Ventilated façade design in hot and humid climate

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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 [1]. Looking at examples in European countries a strong emphasis on energy efficiency can be noticed.

1.1 Energy and Buildings

52% of the total energy in Hong Kong is used by buildings. Office and commercial buildings are using 37% total energy [2]. Several paths for reducing energy consumption have been identified. One possibility is the use of energy efficient technology in the built environment [3-7]. Thus it is important to develop buildings that consume less operational energy during its life cycle.

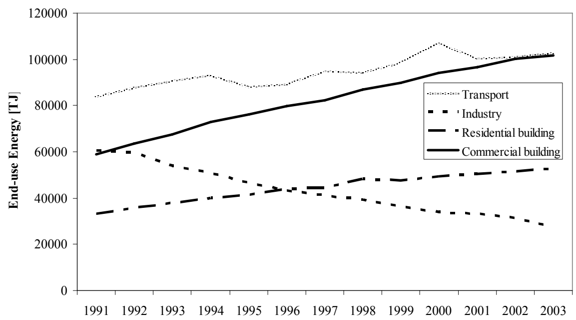

Fig. 1.: Energy consumption in Hong Kong

1.2 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 [8-10]. Especially for the top-end market sector of office buildings advanced façade technologies were developed [11]. 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 [12,13]. This is particularly interesting since the building types and the climate are very different in Hong Kong [14-16] with an urban environment that is dense and high-rise with usually 40 floors and above [17]. This paper tries to find a DSF solution for this particular environment and uses a climate responsive approach.

1.3 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 DSF design has to take the climatic factors into account to reduce the energy consumption in office buildings in a hot and humid climate.

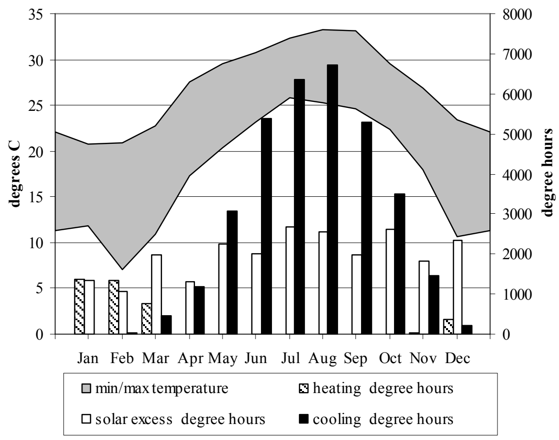

Fig. 2.: Hong Kong climate

2. DOUBLE-SKIN FAÇADE TECHNOLOGY

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 [18-23]. 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 [24]. 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 [25-27].

2.2 Classification of DSFs
Many types of DSFs have been developed since the first double layer was used in the building envelope [28]. It is helpful to agree on a consolidated classification of DSFs [29]. Figure 4 gives an overview of the main characteristics often used when describing the various features of DSFs.

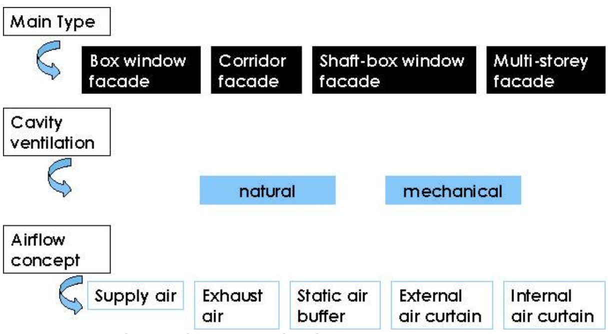

Fig. 3.: Classification of DSFs

2.3 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 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 [30].

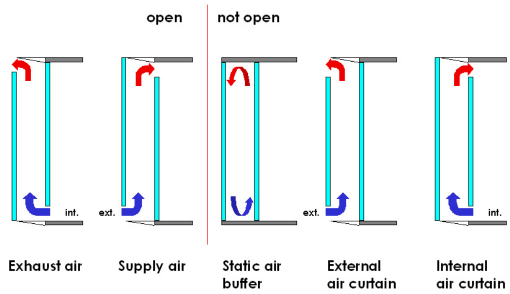

Fig. 4.: Airflow concepts of DSFs

2.4 Advantages of DSFs
The development of DSF technology involves several advantages by improving the thermal, visual and acoustic comfort [31]. 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 [32,33]. 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 [34-42].
Then, it creates a space for advanced sunshading devices. Positioned into the cavity of the DSF it seems to reduce heat gain [43]. In addition, natural daylight filtered into a building for lighting appears to reduce the heat load for artificial lighting on air conditioning [44,45]. Thus, it is important to enhance the use of natural daylighting in office buildings [46-48]. This provides not only energy saving potential but also acknowledges the growing awareness for natural daylight and its effects on a healthy environment [49].
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 [50].
Finally, DSFs provide an additional layer that helps to reduce the acoustic impact into the building [31].

