VENTILATED FACADE DESIGN FOR HOT AND HUMID CLIMATE

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ABSTRACT: There is a need for sustainable building design. In warm humid climate (like Hong Kong) usually a mechanical ventilation and air conditioning (MVAC) system is 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 facade which determines great portions of the peak cooling load. The support of the MVAC system by means of natural ventilation is in the summer period limited due to the very high humidity. Additionally a trend towards highly glazed faced design for office buildings has been observed. There is nevertheless the possibility for energy consumption savings by applying double-skin facade (DSFs) to this type of building. This work evaluates different ventilated facade designs in respect to savings in operational energy consumption. It further proposes an exhaust airflow window to link with the MVAC system. The work is based on dynamic computer simulation which helps to demonstrate that this facade design can be applied in highly glazed buildings. But it also shows that it has to be coupled with an appropriate control system in order to be effective. A key role played the development of a climate sensitive regulator which is based on enthalpy difference that helps to take advantage of the hot and humid climate.

Keywords – Climate design, Moisture & Humidity Control, Envelope Issues

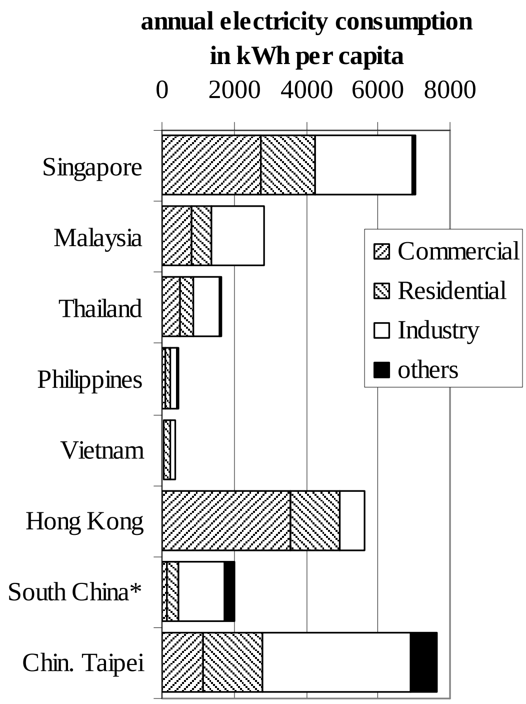
SUSTAINABILITY AND THE BUILT ENVIRONMENT

The importance of sustainable development is increasingly being recognized around the world (Behling 1996). There are basic explanations of what sustainable development is and how it is reached (SusDev). Looking at examples in European countries a strong emphasis on energy efficiency can be noted.

Energy and Buildings

There is considerable potential for improving the sustainable development of the built environment in Hong Kong (Hui 2000). The improvements can be reached by taking an energy responsible approach to design buildings that have a reduced impact on the environment (Bansal 2001; Hensen and Nakahara 2001; Hui 2001; West 2001).

52% of the total energy in Hong Kong is used by buildings. Office and commercial buildings use 37% of this total energy (emsd 2003). Several paths for reducing energy consumption have been identified. One possibility is the use of energy efficient technology in the built environment (Baker 2002.; European Commission 1992.; Goulding et al. 1992; Krishan 2001.; Lee et al. 1998). In order to evaluate the measures in a comprehensive way they must include the embodied energy as well as the overall energy consumption of the buildings. A major step towards sustainability will be achieved if the energy consumption of buildings over their whole life cycle can be reduced. In this respect it should be remembered that the operational energy consumption is the major source of environmental impacts (Amato et al. 2004). An obvious step in reducing building energy consumption is therefore to develop buildings that consume less operational energy during their life cycle.



* Guangdong, Guangxi, and Hainan province

Fig. 1.: Specific electricity consumption in different Asian countries (IEA 2004)

Buildings and Climate

New concepts have predominantly been tested in European countries subject to a moderate to cold climate. Experimental designs have taken into account the outdoor conditions and tried to create a climatic responsive building (Givoni 1992; Szokolay 1980b; Wigginton 1996). Advanced facade technologies have been developed, notably for the top-end market sector of office buildings (Wigginton 2002). These technologies have tried to integrate more and more building services into the facade 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 DSFs 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). Hong Kong is characterized by a dense, high-rise urban environment, in which buildings usually have at least 40 floors (Close 1996). This paper tries to find a DSF solution for this particular environment and uses a climate responsive approach.

Climate in Hong Kong.

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 DSFs has to take the climatic factors into account to find out if a DSF can help to reduce the energy consumption in buildings in a hot and humid climate.

