Energy efficient glazed office buildings with double skin façades in Europe

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Abstract

Many modern office buildings have highly glazed façades. Their energy efficiency and indoor climate are, however, being questioned. Therefore more and more of these buildings are being built with double skin façades, which can provide improvements: a thermal buffer zone, energy savings, solar preheating of ventilation air, sound protection, safe night cooling, and a suitable site for incorporation of PV cells etc.

A project BESTFACADE, with participants from Austria, Germany, Greece, Portugal, France and Sweden, was therefore funded by the European Commission (IEE) to actively promote well-performing concepts of double skin facades. Included were best practice guidelines, which included the determination of the energy use and thermal comfort by simulations for warm, mild and cold climates.

The main conclusion is that the choice of glazing properties such as glazing area, U-value (thermal transmittance) of the glazing and its profiles, g-value (the total solar energy transmittance) of the glazing and type of solar shading are crucial for the energy and indoor climate performance of an office. The choice of control strategies for ventilation of the cavity and operation of solar shading are crucial. The above choices are very dependant on the climate. Choices which are optimal in a cold climate, will not work very well in a warm climate, and vice versa. From an energy and indoor climate point of view a highly glazed office with a double skin façade is often preferred to a single skin façade.

Introduction

The potential for energy savings and improvements in indoor climate is often high for modern office buildings. Many modern office buildings may have a lower energy use for heating, but have on the other hand often a higher use of electricity than older office buildings, which is due to a higher energy use for ventilation, cooling, lighting and office equipment. Especially during the nineties office buildings with glazed façades have been built in many countries in Europe. The increased use of glazed façades has been enabled thanks to the development of façade construction technology and to the improved physical properties of glass, especially during the last decade.

Office buildings with glazed façades are likely to have a higher use of energy for cooling and heating than an office building with a traditional façade. With improvements in the design of windows/glazing and solar shading this difference can be lowered to an energy use some 15% higher (Poirazis 2005). A traditional glazed façade increases the risk for unsatisfying thermal comfort close to the façade and glare problems further inside the building. Glazed buildings have less tolerance for design and construction errors and therefore require more careful planning (Brunner 2001).

Therefore there has been a growing interest among clients to build and among architects to design glazed double skin façades. Improvements, which can be provided are: energy savings, wind protection with open windows, fire protection, aesthetics, solar preheating of ventilation air, sound protection, night cooling and a site for the incorporation of PV cells.

Commercial buildings with integrated double skin façades can be very energy efficient buildings with all the good qualities listed above. However, far from all double skin façades built in recent years perform well. In many cases the energy consumption badly exceeds the intended heating energy performance.

Therefore the European Commission partially (50%) financed a project, BESTFACADE, to promote the concept of well-performing double skin façades. One of the outputs is a best practice guideline for double skin façades (Blomsterberg 2007). The guidelines include predicted performance. Due to the difficulties of determining the influence of a double skin façade on the energy and indoor climate performance from energy monitoring and lack of monitored data for real buildings this performance was predicted for a typical cell office.

Double skin façades

A ventilated double skin façade can be defined as a traditional single façade doubled inside or outside by a second, essentially glazed façade. Each of these two façades is commonly called a skin (hence the widely-used name "ventilated double-skin façade"). A ventilated cavity – having a width which can range from 10 centimetres at the narrowest to 2 meters for the widest accessible cavities – is located between these two skins. The cavity can be ventilated with natural, mechanical or hybrid ventilation. The double skin façade can be classified as follows:

- Ventilated double window
- Façade partitioned per storey with juxtaposed modules
- Façade partitioned per storey – corridor type
- Shaft-box façade
- Multi-storey façade
- Multi-storey louver façade

The choice of the glass types for the interior and exterior panes depends on the typology of the façade. In case of a façade ventilated with outdoor air, an insulating pane (thermal break) is usually placed at the interior side and a single pane at the exterior side. In case of a façade ventilated with indoor air, the insulating pane is usually placed at the exterior side, the single pane at the interior side.

The shading device is placed inside the cavity for protective and maintenance reasons. Often a venetian blind is used. The characteristics and position of the blind influence the physical behaviour of the cavity, as the blind absorbs and reflects radiant energy. Thus, the selection of the shading device should be made considering the proper combination of pane type, cavity geometry and ventilation strategy.