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 [25,40,42]. 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).

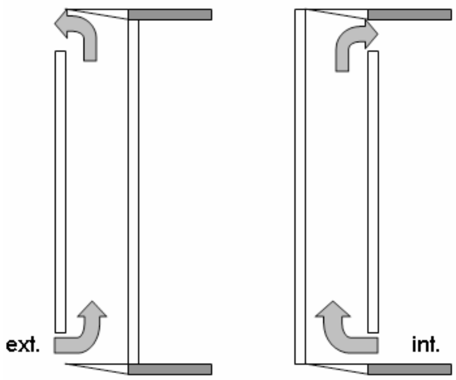

Fig. 5.: Simple DSFs with EAC and IAC

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, see Fig 6 for details.
A simple DSF can be described as naturally ventilated external (EAC) as shown in Fig 5. This DSF does not require a control strategy. The other possibility which is used in HK is a mechanically ventilated internal air curtains (IAC). A survey of office buildings with DSF in HK has been undertaken. Results will be published soon. Figure 7 shows an application of an EAC in HK and Figure 8 gives an example of application of an IAC in HK.
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.

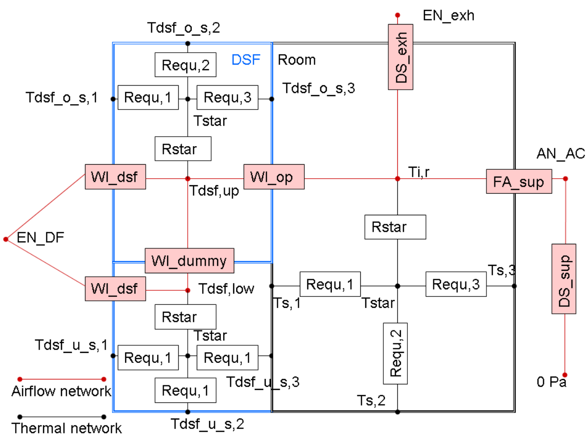

Fig. 6.: Thermal and airflow simulation DSF

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.

3.1 Base Case Curtain Wall

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%.

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. 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 (WI_op).

Fig. 7.: Example of a DSF with EAC in HK

3.3 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. 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

Fig. 8.: Example of a DSF with IAC in HK

which is expected to result in reduction of cooling load.

Table 1: Glass properties

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

3.4 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). 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 [40].

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% [51].

Table 2: List of control strategies

Description	Airflow control	Solar control
BC	no	yes
DSF1	no	yes
DSF2	yes	yes
AFW1	no	yes
AFW2	yes	yes

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 Fig 9 give the cooling energy reduction annually, for the four hottest months and for the hottest month, indicating peak load reduction of the MVAC system.

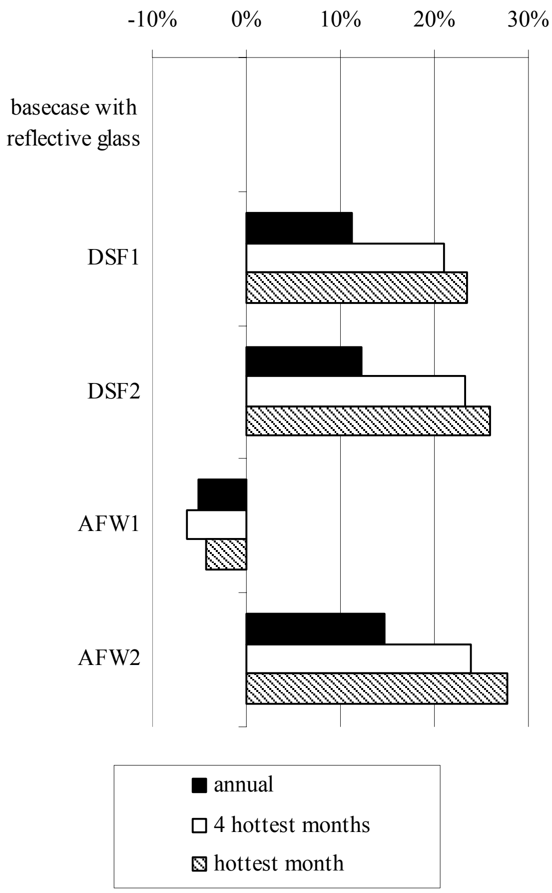

Fig. 9.: Cooling energy reduction for different DSF

It can be seen from Fig 9 that the DSF saves 11% annually, while a peak reduction of 23%. The enthalpy control strategy results in a further peak reduction to 26% and the annual savings are 12%. The airflow window (AFW) without control strategy increases the annual cooling load by 5%. This is due to clear glass as outside layer compared to reflective glass layer in the base case (see Tab 1 for details). The heat gain in the cavity is in the building and adds to the cooling load. With enthalpy control strategy the annual cooling load reduction is 15%. The cooling reduction for the hottest month is 28% and 24% for the hottest four months. Here, the control was only used during the summer season (four hottest months).

