow using a climate sensitive regulator. It is shown that up to 26% reduction of annual cooling load can be achieved. This results in significant energy conservation and a reduction in system cooling size.

INTRODUCTION

There is a world-wide need for a sustainable development (Behling 1996). Looking at examples in European countries a strong emphasis on energy efficiency can be noticed (Baker 2002.; European Commission 1992.; Goulding et al. 1992; Krishan 2001.; Lee et al. 1998).

Energy and Buildings

The build environment in Hong Kong has a great potential for improving its sustainable development (Hui 2000). 52% of the total energy in Hong Kong is used by buildings. Office and commercial buildings are using 37% total energy (emsd 2003). Thus it is important to develop buildings that consume less operational energy during its life cycle.

Buildings and Climate

Especially in moderate to cold climate like Europe new 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 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. One promising development of advanced façade systems is the double-skin façade (DSF).

Climate in Hong Kong

However, little work has been done on the behaviour of double-skin façades in hot and humid climates (Haase and Amato 2005; Rajapaksha et al. 2003). This is particularly interesting since the building types and the climate are very 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 double-skin facades (DSFs) has to take the climatic factors into account to find out if a double-skin façade can help to reduce the energy consumption in buildings in a hot and humid climate.

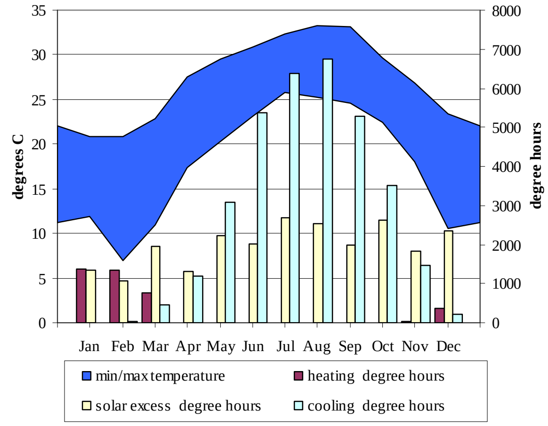

Figure. 1. Hong Kong climate

DOUBLE-SKIN FAÇADE TECHNOLOGY

In the following chapters a classification of DSFs and some advantages of this technology is given.

Classification of DSFs

Many types of DSFs have been developed since the first double layer was used in the building envelope (Wigginton 2000). It is helpful to agree on a consolidated classification of DSFs (Parkin 2004). Figure 2 gives an overview of the main characteristics often used when describing the various features of DSFs.

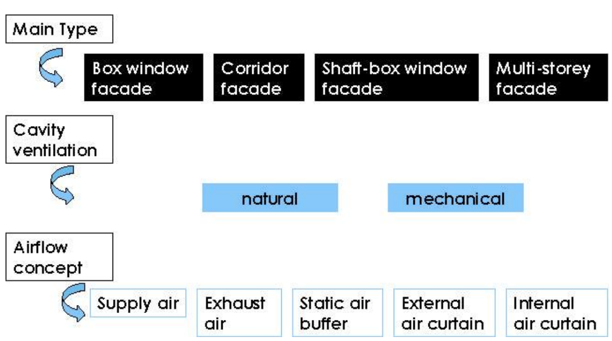

Figure.2. Classification of DSFs

Airflow concepts

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 results in a great variety of DSFs.

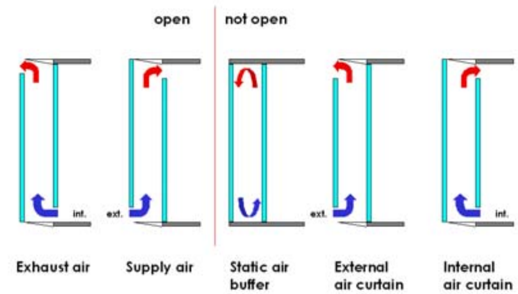

Figure. 3. Airflow concepts of DSFs

Figure 3 shows the different airflow concepts that can be applied to DSFs. They can be devided into open systems that allow an exchange of air through the envelope from inside to outside or vice versa and not open concepts that consist of sealed envelopes which do not provide this possibility. 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 2002).