Method

The aim was to determine the energy use and thermal comfort for a typical single cell office with a double skin façade for warm, mild and cold climates respectively. For a fully glazed double skin façade the optimal types of glazing and shading are chosen, which will for different climates result in an energy efficient building with good thermal comfort. As a reference, a single skin façade was used, thereby enabling a study of a retrofit situation. The building energy simulation tool Parasol-DSF was used (Parasol).

DESCRIPTION OF THE CELL OFFICE

The simulated cell office has the following dimensions: room height 3.5 m, room width 2.4 m, room depth 4.2 m, floor area 10 m², windows: 1.3 m x 1.0 m or 3.5 m x 2.4 m facing south.

Single skin façade: the U-value (excluding windows) is 0.32 W/m²K and the construction is light.

Double skin façade: The double skin façade is naturally ventilated with an opening area of half the depth of the cavity (800 mm deep) at the top and the bottom. The outdoor air enters at the bottom and leaves at the top. The windows facing the cavity are always closed. The U-value of the façade (excluding windows) is 0.32 W/m²K and the construction is light.

The windows have glazing with different U- and g-values (total solar energy transmittance). These were chosen from commercially available products commonly used in office buildings (see tables 1-3). The glazing was also chosen to allow for a reasonable amount of daylight. The light transmittance is for all windows higher than 0.55. The U-value of the profiles was assumed to be 1.6 W/m²K.

Internal walls, floors and ceiling are adiabatic.

The solar shading consists of Venetian blinds and for some alternatives in combination with solar control glazing. The Venetian blinds are controlled according to solar radiation at the façade i.e. the blinds are down if the solar radiation is higher than 15 kLux (150 W/m²). The slat angle of the Venetian blinds are for Stockholm 30 degrees, for Paris 20 degrees and for Lisbon 10 degrees. The Venetian blinds placed in the outer cavity for triple-glazed windows, on the inside for double-glazed windows and for the double skin façade alternatives they are located in the 800 mm deep cavity.

The ventilation system is balanced with heat recovery, 10 l/s. The heating is district heating and cooling. The infiltration is assumed to be 0.1 air changes per hour. The supply air temperature is 18°C. The efficiency of the air-to-air heat recovery is 60%. The operating time of the ventilation is weekdays 5:00-18:00. The set points for the indoor air temperature are: for heating 21°C and cooling 26°C. Three different climates were used in the simulations, warm (Lisbon in Portugal), mild (Paris in France), cold (Stockholm in Sweden).

The internal gains in the cell office are:

- One person i.e. an average value of 96 W between 8:00-17:00, lunch break 12:00-13:00
- Lights, installed power 10 W/m², with an average use of 7.5 W/m² i.e. 75 W between 8:00-17:00.
- PC, 125 W, with an average use of 111 W between 8:00-17:00

The total internal gains for the cell office during office hours equal 28.3 W/m².

Results

The energy use for heating and cooling of an office buildings is of course different for the three cities (see figure 1-3). For Lisbon, with the warm climate, the cooling demand is dominating and there is hardly any need for heating. For Stockholm, with the cold climate, the heating need is for some cases higher than the cooling need, although the internal gains are fairly high. For each city the glazing case resulting in the lowest energy use i.e. the sum of

Table 1. Glazing combinations for the single skin façade. Optitherm is a pane with low emissivity coating.

Case	External pane	Gap	Intermediate pane	Gap	Internal pane	U-value glazing W/m²K	g-value glazing	g-value system
G1A	Clear pane 4mm	Air 35 mm	Clear pane 4mm	Air 12mm	Clear pane 4mm	1.83	0.50	0.28
G1B	Floatglas 6mm	Argon 15 mm			Optitherm S3 4mm	1.18	0.48	0.36
G1C	Floatglas 6mm	Air 15 mm			Optitherm S3 4mm	1.49	0.45	0.38

Table 2. Glazing combinations for single skin façade retrofitted to a double skin façade.

Case	External pane	Gap 800mm	Inter-mediate pane	Gap	Internal pane	Gap	Inter-nal pan	U-value glazing closed gap W/m²K	g-value glazing, opened gap	g-value sys-em, open-ed gap
G2A	Clear pane 8mm	Ventilated cavity	Clear pane 4mm	Air 35 mm	Clear pane 4mm	Air 12mm	Clear pane 4mm	1.32	0.41	0.15
G2B	Clear pane 8mm	Ventilated cavity	Floatglas 6mm	Argon 15 mm	Optitherm S3 4mm			0.91	0.36	0.10
G2C	Clear pane 8mm	Ventilated cavity	Floatglas 6mm	Air 15 mm	Optitherm S3 4mm			1.10	0.34	0.14

Table 3. Glazing combinations for the double skin façade.