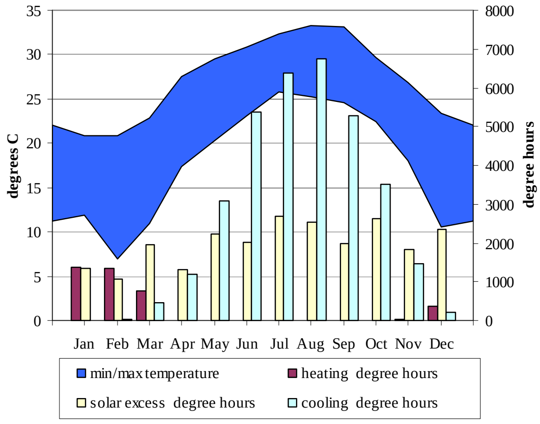


Fig. 2.: Hong Kong climate

Office Buildings in Hong Kong.

Lam examined the energy performance of office buildings in Hong Kong (Lam 2000) and Lam et al. determined the influence of the different energy consuming units in office buildings (Lam et al. 1997). Lam and Li´s analysis of daylighting and solar heat for cooling dominated office buildings is also a very useful study (Lam and Li 1999). Their analysis of the building energy consumption in Hong Kong gave peak cooling energy which is shown in Fig. 3. It can be seen that the building envelope design accounts for 36% of the peak cooling load. It is possible to take the amount of cooling load from artificial lighting into account since the daylight design can help to reduce this further. That means that more than 55% of the peak cooling load is influenced by the building envelope design.

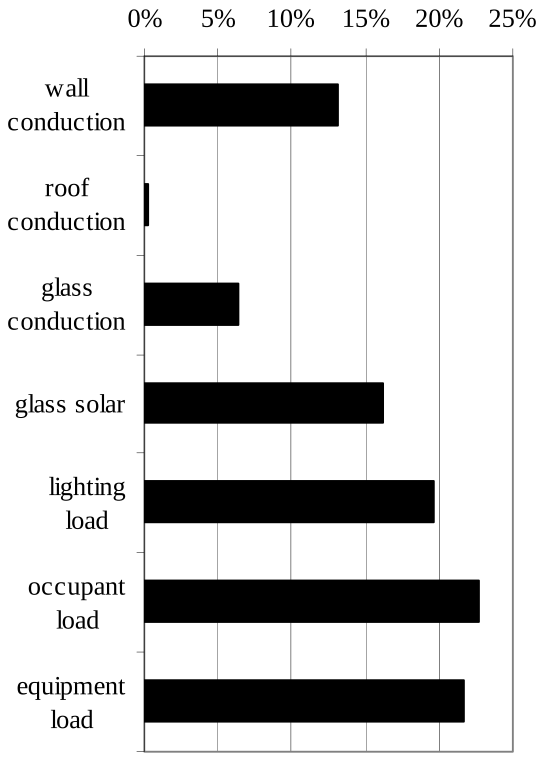


Fig. 3.: Peak cooling load (Li et al 2003)

This shows that one of the most significant technologies for energy savings in a building is facade system design. Recent advances in the fields of materials, manufacturing and thermo sciences have already been exploited in the construction of new buildings, in the retrofit or rehabilitation of existing buildings, and in the efficient operation of buildings (Compagno c2002.). Architects working in collaboration with engineers have started to take an energy-responsible approach to the design of building facades (Karsai 1997; Szokolay 1980a; Watson 1993.). The facade contributes to both the embodied energy and the operating energy of a building (Amato 1996).

DOUBLE-SKIN FACADE (DSF) TECHNOLOGY

One promising development of advanced facade systems is the double-skin facade (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 careful and responsible planning. Heat transfer due to convection is a very complex process, depending on the temperature distribution in the gap, the air velocity and pressure field. To predict the performance of a DSF is not a simple exercise. 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 DSF 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).

Classification of DSFs

Many types of DSFs have been developed since the first double layer was used in the building envelope (Wigginton 2001). It is helpful to agree on a consolidated classification of DSFs (Parkin 2004). Figure 4 gives an overview of the main characteristics often used when describing the various features of DSFs.

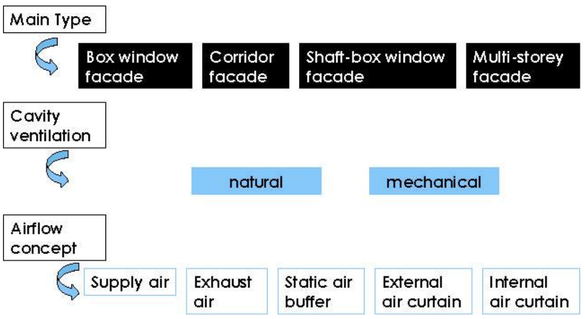


Fig. 4.: Classification of DSFs

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.