Advantages of DSFs

The development of DSF technology involves several advantages by improving the thermal, visual and acoustic comfort (Oesterle 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; Hensen 2002; Hensen 1993; Saelens et al. 2003; Stec and Paassen 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).

Finally, DSFs provide an additional layer that helps to reduce the acoustic impact into the building (Oesterle 2001).

The purpose of this study was to find out the design criteria of façade design that influence the cooling load of an office building.

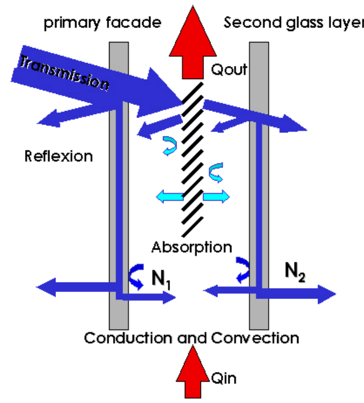

Figure. 4. Physics of DSFs

DSF SIMULATION

The heat transfer through the buildings envelope depends on various factors as shown in Figure 4. It illustrates the window physics, showing the complexity and impact of solar radiation, conduction and convection on the airflow through the double-skin gap. 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 2001a; Xu and Chen 2001b; 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 and (Yan) Chen).

Several possible calculation models have been developed to simulate the thermal behaviour of DSF (Saelens et al. 2003, Stec and Paassen 2004, Manz 2003). But only few take the dynamic wind pressure on the façade into account (Flamant et al. 2004). The most detailed model recently developed is the model used by Sealens (2002). Saelens studied different DSFs and compared heating and cooling load for temperate climate of Belgium. The results are however not easy to transfer to a hot and humid climate and he simulated only single-storey DSFs.

For this study a combined thermal and airflow simulation was chosen. TRNSYS and TRNFLOW (coupled with COMIS) was used to model an office room with DSF (Trnsys 2004; Dorer 2001).

For vertical surfaces, TRNSYS calculates the convective heat transfer coefficient due to the difference between the surface temperature and the temperature of the air right near the surface with

$$\mathbf{h_c} = 1.5\ (\mathrm{Tsurf} - \mathrm{Tair})^{K}$$

with
$\mathbf{h_c}$ = convective heat transfer coefficient
Tsurf = surface temperature
Tair = air temperature
K = correlation coefficient (= 0.25, see TRNSYS 2004)

A simple DSF can be described either as natural ventilated external air curtains (EAC) as shown in Figure 3. In order to find out appropriate widow sizing and glazing materials a series of simulations have been conducted. External shading devices have not been taken into consideration in this study.

Modelling

Seven simulation models were used to compare different façade designs and its impact on cooling load. First, the window to wall ratio was changed. Then, the glazing type was changed. Finally, a natural ventilated external air curtain model was used. An internal shading device was positioned in the 600mm deep cavity. The model room was simulated with 6.6m width and 8m depth. A schedule was used to simulate the office use (working hours from 8am to 5pm on weekdays).

Base Case Curtain Wall

The model consists of a single glazed curtain wall system. In order to evaluate the performance of a curtain wall system and the influence of the window to wall ratio (WWR) and glazing type on cooling load a set of design criteria were used. Table 1 gives a list of the glazing types and WWR used in the simulations.

Table 1: List of used in base case simulation

	BC1	BC2	BC3
WWR [-]	0.633	0.911	0.32
Glazing type	Clear Reflective Solar control		

Table 1 gives a summary of the parameters. Figure 5 gives a summary of the physical properties of the different glazing types (without shading device).