5. CONCLUSION

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 heat transfer.
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 as well as peak cooling loads of an office room. The results can be slightly better for the EAC with a climatic control during summer season.
The IAC does not reduce the cooling load of the office room. The system depends on an enthalpy based control that extracts air in order reduce the cooling load of an office room. This system is giving the best results.
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.
The airflow through the double-skin façade depends on the cp-values of the façade. In this study pressure coefficients for two-storey houses were used. Ongoing research estimated the cp-values for different building shapes and heights. This will allow testing the robustness of the system for high-rise application.

REFERENCES

[1] S. Behling, Sol power : the evolution of solar architecture (Prestel,, Munich :, c1996.) 240 p. :.
[2] emsd, Hong Kong Energy End-use data (1991-2001), in: (EMSD, Hong Kong, 2003).
[3] N. Baker, Daylight design of buildings (James & James,, London :, c2002.) x, 250 p. :.
[4] CEC, COMMUNICATION FROM THE COMMISSION ON IMPACT ASSESSMENT, in: (2002).
[5] J.R. Goulding, J.O. Lewis, T.C. Steemers, Energy conscious design: a primer for architects (Commission of the European Communities,, London :, 1992) 135 p. :.
[6] A.E. Krishan, Climate responsive architecture : a design handbook for energy efficient buildings (Tata McGraw-Hill,, New Delhi :, c2001.) xxiii, 409 p. :.
[7] E.S. Lee, D.L. DiBartolomeo, S. Selkowitz, Thermal and Daylighting performance of an automated venetian blind and lighting system in a full-scale private office, Energy and Buildings 29 (1998) 47-63.
[8] B. Givoni, Comfort, Climate Analysis and Building Design Guidelines, Energy and Buildings 18 (1992) 11-23.
[9] S.V.S.V. Szokolay, Environmental science handbook for architects and builders (Construction Press,, Lancaster :, 1980.) [vi], 532 p. :.
[10] M. Wigginton, Glass in architecture (Phaidon Press,, London :, 1996.) 320 p. :.
[11] M. Wigginton, Intelligent skins (Butterworth-Heinemann,, Oxford :, 2002.) ix, 176 p. :.
[12] M. Haase, A. Amato, Double-skin facades in Hong Kong, in: 5th International Postgraduate Research Conference (University of Salford, Salford, U.K., 2005).
[13] W. Ding, Y. Hasemi, T. Yamada, Natural ventilation performance of a double-skin facade with a solar chimney, Energy and Buildings 37 (2005) 411-418.
[14] J.C. Lam, Building envelope loads and commercial sector electricity use in Hong Kong, Energy 20 (1995) 189-194.
[15] J.C. Lam, Climatic influences on the energy performance of air-conditioned buildings, Energy Conversion and Management 40 (1999) 39-49.
[16] D.H.W. Li, J.C. Lam, An analysis of climatic parameters and sky condition classification, Building and Environment 36 (2000) 435-445.
[17] J. Close, Optimising daylighting in high-rise commercial developments in SE Asia and the use of computer programmes as a design tool, Renewable Energy 8 (1996) 206-209.
[18] Q. Chen, J. Van Der Kooi, A methodology for indoor airflow computations and energy analysis for a displacement ventilation system, Energy and Buildings 14 (1990) 259-271.
[19] F. Garde-Bentaleb, F. Miranville, H. Boyer, P. Depecker, Bringing scientific knowledge from research to the professional fields: the case of the thermal and airflow design of buildings in tropical climates, Energy and Buildings 34 (2002) 511-521.

