DOUBLE SKIN FACADES – FASHION OR A STEP TOWARDS SUSTAINABLE BUILDINGS

Ole J. Hendriksen and Henrik Sørensen
Esbensen Consulting Engineers A/S, Vesterbrogade 124 B, DK-1620 København V, Denmark,
Tel.: +45 33 26 73 00, Fax.: +45 33 26 73 01, e-mail: o.j.hendriksen@esbensen.dk

Anders Svensson and Pontus Aaqvist
White Architects AB, Skeppsbron 7, S-211 20 Malmö, Sweden,
Tel.: +46 40 660 93 00, Fax.: +46 40 611 44 79, e-mail: anders.svensson@white.se

Abstract – In recent years double skin facades has found increased use both as part of renovation of buildings or as part of new buildings to improve transparency. Double skin facades lead to improvement of daylight levels and view to the outside, but glare problems can be increased. It is possible to reduce heat loss and external noise, when taking the extra layer of glazing into account, compared to a traditional glazed facade. Protection of external solar shading devices against wind, and degradation seems to be a very important issue. Furthermore, ventilation and fire safety measures need careful consideration at the design process.

1. INTRODUCTION

In recent years double skin facades have found increased use both as part of renovation of buildings or as part of new buildings to improve transparency. This paper deals with the question: Are double skin facades an architectural trend or a step towards sustainable buildings?

One of the objectives of double skin facades is to reach a satisfying indoor climate with a reasonable energy consumption for the building. In order to reach that objective several indoor climate and energy aspects must be taken into account, when double skin facades are designed. Furthermore, fire safety conditions play an important role in the design of these facades.

Double skin facades are very sensitive to outdoor climate due to large glazed surfaces compared to a traditional window facade, this calls for a detailed analysis of transparency, solar gain, glare, daylight, view to the outside, ventilation and control strategy, heat loss, noise and weather protection.

The paper is based on a Swedish research project on double skin facades, which was carried out as case study of existing double skin facades of non-domestic buildings. The focus is on architectural aspects as well as indoor climate and energy issues presented in an overall way. The case study deals with North European office buildings.

2. DEFINITIONS AND TYPOLGY

A double skin facade could be defined as glazing layers divided by a cavity. One of the main characteristics of a double skin facade is the combination and position of the glazing layers, which could lead to the typology shown in table 1.

<table>
<thead>
<tr>
<th>DSF Type</th>
<th>Type</th>
<th>Sub-type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Inside</td>
<td>1</td>
<td>1.1 Opening(s) in outer layer</td>
</tr>
<tr>
<td>Outside Inside</td>
<td>1</td>
<td>1.2 Opening(s) in inner layer</td>
</tr>
<tr>
<td>Outside Inside</td>
<td>1</td>
<td>1.3 Opening(s) in both layers</td>
</tr>
<tr>
<td>Outside Inside</td>
<td>2</td>
<td>2.1 Opening(s) in outer layer</td>
</tr>
<tr>
<td>Outside Inside</td>
<td>2</td>
<td>2.2 Opening(s) in inner layer</td>
</tr>
<tr>
<td>Outside Inside</td>
<td>2</td>
<td>2.3 Opening(s) in both layers</td>
</tr>
</tbody>
</table>

Table 1 Typology for Double Skin Facades (DSF).

3. MAIN FEATURES OF DOUBLE SKIN FACADES

Glazed facades have large impact on the impression of a building, it affects indoor climate and energy aspects of the adjacent buildings and has some aspects, which more or less interact or depend of each other. These aspects are shown in figure 1.

Besides these aspects of architecture, indoor climate and energy some basic functions of facades should also be fulfilled for double skin facades without depreciation compared to a traditional facade. The basic function of a facade is to serve as a building envelope, keeping out cold and water and letting in air and light. The double skin facade serves as an extra buffer zone and collector of solar energy or as a shaded ventilated cavity protected from rain and strong wind. (Tombazis, 1996).
4. INDOOR CLIMATE AND ENERGY ASPECTS

The increased glazing area in double skin facades compared to traditional window facades intensifies almost all indoor climate conditions as well as it increases the occupants perception of the outdoor climate.