Case	External pane	Gap (800mm)	Intermediate pane	Gap (12mm)	Internal pane	U-value glazing, closed gap W/m²K	g-value glazing, opened gap	g-value system, opened gap
G3A	Clear pane 8mm	Ventilated cavity	Clear pane 4mm	Air	Clear pane 4mm	1.83	0.48	
G3B	Clear pane 8mm	Ventilated cavity	Clear pane 4mm	Argon	Low E Coated 4mm	1.07	0.46	
G3C	Clear pane 8mm	Ventilated cavity	Optigreen (solar control tinted) 6mm	Argon	Clear pane 4mm	1.75		
G3D	Optigreen (solar control tinted) 8mm	Ventilated cavity	Clear pane 4mm	Argon	Clear pane 4mm	1.75	0.24	0.10
G3E	Optigreen (solar control tinted) 8mm	Ventilated cavity	Clear pane 4mm	Argon	Low E Coated 4mm	0.93		
G3F	Clear pane 8mm	Ventilated cavity	Solar control + lowE (soft coated) 6mm	Argon	Clear pane 4mm	1.12	0.25	0.10
G3G	Solar control +lowE (hard coated) 8mm	Ventilated cavity	Clear pane 4mm	Argon	Low E Coated 4mm	0.93	0.31	

energy use for cooling and heating was chosen for each type of façade. For the double skin façade alternative the choice between open and closed cavity during the intermediate seasons (spring and autumn) was based on the lowest total energy use.

For the three cities the case with the lowest total energy use is the case with a single skin façade and a modest window area. The total energy use is below 40 kWh/m²year for all three cities, with the lowest energy use in Paris. For Stockholm and Paris the best choice for glazing is the alternative with the lowest U-value, but not the lowest g-value including Venetian blinds. For the warm climate it is more important to choose an alternative with a low g-value including Venetian blinds, to reduce the solar gains and thereby the cooling demand. The heating demand here is low and a normal level of internal gains is sufficient for most of the heating during winter.

A fully glazed single skin façade results in a drastically increased total energy use. The highest energy use is in the cold and the warm climate. For all three climates the best choice is

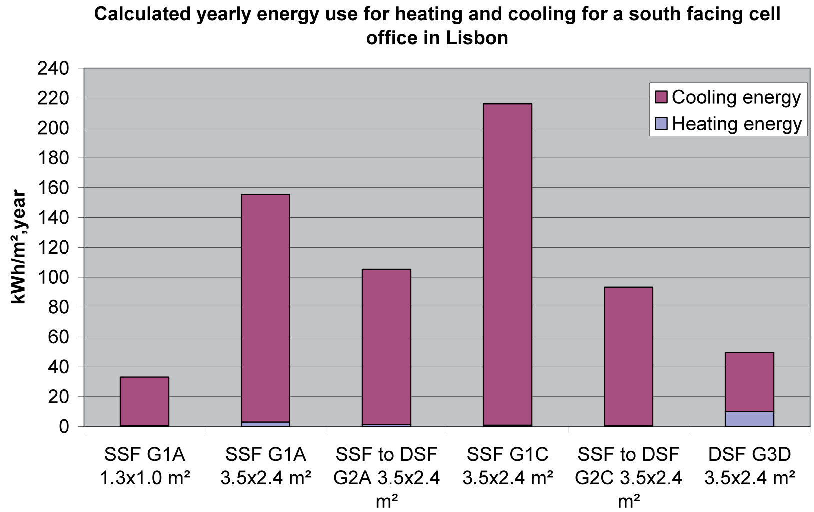

Figure 1. Calculated yearly energy use for heating and cooling for a cell office in Lisbon. The glazing types can be found in table 1 for SSF, table 2 for SSF to DSF and table 3 for DSF. SSF = single skin façade and DSF = double skin façade. SSF to DSF means retrofit of a single skin façade to a double skin façade.