[20] E. Prianto, P. Depecker, Characteristic of airflow as the effect of balcony, opening design and internal division on indoor velocity - A case study of traditional dwelling in urban living quarter in tropical humid region, Energy and Buildings 34 (2002) 401-409.
[21] C. Qingyan, X. Weiran, A zero-equation turbulence model for indoor airflow simulation, Energy and Buildings 28 (1998) 137-144.
[22] W. Xu, Q. Chen, A two-layer turbulence model for simulating indoor airflow: Part II. Applications, Energy and Buildings 33 (2001) 627-639.
[23] W. Zhang, Q. Chen, Large eddy simulation of indoor airflow with a filtered dynamic subgrid scale model, International Journal of Heat and Mass Transfer 43 (2000) 3219-3231.
[24] J. Hensen, Bartak, M., Drkal, F., Modeling and simulation of a double-skin facade system / Discussion, ASHRAE Transactions 108 (2002) 1251.
[25] H. Manz, Numerical simulation of heat transfer by natural convection in cavities of facade elements, Energy and Buildings 35 (2003) 305-311.
[26] S. Reichrath, T.W. Davies, Using CFD to model the internal climate of greenhouses: past, present and future, Agronomie 22 (2002) 3-19.
[27] Z. Zhai, Q. Chen, P. Haves, J.H. Klems, On approaches to couple energy simulation and computational fluid dynamics programs, Building and Environment 37 (2002) 857-864.
[28] M. Wigginton, in. http://www.battlemccarthy.demon.co.uk/research/doubleskin/mainpage.htm
[29] S. Parkin, A description of a ventilated double-skin façade classification, in: International Conference on Building Envelope Systems & Technology (ICBEST2004 Pty Ltd, Sydney, Australia, 2004).
[30] P. Heiselberg, K. Svidt, P.V. Nielsen, Characteristics of airflow from open windows, Building and Environment 36 (2001) 859-869.
[31] E. Oesterle, R.-D. Lieb, G. Lutz, B. Heusler, Double-skin facades : integrated planning : building physics, construction, aerophysics, air-conditioning, economic viability (Prestel,, Munich :, 2001) 207 p. :.
[32] C.-S. Park, Occupant-Responsive optimal control of smart facade systems, PhD thesis, Department of Architecture, Georgia Institute of Technology, 2003.
[33] C. Balocco, A simple model to study ventilated facades energy performance, Energy and Buildings 34 (2002) 469-475.
[34] C. Allocca, Q.Y. Chen, L.R. Glicksman, Design analysis of single-sided natural ventilation, Energy and Buildings 35 (2003) 785-795.
[35] K.T. Andersen, Theory for natural ventilation by thermal buoyancy in one zone with uniform temperature, Building and Environment 38 (2003) 1281-1289.
[36] E. Gratia, A. De Herde, Natural ventilation in a double-skin facade, Energy and Buildings 36 (2004) 137-146.
[37] E. Gratia, A. De Herde, Optimal operation of a south double-skin facade, Energy and Buildings 36 (2004) 41-60.
[38] E. Gratia, A. De Herde, Is day natural ventilation still possible in office buildings with a double-skin facade?, Building and Environment 39 (2004) 399-409.
[39] E. Gratia, A. De Herde, Natural cooling strategies efficiency in an office building with a double-skin facade, Energy and Buildings 36 (2004) 1139-1152.
[40] D. Saelens, J. Carmeliet, H. Hens, Energy performance assessment of multiple skin facades, International Journal of HVAC&Research 9 (2003) 167-186.
[41] W. Stec, van Paassen, A. H. C., Controlled double facades and HVAC, in: 7th Clima 2000 World Congress (Napoli (I), 2001).
[42] W.J. Stec, A.H.C.v. Paassen, Symbiosis of the double skin facade with the HVAC system, Energy and Buildings In Press, Corrected Proof (2004).
[43] J. von Grabe, A prediction tool for the temperature field of double facades, Energy and Buildings 34 (2002) 891-899.
[44] V. Garcia-Hansen, A. Esteves, A. Pattini, Passive solar systems for heating, daylighting and ventilation for rooms without an equator-facing facade, Renewable Energy 26 (2002) 91-111.
[45] F.-W.a.L. Grimme, M., Energy Efficiency in Tropical Office Buildings. Latest Developments in Daylight Guidance Systems. Modern Glazings - Efficient for Cooling and Daylighting. Development of Energy Efficiency Policy for Buildings and Research Activities after 1970 in the field of Low Energy, in: Conferencia Internacional de Energía Renovable y Educación Energética (Havanna, Kuba, 1999).
[46] M. Bodart, A. De Herde, Global energy savings in offices buildings by the use of daylighting, Energy and Buildings 34 (2002) 421-429.
[47] J.C. Lam, D.H.W. Li, Daylighting and energy analysis for air-conditioned office buildings, Energy 23 (1998) 79-89.
[48] J.C. Lam, D.H.W. Li, An analysis of daylighting and solar heat for cooling-dominated office buildings, Solar Energy 65 (1999) 251-262.
[49] D.H.W. Li, J.C. Lam, Evaluation of lighting performance in office buildings with daylighting controls, Energy and Buildings 33 (2001) 793-803.
[50] M. Haase, A. Amato, DEVELOPMENT OF A DOUBLE-SKIN FACADE SYSTEM THAT COMBINES AIRFLOW WINDOWS WITH SOLAR CHIMNEYS, in: Sustainable Building 2005 (Tokyo, Japan, 2005).
[51] M. Haase, A. Amato, Fundamentals for climate responsive envelopes, in: Glass in Buildings 2 (CWCT, Bath, UK, 2005).