4.1 Daylight, glare, view and transparency

The increased glazing area in double skin facades intensifies almost all daylight conditions as well as it increases the occupants sensitivity to selected daylight conditions.

Daylight conditions for office buildings have been studied in a post-occupancy evaluation by (Christoffersen et al., 1999). This study is carried out for smaller offices in 20 buildings with a total response of 1823 occupants. The facades of the surveyed buildings are traditional window facades with glazing ratios of 18% to 49% (net glazing area/net facade area) and it should be emphasised, that none of the buildings had double skin facades, but nevertheless there are some of the findings of this study, which could be interpreted for double skin facades.

Daylight levels are generally larger in rooms facing a double skin facade compared to rooms facing a traditional window facade. The daylight levels depends on the light effective glazing ratio (the product of light transmittance LT and net glazing ratio R_g). Table 2 shows typical values for a double skin facade and a traditional window facade.

Table 2 shows that although the light transmittance are reduced for double skin facades compared to a traditional window facade the relative light effective areas will be doubled. This will first of all increase the daylight level close to the facade, but will only have limited influence on the daylight levels in depth of a room i.e. beyond approximately 6 meters of depth.

In case of small office rooms it will be a benefit with larger light effective areas, but when it comes to open plan offices the contrast might be too large and it could lead to disability glare. This is also supported in the study by (Christoffersen et al., 1999), where one of the main conclusions is that glare is the most frequent negative aspect of the windows and that the frequency of glare problems increases with increasing glazing areas.

Double skin facades are often equipped with glazing from floor to ceiling and glare is therefore a major issue in the design of double skin facades.

When it comes to view conditions it is obvious that double skin facades offer a better view to the outside compared to a traditional window facade. Another main conclusion of (Christoffersen et al., 1999) is that view to the outside is responded as the most positive aspect of a window and this is in fact what double skin facades offer in the most extreme way. View from the outside will change radically during the day due to variations in sunlight and the belonging reflections. Furthermore, dark and light periods affect the view to the inside, which claims for considerations of the interior of rooms facing to a double skin facade.

Transparency is often seen as the main architectural reason for a double skin facade, because it creates close contact to the surroundings. This in fact is also derived from a clients point of view saying that physical transparency of a company gives a signal of a transparent organisation with a large degree of openness.

4.2 Heat loss

A double skin facade is characterised by one or several extra layers of glazing compared to a traditional glazed facade resulting in decreased heat loss.
An estimate of the reduction in heat loss can be calculated by adding thermal resistance of the extra glazing layer.

In practice some variations of convective and radiative heat transfer occur in double skin facades. Furthermore, two-dimensional effects and heat loss from frames will also occur. These effects are not taken into account in the calculation of the heat loss estimate.

The assumptions of thermal surface resistance for different layer combinations are shown in Table 3. The thermal resistance of the glazing is based on a U-value for single layer of glazing of 5.9 W/m²K and a U-value of double low-E glazing varying from 1.0-1.5 W/m²K. Standard values of thermal surface resistance of 0.04 m²K/W and 0.13 m²K/W have been used for conversion from U-values to thermal resistance of the glazing layers.

<table>
<thead>
<tr>
<th>Layer combination</th>
<th>Thermal surface resistance [m²K/W]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outer layer</td>
</tr>
<tr>
<td>Double glazing</td>
<td>0.04</td>
</tr>
<tr>
<td>DSF 1+2</td>
<td>0.04</td>
</tr>
<tr>
<td>DSF 2+1</td>
<td>0.04</td>
</tr>
<tr>
<td>DSF 2+2</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 3 Thermal surface resistance for different combinations of glazing layers in double skin facades (Hansen et al., 1997).