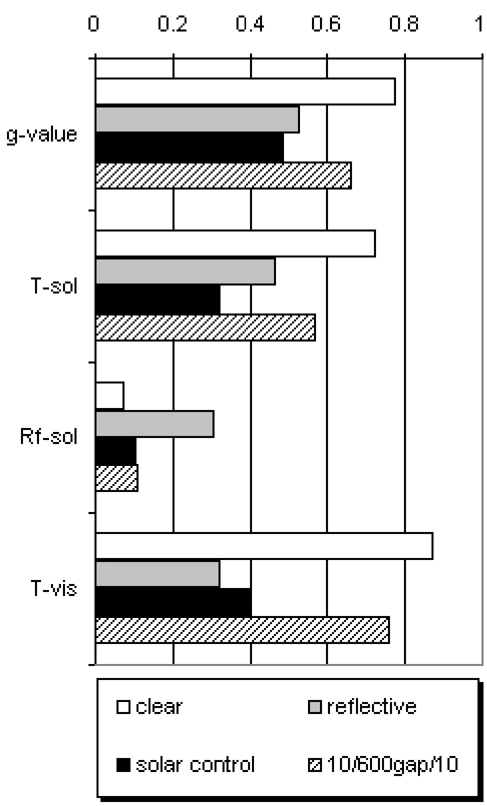

Figure 5. Glazing properties of glazing types used

External Air Curtain

The design proposal includes a DSF with 600mm cavity with one-storey double-skin façade. Both glass layers were selected as single clear glass (10mm). The inner window was assumed to have a WWR of 63% (as BC1) and fully glazed on the outside. The DSF is open on bottom and top to the outside allowing a naturally ventilated cavity. A shading device is positioned in the cavity and solar controlled (Haase and Amato 2006).

Similar to the CW simulation the WWRs of the internal window area were changed. The glazing type remained the same clear glazing for both layers for all DSF simulations. Table 2 gives a summary of the parameters used.

Table 2: List of used in DSF case simulation

	DSF1	DSF2	DSF3
WWR [-]	0.633	0.911	0.32
Glazing type	Clear for both layers		

RESULTS

The simulation results for the different base cases are summarized in Figure 6. It shows the influence of WWR on annual cooling load for a south facing façade. For clear glazing the cooling load varies between 142 and 171kWh/sqm. For the reflective glazing the cooling load varies between 135 and 155kWh/sqm. For solar control glazing cooling load varies between 136 and 157kWh/sqm.

For the different WWR it can be seen how the type of glazing influences the annual cooling load. A clear glazing is worst for all WWR followed by the solar control glazing. The reflective glazing performs slightly better than the solar control glazing.

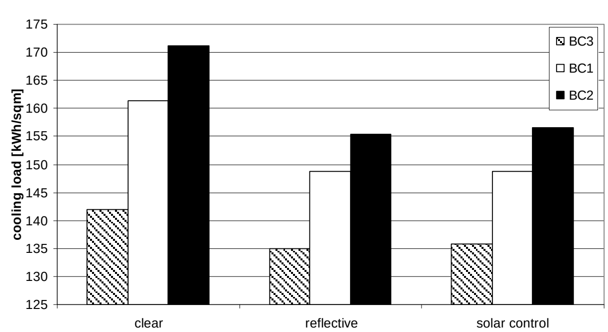

Figure 6. Results for CW simulations

The results for the DSF simulation show that it is better than all CW systems. The influence of the different WWR of the internal window on the annual cooling load is rather small. It ranges between annual cooling load of 126 and 135 kWh/sqm.