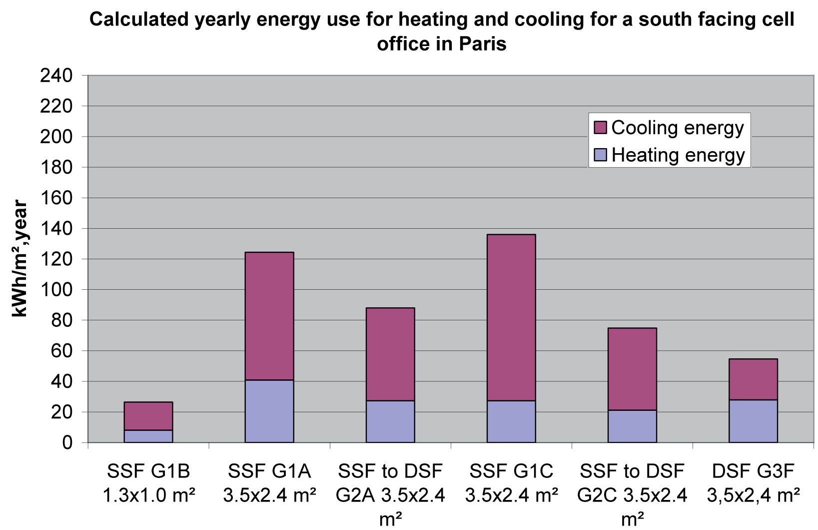

Figure 2. Calculated yearly energy use for heating and cooling for a cell office in Paris. The glazing types can be found in table 1 for SSF, table 2 for SSF to DSF and table 3 for DSF. SSF = single skin façade and DSF = double skin façade. SSF to DSF means retrofit of a single skin façade to a double skin façade.

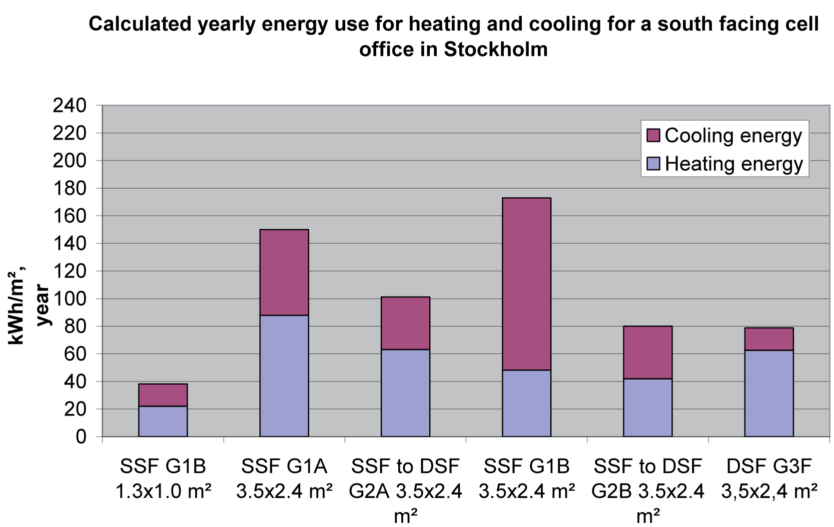

Figure 3. Calculated yearly energy use for heating and cooling for a cell office in Stockholm. The glazing types can be found in table 1 for SSF, table 2 for SSF to DSF and table 3 for DSF. SSF = single skin façade and DSF = double skin façade. SSF to DSF means retrofit of a single skin façade to a double skin façade.

Table 4. Calculated g_{system} x $Area_{glazing}$ for a south facing cell office in Lisbon, Paris and Stockholm.

gxA	Lisbon	Paris	Stockholm
SSF G1A 1.3x1.0 m²	0,3		
SSF G1B 1.3x1.0 m²		0,4	0,4
SSF G1A 3.5x2.4 m²	1,8	1,8	1,8
SSF G1B 3.5x2.4 m²			2,7
SSF G1C 3.5x2.4 m²		2,7	
SSF to DSF G2A 3.5x2.4 m²	1,2	1,1	0,9
SSF to DSF G2B 3.5x2.4 m²			0,7
SSF to DSF G2C 3.5x2.4 m²	1,1	1,0	
DSF G3D 3.5x2.4 m²	0,8		
DSF G3F 3,5x2,4 m²		0,8	0,6

Table 5. Calculated $U_{façade}$ x $Area_{façade}$, W/K, for a south facing cell office in Lisbon, Paris and Stockholm.