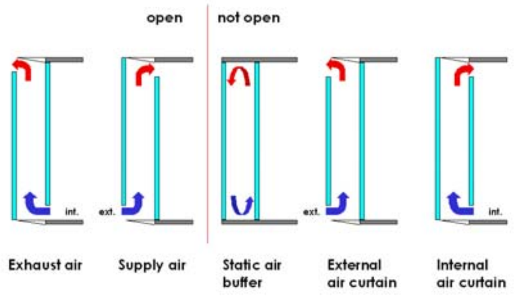


Fig. 5.: Airflow concepts of DSFs

Figure 5 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 2002).

Advantages of DSFs

The development of DSF technology produces a number of benefits, improving both thermal, visual and acoustic comfort (Oesterle 2001). In moderate climates the air layer helps to insulate the building and thus reduces 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 can also support the HVAC-system (heating, ventilation and air-conditioning). It can also 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).

It also 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).

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 2005c).

Further, it is important to enhance the use of natural daylighting (Bodart 2002; Lam and Li 1998; Lam and Li 1999). This provides not only energy saving potential but also acknowledges a growing awareness of the importance of natural daylight and its effects on a healthy environment (Li and Lam 2001).

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

DSFs in Hong Kong Offices

Different DSF systems have been applied to different office buildings in Hong Kong. A survey of the existing buildings in Hong Kong identified six recent projects that have implemented a DSF (Haase and Amato 2006). Three of these buildings have external air curtains (EAC) while the other three use internal air curtains (IAC) as a DSF system (Table 1). None of the systems is permeable.

Tab.1
List of buildings in HK with DSFs

Build ing	year of comple tion	number of storeys total	with DSF	GFA in m²	type of DSF
1	2000	10	10	13912	EAC
2	2001	19	16	33800	IAC
3	2002	8	8	10400	EAC
4	2002	6	5	32500	EAC
5	2003	29	14	12200	IAC
6	2004	8	2	81800	IAC

DSF AIRFLOW AND CONTROL STRATEGY

There 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 (from internal to external or vice versa).

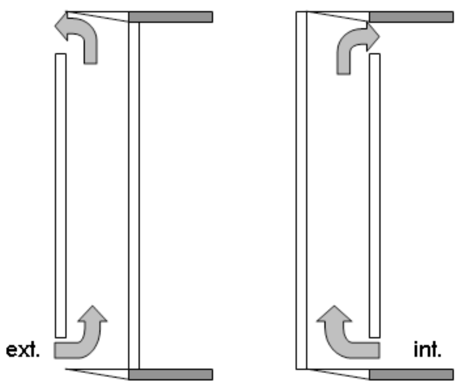


Fig. 6.: Airflow concept of EAC and IAC DSFs in HK

Both strategies involve climatic indicators. In the first case a sensor is used to detect the amount of solar radiation on the facade and to shade the window accordingly.

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

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 (Figure 7). In Hong Kong, thermal comfort improvements of natural ventilation during the three hottest months (June, July, and August) are 10% (Haase and Amato 2005a).

Existing buildings with DSF in Hong Kong have therefore applied either external or internal air curtains (EAC or IAC) (Table 1). However, it is possible to control switch able openings to the outside allowing to exhaust air at certain times. The switch must be controlled by a climate sensitive regulator which allows controlling the exhaust airflow. The aim is together with the optimisation of the shading device to reduce solar heat gain and thus reducing the peak cooling load of the building.

The dense and high rise Hong Kong building situation has been simulated in order to derive Cp values for the facade. Here a PAD of 35% was used together with 120m building height. The basic building was assumed to be 35m wide and 35m long. The cp values have been used in TRNFLOW as an input for two different scenarios. The first scenario used idealised cp values as shown in Tab 2. The second scenario used the calculated cp values for 18m reference height.

Tab.2
List of cp values used in DSF simulation

Orientation	"ideal" values	calc. values
0	-0.5	0.016
45	1	0.0169
90	1	0.0352
135	1	0.0024
180	0.25	0.0074
225	1	0.0024
270	1	0.0352
315	1	0.0169
roof	-0.2	-0.05

Modelling

For this study a combined thermal and airflow simulation was chosen. Three models were used according to the analysis of the existing DSF systems described in Tab 1. 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. The third model is a mechanical ventilated internal air curtain with a cavity depth of 240mm.

Base Case Curtain Wall.

The model room was simulated with a width of 6.6m and a depth of 8m. The facade faced south and a schedule was used to simulate the office use (working hours from 8am to 8pm). The model consisted of a single glazed curtain wall (CW) system. The window to wall ratio was 44%. In order to see the influence of different glazing a study was conducted. The first CW case had clear glass with an internal shading device (CW1). The second CW case had reflective glass without shading (CW2). The third CW case had solar control glass without shading (CW3). The physical properties of the glass is summarized in Table 3.