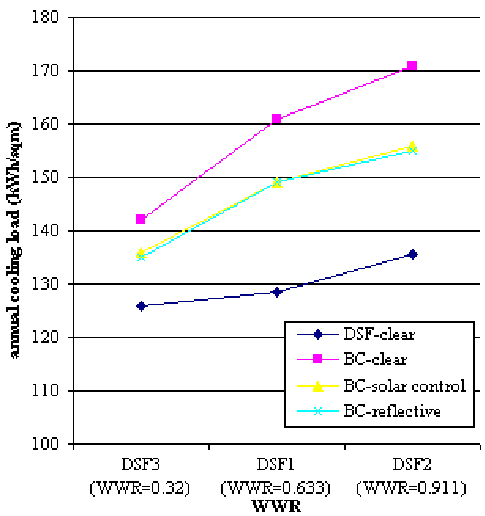

Figure 7. Results for DSF simulations

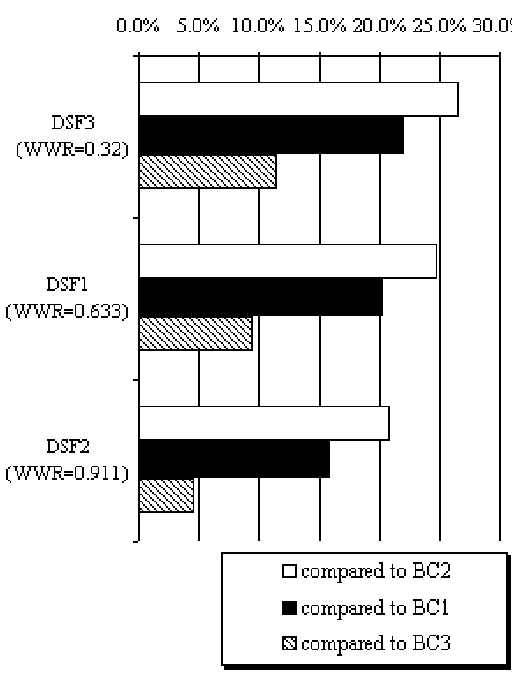

Figure 8. Results of comparison DSF with CW with clear glazing

A comparison with the best performing CW system with the different base cases was done. The DSF results were compared with CW system first with clear glazing then with reflective glazing.

Figure 8 shows the results in percentage annual cooling load savings compared to the different base cases with claer glazing from Table 1.

It can be seen from the results in Figure 8 that the DSF system has reduced annual cooling loads compared with all CW systems. The maximum annual savings are reached for DSF3 (with WWR=0.32) compared to BC2 (with WWR=0.911) of 26.4%.

The smallest annual cooling load savings are found for all DSF when compared with BC3 (WWR=0.32). Here, DSF2 (WWR=0.911) shows the smallest savings with 4.6%.

Figure 9 is showing the results in percentage annual cooling load savings compared to the different base cases with reflective glazing from Table 1.

It can be seen from the results in Figure 9 that the DSF system with large internal window area (WWR=0.911) has the same annual cooling load as the CW system BC3 with small window area (WWR=0.32). This indicates the importance of appropriate façade design and window sizing in hot and humid climates.

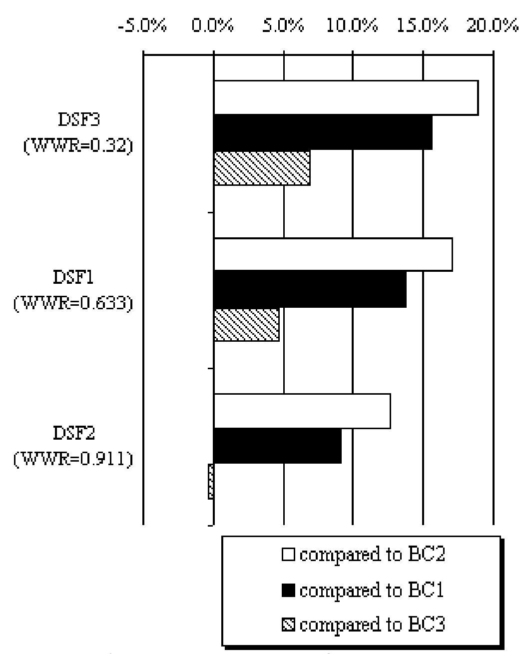

Figure 9. Results of comparison DSF with CW with reflective glazing

CONCLUSION

The facade design parameter WWR and glazing type have been identified as having major influence on annual cooling load. A parametric study with three different WWR and three different glazing types shows annual cooling load saving potential for CW systems.

It is further possible to design an energy efficient DSF system. The amount of heat gain through the buildings envelope can be reduced significantly by designing a ventilated DSF using two clear glazings in internal and external layer.

The EAC uses natural ventilation in the cavity to reject heat gain. Wind pressure on the building envelope was taken into consideration. The system provides a possibility to reduce annual cooling loads of a south facing office room.

Annual savings highly depend on the choice of base case for comparison. From a building design point of view a highly glazed outside facade can be achieved with a CW system. But the performance of this type of CW system (BC2) has the highest amount of annual cooling load. Even with reflective glazing the annual cooling load is 155kWh/sqm. The DSF system provides a fully glazed appearance with its layer on the outside. It is still possible to choose different window sizes for the internal layer.

The results have to be validated against measured data from different facade types. This will be done in the near future.

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.

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