UA(facade)	Lisbon	Paris	Stockholm
SSF G1A 1.3x1.0 m²	4,6		
SSF G1B 1.3x1.0 m²		3,9	3,9
SSF G1A 3.5x2.4 m²	14,2	14,2	14,2
SSF G1B 3.5x2.4 m²			9,6
SSF G1C 3.5x2.4 m²		11,8	
SSF to DSF G2A 3.5x2.4 m²	10,6	10,6	10,6
SSF to DSF G2B 3.5x2.4 m²			7,7
SSF to DSF G2C 3.5x2.4 m²	9,0	9,0	
DSF G3D 3.5x2.4 m²	13,6		
DSF G3F 3,5x2,4 m²		9,2	9,2

an alternative with a modest U-value and a low g-value including Venetian blinds. However, if a second skin is added to the single skin fully glazed façade i.e. conversion to a double skin façade, the total energy use is reduced a considerable amount. This is due to the fact that both the U- and g-value are reduced. If the starting point is not the best alternative for a single skin fully glazed façade, then retrofit to a double skin façade results in the lowest total energy use. The reason for this is that the final U- and g-values are the lowest for these cases.

The double skin alternative with the lowest total energy use is a double skin façade which is designed properly from the beginning. The total energy use is lowest for the office in Lisbon, where solar control glazing combined with "exterior" Venetian blinds results in a very low g-value, 0.10, but not in a very low U-value. Some architects might not like the alternative, as the exterior glazing is tinted. An alternative would then be to use G3F, which would increase the total energy use about 25%. For the office in Stockholm it is mostly heating and not very much cooling needed, thanks to the low g-value, when the Venetian blinds are included.

For the studied alternatives the product of g-value including Venetian blinds and glazing areas was calculated (see table 4). The ratio for the different alternatives is similar to the ratios between the different uses of energy for cooling. The best double skin façade alternative allows higher solar gains than the best single skin façade alternative with a modest glazing area. There is of course a difference in daylight access.

For the studied alternatives the sum of the products of U-values and façade areas was calculated i.e. the transmission heat losses through the façade (see table 5).

Especially for the office in Stockholm, with the cold climate, it can be seen that the ratios between U x A values is similar to the ratios between energy use for heating. For Stockholm it is obvious that for a façade with a modest window area, the U-value should be low and the g-value including Venetian blinds should be reasonably low. The other studied alternatives for a modest window area showed a slightly higher total energy use. For the fully glazed alternative with a single skin façade and double skin façade, it is important with a low g-value. The situation is similar for Paris. The difference in energy use between the different glazing alternatives is higher for Paris, the difference between the best and worst alternative was a factor 2.

For Lisbon a low g-value is needed, but not too low a U-value. The reason is that the climate is warm. The difference in energy use between the different glazing alternatives is high, the difference between the best and worst alternative was a factor of 2.5.

The indoor climate was compared by analysing high and low operative temperatures. The set point for heating was an air temperature of 21°C and for cooling 26°C. The total of number hours in a year with an operative temperature above 26°C and below 20°C was calculated. The office in Lisbon has the highest number of hours with high operative temperatures, but no hours with low operative temperatures. The only location with low operative temperatures is Stockholm. However for all three locations the two best alternatives are the single skin with a modest window area and the double skin highly glazed façade, where the single skin is somewhat better in comparison. For both alternatives glazing and solar shading have been chosen carefully.

If indoor climate had been used as criterion for choosing the best alternatives, then in most cases the same alternatives would have been chosen as the ones with the lowest total energy use.

Conclusions

The main conclusion is that the choice of glazing properties such as glazing area, U-value (thermal transmittance) of the glazing and profiles, g-value (the total solar energy transmittance) of the glazing and type of solar shading is crucial for both the energy and indoor climate performance of an office building. In particular for a double skin façade, the choices of control strategy for ventilation of the cavity and operation of solar shading are crucial. The above choices are very dependent on the climate. Choices which are optimal in a location with cold climate, such as Stockholm, will not work very well in a location with a warm climate, such as Lisbon, and the contrary. The energy use and thermal comfort for different façade alternatives have to be calculated and compared using validated tools. Different façade alternatives may have to be chosen for different orientations. The most energy efficient office seems to have a façade with modest window areas, which will also result in a good indoor climate. From an energy and indoor climate point of view a highly glazed office with a double skin façade is often preferred to one with a single skin façade. A well designed highly glazed façade with double skin façades can result in almost as low energy use and good thermal comfort as for a traditional single skin façade with a modest window area.

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