The estimate on reduction in heat loss expressed by U-value is shown in Figure 2.

It is seen from Figure 2, that the introduction of an extra single layer or an extra double low-E glazing is taken in to account.

4.3 Venting and natural ventilation

In double skin facades venting are a very common feature to remove surplus heat in warm periods. It is possible to reach relative high air flows in the cavity due to natural driving forces, which is reached by large openings in bottom and top of double skin facades and in some cases the air flow can be further increased when openings are designed to use wind driving forces as well. The venting principle is shown in Figure 3.

Venting is often seen in combination with solar shading devices in the cavity, which is ventilated in order to reach a situation nearly similar to outdoor conditions. This is described in more details in section 4.4.

The ability for occupants to open windows is increased, especially for high-rise buildings, due to the protection against strong wind offered by a double skin facade, but there is also a potential risk of having short circuit of odours via the cavity.

In some cases the double skin facade serves as an element in ventilation strategy of the adjacent building, often seen as preheating of inlet air or extract of air. Furthermore, the inlet air can be supplied to the adjacent building with relative low air velocity.

Another feature of double skin facades is passive night cooling, which calls for large opening areas, which could be safe to burglary, when a double skin facade is used.

In the case where the double skin facade is part of a ventilation strategy the degree of complexity is increased.
The double skin facade is not only a part of the building envelope, but also a part of the ventilation system in the adjacent building. This calls for detailed analysis of the varying conditions, which occur in the cavity due to variations in outdoor climate and the interaction with the occupants needs for ventilation. The ventilation principles are shown in figure 4-6.

4.4 Solar shading
One of the important benefits of double skin facades is protection of solar shading devices against rain, wind and degradation. Table 4 lists solar shading factors.

Maintenance issues for protected solar shading devices is often seen as the prior technical reason for a double skin facade.

<table>
<thead>
<tr>
<th>Shading device</th>
<th>Solar Shading Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double low-E glazing, g = 77%</td>
<td>1.0</td>
</tr>
<tr>
<td>Double low-E glazing with solar reflective coating, g = 33%</td>
<td>0.43</td>
</tr>
<tr>
<td>Internal shadings</td>
<td>0.5-0.7</td>
</tr>
<tr>
<td>Integrated shading in double glazing</td>
<td>0.25-0.35</td>
</tr>
<tr>
<td>External shading (curtain types)</td>
<td>0.1-0.25</td>
</tr>
<tr>
<td>Double skin facade with shading in cavity</td>
<td>0.25-0.35</td>
</tr>
<tr>
<td>Double skin facade with shading device in cavity plus venting</td>
<td>0.1-0.2</td>
</tr>
</tbody>
</table>

Table 4 Solar shading factors for different glazing types and shading devices.

4.5 Noise and fire
Another important benefit of double skin facades is the ability to protect against external noise for example from traffic. Table 5 gives an overview of noise conditions.

Increased space between glazing layers will result in increased noise reduction values, especially for low frequent noise, e.g. traffic from heavy vehicles. This is relevant for double skin facades with a certain air gap between the layers because it is often hard to reduce low frequent noise with traditional window facades.

<table>
<thead>
<tr>
<th>Noise reduction levels of different glazing layouts</th>
<th>Standard</th>
<th>Possible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise reduction levels of glazing layouts</td>
<td>R_W dB</td>
<td>R_A dB</td>
</tr>
<tr>
<td>Single layer glazing</td>
<td>29</td>
<td>26</td>
</tr>
<tr>
<td>Double glazing</td>
<td>31</td>
<td>25</td>
</tr>
<tr>
<td>Two coupled layers</td>
<td>37</td>
<td>32</td>
</tr>
<tr>
<td>Single layer plus double glazing</td>
<td>38</td>
<td>33</td>
</tr>
<tr>
<td>Three layer glazing</td>
<td>32</td>
<td>27</td>
</tr>
<tr>
<td>Two coupled layers with increased space (DSF)</td>
<td>38</td>
<td>33</td>
</tr>
<tr>
<td>Single layer plus double glazing with increased space (DSF)</td>
<td>39</td>
<td>35</td>
</tr>
</tbody>
</table>