Tab.3
List of glass used in base case simulation

Description	clear	reflective	solar control
U-Value	5.46	5.73	5.73
g-value	0.774	0.527	0.482
T-sol	0.72	0.463	0.322
Rf-sol	0.07	0.304	0.103
T-vis	0.87	0.322	0.403

External Air Curtain.

The design proposal includes a DSF with 600mm cavity with one-storey DSF. Both glass layers were selected as single clear glass (6mm). The DSF is open to the outside at both the top and the bottom, allowing a naturally ventilated cavity. A venetian blind is positioned in the cavity and solar controlled (DSF1). A regulator indicates the times of the year when the enthalpy of the air in the window gap exceeds the enthalpy of the outside air (DSF2). The regulator will then exhaust the air which is expected to result in energy savings.

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 (Figure 6). Both glass layers were selected as single clear glass (6mm). The mullion's depth of around 240mm is needed for structural purposes and leaves space to allow the venetian blind to function as a 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, allowing used air from the room to be forced through the gap and back to the air handling unit. The purpose of this design is to improve the thermal microclimate in the space next to the window.

RESULTS

A simulation study was conducted in order to calculate the reduction in cooling energy for different DSF systems. The Hong Kong climate offers short warm winters which together with a high internal heat gain make heating redundant.
Figure 7 illustrates the simulation results of cooling energy savings. The results show significant cooling savings of up to 17% (DSF2) for the external air curtain system compared to the curtain wall system. It also becomes obvious that the peak cooling load is reduced by 25% for the three hottest months.
The different airflow around the building did not affect the results significantly.

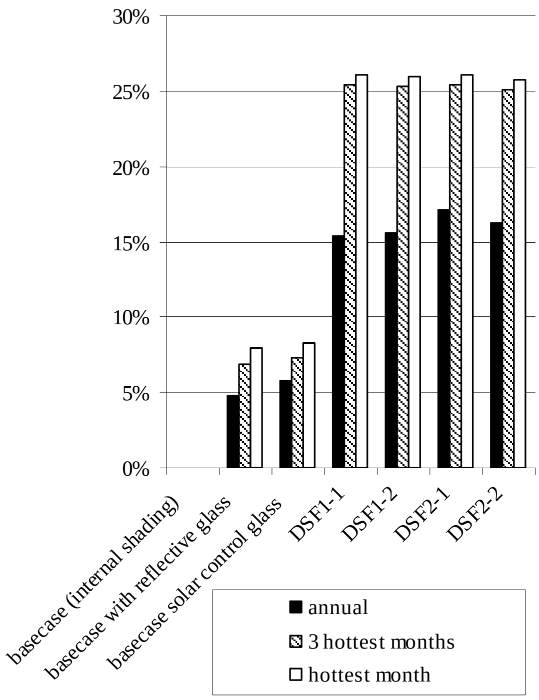


Fig. 7.: Results of DSF study

CONCLUSIONS AND FURTHER STUDIES

It is possible to design an energy efficient DSF system. The amount of energy resulting in cooling loads through the building envelope can be reduced by designing a ventilated airflow window that is optimised in respect to heat transfer. The heat transfer through the building envelope can be divided into radiation, conduction and convection. While a reduction of radiation is met by using solar shading devices, there are constraints from maximizing the use of daylight.
The airflow through the DSF depends on the cp-values of the facade. Ongoing research estimated the cp-values for different building shapes and heights. This did not influence the performance of the model with DSF.

Further reductions of cooling load can be achieved by using energy efficient office equipment (Burnett and Deng 1994). It is hoped to cover the remaining cooling load with solar cooling units. Ultimately, we should be aiming for a zero energy office building (Haase and Amato 2005b).

Further studies will focus on thermal comfort and visual comfort. Initial studies have already demonstrated that the internal air curtain system provides better thermal comfort than the curtain wall system.

A solar chimney will be applied to the airflow window to allow air to be extracted in an energy efficient and natural manner (Chen et al. 2003). It can be used to ventilate the airflow window and will also help to reduce the impacts of wind on building envelope openings (Haase et al. 2004a; Haase et al. 2004b; Lieb 1997; Pang et al. 2004).

With this optimised system the overall environmental impact of an office building in a hot and humid climate can be significantly reduced. We intend to demonstrate in the near future that although the use of an additional glass layer results in additional material consumption, it also produces significant energy consumption savings and associated reduced environmental impacts (Amato et al. 2004). This is a trade-off which we think is well worthwhile.

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