Table 5 Noise reduction levels for different layouts of glazing. The noise reduction levels are shown as R_W values for noise dominated by middle frequencies and as R_A values for noise dominated by low frequencies. (Pilkington, 1999)
A disadvantage is internal noise distribution between rooms facing a double skin facade. A further disadvantage of external noise is openings which are needed for venting. In order to decrease external noise these openings should be silenced, but still have a very low pressure drop. This is one of the design challenges of double skin facades.

Fire conditions plays an important role in the design of double skin facades. There is a potential risk that double skin facades can increase the spread of a fire. If a fire occurs in a room or compartment facing the double skin facade and smoke is intended or unintended removed via the double skin facade and if the smoke is cooled and reaches a certain temperature it can lead to explosions and extended spread of fire. This issue has been studied in laboratory tests in Germany. This is another challenge in design of double skin facades.

4.6 Design approach and calculation models
To ensure a proper design resulting in a satisfying indoor climate and a reasonable energy consumption, numerous aspects of double skin facades and of the adjacent buildings should be treated in an integrated way. An integrated design approach leads to facade elements and mechanical systems, which work together and excludes sub-optimising.

Integrated design approach has been presented in (Heiselberg and Tjelflaat, 1999) and can be described as an iterative process, where design teams including both architects and engineers are formed at an early stage having a close collaboration from conceptual design ideas to a final detailed design. Furthermore, this leads to a step-wise procedure which is beneficial for a bio-climatic design of a building. The design procedure could be divided in to three main design steps:

- Basic design
- Climatic design
- Design of mechanical system

This design approach is essential for double skin facades considering the complexity of facade elements and mechanical systems.

In the design of double skin facades there are different calculation models available, which are suitable for solving problems at different design stages, i.e. different degrees of complexity. The calculation models are implemented in computer software with different aims, which often results in the need for using different models and using results from one model as boundary conditions in another model. This can also lead to an iterative or step-by-step procedure.

To some extend it is possible to carry out hand calculations or spreadsheet calculations to get a first impression of performance or as an estimate before starting with computer calculations, which could be some of the following models and software:

- Thermal simulation models
  Simulations based on weather data, internal and external loads, thermal mass and building services (tsbi3, FRES, DEROB, TRNSYS, ESPr etc.)
- Window and glazing models
  Calculation of transmittance, U-values and shading conditions for different glazing properties (WINDOW, REVIS etc.)
- Multi-zone air flow models
  Calculation of air exchange in-between rooms and outdoor (Comis, Contam96 etc.)
- Computational Fluid Dynamics CFD
  Detailed calculations of air flow in rooms. (Flovent, Fluent etc.)

5. ACKNOWLEDGEMENTS
The work on double skin facades was carried out with support of the Swedish Foundation Arkus and the Research Foundation of White Architects.

6. SELECTED EXAMPLES OF BUILDINGS
On the next pages follows a short description of Götz office building in Germany and the Royal Library, Amager in Denmark.

Further examples will be available in the Swedish report (Aaqvist and Svensson, 2000).
6.1 Götz office building, Würzburg, Germany

The building is the headquarter of the German company Götz, which manufactures facade systems. The building was completed in 1996, and the architect was Weber & Geissler.

The building is situated in the outskirts of an industrial area close to open fields. The basic idea was to create an office building, which creates contact between occupants and the surrounding landscape.

The building is based on a quadratic floor plan with similar double skins at each facade giving the opportunity to remove surplus heat from sunlit facades to shaded facades using fans at each partition in the corners of the cavities. See figure 7-10 with photos of Götz office building.

The double skin facade has double low-E glazing in both outer and inner skin in order to fulfil the requirements of heat loss. The double skin facade has an air gap of 60 cm containing maintenance and escape routes and a louver blind system with one reflective and one black absorptive side. Furthermore, the blinds are 10% perforated to guarantee visual contact with the surroundings.

Figure 7 Double skin facade at the south-west entrance of Götz office building, Würzburg, Germany.

Figure 8 South-east elevation of double skin facade of Götz office building, Würzburg, Germany.

Figure 9 Fans in corner of cavities. Götz office building, Würzburg, Germany.

Figure 10 Corner detail of double skin facade with air inlets and venetian blinds. Götz office building, Würzburg, Germany.
6.2 The Royal Library, Amager, Copenhagen, Denmark

The building serves as the main archive of the national library in Denmark, which is a closed and heavy construction. In contrast to the archive the administrative part is open having double skin facade.

The building was completed in 1997, and the architect was Dissing + Weitling.

The building is situated in an open area close to Copenhagen University.

The double skin facade consist of double low-E glazing with solar reflective coating in the outer skin and a internal single layer glazing in sliding doors in full room height. The profile system in the outer layer is special designed with insulation against cold bridges.

The double skin facade has an air gap of 30 cm and perforated louver blinds to guarantee visual contact with the surroundings. The cavity is used as a buffer zone in the heating season to reduce heat loss and cold down draught. The extract of air from the offices are lead through gaps below the sliding doors and are further extracted via outlets in the horizontal division. In the summer period automatic opening of windows in the outer layer and the sliding doors are used for supplementary venting of the offices, (Byggeindustrien, 1999).

Figure 11 Details of double skin facade with low positioned automatic windows for venting. The Royal Library, Amager, Copenhagen, Denmark. Photo: Dissing + Weitling.

Figure 12 West elevation of double skin facade at The Royal Library, Amager, Copenhagen, Denmark.

Figure 13 Detail of lower part of double skin facade. The inner skin is full sized sliding doors with single layer glazing. The Royal Library, Amager, Copenhagen, Denmark.

Figure 14 Detail of facade system. The Royal Library, Amager, Copenhagen, Denmark. Dissing + Weitling.
7. CONCLUSIONS

Double skin facades affect a lot of aspects of indoor climate and to some extent energy consumption.

Transparency, view to the outside and daylight levels are increased when double skin facades are used compared to the use of traditional window facades.

An increased glazing area will also lead to increased glare problems and this is crucial for open plan offices, where disability glare might occur in depth of the rooms.

Venting is crucial during summer periods to prevent overheating of the adjacent rooms. Double skin facades can be used as part of a natural and mechanical ventilation strategy, but the complexity of ventilation is increased compared to a free facade.

The maintenance of solar shading devices in cavities are significantly reduced and the life time increased. Furthermore, the shading ability can be very effective in combination with venting.

Glazing in double skin facades offers an increased noise reduction, especially for low frequencies, compared to traditional double glazing. Fire is an important issue of double skin facades and should be analysed carefully in each case.

When a single layer of glazing is added to a double low-E glazing in a double skin facade construction the reduction in heat loss expressed by the U-value is modest (<20%). Introducing an extra double low-E glazing will reduce the heat loss by approximately 50%. It is obvious that a traditional window facade offers better conditions regarding heat loss than a fully glazed or a double skin facade, due to the reduced heat loss from non-transparent parts of a traditional facade.

The aspects of indoor climate are characterised by interaction and in some cases conflicting relations, which complicates the priority of several aspects. So an overall or holistic approach is important to reach good design solutions for double skin facades. In the same way suitable tools for analysing performance of double skin facades are crucial for the different design steps.

Clients want double skin facades due to transparency and image, and architects like double skin facades to reach a lighter facade expression and creating contact for occupants to the surroundings. The design teams are facing a challenge of reaching acceptable indoor climate with a reasonable energy consumption, but it seems to be attainable.

REFERENCES

Books and reports:


Journal article:

Page(s) in a Proceedings: