BESTFAÇADE

Best Practice for Double Skin Façades

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WP5 Best Practice Guidelines

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1 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 on the other hand often have a higher use of electricity than older office buildings, due to a higher energy use for ventilation, cooling, lighting and office equipment.

Since the nineties, there has been an increase in new office buildings with glazed facades. The increased use of glazed facades has been enabled thanks to the development of façade construction technology and physical properties of glass during the last decades. There has been and is a growing interest among clients to build and among architects to design office buildings with glazed double skin facades. The purpose of the double skin facades has often been to reduce the high temperatures in the building behind during the summer and to lower the heat losses during winter compared with a glazed single skin façade. Other improvements, which can be achieved are: wind protection with open windows, fire protection, aesthetics, preheating of ventilation air, sound protection, night cooling and a site for incorporation of PV cells.

Commercial buildings with integrated double skin facades can be very energy efficient with all the good qualities listed above. However not all double skin facades built in the last years perform well. Far from it, in many cases large air conditioning systems have to compensate for summer overheating problems and the energy consumption badly exceeds the intended heating energy savings. Thus the architectural trend has in many cases unnecessarily resulted in a step backwards regarding energy efficiency and the possible use of passive solar energy.

Therefore the European Commission partially (50 %) financed a project, BESTFACADE, to promote the concept of energy efficient and well-performing double skin facades. An important output or the project are these best practice guidelines for double skin facades. The guidelines are based on a survey of double skin facades in Europe (Streicher 2005). Information on built examples of double skin facades in European office buildings has been collected, investigated and assessed. A simple calculation method for estimating the energy demand and comfort parameters, during pre-design, for a building with an integrated double skin façade, has been developed (Erhorn 2007). This new energy calculation method for double skin facades will be presented to relevant CEN committees and could be integrated into the assessment methods of the EPBD (energy performance of buildings directive of the European Commission). Energy related benchmarks and a certification method for double skin facades have been outlined as well (Matos 2007).

In many countries the level of knowledge on double skin facades (especially advantages/-disadvantages and costs) is insufficient for all target groups, apart from some educational/research institutes (Santamouris 2007). It was also concluded that there are many existing buildings with double skin facades, but very few of them are documented with regard to energy and environmental performance. The best practice guidelines aim to fulfil this knowledge gap.

The best practice guidelines aim at offering, information supporting the design, choice, implementation and management of energy efficient double skin façade office buildings with a good indoor climate (new construction and retrofitting). The main focus is on energy use and indoor climate. The target groups are governmental bodies, standardization bodies, decision makers, clients/-developers, architects, engineers, HVAC engineers, façade suppliers and facility managers.

The guidelines consist of three parts:

Part 1 Fundamentals: The purpose is to provide to the targeted audience common basic scientific, technical and economic knowledge on double skin facades. The following aspects are dealt with: architecture, technology, glazing, façade construction and costs.

Part 2 Applications: The purpose is to provide the targeted audience with practical information in order to design, choose, manage, use and maintain double skin facades and to design, manage, use and maintain buildings with integrated double skin facades (case studies - examples of technical solutions and buildings; potential advantages and disadvantages with double skin facades, situations where double skin facades can be appropriate, impacts of double skin facades).

Part 3 Tools: General information on simulation tools, review of simulation tools and existing standards. The simple calculation method is described.

2 Summary

Many modern office buildings have highly glazed facades. Their performance is, however, being questioned, especially in terms of energy use and indoor climate. Therefore more and more of highly glazed office buildings are being built with double skin facades, which can provide improvements such as a thermal buffer zone, energy savings, wind protection with open windows, fire protection, aesthetics, solar preheating of ventilation air, sound protection, night cooling and a site for incorporation of PV cells. However not all double skin facades built perform well. Far from it, in many cases large air conditioning systems have to compensate for summer overheating problems and the energy consumption exceeds the intended heating energy savings. Thus the architectural trend has in many cases unnecessarily resulted in a step backwards regarding energy efficiency and the possible use of passive solar energy. Therefore these best practice guidelines were developed.

2.1 Objectives of the guidelines

The best practice guidelines aim at offering information supporting the design, choice, implementation and management of energy efficient double skin façade office buildings with a good indoor climate (new construction and retrofitting). The guidelines consist of three parts:

Fundamentals: Common basic scientific, technical and economic knowledge on double skin facades is provided.

Applications: Practical information in order to design, choose, manage, use and maintain first of all double skin facades but also buildings with double skin facades is provided.

Tools: General information on tools, review of simulation tools and existing standards is given. The simple calculation method is also described.

2.2 Fundamentals

2.2.1 Architecture

No other building material has during the last two decades experienced such an innovative evolution as glass. It has evolved into a high-tech product that in its right use can create slender and bold constructions. Glazed buildings (single and double skin) have become an important part of modern architecture. Architecturally an airy, transparent and light building is created, where the access to daylight is higher than in more traditionally built office buildings. The idea is often to create a building with openness and to give a futuristic outlook. The complete transparency also shows a corporate will of communication and openness towards society outside.

The daylight and its positive effects on humans have always been a main ingredient in architecture. However, careful planning is necessary for a glazed facade with the amount of light that is allowed into the building. If glass architecture is to survive it must limit its influence on energy losses by new innovative solutions e.g. double skin facades.

2.2.2 Technology

A ventilated double skin facade can be defined as a traditional single facade doubled inside or outside by a second, essentially glazed facade. A ventilated cavity – with a depth from about 10 centimetres at the narrowest to 2 meters for the deepest 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 – a window doubled outside or inside by a single pane or a second window
- Facade partitioned per storey with juxtaposed modules, where the air cavity is delimited horizontally and vertically
- Facade partitioned per storey - corridor type, where a minimum depth of the air cavity should enable a person to be there and service the equipment
- Shaft-box façade – similar to façade partitioned per storey with juxtaposed modules, but connected to vertical shaft for increased use of the stack effect
- Multi-storey façade, where the air cavity is open at the top and the bottom, however often with a closable damper at the top
- Multi-storey louver façade – a multi-storey façade where the outer skin can be opened

Double skin facades can be used for new construction and refurbishment.

The choice of the glass type for the interior and exterior panes depends on the type of facade. In case of a facade ventilated with outdoor air, an insulating pane (sealed double-glazed unit) is usually placed as a thermal break as the inner skin and a single pane as the outer skinside. In case of a facade ventilated with indoor air, the insulating pane is usually placed as the outer skinside, the single pane as the inner skin.

The shading device is placed inside the cavity for protective reasons. Openings in the external and internal skin allow the ventilation of the cavity. The choice of pane type, shading device, geometry of the cavity, and type, size and positioning of interior and exterior openings of the cavity and ventilation strategy is crucial for the performance of a double skin facade system.

The high daylight access for a building with a highly glazed single or double skin facade, combined with an intelligent lighting control system, may lead to important savings in use of electricity for lighting. However this high daylight availability can cause glare problems and be responsible for visual discomfort.

Important factors when choosing a facade system are the costs of the façade itself and its relation to the costs of the entire building. Today usually the investment cost and not the life cycle cost is considered. Only taking into account the investment cost often results in a facade system and a building that just fulfils the requirements of the building code at the lowest investment costs. A glazed double skin façade is usually more expensive than a glazed single skin facade, which is usually more expensive than a traditional façade, at least considering the investment cost. Justification of its inclusion in a building design can be based on energy efficiency and associated cost savings e.g. less expensive HVAC system. Qualitative benefits of solar control, moderated surface temperatures, noise reduction, reduced glare, aesthetic purity and increased daylighting are generally seen only as intangible ‘bonus’ benefits.

Preferably the cost of the entire building is taken into consideration, in order to avoid sub optimisation. A well designed double skin facade can result in lower operating cost (mainly lower energy costs compared to a glazed single skin façade). The cleaning costs for the façade can be higher.

2.3 Applications

The great challenge for a glazed office building (single and double skin) is to optimise energy use, use of daylight, visual and thermal comfort at a reasonable investment and life cycle cost. Office buildings with glazed facades often risk having a higher use of energy for cooling and heating than an office with a traditional façade. A traditional glazed façade increases the risk for an unsatisfying thermal comfort close to the façade and glare further inside the building. A properly designed double skin façade will lower these risks. Glazed buildings require more planning and have less tolerance for design and construction errors.

In order to arrive at a glazed double skin façade office building with a reasonable energy use, and good thermal and visual comfort the following actions are required during the building process:

- energy use and environmental requirements as performance specifications should be drafted in the brief, and then refined during the building process.
- an energy and environmental coordinator from the brief phase until the first year of operation is required.
- a comprehensive view must be applied to the design of the building.

- energy and indoor climate simulations should be carried out starting already during the brief phase and then being refined during the building process.
- good cooperation between designers is required to ensure a well performing system: architecture, HVAC, structural engineering, electrical engineering and building physics.
- good cooperation is required between client, designers and contractors.
- a life cycle cost analysis should be carried out to avoid prioritising investment costs and neglecting operating, maintenance and energy costs.
- a separate performance specification should be worked out for a double skin facade based on analysis of the entire building, to avoid sub optimisation
- performance checks should be carried out during construction and when the building including the double skin façade is finished, in order to check that the performance specifications are fulfilled.

2.3.1 Performance specifications

The performance specifications for the double skin façade must cover the following aspects:
Building physics

- Influence of weather on inner and outer skin: airtightness, water tigthness, wind load resistance.
- Energy conservation and thermal comfort: thermal and solar energy transmittance.
- Sound insulation: sound attenuation.
- Fire protection: spread of fire etc.
- Light: daylight factor and visual comfort.

Technology

- System – method of production: loads and tolerances.
- Outer and inner skin: durability and need of maintenance.
- Glazing: thermal, solar energy and light transmittance.
- Safety: personal safety.
- Shading devices: solar shading properties.
- Ventilated cavity: ventilation rates.
- Cleaning and service devices: access and equipment.
- Costs

Building process planning

Operation and maintenance

To ensure optimal operation of a building with a double skin facade, it is crucial to have an intelligent control system for the double skin facade and the installations of the building, and a usable and user friendly building energy management system (BEMS).

2.3.2 Some remarks on how to succeed

Some recommendations on how to succeed during the design of a double skin façade are given here:

- The internal gains must be minimized.
- Increasing the glazed area results in increased risk and lowered tolerance for errors.
- Corner rooms with two glazed facades requires special attention, as the risk for poor thermal and visual comfort is high.
- U- (thermal transmittance), g- (the total solar energy transmittance) and τ_V (light transmittance) -values have to be chosen correctly. The choice of these values do of course depend upon many factors e.g. the climate, the size and shape of the building, the size, type and orientation of the glazed areas, type of shading and the geometry and ventilation of the cavity of the double skin facade. A thorough analysis is required to determine these values.
- An appropriate control strategy for ventilation of the cavity and operation of the solar shading has to be determined.

2.3.3 Case studies – predicted performance

The energy and indoor climate performance for a highly glazed office building with a double skin façade is very dependant on the climate and the design of the facade. The design of a highly glazed office building, which is optimal for location with a cold climate, such as Sweden, will not work very well in a location with a warm climate, such as Portugal and the contrary. Different façade alternatives may have to be chosen for different orientations. From an energy and indoor climate point of view a highly glazed office with a double skin façade is often preferable to a highly glazed single skin façade. A well designed highly glazed façade with double skins can result in an office with almost as low an energy use and good thermal comfort as for an office with a traditional single skin façade with traditionally sized window areas. Besides a highly glazed double skin façade has other advantages, which are mentioned elsewhere in this report.

2.4 Energy and indoor climate tools

The modelling of ventilated double skin facades or a building with a double skin façade is a complex, but necessary task. The choice of the most appropriate software for simulation depends on the objective of the simulations. For the pre-design the simple calculation method developed within the BESTFACADE project can be used to make a first decision concerning type of façade and to make an energy performance certificate. There are tools for simulation of the double skin façade and there are building energy simulation programs capable of simulating a ventilated double skin façade. During the detailed design the role of simulation is important and simulation represents the only method to predict the yearly energy consumption and to dimension a building equipped with a ventilated double skin façade and to assess the impact of different control systems and control strategies on the building performance. The simulations have to be carried out using a validated tool.

2.5 Conclusions

The interest to design and build highly glazed office buildings with double skin facades is very high. The buildings can be high and low-rise, mainly office buildings. The application is often new construction, but can also be refurbishment of existing facades.

If the starting point is a glazed building, then adding a properly designed second skin can result in energy savings (heating and cooling) and improved thermal and visual comfort, improved sound attenuation and an exterior solar shading, which is protected being covered by the second skin. However, the double skin facades are often more expensive than single skin facades. The reduction in use of energy can compensate for the additional investment costs . For a building, which is not highly glazed and with a high level of thermal insulation, the energy use for heating and cooling is likely to be lower, than for a highly glazed building with a double skin facade.

In order to ensure a well performing, in terms of energy use and indoor climate, building with a double skin façade, simulations of the double skin facade and building are necessary. The simulations have to be carried out using a validated tool.

The best practice guidelines for double skin facades provide information supporting the choice, design, implementation and management of office buildings with double skin facades.

3 Fundamentals

3.1 What is a glazed building?

Written by Åke Blomsterberg

Most double skin facades are applied to glazed office buildings, which means that both the inner and outer façade skins are glazed. However there are also buildings where the inner skin is a wall with traditionally sized windows. This situation can also occur when a building is retrofitted with a double skin façade. What is then a glazed office? There is no exact definition as to what constitutes a glazed office building. The glazed part of the facade is likely to be larger than for a traditional office. If the assumption is made that a traditional office building has a window area of 30 % of the façade area seen from the outside or 17 % of the floor area, then the window area seen from the inside is approximately 40 % of the façade area. Usually the glass area constitutes 70 – 85 % of the window area depending upon the window size and type of profiles. A glazed office building is here defined as a building where at least one façade has more than 2/3 of the façade area as window.

3.2 Architectural aspects

Written by Christer Blomqvist

3.2.1 The concept of architecture

During a long period of time the European architecture was bound by a classical idiom descending from the ancient Greek art of building (see figure 3.1). The values were mainly aesthetical where shape, proportions material and daylight were the main elements.

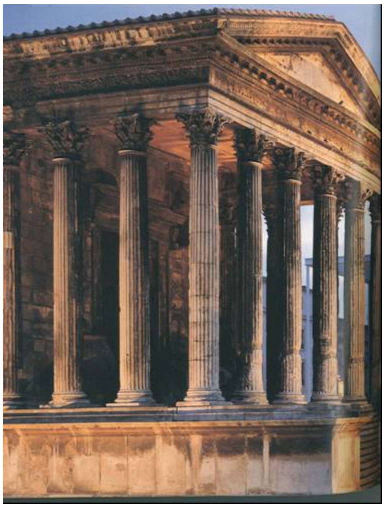


Figure 3.1 Greek temple.

During the later half of the 20th century global, climatic changes together with diminishing resources were evident signs that we must change our view on buildings and our way of living. Architecture is now a complex concept that applies to the appearance, the function, the technology of a building, as well as the approach to environmental issues and the influence on users and viewers.

Architectural aspects on the double skin glazed facade should rely on a complex evaluation of the whole of the building (see figure 3.2).

Figure 3.2 A glazed double skin façade.

3.2.2 Glass architecture

No other building material has during the last two decades experienced such a innovative evolution as glass. It has evolved into a high-tech product that in its right use can create slender and bold constructions. In the beginning the increase of use was depending on the symbolic value of development and future. Glazed buildings have become an important part of modern architecture. Many modern glazed office buildings have been built. Architecturally an airy, transparent and light building is created, where the access to daylight is higher than in more traditionally built office buildings. The idea is often to create a building with openness. The complete transparency also showed a corporate will of communication and openness towards society outside. In many cases the glazed office building is meant to display the profile of a company. The glazed office building can be a vision of an energy efficient building, which however is not easy to realize. More recently the improved properties and its possibilities to be incorporated in a complex construction increased the use of this type of facades. The double skin glazed façade becomes a part of the building technology and the concern of the owner/developer concerning ecology and energy is transferred visually to the outer shell of the building (see figure 3.3).

Figure 3.3 Section showing constructive elements of a double skin façade.

3.2.3 Collaboration

A double skin glazed facade becomes apart from an architectural expression also a part of the technical systems of the building. A demand on a holistic approach and collaboration between participants becomes more significant than in a traditional building system where the façade usually acts a passive part of the building. In an outer wall with two layers the façade becomes an active climatic screen, that can be used in the energy system of the building and improve the indoor climate, increase the use of daylight, solar shading and decrease the noise in exposed areas. If the traditional façade gives the architect a freedom of expression, the double skin facade and the design of its building demands collaboration with engineers and suppliers. This cooperation will affect the architecture in many ways.

3.2.4 Light

The daylight and its positive effects on humans have always been a main ingredient in architecture. The treatment of the light affects the experience of space and the inner clock of humans: alert and awake, tired and drowsy. Examples of the effect on the experience of space are stage design and sense of well being, shadows, reflection, dazzling, the colour of light and its distribution.

Surveys show that daylight has significant effect on performance as well as physical health. Humans living in the northern hemisphere, with short days during the winter season, are more likely to be affected by depressions due to lack of daylight, than those living closer to the equator. To increase the amount of daylight, especially during dark winters, is apart from its effects on humans an important environmental factor since it diminishes the use of electricity for light.

The glazed double skin façade has increased the interest for daylight issues. The large share of glass enables light to penetrate the building. A glazed building should be designed with a optimization of light intake in mind, in order to minimize the dark parts in the core. St Mary Ax in London is a good example with its circular layout where pie slices have been cut out to bring light in to the building, avoiding darkness in the central core (see figure 3.4).

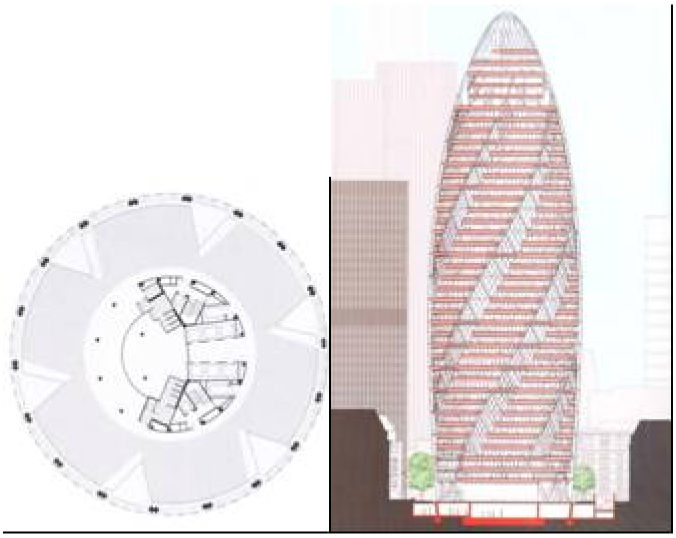


Figure 3.4 St Mary Ax, plan and section

However, careful planning is necessary for a glazed facade with the amount of light that is allowed into the building. Glare may occur particularly when the sun is low.

In the evening the glazed building receives a third dimension and becomes a lantern expressing comfort in the dark (see figure 3.5).

Figure 3.5 Night picture of a glazed office building.

3.2.5 The multitude of the city

The city contains a large amount of buildings where the expression of the single building contributes to varied experience. There is the stone town with a grid and heavy facades in masonry or plaster, there are the monotonous residential areas in the periphery with its rational and similar buildings, there are large scale industrial or commercial complexes and there is small scale single family housing areas. The history of the city growth can be read in the characters and the style of the different epochs. A glazed building is to be added to this collection and contributes to the multitude that is of great importance in the city structure, telling its story about time to come yet reflecting the old in the façade (see figure 3.6).

Figure 3.6 Baltzar City, Malmo, Sweden.

3.2.6 General Buildings

Increasing costs for buildings demands e.g. generality of the building. During an approximated life span of 100 years for a building it will shift tenants and interiors many times. In every change extensive reconstruction will be made, possibly leading to extensive and expensive interference. A fully glazed façade enables a generic layout with a high level of use as a consequence.

3.2.7 Environmental Architecture

Out of the total energy consumption by a building, from erection to the demolition 15 percent derives from the actual construction, while 85 percent is used for the operation. During the last decades the common attitude has changed concerning environmental and energy consumption, making it a natural part of architecture. The glazed double skin façade claims to keep energy in mind and fits very well with this new way of thinking, however it is not always obvious to design the façade with a transparent shell.

Seen from the perspective of energy consumption there are no reasons to have identical facades facing different directions. On the contrary the design can be based on the orientation of the façade. The south façade is suited for making use of solar heat. Solar panels and double skin glazed facades where the cavity is used for ventilation, collection of heat and as protection for solar shading functions. The façade facing north can have a more traditional expression with smaller windows and have higher level of insulation. In this way the architecture becomes more environmentally adjusted depending on the location of the building. If the site allows a large amount of facades facing east or west both of these can be constructed as glazed double skins with a function in between e.g. solar shading.

3.2.8 The facade of communication

During the 21st century the increased use of glass has given birth to a new kind of architecture, with facades communicating with its surroundings. In the water-saturated town of Stockholm, a new hotel is designed using glass façade with water sparkles, telling the story of the seabed transformed into the site. A double skin glazed façade can mediate something about the contents on the outer glass by moving- or still pictures. With cameras placed in the void producing chosen pictures expressing an animated exterior.

Figure 3.7 Model of a façade with water sparkles.

The building can be used to express the corporate policy and the glass will act as a potential billboard.

3.2.9 The sound attenuating façade

The site determines the orientation and shape of a building, as well as the choice of facade and technology. All sites are not suitable for single- or double skin glazed facades, and all sites are not suited for a closed building typology. Close to a highway or a loud industry the double skin façade can act as an effective noise suppressor and create a comfortable indoor climate. Earlier the architect would choose a heavy façade with smaller windows, thereby creating a dim and dark interior. Now the transparent façade with its views and daylight can be used, yet protecting its inhabitants from the noisy exterior.

3.2.10 The aesthetic façade

Written by Sabrina Prieus

Designers can be creative with the cavity or in choosing for example a distinguishable solar shading. Sail-like shading devices (see figure 3.8) or screens in different colours (see figure 3.9). Actually the double skin façade does not even need these additions to give an impressive outlook: using spider glass, steel bars and cables it automatically has a high-tech appearance (see figure 3.10).

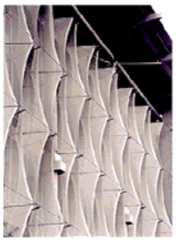


Figure 3.8 Sail-like shading devices on the north elevation of the Phoenix Public Library

Figure 3.9 GSW building; Gemeinnützige Siedlungs-und Wohnbaugenossenschaft mBH (GSW) Headquarters, Berlin, Germany, Sauerbruch Hutton Architekten, 1995-1999

Figure 3.10 Banque Populaire, Rennes, France

3.2.11 Future

Utopian portraits almost always include transparent buildings of different kinds. Will the double skin glazed façade become the skin of buildings in the future? Glass can now be delivered with almost all the properties that are needed for a shell with an exception for efficient energy insulation. If glass architecture is to survive it must limit its influence on energy losses by new innovative solutions.

It is not likely that we will rely entirely on glass buildings in the future. The site, demands and supply of material, architectural trends will still be decisive. A positive development for the glass as a material increases the possibility of making it into a universal building material with more glass buildings as a consequence. Since immemorial time humans have searched for one material to build with. Multifunctional glass facades can be this building technique of the future. Gone are the masonry walls with its many layers in the solid parts and with openings for light and communications.

Architects, artists and engineers will stretch the borders in a quest to create new expressions, giving vivid façade surfaces.

3.3 Technology

Written by Sabrina Prieus and Gilles Flamant

3.3.1 Definition

A ventilated double skin facade can be defined as a traditional single skin facade doubled inside or outside by a second, essentially glazed facade. Each of these two facades is commonly called a skin (hence the widely-used name "ventilated double skin facade"). A ventilated cavity - having a depth which can range from about 10 centimetres at the narrowest to 2 metres for the deepest accessible cavities - is located between these two skins.

There exist facade concepts where the ventilation of the cavity is controllable, by fans and/or openings, and other facade concepts where this ventilation is not controllable (the ventilation is natural and there are fixed permanent ventilation openings). The indoor and outdoor skins are not necessarily airtight (for example, the "louver" type facades). Automated equipment, such as shading devices, motorised openings or fans, are most often integrated into the facade. The main difference between a ventilated double skin facade and an airtight multiple glazing, whether or not integrating a shading device in the cavity separating the skins, lies in the intentional and possibly controlled ventilation of the cavity of the double skin facade.

3.3.2 Typology

Ventilated double skin facades can be classified according to three different criteria which are independent of one another and are based not only on the geometric characteristics of the façade but also on its mode of working.

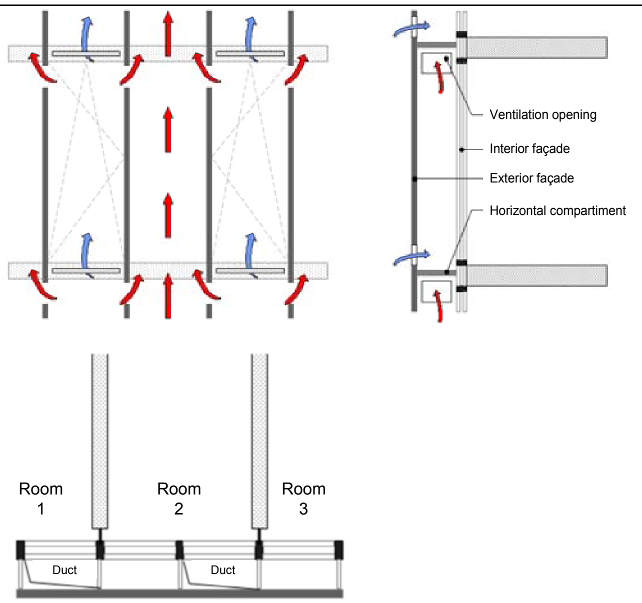
The criteria are:
• Type of ventilation
• Partitioning of the façade
• Ventilation mode of the cavity

Type of ventilation
The type of ventilation refers to the driving forces at the origin of the ventilation of the cavity located between the two glazed facades. Each ventilated double skin facade concept is characterised by only a single type of ventilation. One must distinguish between the three following types of ventilation: natural, mechanical or hybrid ventilation (mix between natural and mechanical ventilation).

Partitioning of the façade
The partitioning of the cavity gives the information on how the cavity situated between the two glazed facades is physically divided. The partitioning solutions implemented in practice can be classified as follows:
• Ventilated double window
• Facade partitioned per storey with juxtaposed modules
• Facade partitioned per storey - corridor type
• Shaft-box facade
• Multi-storey facade
• Multi-storey louver façade

Ventilated double window	
A facade equipped with a ventilated double window is characterised by a window doubled inside or outside by a single glazing or by a second window. From the partitioning perspective, it is thus a window which functions as a wall filling element. Some concepts of naturally ventilated double windows are also called ´Box-window´ in the literature.	

Facade partitioned per storey with juxtaposed modules	
In this type of facade, the cavity is physically delimited (horizontally and vertically) by the module of the facade which imposes its dimensions on the cavity. The facade module has a height limited to one storey.	
The corridor-type ventilated double skin facade partitioned per storey	
´Corridor´ type ventilated double skin facades partitioned per storey are characterised by a large cavity in which it is generally possible to walk, which determines the minimum depth. While the cavity is physically partitioned at the level of each storey (the cavities of each storey are independent of one another), it is not limited vertically, and generally extends across several offices or even an entire floor.	

The ´Shaft-box´ ventilated double skin façade	
The objective of this partitioning concept is to encourage natural ventilation by adapting the partitioning of the facade so as to create an increased stack effect (compared to the naturally ventilated facades which are partitioned by storey). Thus it is logical that this type of facade and partitioning is applied only in naturally ventilated double skin facades. This type of facade is in fact composed of an alternation of juxtaposed facade modules partitioned by storey and vertical ventilation ducts set up in the cavity which extends over several floors. Each facade module is connected to one of these vertical ducts, which encourages the stack effect, thus supplying air via the facade modules. This air is naturally drawn into the ventilation duct and evacuated via the outlet located several floors above.	 View in elevation, section and plan
The multi-storey ventilated double skin façade	
These facades do not have a cavity which is partitioned horizontally or vertically Therefore the space between the two glazed facade layers form one large volume. Generally, in this type of facade, the cavity is deep enough to permit access to individuals (cleaning service, etc.) and floors which can be walked on are installed at the level of each storey in order to make it possible to access the cavity, primarily for reasons of cleaning and maintenance. In some cases, the cavity can run all around the building without any partitioning. Generally, the facades with this type of partitioning are naturally ventilated; however, there are also examples of facades of this type which are mechanically ventilated. It should be noted that the facades of this type generally have excellent acoustical performances with regard to outdoor noise. This characteristic can be the reason for applying this particular type of facade.	

<table>
<tr><th>The multi-storey louver naturally ventilated double skin façade</th><th></th></tr>
<tr><td>The facade is very similar to a multi-storey ventilated double skin facade. Its cavity is not partitioned either horizontally or vertically and therefore forms one large volume. Metal floors are installed at the level of each storey in order to allow access to it, mainly for cleaning and maintenance.

The difference between this type of facade and the multi-storey facade is that the outdoor facade is composed exclusively of pivoting louvers rather than a traditional monolithic facade equipped (or not) with openings. This outside facade is not airtight, even when the louvers have all been put in closed position, which justifies its separate classification. However, the problems encountered with these facades are generally comparable to those encountered in the other ventilated double skin facades.</td><td>

a. View of the louvers in horizontal position
b. View of the large cavity and the louvers in vertical position
Ventilated double skin facade with louvers
Berlaymont 'building'
Architect : Berlaymont 2000 s.a., P. Lallemand, S. Beckers</td></tr>
</table>

Ventilation mode of the cavity

The ventilation mode refers to the origin and the destination of the air circulating in the ventilated cavity. The ventilation mode is independent of the type of ventilation applied (the first classificatory criterion presented).

Not all of the facades are capable of adopting all of the ventilation modes described here. At a given moment, a facade is characterised by only a single ventilation mode. However, a facade can adopt several ventilation modes at different moments, depending on whether or not certain components integrated into the facade permit it (for example operable openings). One must distinguish between the following 5 main ventilation modes (see figure 3.11)

1. Outdoor air curtain

In this ventilation mode, the air introduced into the cavity comes from the outside and is immediately returned to the outside. The ventilation of the cavity therefore forms an air curtain enveloping the outside facade.

2. Indoor air curtain

The air comes from the inside of the room and is returned to the inside of the room or via the ventilation system. The ventilation of the cavity therefore forms an air curtain enveloping the indoor facade.

3. Air supply
The ventilation of the facade is created with outdoor air. This air is then brought to the inside of the room or into the ventilation system. The ventilation of the facade thus makes it possible to supply the building with air.

4. Air exhaust
The air comes from the inside of the room and is evacuated towards the outside. The ventilation of the facade thus makes it possible to evacuate the air from the building.

5. Buffer zone
This ventilation mode is distinctive inasmuch as each of the skins of the double skin facade is made airtight. The cavity thus forms a buffer zone between the inside and the outside, with no ventilation of the cavity being possible.

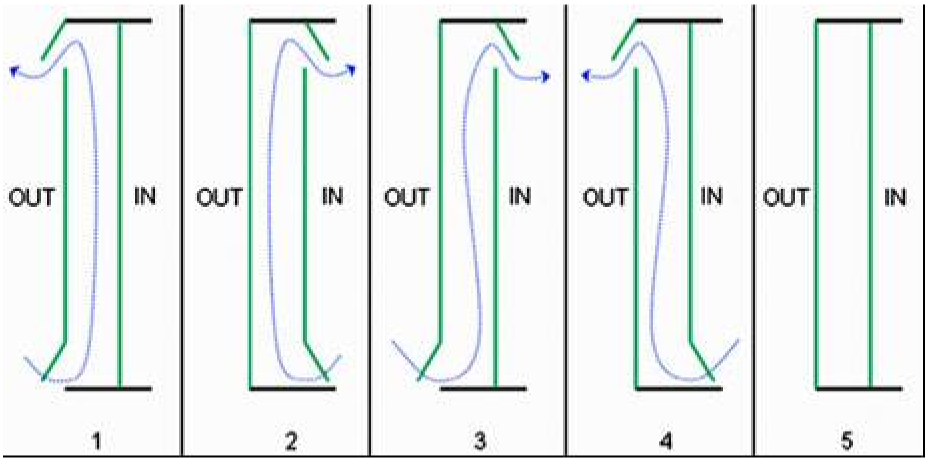


Figure 3.11 Ventilation modes for double skin facades.

3.3.3 Technical description

A double skin facade system consists of:

<u>Exterior and interior glazing:</u>
The choice of the glass type for the interior and exterior panes depends on the typology of the facade. In case of a facade ventilated with outdoor air, an insulating pane (sealed double-glazed unit) is usually placed as a thermal break at the interior side and a single pane at the exterior side. In case of a facade ventilated with indoor air, the insulating pane is usually placed at the exterior side, the single pane at the interior side. For some specific types of facades, the interior window can be opened by the user to allow natural ventilation of the building.

An air cavity between the exterior and interior glazing:
The ventilation of the cavity may be totally natural, fan supported (hybrid) or totally mechanical. The depth of the cavity can vary as a function of the applied concept between 10 cm to more than 2m. The depth influences the physical properties of the facade and also the way that the facade is maintained.

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

Openings
Openings in the external and internal skin and sometimes ventilators allow the ventilation of the cavity.

The choice of the proper pane type and shading device is crucial for the function of the double skin facade system. Different panes can influence the air temperature and thus the flow in case of a naturally ventilated cavity.

The geometry (mainly depth and height of the cavity) and the properties of the blinds (absorbance, reflectance and transmittance) may also affect the type of air flow in the cavity. When designing a double skin facade it is important to determine type, size and positioning of interior and exterior openings of the cavity since these parameters influence the type of air flow and the air velocity and thus the temperatures in the cavity (more important in high-rise buildings). The design of the interior and exterior openings is also crucial for the flow indoors and thus the ventilation rate and the thermal comfort of the occupants.

It is really important to understand the performance of the double skin facade system by studying the physics of the cavity. The geometry of the facade, the choice of the panes and shading devices and the size and position of the interior and exterior openings determine the use of the double skin facade and the HVAC strategy that has to be followed in order to succeed in improving the indoor environment and reducing the energy use. The individual facade design and the proper facade integration are the key to a high building performance.

3.3.4 Fire

In order to prohibit the propagation of a fire in a building, generally a form of compartmenting is appropriate (see figure 3.12). This means the building needs to be divided by construction elements (floors, walls, doors, …) that during a certain period of time can prevent the propagation of a fire, inside the building, to the adjacent compartment. The propagation of fire could also occur via the outside of the building: the glass façades are often a weakness in the fire compartmenting of a building.

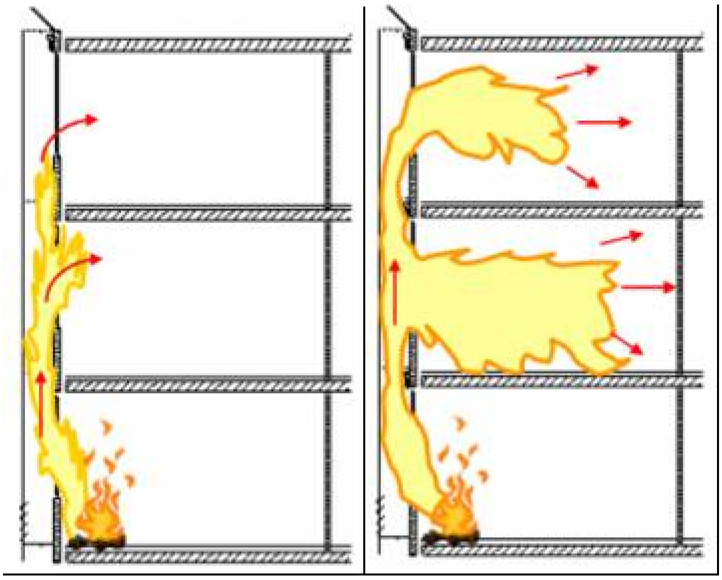


Figure 3.12 Propagation and penetration of the fire along a double skin facade

Not only the propagation of a fire along the façade, but also the evacuation of the employees and the action of the fire brigade are elements to be looked at carefully in the case of a double skin façade. Indeed in comparison with a traditional façade, the following dangers have to be taken into account:

- The cavity can aggravate the situation in case of fire when it connects multiple floors (compartments) with each other.
- The evacuation of people via the façade is harder or even impossible.
- The danger exists that the outer façade comes apart from the rest of the building and thus endangering the fire brigade and other emergency services. Therefore the anchoring should be fire resistant or protected by fire resistant elements.
- The view on the fire and the people to be evacuated become disrupted when the cavity is filled with smoke.

In accordance with the type of façade, different precautions can be made. In the case of mechanically ventilated double skin façades, HVAC fire regulations must be respected to prevent smoke and flame spread.

In consultation with the different parties (fire brigade, insurers, authority) several improvements can be considered:

- Permanent compartmenting of the cavity of the double skin façade with construction elements with fire resistance performance;
- Compartmenting in case of fire of the cavity of the double skin façade (automatic closing elements, foaming elements, …);
- The use of glazing with fire resistance performance in the inner façade (long term behaviour – temperatures, UV-rays – has to be taken into account to prevent the properties of the glazing to become inactive);
- Opening (permanent or in case of fire) of some elements in the outer façade
- Sprinkler systems in the cavity of the façade oriented towards the inner façade;
- Creation of a difference in shock resistance between inner and outer façade so that the outer façade breaks as soon as the inner façade is broken;
- Emergency exits on regular places in the façade and stairs on the outside of the building can serve as means of evacuation.

In the event of fire, a building must ensure a certain safety to the occupants and fire emergency services. This essential requirement is translated in the majority of the regulations of the Member States into principles of construction (stability, compartmenting, measures against smoke propagation, etc.) as well as in regulations on the fire behaviour of the construction products used.

The implementation of the Construction Products Directive (CPD) within the European Union requires the harmonization of the methods for assessing the performance of the products incorporated in works for which essential requirements on security are formulated. The national fire tests of today (fire resistance and fire reaction tests) strongly differ from one Member State to the other. No law of correspondence exists to pass from a national classification system to another. The CPD aims to harmonize these tests and classifications, which is evident from several Commission Decisions.

There are several European standards on fire, relevant for office buildings with double skin facades:

- NEN-EN 13501-2 (2004) Fire classification of construction products and building elements.
- EN 1364-4 (2007) Fire resistance tests for non-loadbearing elements - Part 4: Curtain walling - Part configuration.
- EN 1364-3 (2006) Fire resistance tests for non-loadbearing elements - Part 3: Curtain walling - Full configuration (complete assembly).
- CR 12101-5 « Smoke and Heat Control Systems: guideline on functional recommendation and calculation methods for smoke and heat exhaust and ventilation systems ». Bruxelles, CEN, 2000, Comité européen de normalisation.
- EN 12845:2004: Fixed firefighting systems - Automatic sprinkler systems - Design, installation and maintenance.

3.3.5 Acoustics

The choice of façade type depends primarily on the climate conditions of the region. Nonetheless, sound insulation to the outside is one of the most persuasive reasons to implement a double skin façade. The glass façade screens off the noise like a protective wall, while openings in the inner skin can be opened and receive less noise, thus ensuring natural ventilation of the room. However, the noise coming from within the building is also reflected back into the room and adds to the noise inside or can be transmitted to adjacent rooms. Openings in the outer skin, necessary to ventilate the cavity, determine a certain upper limit value of acoustical insulation. The best sound insulation to the outside is of course obtained it there are no openings in the inner and outer skin.

The acoustical European standard EN 12354 (2000) offers the possibility to predict façade insulation and insulation between rooms interconnected with a cavity. Studies have proven that a double skin glazed façade can have an acoustical façade insulation that is far better (up to 10 dB) than that of traditional façades (office buildings). Hereby the ventilation mode and the 'doubling' of the façade skin play an important role.

On the other hand, the acoustical insulation between rooms (on different floors) situated at the façade side, is lower compared to buildings with the same internal construction but with no cavity (values up to 8 dB), when no special measures are taken to prevent the (airborne) indirect transmission. This is due to the transmission of sound through the cavity.

Figure 3.13 Acoustic screening wall in front of Neven-DuMont-Schauberg publishing house, Cologne. Architects: Hentrich Petschnigg und Partner, Düsseldorf.

Figure 3.14 Airport Gardens lies in the flight route of Brussels airport and near major highways. Architects: M.Jaspers-Eyers & Partners

Parameters of performances

When determining the acoustical performance of a double skin façade by simulation, the acoustical performances of the various (constituent) elements need to be measured in the laboratory. By combining these data and applying one or several predictive models, an acoustical performance determination can be done by approximation. If one is interested in knowing what impact changing one of the elements of a façade has on the overall acoustical performances e.g. changing the type of glazing, then mathematical models can provide an answer to this, but still only by approximation, since they are prepared for infinite walls and generally do not contain an entirely correct formulation of the various junction points (ref. the European standard EN 12354) and edge effects.

Therefore a type of preliminary calculation could be done on the basis of fundamental acoustical principles and their impact on the overall performances, thus making a forecast which gives no precise values, but rather a series of results fluctuating between a minimum and maximum value. This kind of evaluation can give an effective tool for quickly evaluating the mutual impact of different configurations on the acoustical façade insulation.

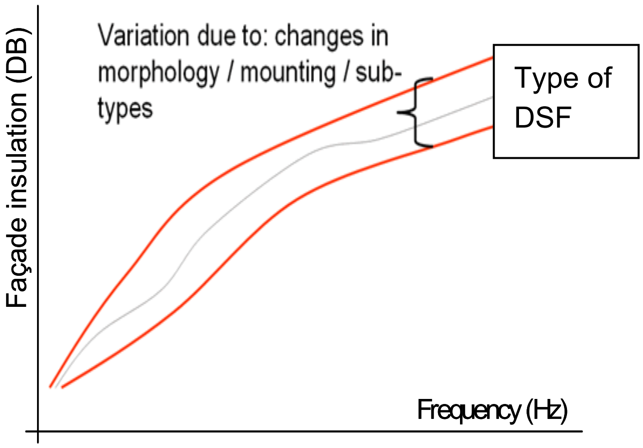


Figure 3.15 Façade sound insulation as function of frequency.

The acoustical performance of a façade depends on the materials used in the structure and on the configuration or geometrical arrangement of the constituting parts. Primarily the materials used are glass, steel and concrete.

To calculate façade insulation, the properties of the glazing and wall parts need to be measured in the laboratory. In the laboratory specific standard dimensions are handled. According to the standard EN ISO 140-3 (1995) these dimensions are 1,23 m x 1,48 m. This surface is rather small compared to the in situ dimensions of a glass façade. A bigger surface induces a reduction of the acoustical performance. Other parameters, such as the air impermeability of the façade, absorption in the cavity, flanking (through the construction), user conditions of the inner façade, etc. also determine the ultimate performance on site.

The parameters of acoustical performances of a double skin façade are mainly the façade insulation and the acoustical insulation between rooms located on the façade side, as indirect airborne transmission via the cavity can occur.

Comparison with traditional façades

According to measurement, the acoustical façade insulation of double skin facades lies above 43 dBA. This corresponds to the acoustical performance of 14 cm of brick (180 kg/m²). The acoustical performance of a double skin façade of 54 dB corresponds to the acoustical insulation of 14 cm of poured concrete (350 kg/m²) or 19 cm of concrete blocks (285 kg/m²). This proves double skin facades perform very well in the field of acoustical façade insulation.

There are quite a few parameters which influence the acoustical performances of double skin facades: type of façade system, type of glass, size of glazed surfaces, properties of receiving room, openings, cavity depth, resonance of one and two layers, source properties. Most of these parameters are also applicable to traditional façades.

Indirect sound transmission

The transmission of sound via the cavity of the double skin façade is an important parameter when considering the acoustical insulation between the rooms located on the façade side. This can be an issue especially when the (glass) inner façade can be opened.

It can be stated that the acoustical insulation between the rooms is less important between two rooms on the same storey than between two rooms situated above each other. The vertical partition walls in office buildings are often made of a light weight material and thus provide less acoustic insulation. The sound that comes in via the cavity from the adjoining room will be as a result less noticeable. If the floors however, are made of (heavy) concrete, then the difference with the inner façade opened will be more evident.

3.3.6 Daylight

The daylight availability is a very contradictory aspect for glazed double skin façades. If, on one hand, the additional pane (outer skin) combined with the framing of the exterior surface and shading equipment are responsible of a reduction by 10 up to 20 % of the light transmission compared to traditional façades, on the other hand, the higher surface of glass to wall façade ratio compensate for it so that, ordinarily, the total daylight access is higher in double skin façade buildings than in traditional buildings.

This high daylight access for the building, combined with an intelligent lighting control system with daylight and presence detection, may lead to very important savings in the use of electricity for lighting (up to 50 %).

However this high daylight availability can cause glare problems and be responsible for visual discomfort. To avoid any glare problems (direct and indirect glare), special attention has to be paid to the material of the indoor surfaces and the control of daylight.

Figure 3.16 Glare through light reflection

The indoor surface materials have to be non-specular and of light colour. Best is to have reflection coefficients of about 0.7 for the ceiling, 0.5 for the walls and 0.2 for the ground.

The most effective way to assure visual comfort under daylight conditions is to control the daylight penetration with solar shading devices (mainly screens or Venetian blinds).

Solar shading devices have three different functions :

- to protect against direct exposure of the sun
- to protect against glare
- to avoid overheating

For double skin facade where the solar shading is included in the façade concept (see figure 3.17), there is an interaction between the control of the solar shading and the control of the indoor comfort. Often the solar shading consists of Ventian blinds, which have the advantage when not needed they can be pulled up completely giving free view and access to daylight.

The shading device placed between the two glass skins is protected against weathering and soiling.

Figure 3.17 Venetian blinds in the cavity of a double skin façade.

The optimisation of the energy consumption of a double skin facade mainly requires a full automation of the solar shading control. In this manner there is a balance between the advantages of high daylight penetration and the increase in solar gains.

Although this solution is theoretically the best, studies have shown that the user needs to have a full or some control of its environment. A manual control/override of the solar shading is required in order to attain user satisfaction.

The combination of full automation and manual derogation is the best way to assure a double skin facade to be efficient.

Some of the double skin facade with exterior solar protection are multi-storey naturally ventilated louver façades. The exterior louvers are made of glass and are controlled as a function of the daylight availability (see figure 3.18 and 3.19). If there is direct sunshine, they are used as solar shading. If there is no direct sunshine (overcast sky), the louvers are used as light reflectors in order to increase the penetration of diffuse daylight.

Figure 3.18 View on the louvers in horizontal position.

Figure 3.19 View on the cavity with louvers in vertical position.

3.3.7 Structural stability

The stability study of a double skin façade can be separated into three parts:

1. The stability control of the glass element or panel
2. The stability control of the fixations of the glass elements
3. The security aspects of the elements for the people walking beneath

The stability aspects (like all the other aspects) of the double skin facades are very depending on the type of the façade. The most important issues are:

1. The distance between the two skins
2. The separation between the floors into the gap

3. The permeability of the external and internal façades

The most important structural load acting on the façade is the wind. If there is roof glazing, snow must be taken into account as well. The action of dead weight, and mechanical devices included in the façade have to be treated. All the loads and combinations must be taken into account according to the Structural Eurocodes EN 1990 and EN 1991-1-x. Specific levels of reliability can be used.

From the point of view of stability, double skin facades differ from light weight facades:

- The calculation of the wind effect and the eventual buffer effect associated are specific. The pressure coefficients depend highly on boundary conditions and certain calculation aspects following the Eurocodes have been considered as unsafe when applied for double skin facades. This is really depending on the depth of the gap;
- Some execution problems, like the different combinations between construction materials or systems that cause aesthetic defaults or an elevation of local stresses, especially in the fixations ;
- The extra weight that has to be taken into account when the gallery between the inner and outer skin is used e.g. for maintenance reasons.

3.4 Glazing

Written by Natalia Kiossefidi

Glass has many properties, which are valuable for building applications. It allows daylight to enter the building, gives a view to the outside, protects against weather and noise, and can be used architecturally and aesthetically. It also offers safety, security, solar energy performance, and ultraviolet screening. Glass is a durable material, which does not need a lot of maintenance, apart from regular cleaning.

Common types of glazing used in architectural applications include clear and tinted float glass, tempered glass, and laminated glass as well as a variety of coated glasses, all of which can be single, double, or even triple glazing units.

Different types of glass can be used in a building:

Annealed glass

This is a clear glass that can be processed in all ways for use in numerous sectors and it has high light transmission. When annealed glass breaks, it produces razor-sharp shards of glass that can cause terrible injury. It is used in single glazing, insulating glazing and for manufacturing laminated glass and toughened glass. It is also used as a base glass to which coatings are applied for a better thermal and/or solar energy performance. The European standard for annealed glass is EN 572-9.

There are many types of coated glass with different characteristics and solar energy performance. Glass companies refer to their coated glass by using different names, however, the characteristics of the glass are more or less the same. Examples of glazing are given:

Reflective solar control glazing: It is a hard-coated glass and it is applied in single glass, laminated glass and double glazed units. It is often applied in commercial buildings.

Low reflecting solar control glass with thermal insulation properties. It is hard-coated glass and can be processed in many ways. It has numerous applications e.g. in double skin façades and atriums.

Solar control glazing with thermal insulation: It is always applied in double glazed units.

Low-emissivity single glazing: It can be hard-coated or soft-coated glass. The low-emissivity coatings help to lower the energy consumption.

The values of the light transmittance, the total solar energy transmittance (solar factor or g-value) and the U-value depends on the type and the thickness of the glass. The data of the measurements or calculations are only informative and can deviate depending on the conditions of the site. The light transmission and the total solar energy transmittance (g-value) have been determined according to the EN 410 standard. The U-value has been calculated according to EN 673 standard.

Table 3.1 Properties of single glazing.

	8mm Annealed glass	8mm Stopsol classic	8mm Stopsol Supersilver	8mm Sunergy	6mm Planibel Low-E G
Light trans-mittance – LT[1] t_v	88	37	62	67	81
Solar factor – g[1]	82	51	64	59	71
U – Value[2] W/(m^2.K)	5.7	5.7	5.7	4.1	3.7

[1] The tolerance of published data with respect to photometric properties is +/- 3 points
[2] The U-Value tolerance is +/- 0.1 W/(m^2.K)

Laminated glass:

This consists of two or more layers of glass that are bonded together with one or more polyvinyl butyral (PVB) interlayer. Once sealed together, the glass "sandwich" behaves as a single unit and looks like normal glass. Annealed or tempered glass can be used to produce laminated glass. Laminated glass may crack upon impact, but the glass fragments tend to adhere to the protective interlayer rather than falling free and potentially causing injury. Some of the benefits of laminated glass is security, safety, sound control, solar energy performance and ultraviolet screening. Especially, solar energy performance and ultraviolet screening can achieve a better performance by using coated (for example, Low-E) glass. The European standard for the laminated glass is EN 14449.

The light transmittance, the total solar energy transmittance (g-value) and the U-value depend on the type and the thickness of the glass. The light transmission and the total solar energy transmittance (g-value) have been determined according to the EN 410 standard. The U-value has been calculated according to EN 673 standard.

Table 3.2 Properties for laminated glass.

		44.1 Laminated glass
Light transmittance – LT	t_v	88
Solar factor – g	g	78
U – Value[1]	$W/(m^2.K)$	5.6

[1] The U-Value tolerance is +/- 0.1 $W/(m^2.K)$

Tempered glass

This is a type of glass that has increased strength and will usually shatter into small fragments when broken. Tempered glass is four to six times stronger than the annealed glass. Concerning the energy performance of the glass, tempered glass has the characteristics as annealed glass. So it is better to use coated glass in order to achieve solar control and thermal insulation. The European standard for the tempered glass is EN 12150-2.

As far as the thermal transmittance of the tempered glass is concerned, the values of the annealed glass are very similar. The only thing that changes in a tempered glass compared with an annealed glass is the strength and not the characteristics of the glass.

Sealed glazing unit

This consists of two or three sheets of annealed glass spaced apart and hermetically sealed to form a single glazed unit with a space between each glass sheet. Rarely, we use three sheets of glass, called "triple glazing", and mostly it is used in very cold climates. The key function of basic insulating glazing is thermal insulation. More functions can be added by replacing one of the glass components: enhanced thermal insulation, solar control, acoustic insulation and safety. The European standard for the double glazing unit is EN 1279.

The values of the light transmittance, the total solar energy transmittance (g-value) and U-value depend on the type and the thickness of the glass. The data of the measurements or calculations are only informative and can deviate depending on the conditions of the site. The light transmittance and the total solar energy transmittance (g-value) have been measured according to EN 410 standard. The U-value has been measured according to EN 673 standard.

Table 3.3. Properties of double glazing.

		4mm - 6mm Air – 4mm Double glazing unit	6mm Stopray Vision 50 – 12mm Air – 6mm
Light Transmission – LT[1]	t_v	81	81
Solar Factor – SF[1]	G	77	71
U – Value[2]	$W/(m^2.K)$	3.3	3.7

[1] The tolerance of published data with respect to photometric properties is +/- 3 points
[2] The U-Value tolerance is +/- 0.1 $W/(m^2.K)$

The properties of glass such as solar shading and emissivity influence the transmission through the glass (Carlsson 2005). Drastic changes can be obtained by applying a coating on the glass. Coatings can influence the range of transmitted radiation and its absolute level. The coatings can be reflective and selective.

Efficient solar shading can be obtained by reflective coatings. Increased reflection results in reduced total transmission. Currently the total solar energy transmittance, the g-value, for a sealed double glazed unit can be varied between 0.2 and 0.7 with a light transmittance t_v between 0.3 and 0.8.

Lower U-values can be obtained with coatings with low emissivity. The emissivity can be reduced from 0.87 to 0.01. The infrared radiation can be reduced to 20 %, without lowering the light transmittance below 0.75. This type of coating is selective, as it allows transmittance of the main part of the daylight, but has a high reflectivity of the infrared radiation. Currently the U-value (centre of the glass) for a sealed double glazed unit can be varied between 2.8 and 1.1. In modern office buildings sealed double glazed units are preferably used, often with a reflective coating.

3.5 Façade construction

Written by Danny Geysels

3.5.1 Introduction

In many projects standard curtain walls and window systems are combined to form a double skin façade. The choice is often done by the engineering company which does the design of the façade and the calculation of the performance.

A curtain wall is a construction consisting of vertical profiles (mullions) and horizontal profiles (transoms), which is built in front of a building structure to form the outside façade of the building and to guarantee the wind and water tightness of the building (see figure 3.20).
According to EN 13830, the definition of a curtain wall is following:
'Curtain walling usually consists of vertical and horizontal structural members, connected together and anchored to the supporting structure of the building and in filled, to form a lightweight, space enclosing continuous skin, which provides, by itself or in conjunction with the building construction, all the normal functions of an external wall, but does not take on any of the load bearing characteristics of the building structure'
The main difference with windows is that curtain walls are built in front of the building structure, while windows are built into the building openings.

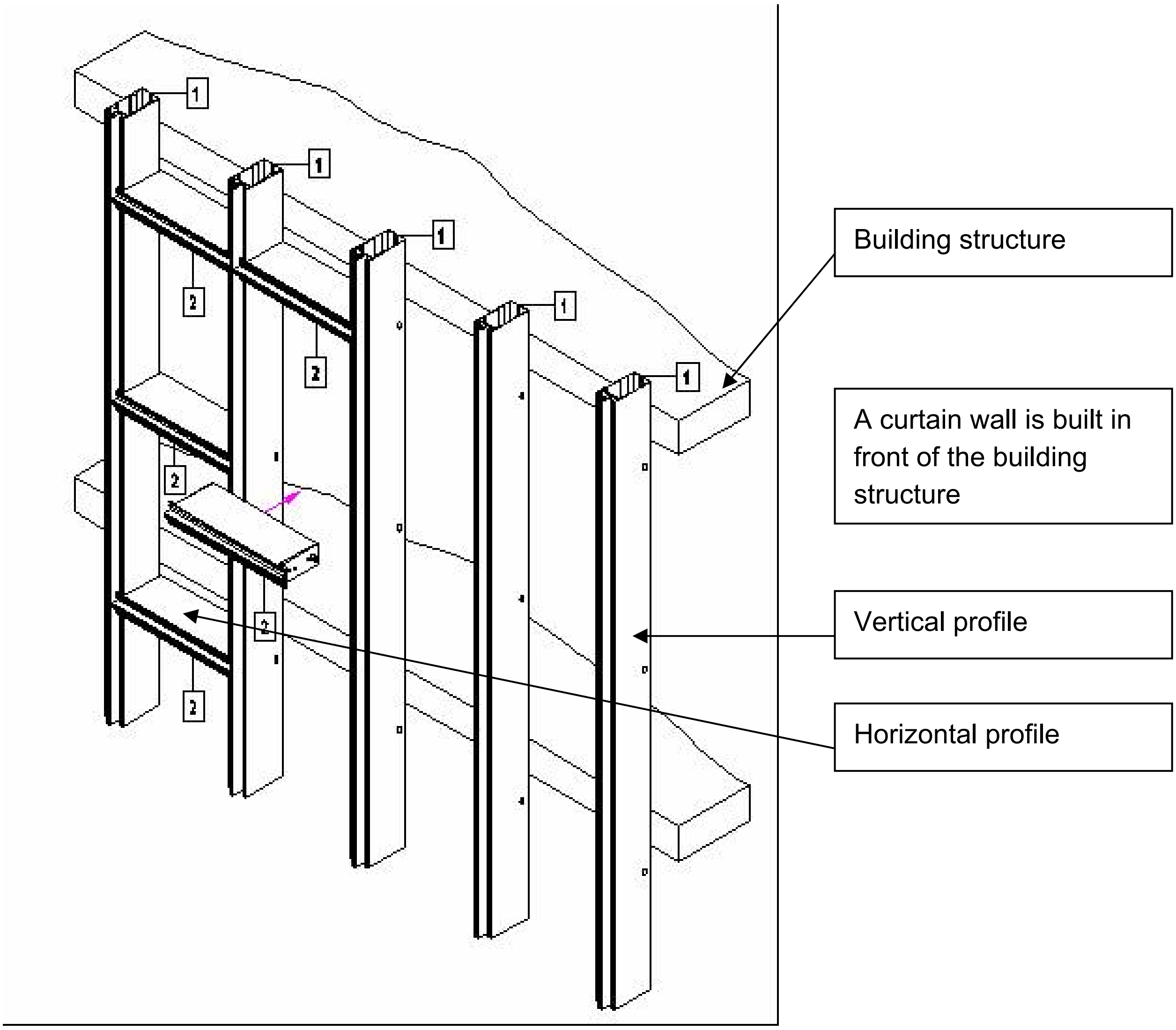


Figure 3.20 The principles of a curtain wall.

Two main systems of curtain walls exist:

- The classic curtain wall: First the transom-mullion construction is installed, afterwards, the glazing of the façade is done, mostly from outside.
- Element façade: the façade is built up storey per storey. The different elements of the element façade are entirely pre-fabricated, including the glazing. The completely finished elements can be installed on-site, the elements are placed on the outside of the building and not in the building, as for windows. One of the main advantages of this kind of systems is the fact that the fabrication can be done completely in a factory

under controlled environmental conditions and quality control. A more detailed practical example of an element façade is given in 3.5.4.

The curtain wall structures are usually made of extruded aluminium profiles because of the good ratio weight/stability and because with the extrusion process of aluminium profiles there is a very large flexibility in profile design.

Depending on the type of double skin façade (see also 3.3.2), a combination of window-window system (see example in 3.5.3) façade-window system and even a façade-façade system (see 3.5.5) can be used to form the double skins.

3.5.2 Main requirements on the glazed façades

More detailed description of the facades are given in chapter 3.3 – Technology.

The façade has to fulfil following requirements:

- Air tightness
- Water tightness
- Condensation
- Resistance to wind load
- Resistance to impact (safety of people)
- Airborne sound insulation
- Light
- Thermal insulation
- Fire resistance, reaction to fire and fire propagation
- Of course items such as equipotentiality and durability should also be taken into account.

Air-and water tightness:
One of the main requirements of a glazed façade is to guarantee the air and watertightess of the building. In general two systems are used to achieve this:

- Siliconised glazing: the sealing between the frames and the glass is done by using silicones. When carried out correctly, this way of glazing gives very good air and water tightness, but depends strongly on the quality of the worker who applies the silicones.
- Use of pre-formed EPDM gaskets. One of the main advantages of this way of glazing is the fact that the quality of the sealant is guaranteed by the extrusion of the gaskets. The gaskets can be applied very easily and very rapidly on site during the installation of the glass. Replacement of damaged glass panels can be done easily without having to cut away silicones.

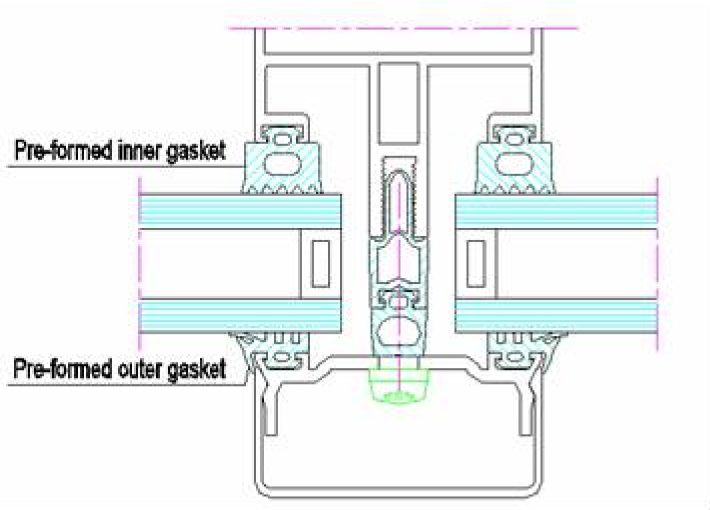


Figure 3. 21 Tightness of a glazed façade using inner and outer gaskets.

The inner gasket ensures the air- and water tightness (see figure 3.21). The outer gasket is used to avoid direct contact between the glass and the metal parts of the construction.

Double skin facades should be tightened in two steps, the inner skin and the outer skin. For a façade where the cavity is ventilated by outdoor air the outer skin should be as rain proof as possible and pressure equalizing, with a ventilated and drained cavity, so that moisture that still makes into the cavity can come out again. The inner skin must be airtight and diffusion tight, which must be placed on the warm side of the wall (in winter). This tightness will prevent air leakage between outside and inside.

Resistance to wind load:
Because the façade is not part of the 'primary construction', in the design of the façade specific safety factors can be applied (see also chapter 3.3.7). This is taken into account by designing profiles with the correct inertia values and to design correct connections (anchors) to the building structure.

Resistance to impact:
The required impact resistance of the façade strongly depends on the use and function of the façade. In general the impact resistance must ensure that people cannot fall through with injuries as a result. Depending on the situation, it is allowed that people can fall through in case of an impact (e.g. the inner skin of a double skin façade with a walkway in the cavity, where people cannot fall from a large height, when the correct glass type is chosen, no injuries because of the fall trough the glass occur). The impact resistance is a combination of profile design and the choice of the correct glass type.

Airborne sound insulation:
One of the main factors is the choice of the glass (see also chapter 3.3.5). It is evident that the profile design (mainly mass) has it influence, but certainly a major factor is the glass.

Fire resistance, reaction to fire and fire propagation:
Depending on the building, the façade also has to guarantee fire resistance (see also 3.3.4). Depending on the used systems (window/curtain wall, combination of both), the fire resistance can be guaranteed by the system itself, since some window and curtain wall systems are fire resistant. For specific project solutions, mostly project tests have to be carried out.

Thermal insulation:
In a single skin façade the thermal insulation is improved with special profile designs (incorporating thermal breaks) and the use of special shaped gaskets. In the double skin façade it is evident that the thermal properties strongly depend on: the type of double skin façade, the used blinds, the ventilation type which is being used etc.

In the following subchapters some examples of built constructions are given.

3.5.3 Example of a ventilated double window - box window

In this project, a special window section was designed to create a 'double skin window', with an internal skin with double glazing, outside single glazing. Instead of using two separate window systems behind each other, one specific window section was generated, which could be mounted as one piece into the building (see figure 3.22).

The movable part can be opened completely (inner and outer skin together). When opened, the outside pane can be opened for cleaning purposes. No mechanical ventilation was foreseen, ventilation between the inner and outer skin was only foreseen to avoid condensation between the two glass panels. The cavity (60 mm deep) was ventilated with outside air by means of interruptions in the gasket between the 2 openable parts (see figure 3.23). This was done both at the bottom and at the top of the window to create a small airflow in the cavity. At the first stage of the project, the interruption of the top gasket was forgotten by the workmen and condensation in the cavity occurred. After the modification, the condensation problem was solved.

One of the main goals of this double skin 'window' was to generate good acoustical performances with standard glass configurations. With standard glass configuration 6/18/4 in the inner skin and 6mm float glass in the outer skin, Rw=40 dB was reached, while for a standard window with the same IGU composition only Rw=34dB was reached.

A second goal of these windows was to generate excellent U_w-values. The overall measured U_w of a window was: U_w=1.28W/m²K.

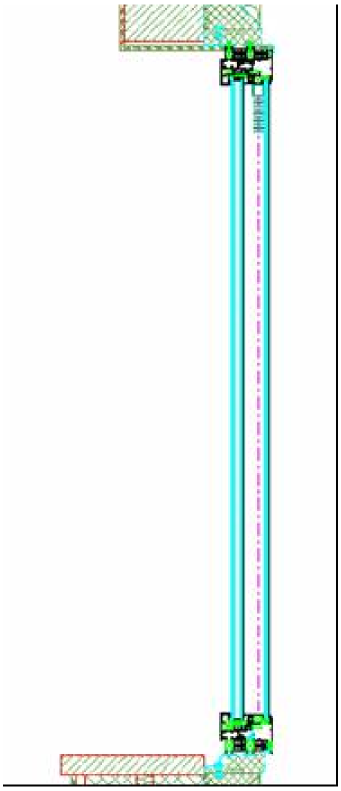


Figure 3.22 General view of the window.

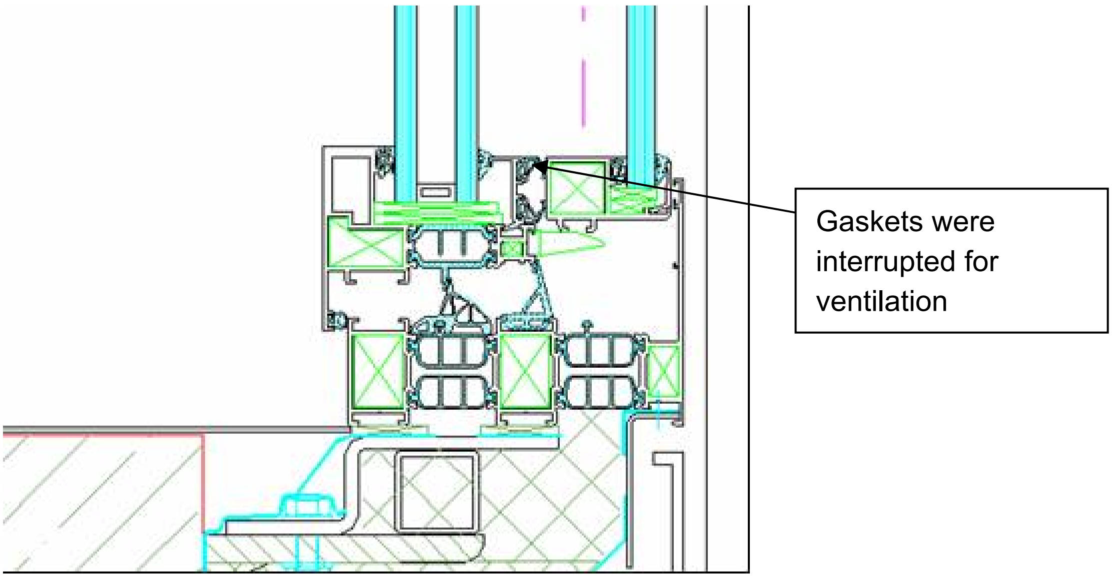


Figure 3.23 Detailed horizontal section of the window.

3.5.4 Example of a ventilated façade with double glazing outside – partitioned per storey

In this case the outside construction is formed by a façade construction with fixed glazing and thus cannot be opened. The outside skin is a sealed double-glazed unit, the inside skin is a single glass. The cavity in-between the two skins is ventilated by means of mechanical ventilation.

The following variants have been worked out:

- Continuous façade on the outside, the partitioning per storey is achieved by the transom configuration internally. The outer skin is built like a classic façade. First the transom-mullion construction is installed, afterwards, the glazing is done.
- Element façade: the façade is built up storey by storey. The façade consists out of ‘elements’ which contain the separation floor to floor. With this kind of construction, already glazed elements can be mounted on site level per level. An example of this system is described below.

The air in the cavity is extracted by means of a mechanical ventilation system. The profile system is designed so that ventilation holes can be created into the transoms. The internal glass panel can be opened for cleaning purposes. The extracted air enters the cavity through an opening (gap) at the bottom of the internal glass panel (see figure 3.24).

For this project, also internal sun shading is foreseen (integrated) in the cavity. One of the advantages of such a system is the small depth of the system, a disadvantage of this system is the fact that it has to be taken into account that the inside glass panel must be openable for cleaning. This influences the arrangement of furniture in the office.

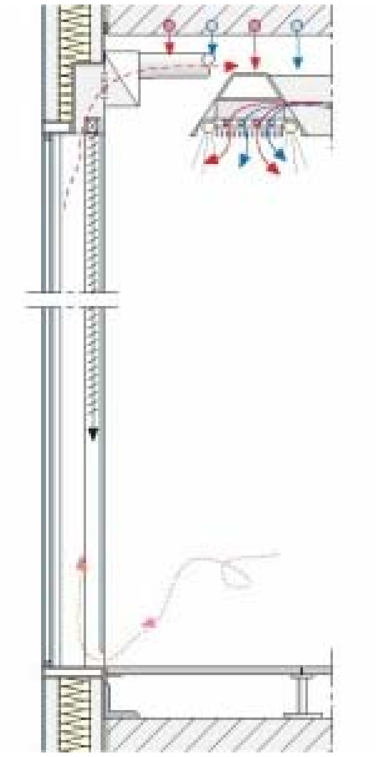


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Figure 3.24 General extraction principle.

Figure 3.25 shows a horizontal section of the construction. The inside glass panels are single glass units which can be rotated via a simple hinge mechanism for cleaning.

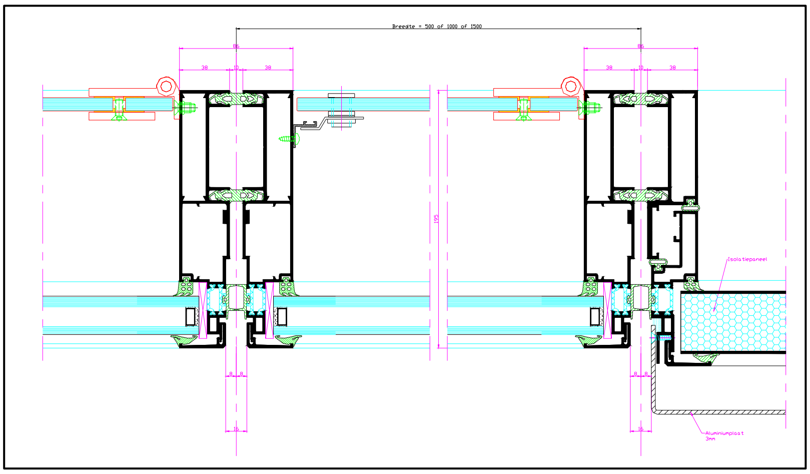

Figure 3.25 Horizontal section

Figure 3.26 shows a vertical section of the construction. A special transom was designed to integrate the sun blinds and the holes for the extraction of the air. The air enters the cavity at the bottom of the inner glass panel. The horizontal profiles we designed so that the sun blinds could be integrated inside the profiles.

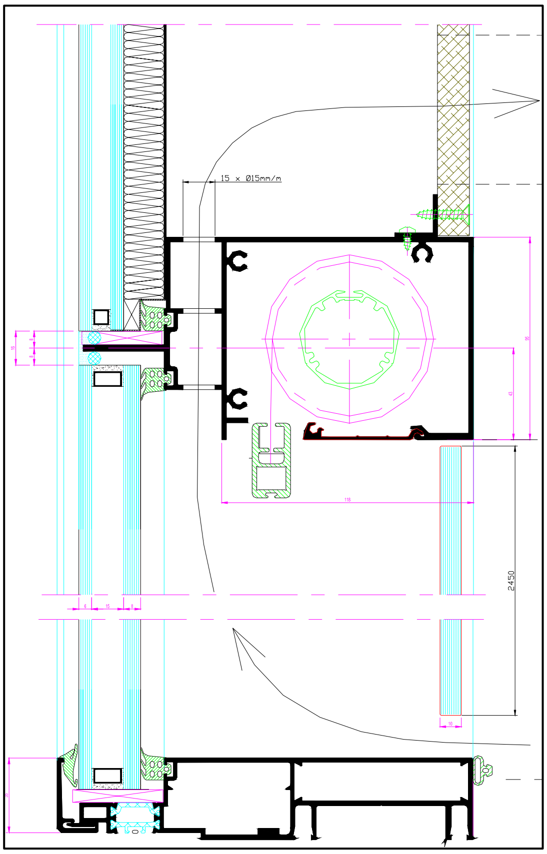

Figure 3.26 Vertical section

One of the advantages of an element facade with double skin is the mounting of the system. The elements can be fully prepared in a factory. The already glazed elements are then mounted on site element per element (see figure 3.27 and 3.28). Depending on the configuration, different glazed parts can be combined in one element. The complete façade is built up level per level.

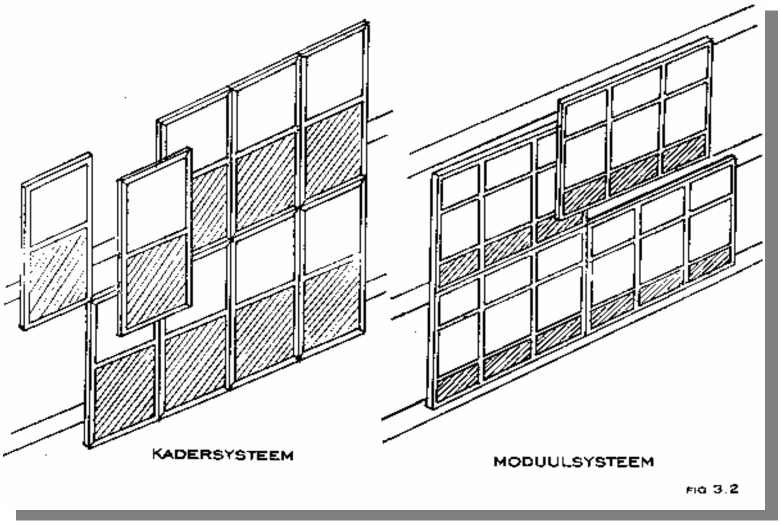

Figure 3.27 Combination of glass panels in element façade.

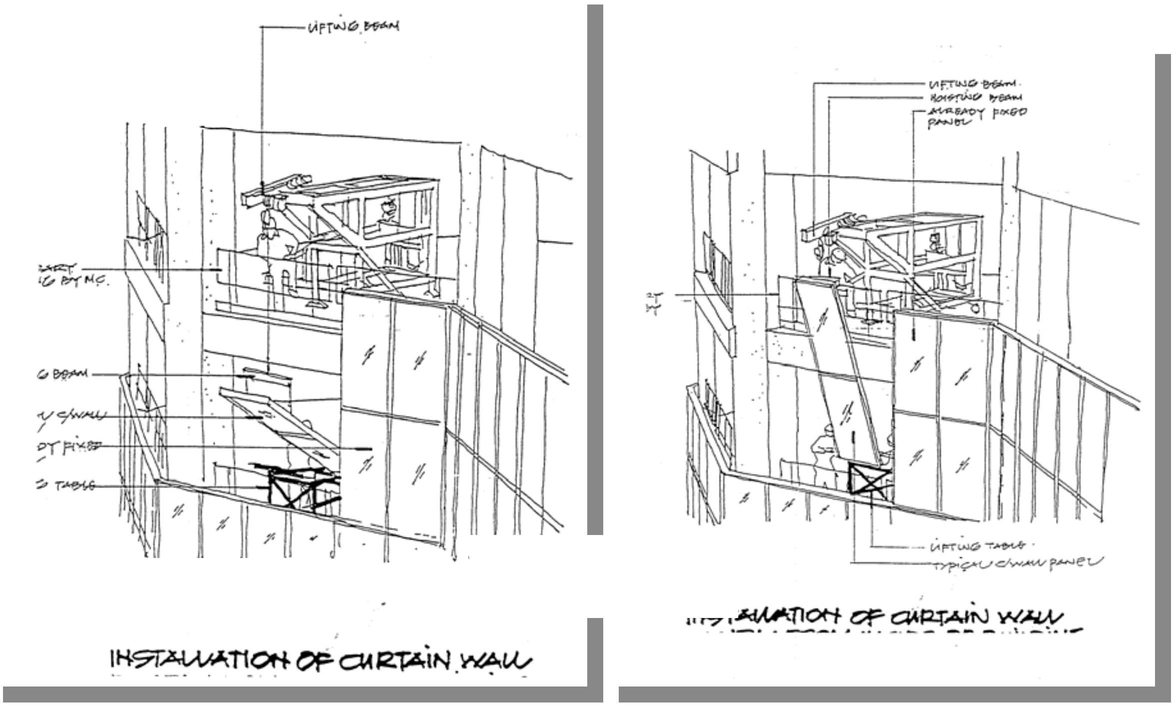

Figure 3.28 Schedule of installation.

3.5.5 Example of a 'Shaft box' ventilated double skin façade

In the 'shaft box' façade, both the inner and outer skin are continuous over the height of the building. The ventilation of the cavity between the inner and outer skin is done over the complete height of the cavity through the holes in the walkway at the floor level (see figure 3.29 and 3.30). In this project standard curtain wall profiles were used.

Figure 3.29 Views of the double skin façade.

Figure 3.30 View of the walkway through which air is extracted.

Both the inner and outer skin consist of a façade system. In this case the inner façade is built in-between the storeys to allow the mounting of the air conditioning devices.
For the outer skin, single laminated glass is used because the glass also needed to guarantee the safety of people walking in-between the 2 skins, the inner skin is glazed with double glazed units. The cavity between the inner and outer glazing has a depth of 600mm. At each floor level, 2 doors were foreseen in the inner skin to access the walkways.

In this project 2 regimes were distinguished:
<u>Winter regime:</u>

- Fresh air necessary for the central air conditioning system is supplied by the bottom side of the cavity between the inner and outer skin.
- Off-set horizontal pivot windows provided at the upper side of the outer curtain wall can be opened electrically (air current from top to bottom).
- The cold air current that is created in the cavity is partly heated by the heat loss of the inner curtain wall, which implies energy saving. The air speed of the inner curtain wall must be max. 1,1m/s in order not to disturb the thermal comfort behind the glazing (too large cooling).

<u>Summer regime:</u>

- Already used and cooled air of the air conditioning system is supplied by the bottom side of the cavity between both inner and outer curtain wall and removed by the open off-set horizontal pivot windows.
- This air current creates an intermediate climate between the high outside temperature and the cooled inside climate.
- Fresh air for the air conditioning system is directly supplied by the outside.
  Heat transportation because of radiation is restricted by the sun screens at the outside of the inner curtain wall.

In figure 3.31 – 3.33 some typical sections are shown.

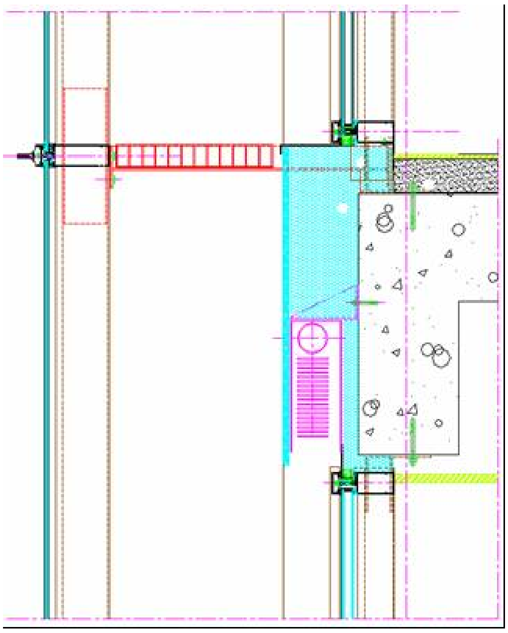

Figure 3.31 General section.

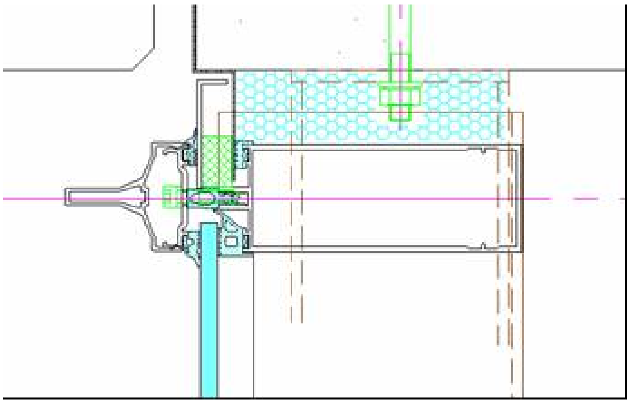

Figure 3.32 Section of the single glazed outer skin.

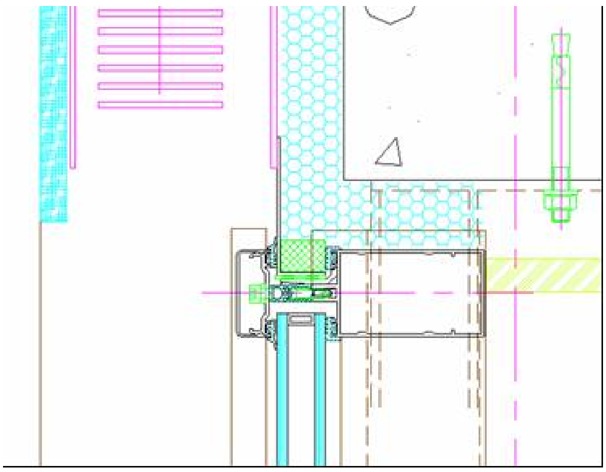

Figure 3.33 Section of the double glazed inner skin with standard curtain wall profiles

3.6 Costs

Written by Åke Blomsterberg

3.6.1 Introduction

Buildings must be made sustainable i.e. a building must have a small as possible impact on the environment during its life time. Responsible for this are several different categories of persons e.g. designers, building managers. Products are to be judged from a life cycle perspective, where attention must be paid to all impacts on the environment during the entire life cycle. At an early stage the designer, the buyer and the contractor can make environmentally friendly choices. A building will change during its life span and besides it consists of several different components with different life spans. Usually the components of the structural parts such as the facade system have a longer life span than many other parts of the building e.g. the ventilation system.

Important factors relevant to life cycle perspectives are:

- Life span.
- Environmental impact.
- Building changes.
- Cost analysis.

Very often the practical life span of e.g. a ventilation system is determined by the time span a building will be used for the current purpose. During design maintainability and flexibility of especially the installations have to be taken into account because the use of e.g. an office building can change several times during the life span of the building. The reasons for renovation or reconstruction are more often changed needs caused by changed use than too much wear and tear or that the installations have become old fashioned, that spare parts for expiring products only are kept in store for a limited period of time or for other reasons do not fulfil the demands of today. The façade, especially a glazed façade, can be very crucial for the choice of installation systems.

An important factor when choosing a facade system is the costs of the façade and the entire buildings. Today usually the investment cost and not the life cycle cost is considered. Only taking into account the investments cost often result in a facade system and a building that just fulfils the requirements of the building code at the lowest investment costs. A glazed double skin façade is usually more expensive than a glazed single skin facade, which is usually more expensive than a traditional façade, at least considering the investment cost. Justification of its inclusion in a building design is however seldom based on energy efficiency and associated cost savings. Qualitative benefits of solar control, moderated surface temperatures, noise reduction, reduced glare, reduced heating/cooling demand, aesthetic purity and increased daylight are generally seen only as intangible 'bonus' benefits.

Preferably the cost of the entire building is taken into consideration, in order to avoid sub optimisation. A well designed double skin facades can result in lower operating cost (mainly lower energy costs compared with a glazed single skin façade) for the building in question. The cleaning costs for the façade can be higher. There is little information available on investment and maintenance cost for existing double skin façade systems.

3.6.2 Methods of life cycle cost calculations

This section describes methods for calculating the Life Cycle Cost (LCC) of double skin façades and buildings with integrated double skin facades. The LCC of an asset is defined as: "the total cost throughout its life including planning, design, acquisition and support costs and any other costs directly attributable to owning or using the asset" (New 2004). To include the qualitative benefits/drawbacks, albeit not complete, a method to convert qualitative in quantitative costs is also included. There are four different methods of calculating the life cycle cost, to calculate:

- the net present value
- the internal rate of return
- the annual cost (annuity method)
- the pay back time

The last method ignores the interest rate and does not really calculate the life cycle cost, and is therefore a rough method. The LCC methods are described for instance in VDI 6025 and there are several sources on the internet which offer online calculation of LCC using the described methods. prEN 15459 shall also be mentioned which describes a method for economic calculation of heating systems which may be adapted to other technical systems.

<u>Net present value method</u>
A common method is to calculate the net present value, which measures the excess or shortfall of cash flows in present value terms. The method combines investment, energy, maintenance and environmental cost during part of or the entire operational phase of a building. The yearly cost for energy, maintenance and environment are recalculated to a cost at present, today. Each cash in- or outflow is discounted back to its present value using an assumed discount rate and then all cash flows are summed. The total life cycle cost can then be defined as:

$LCC = Investment_{installation} + Investment_{building} + \sum Energy\ costs_{electricity,\ heat\ etc.} + \sum Maintenance\ costs + \sum Environmental\ impact\ costs - Remaining\ value$

All costs are calculated back to year 0 (time of investment) and added over the entire life span of the system. The LCC value must be a positive value for an economic successful project. Choosing a realistic discount rate over the life span of the investment is essential for a net present value calculation method as well as for all other described LCC calculation methods. For projects with a higher risk higher discount rates should be used.With this procedure different systems can be compared. The environmental impact in costs is usually very difficult to determine and is therefore often left out. The environmental impact is to a high extent taken into account by including energy. Often the LCC calculations are made to optimise the energy use during the period of operation.

The LCC-calculations can be a very useful decision tool for a retrofit of system as well as for a new system comparing different alternatives. Tools and software are available from manufacturers. In table 3.4 an example of a calculation is given.

Table 3.4 Calculation of life cycle cost for an existing and a new fan by Gebhardt (manufacturer of fans). The following assumptions were made: life span 20 years, calculation interest 4 %, price increase in electricity 2 %/year.

Fan alternative	Existing fan	New fan	Unit
Design air flow	1.5	1.5	m^3/s
Total pressure	250	250	Pa
Total efficiency	16	61	%
Price of electricity, year 0	0.085	0.085	ECU/kWh
Fan investment cost, year 0		2267	ECU
Installation cost, year 0		227	ECU
Total investment	0	2494	ECU
Yearly maintenance	227	57	ECU/year
$LCC_{maintenance}$	3085	775	ECU
Power demand at design air flow	2.5	0.615	kW
Operational time	8760	8760	Hours
Use of electricity	21900	5387	kWh/year
Yearly cost of electricity	1862	458	ECU/year
$LCC_{electricty}$	30435	7488	ECU
LCC_{total}	33520	10757	ECU

New tools and software are being developed.

Internal rate of return (IRR)

The internal rate of return is the return rate which can be earned on the invested capital over the life time of an investment. An economic successful project has an IRR-value which is greater then the interest that could be earned by alternative investments (bank account, bonds, shares).

Annuity method
The annuity method (VDI 2067) allows non-recurring payments/investments and regular payments to be consolidated with the aid of the annuity factor "*a*" during an observation period "*T*" (e.g. 50, 70 or 100 years – the approximated life span of a building). Periodic and non-periodic payments with changing amounts are transformed over an assessment period into constant periodic payments. The annuity as the determined common constant periodic payment can be seen as an interest share for capital to be repaid up to the amount of the capital value. The investment amount and current payments which are subject to changes are transformed with the aid of the annuity factor "a" into average payments over the assessment period "T". With the annuity method capital related, consumption related, operation related and other costs are taken into account.

As an example on LCC calculations the annuity method to calculate the annual LCC of an investment over a given period (life cycle) is described in detail below, as this method is rather common.

3.6.3 Life cycle cost calculation using the annuity method

Written by Reinhard Waldner

Capital-related costs

The annuity of capital-related costs can be calculated using equation:

$$A_{N,K} = \left(A_0 + A_1 + A_2 + \ldots + A_N - R_W\right) \cdot a + \frac{f_K}{100} \cdot A_0 \cdot ba_{IN} \quad \textbf{(3.1)}$$

$A_{N,K}$ annuity of payments linked to capital in €/year

A_0 investment premium in €

$A_{1,\,2,\,\ldots,\,n}$ cash value of 1st, 2nd, nth replacement

R_W net book value

a annuity factor

f_K factor for repairs in % of the investment premium per year

ba_{IN} price-dynamic annuity factor for repair payments

The cash value of replacements is given by equation:

$$A_1 = A_0 \cdot \frac{r^{(1\cdot T_N)}}{q^{(1\cdot T_N)}} \qquad A_2 = A_0 \cdot \frac{r^{(2\cdot T_N)}}{q^{(2\cdot T_N)}}$$

$$A_3 = A_0 \cdot \frac{r^{(3\cdot T_N)}}{q^{(3\cdot T_N)}} \qquad A_n = A_0 \cdot \frac{r^{(n\cdot T_N)}}{q^{(n\cdot T_N)}} \qquad (3.2)$$

T_N service life of installation components in years

q interest factor

r price change factor

n number of replacements within the observation period

The net book value is determined by straight-line depreciation of the investment premium until the end of the observation period and discounted at the beginning of the observation period. If the observation period T exceeds the service life T_N of the components under observation, it is not the (initial) investment premium that undergoes straight-line depreciation, but the replacement investment.

$$R_W = \underbrace{A_0 \cdot r^{(n\cdot T_N)}}_{\text{price at point of purchase}} \cdot \underbrace{\frac{(r_0+1)\cdot T_N - T}{T_N}}_{\text{straight-line depreciation}} \cdot \underbrace{\frac{1}{q^T}}_{\text{discounted at the beginning}} \qquad (3.3)$$

T observation period in years

The annuity factor is given by equation:

$$a = \frac{q^T \cdot (q-1)}{q^T - 1} = \frac{q-1}{1-q^{-T}} \qquad (3.4)$$

If there are price changes in the regular payments for maintenance during the observation period, these payments must be multiplied by the price-dynamic annuity factor.

$$ba_{IN} = b_{IN} \cdot a \qquad ba_S = b_S \cdot a \qquad (3.5)$$

$$ba_V = b_V \cdot a \qquad ba_B = b_B \cdot a$$

The price-dynamic annuity factor is given by determining the annuity of cash value factor *b*, for which the cash value factor is given by equation:

$$b = \frac{1-\left(\frac{r}{q}\right)^T}{q-r} \qquad r = q \text{ implies } b = T/q \qquad (3.6)$$

<u>Consumption-related costs</u>

Price changes for energy costs give rise to the following estimate:

$$A_{N,V} = A_{V1} \cdot ba_V \qquad (3.7)$$

$A_{N,V}$ annuity of consumption-related costs

A_{V1} consumption-related costs in first year

ba_V price-dynamic annuity factor for requirement (consumption)-related costs

r_V annual price change factor for requirement (consumption)-related costs

Consumption-related costs are determined using equation:

$$A_{V1} = Q_{3,Heat} \cdot Price_{Heat} + Q_{3,Cooling} \cdot Price_{Cooling} + Q_{3,Electricity} \cdot Price_{Electricity} + Q_{3,Water} \cdot Price_{Water} \tag{3.8}$$

$Q_{3,Heat}$ energy use for heating in kWh/year

$Q_{3,Cooling}$ energy use for cooling in kWh/year

$Q_{3,Electricity}$ use of electricity in kWh/year

$Q_{3,Water}$ water consumption in m^3/year

$Price$ in €/kWh or €/m^3

Operation-related costs

Changes that can be caused by an alteration in wage levels, among other things, also underlie operation related costs. For these, the following estimate is given, taking into consideration price changes analogous to the consumption-related costs:

$$A_{N,B} = A_{B1} \cdot ba_B \tag{3.9}$$

$A_{N,B}$ annuity of the operation-related costs in €

A_{B1} operation-related costs in first year

ba_B price-dynamic annuity factor for operation related costs

Other costs

Corresponding with the estimate given above, for other costs:

$$A_{N,S} = A_{S1} \cdot ba_S \tag{3.10}$$

$A_{N,S}$ annuity of other costs in €

A_{S1} other costs in first year

ba_S price-dynamic annuity factor for other costs

Annuity of total annual payments

The sum of the capital-related, consumption-related, operation-related and other cost annuities gives the total annuity A_N for all payments:

$$A_N = -\left(A_{N,K} + A_{N,V} + A_{N,B} + A_{N,S}\right) \qquad (3.11)$$

A_n is negative and the most profitable system is that which generates the least costs.

Incoming payments

The annuity method described above may be extended to include also incoming payments (revenue, rental income). The calculation formulae to be used are those given in the section above. As long as incoming payments are not differentiated by individual payment types, they can be obtained by the following estimate – on taking note of price changes:

$$A_{N,E} = E_1 \cdot ba_E \qquad (3.12)$$

$A_{N,E}$ annuity of revenue in €

E_1 revenue in first year

ba_E price-dynamic annuity factor for revenue

Equation (3.11) has to be extended to:

$$A_N = A_{N,E} - \left(A_{N,K} + A_{N,V} + A_{N,B} + A_{N,S}\right) \qquad (3.13)$$

In this case A_N must be > 0 in order for the system to be economical, i.e. the annuity of incoming payments is greater than the annuity of all outgoing payments. If different façades are being compared with one another, preference should be given to that for which the largest total annuity is calculated.

4 Applications

4.1 Energy use, daylight, indoor climate and sustainability

4.1.1 Energy use, daylight and indoor climate

Written by Åke Blomsterberg

The great challenge for a glazed office building (single and double skin) is to optimise energy use, use of daylight, visual and thermal comfort at a reasonable investment and life cycle cost.

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 on the other hand often have a higher use of electricity than older office buildings, which is due to a higher energy use for ventilation, cooling, lighting and office equipment. Even in older office buildings the use of electricity has increased, mainly due to office equipment.

In practice the use of electricity for lighting may very well be at the same level for an office building with large windows as for an office building with traditional window sizes (Poirazis 2005). This can be true if traditional solar shading (fixed exterior or intermediate Venetian blinds) with traditional control (none or manual) is installed. In buildings with a glazed façade the daylight is often not utilized. Often glare problems occur, which is often dealt with by the solar shading device.

Especially since the beginning of the nineties office buildings with glazed facades have been built. These buildings risk having a higher energy use and poorer indoor climate than traditional office buildings. A number of issues concerning glazed office buildings have, however, not yet been satisfactorily answered:

- Is the energy use lower or higher than for an office building with traditionally sized glazed areas?
- Are glazed office buildings ecological and sustainable buildings?
- Is it possible to ensure a good indoor climate during the main part of the year?
- Is the full view from the outside desirable? And vice versa from the inside?
- Is the daylight environment better in a glazed office building?

Office buildings with glazed facades often have a higher use of energy for cooling and heating than an office with a traditional façade, unless they are designed properly. With traditional improvements in the design of windows and solar shading devices this difference can be lowered (Poirazis 2005). A standard highly glazed single skin façade increases the risk for an unsatisfying thermal comfort close to the façade and glare further inside the building. A double skin façade will lower these risks. Glazed buildings (single and double skin) require more planning and have less tolerance for design and construction errors (Brunner 2001).

Energy, indoor climate and daylight simulations show that for a modern office building to be built in Sweden (Blomsterberg 2006), with a larger glass percentage of the façade than traditionally (45 % instead of 20 %), it should be possible to:
- efficiently utilize the increased access to daylight using daylight redirection and intelligent control of lighting and daylight and thereby lowering the use of electricity for lighting and at the same time improve the visual comfort, while ensuring good thermal comfort
- arrive at a reasonable energy use, which is at the same level or lower than for a traditional modern office building

In order to arrive at a reasonable energy use the window percentage of the façade was reduced from about 75 % (fully glazed looking from the inside) to about 50 %, g-value for glass + solar shading facing south, west and east from about 0.35 to about 0.1 and window U-value from 1.8 to 1.1 W/m²K. This means that the g (total solar energy transmittance of glazing and solar shading) x glazing area of the west, south and east facades is similar for the real and the traditional building (20 % glazing). Besides all opaque areas of the facades will be well insulated, U-value of 0.22 W/m²K. The building will have a double skin façade facing south, east and west for floor 3 – 5. The double skin façade is a multi-storey façade, where the cavity is naturally ventilated through an opening at the top and the bottom. During winter the opening at the top is closed by a damper. The reasons for choosing the double skin façade were the following:
- protected movable solar shading. The building will at times be subject to strong winds, snow, rain and freezing temperatures
- better sound attenuation towards the outside
- window airing possible irrespective of outdoor climate, except very warm days.

4.1.2 Sustainability

Written by Sabrina Prieus and Gilles Flamant

Energy saving is an important element in achieving more environmentally friendly buildings. Conservation of natural resources, limitation of water use, re-use of and recycling of materials or components, and limitation of disposal waste after demolition are also related subjects.

To assess environmental impact as a performance indicator on the building level, life cycle assessment (LCA) is an appropriate tool. The environmental performance is linked to the building's in- and outputs evaluated from cradle to grave. This comprises all energy and mass flows, including also emissions to air, water and soil. Typically, four life cycle stages are considered during the assessment:

- production of all materials, including raw material extraction
- building construction
- building use and operation, which typically accounts for 80 % of the energy life cycle cost
- end of life, including building demolition, waste treatment and disposal

The evaluation of transport is included in all relevant stages of the life cycle. It is however important to note that it is a complex process to quantify all parameters within the LCA evaluation, which makes an assessment and consequent interpretation of results difficult.

Double skin facades require more inputs than a classical solution: additional space, resources, energy for production and construction, building time, etc. In order to realise a solution with a reduced environmental impact, the additional inputs during the production and construction phase need to be compensated by a significant decrease in outputs during the use and demolition stage of the building.

For double skin facades, this can be realised by the fact that they can reduce the energy consumption for heating, cooling and/or lighting or by the improvement of other performances like less frequent maintenance of the shading devices, etc.

With a systematic design, a collection of components can be realised that are easily assembled. This makes construction and dismantling easier and less energy consuming.
A few recommendations:

- Design the façade system so that its parts (the frames, the components…) are interchangeable.
- Ensure modular junctions that can be fabricated without a large amount of energy.

- Conceive the different components so that they are easy removable or replaceable by other components.

4.2 Potential advantages with double skin facades

Written by Åke Blomsterberg

Since the nineties, there has been an increase in new office buildings with glazed facades. The increased use of glazed facades has been enabled thanks to the development of façade construction technology and physical properties of glass during the last decade. There has been and is a growing interest among clients to build and among architects to design glazed buildings with double skin facades. The purpose of these double skin facades has often been to reduce the high temperatures in the building behind during the summer and to lower the heat losses during winter compared with a glazed single skin façade. Other benefits are that the double skin façade can provide: a thermal buffer zone, wind protection with open windows, fire protection, aesthetics, solar preheating of ventilation air, sound protection, night cooling and a site for incorporation of PV cells.

Why are fully glazed facades being built? Architecturally an airy, transparent and light building is created, where the access to daylight can be higher than in a more traditional office building. The idea is often to create a building expressing openness and future. In many cases a glazed building is built to display the profile of the company in the building. Glazed buildings can be a vision of an energy efficient building, which however is not easy to realize.

Commercial buildings with integrated double skin facades can be very energy efficient buildings with all the good qualities listed above. However not all double skin facades built in the last years perform well. In most cases large air conditioning systems have to compensate for summer overheating problems and the energy consumption badly exceeds the intended heating energy savings. Therefore the architectural trend has in many cases unnecessarily resulted in a step backwards regarding energy efficiency and the possible use of passive solar energy.

4.2.1 Potential technological advantages

Written by Åke Blomsterberg

There are a number of potential advantages, mentioned in several reports and articles. The potential technological advantages are:

- Individual window airing almost independent of wind and climate conditions, mainly during sunny winter days and intermediate seasons (spring and fall)

- Reduced heating demand thanks to preheating of outdoor air in the cavity
- Night cooling of the building – when opening of inner windows is possible
- Improved burglary protection thanks to the double skins
- Better sound attenuation towards outside
- Efficient outer (intermediate) solar shading, as it can be used on windy days also
- Wind load on the façade can be reduced

4.2.2 Potential non-technological advantages

Written by Ifigenia Farrou

Non-technological advantages:

- Full transparency of the double skin facades, which is appealing to architects to use in the building design
- With proper design, double skin facades are compatible with all climatic conditions
- The use of double skin facades is encouraged by the existing legislation. i.e. :
  - Legislation on sound protection as double skin facades provide better sound insulation than single skin buildings
  - Legislation on thermal insulation as double skin facades provide lower U-values than the conventional single skin glazed facades
- A proper design with double skin facades can result in adequate visual comfort
- Good level of knowledge in the majority of the research institutions and big companies usually working at an international level concerning the typology, performance, design and construction of double skin facades
- Good reputation among architects for aesthetics reasons and the possibility to characterise the building by the structure of the double skin façade.

4.3 Potential disadvantages with double skin facades and how to overcome them

4.3.1 Potential technological disadvantages

Written by Åke Blomsterberg

There are also a number of potential technological disadvantages with double skin facades. They are:

- Less efficient for cross airing and insufficient heat removal from office rooms at calm weather, if mainly natural ventilation
- Risk of high temperatures in office rooms when window airing during warm summer/spring/fall days
- Difficult to efficiently filter outdoor air, mainly if natural ventilation
- High investment costs
- High operation and maintenance costs

- Reduced office floor area
- Risk of sound transmission via the facade between offices with open windows
- Cleaning can cause additional costs
- Energy savings potential often overestimated

4.3.2 How to overcome technological barriers

Most of the disadvantages can be avoided and most of the advantages achieved by implementing appropriate performance specifications followed by careful design, construction, commissioning and operation.

4.3.3 Potential non-technological disadvantages

Written by Ifigenia Farrou

Potential non-technological disadvantages are:

- No awareness of any specific legislation on double skin facades among architects, engineers and clients. Usually governmental bodies and façade suppliers especially those working at international level are aware of the legislation but dissemination of the knowledge to professional engineers and clients is missing
- Lack of legal standardized schemes among architects, engineers and clients/developers
- There is no documentation of the built double skin facade examples in terms of their energy and environmental performance. Engineers and façade suppliers, who were involved in the design of double skin facade system are not aware of the success or malfunctions of the system
- Low level of knowledge in the group of architects, building owners and investors concerning the typology, performance and design of double skin facades
- Low level of knowledge on the energy performance of double skin facades among all target groups engineers, architects, developers, façade suppliers and governmental bodies. Currently there is no way for engineers, architects, decision makers and façade suppliers to get informed on the performance of the system in terms of actual figures i.e. energy figures (kWh/m²) and internal temperatures (°C) that can be attributed to the double skin facade system.
- Double skin facade systems have been designed mainly for office buildings and not so much for residential and other type of buildings because of their increased construction and investment cost.
- The reputation of double skin facades is not always good among the different target groups. It seems there is scepticism in the scientific field, the clients and the decision makers concerning the energy efficiency, the indoor air quality and thermal comfort levels that this type of façade can provide. The reputation is good among the building industry/façade suppliers that try to promote this type of façade but there is also

concern because of the high investment cost. Among the majority of the architects the reputation is good mainly because of aesthetic reasons.
- Lack of planning policy regarding double skin facades.
- Inadequate promotion of the product from the relevant companies and façade suppliers. Therefore architects and clients/developers are not convinced of the utility and advantages of the product and the facility managers do not suggest its use.

4.3.4 How to overcome non-technological barriers

Provide information on double skin facade legislation. This can be realised by:
- Introduce the EN standards: EN 13830 'Product Standard - Curtain Walling' and prEN 13119:2004 that gives a definition of double skin facades. It is suggested that all countries would comply with the EN standards and fit these standards to their markets and needs. Architects, engineers, decision makers and façade suppliers should be made aware of the legal schemes.
- Introduce homogenous calculation procedures and predictive tools to engineers and façade suppliers in order to have comparable results when assessing the performance of the system. This can be covered by the standards prEN 13947:2005 Annex D that gives the equation for the calculation of the U-value of curtain walls; additionally the simple calculation method developed within the BESTFACADE project could be used in all European countries for the thermal and visual performance of double skin facades.

Additionally it is important to:
- Increase knowledge on double skin facades regarding the system's characteristics, advantages and disadvantages compared to conventional systems among architects, engineers and clients/developers.
- Provide better-documented examples of double skin facades including real data on the energy and environmental performance of the system along with operational and investment costs in order to increase reliability of the product and awareness among all target group.
- Increase dissemination of best practice examples through seminars on national level, workshops, education at university level and the use of internet.
- Develop and distribute a best practice guideline with illustrations of double skin facade built examples. The document should be user friendly and easily accessible to engineers, architects and clients.
- Expand the use and applicability of double skin facades to other types of buildings (i.e. schools, public buildings).
- Carry out marketing from the involved associations and façade suppliers: Companies with experience on international level, i.e. EuroWindoor, could act as a driving force to this on EU level in collaboration with the national markets and the national chamber of engineers. Additionally, the establishment of a board/institution of façade

engineering on EU and national level could define specific standards for double skin facades and be the link between the designers and the construction industry.

- Governmental bodies should provide funding to support both research and construction of double skin facades.
- Facility managers and façade suppliers could provide 'demonstration' projects in to order to demonstrate the double skin facade systems, to document the whole procedure from the pre-design building until the occupancy of the building and to indicate the performance of the technology.
- The cost of the double skin façade should be reduced.

4.4 Performance specifications and requirements

Written by Ake Blomsterberg

4.4.1 Introduction

Applying performance specifications to double skin façade systems and buildings with these facades provide a more flexible and less rigid approach to facade system and building design and operation whereby targets are set which must be met in order for the facade system and the building to perform as required. This approach also facilitates the implementation of innovative systems.

Performance specifications can be applied to a wide range of criteria that influence the overall performance of a building and at three different levels, which should be applied in the following order:

1. building performance specifications (energy use, thermal comfort, maintenance cost, indoor air quality, noise levels) for e.g. an entire office building
2. system performance specifications (energy use, maintenance, indoor air quality, ventilation rate, noise levels, draft, air/operative temperature, thermal comfort, visual comfort, humidity) for e.g. a double skin facade
3. component performance specifications for e.g. glazing

Double skin facade systems can cause the use of significant amounts of energy and therefore it is important that the facade system is energy efficient.

Performance specifications must meet certain criteria in order to be successfully implemented: measurable in order to enable verification and checking against set targets, predictable in order to enable design to fulfil the specifications, technically "sound", relevant to the criteria in question, resulting in reasonable life cycle cost, and defensible during possible litigation.

The overall performance specifications should be specified by the client and/or the user, and the detailed specifications (mainly on system and component level) for technical performance, commissioning, operation, maintenance and deconstruction by the designer. During the design phase additions and changes to the detailed specification often have to be carried out.

The specifications should also include non-technical aspects such as the degree of user and occupant control, the level of user friendliness and user instructions.

An example of energy and thermal comfort related performance specifications on the building level for an office with double skin facades being built in Malmö (Blomsterberg 2007) is :

- The overall energy use: 120 kWh/m²year (district heating + district cooling + electricity for pumps, fans etc. + electricity for lighting, PC’s, servers etc.)

Table 4.1 Energy performance specifications for an office building with double skin facades being built in Malmo, Sweden. The limit for the total energy use is 120 kWh/m²year.

kWh/m^2/year	Maximum	Target
District heating	80	50
District cooling	60	30
Use of electricity for pumps, fans etc.	20	10
Use of electricity for lighting, PC’s, servers etc.	50	40
Total		120

- Thermal comfort in offices and meeting rooms, within the occupied zone: operative temperature during winter 21 °C – 24 °C and during summer 22 °C – 25 °C (30 hours > 27 °C), air velocity < 0.15 m/s in winter < 0.25 m/s in summer, vertical air temperature difference between 1.1 and 0.1 m < 3 K, temperature radiation asymmetry from vertical surfaces < 10 K, 90 % of the time PPD < 10 % (ISO 2005).
- Assumed level of activity (number of people, office hours, presence frequency, operating times etc.) as agreed with the client

Examples of energy and comfort performance specifications on the system level for the building above:

- Roof, walls excluding windows, and floor: U-values incl. thermal bridges of < 0.12, < 0.22 and < 0.32 W/m²K.
- Windows: area < 53 % of facade; U-value < 1.1-1.2 W/m²K; light transmittance > 55 %; daylight factor between 2 and 10 %;

- Solar shading (south, east, west): total solar energy transmittance for glazing + solar shading $g_{system} < 0.1$
- Heat recovery on air: efficiency > 70 %
- Ventilation: average SFP (specific fan power) < 2.0 kW/m³/s
- Lighting: installed electric power < 10 W/m² at 500 luxServers: use of electricity (< 5000 W) and cooling
- PC: use of electricity < 125 W incl. screen.

Examples of energy and comfort performance specifications on the component level for the building above:
- Window profiles: U-value < 1.8 W/m²K
- Window glazing: U-value < 1.1 W/m²K, light transmittance > 55 %.

4.4.2 Specifications for double skin facades

Specifications on a double skin façade have to include (see also chapter 3.3 Technology):

Building physics
- Influence of weather on inner and outer skin: The double skin façade must be designed for sufficient tightness against climate influence i.e. specifications on wind load, air tightness, water tightness etc. have to be made.
- If natural ventilation: The cavity of the double skin façade must be designed for natural ventilation e.g. by specifying certain air flows for different boundary conditions.
- Energy conservation and thermal comfort: The double skin façade has to fulfil certain specifications on U- (thermal transmittance) and g-values (solar energy transmittance).
- Sound insulation: The double skin façade has to fulfil certain specifications regarding sound attenuation.
- Fire protection: The double skin façade has to fulfil certain specifications regarding spread of fire between fire cells etc.
- Light: The double skin has to fulfil certain specifications regarding the daylight factor and impact on visual comfort

Technology
- System – method of production: Loads and tolerances.
- Outer and inner skin: The choice of material, durability and need of maintenance
- Glazing: The glazing has to fulfil first of all some basic specification e.g. U- and g-values, light transmittance.
- Safety: personal safety
- Shading devices: The shading devices have first of to fulfil specification regarding solar shading.

- Ventilated cavity: Appropriate ventilation must be ensured.
- Cleaning and service devices: Accessibility and equipment must be considered.
- Costs

Building process planning

- Specifications for of design, construction and commissioning through the whole building process.

Operation and maintenance

- Specifications for of operation and maintenance.

4.4.3 Requirements on double skin facades

In many of the European countries there are legal requirements on buildings, which often have a bearing on double skin façades and therefore has to be taken into account:

- fire protection
- sound protection
- thermal insulation
- environmental issues
- integration of renewable energy
- building energy simulations
- safety regulations
- other legislation

4.5 The building process

Written by Åke Blomsterberg

In order to arrive at a glazed double skin façade office building with a reasonable energy use, good thermal and visual comfort the following actions are required during the building process:

- a comprehensive view must be applied to the building.
- energy use and environmental requirements as performance specifications are drafted in the brief and then refined during the building process.
- there is an energy and environmental coordinator from the brief phase until the first year of operation
- energy and indoor climate simulations are carried out starting already during the brief phase and then being refined during the building process
- a governing quality and environmental program with performance specifications is worked out starting already during the brief phase, and is refined during the building process

- good cooperation between designers to ensure a well performing system: architecture, HVAC, structural engineering, electrical engineering and building physics
- a "network" with energy and climate specialists and designers
- good cooperation between client, designers and contractors
- a life cycle cost analysis is carried out to avoid prioritising investment costs and neglecting operating, maintenance and energy costs.
- a separate performance specification is worked out for the double skin facades based on analysis of the entire building, to avoid sub optimisation
- performance checks are carried out during construction and when the building including the double skin façade is finished, in order to check that the performance specifications are fulfilled.

4.6 Design

Written by Åke Blomsterberg

4.6.1 Determining areas

The eight determining areas of influence on highly glazed buildings (Brunner 2001), which buildings with double skin facades usually are:

- Comfort/daylight: PMV(predicted mean vote on thermal comfort)/PPD (predicted percentage dissatisfied)/ daylight quality (visual comfort), asymmetry (in daylight and thermal comfort)/ cold air (draught)
- Internal gains: equipment/artificial lighting, persons
- Ventilation/cooling: air quality, removal of loads
- Energy use: heating, cooling
- Thermal mass: floor/ceiling, walls/furniture
- Solar shading: type/location/material, operation/control
- Glazing: area, U-value (thermal transmittance)/g-value (solar energy transmittance) incl. and excl. solar shading, surface temperature, light transmittance
- Boundary conditions: size/orientation of building, use of building/outdoor climate

All these areas should be covered by performance specifications.

4.6.2 Some remarks on how to succeed

Some recommendations on how to succeed during design the design of a double skin façade are given here:

- The internal gains must be minimized.
- Increasing the glazed area results in increased risk and lowered tolerance for errors.

- Corner rooms with two glazed facades requires special attention, as the risk for poor thermal and visual comfort is high.
- U- , g- and τ_V -values have to be chosen correctly, as they are crucial for the energy and comfort performance. The choice of these values do of course depend upon many factors e.g. the climate, the size and shape of the building, the size, type and orientation of the glazed areas, the type of shading and the geometry and ventilation of the cavity of the double skin façade. A thorough analysis is required to determine these values. In e.g. a cold climate a low g-value (total solar energy transmittance) is only needed during warm sunny days, the g-value for the combination of glazing and solar shading should be less than 0.1 and the window U-value should be lower than 0.9 W/m²K for a highly glazed façade. The light transmittance (τ_V) should probably be higher than 50 %.
- An appropriate control strategy for ventilation of the cavity and operation of solar shading has to be determined.

To ensure optimal operation of a building with a double skin facade, the following is crucial:
- The design of an intelligent control system for the double skin facade and the installations of the building (see chapter 4.8.1)
- The design of a usable and user friendly building energy management system (BEMS) (see chapter 4.8.1)

4.6.3 Planning steps

When planning a double skin façade ten steps are recommend to be taken to ensure a complete planning concept (Oesterle 2001). The order of steps can be different depending upon the project. Planning according to the ten steps is often an iterative process.

1. Checking the constraints
First the basic constraints regarding the feasibility of window ventilation should be checked. This way the possibilities and limitations of different system alternatives are determined, as well as the necessary requirements on the double skin façade. This could also give an idea as to the costs of the proposed system and building, compared with an alternative with a single skin façade.

2. Determining the type of construction
At this stage it should be known whether window ventilation will be used or not, as well as the level of sound insulation requirements on the façade. This means that the architectural and HVAC concepts can be dealt with. A list of performance specifications should be established, which will help in determining type of double skin façade construction. This step is very important, since the starting point for the following dimensioning is determined at this stage.

3. Ensuring a good fresh air supply
If the decision has been made to apply window ventilation of the building, then the dimensions of the openings and air flow routes into the rooms can be planned.

4. Avoiding overheating of the cavity of the double skin façade
The openings should be dimensioned to limit heat gains in summer in the cavity, in order to ensure thermal comfort in the rooms and to avoid increased cooling loads. For multi-story facades, there is a risk that the temperature stratification in the cavity results in critical cooling loads in the rooms at the top floor. Measures have to be taken to minimize the exhaust air temperature from the cavity and the warm air buffer of the cavity, for days with warm weather.

5. Optimizing the air flow
The following parameters are crucial for the natural ventilation and temperatures of a double skin façade:
- size and position of the openings
- appropriate aerodynamic design of the narrowest cross sections through which the air flow has to pass
- fan assistance

In most cases natural ventilation should be sufficient if the air flow resistance of the cavity is kept low. Wind forces can assist, but often in central and northern Europe the wind speeds are low on hot days. For fan assistance to matter, the fans have to be powerful.

6. Planning the conditions for operation
In winter the double skin façade should provide thermal insulation and all-the-year-round sound insulation. This means that the openings in the façade should be small, while they should be the opposite during periods with warm weather. Therefore the size of the openings should be variable and closable. For this to make sense the control of the openings has to be intelligent. The controls have to be optimized for the different occurring conditions during a year. There has to be a link to the other functions of the building, which has to be recognized in good time. It is usually very costly to install sensors and a control system afterwards.

7. Exploiting the construction to the full
The façade planner or consultant should be involved at an early stage to participate in discussions of air flows and where appropriate the optimization of the aerodynamic design. Only thanks to coordination of concepts from the beginning can detailed solutions, which are practical to construct and economically acceptable, be developed. This coordination ensures that the conclusions made regarding the aero physics will result in a construction, which will work in practice. Another benefit can be that standardized details can be designed enabling prefabrication, which can result in a less expensive construction.

8. Testing the dimensions
When the main characteristics of the double skin façade have been determined i.e. building physics and ventilation technology, then an integration with the HVAC concept of the building has to carried out. This in order to determine the dimensions of the HVAC system. Usually this can only be done with the help of computer simulations, as many varying parameters have to be combined. The optimization of the integrated double skin façade requires, in most cases, an iterative process involving many of the partners. This will ensure that a very good solution is found.

9. Involving clients and users into the planning process
In the optimization of the ventilation of the double skin façade and the HVAC system, it is very important to take into account the needs of the client and, if possible, also the users. This in order to make sure that there is a clear understanding as to the functioning of window ventilation in the double skin façade or the functioning in the case that window ventilation is not possible. One common expectation is that window ventilation can be used instead of mechanical cooling during warm summer days, which is physically impossible.

Savings resulting from a simplification of the HVAC system, can result in certain limitations on user comfort. These savings can be the result of the optimized integration of double skin façade and building, which should only be made with the full understanding of the client. An example is the leaving out of radiators in front of windows thanks to low U-values, which however may cause stronger air flows along the floor. The overall optimization requires all designers involved in the planning to take on their share of the responsibility.

10. Taking the control mechanisms into operation
As the technology of double skin facades has to be well integrated into the building and still is fairly new it is important to ensure a close co-operation between planners and construction firms. This is especially important regarding aero physics and the control of active components of the façade and their interaction with the HVAC system of the building.
The best approach is to assemble a model of the façade, before the actual production of the façade. The clients, architects, façade planners and façade construction firms can then together make checks to ensure that the design, construction and technical goals have been achieved and optimized. Constructional physics and aero physics can be validated by measurements.

Additionally it is important to coordinate the adjustment of the functions of the façade and the HVAC system, and taking the control mechanisms into operation.

4.6.4 The advantage of a façade mock-up

As there are a range of different forms of construction of double skin facades, it is recommended to build a mock-up of the façade (Oesterle 2001) i.e. a full-scale model of the façade for e.g. one cell office. A mock-up is of course an expensive undertaking. The costs are in the range of 25 000 – 50 000 Euros. A mock-up is advantageous to many participants of the building process: clients, architects, façade construction firms, façade consultants .

The client will be able to see the actual façade of the building being planned, in its true colours and dimensions.

The architect can experience his choice of colours and possibly change certain aspects.

The façade construction firm will be able to make a final check on technical aspects. Construction defects, not discovered during design, can be discovered and corrected for before serial production of the façade starts.

The façade consultant can, under realistic conditions, examine construction and formal details. The basis of the specifications can undergo a preliminary quality control.

4.7 Construction

Written by Åke Blomsterberg

How to ensure that the building and its double skin façade is built as designed. Often it will make sense to build a mock-up the façade, for some testing, before the full-scale construction (see 4.6.4). During assembly of a double skin facades certain checks have to be carried out:

- that the ordered glazing, profiles and double skin façade system have been delivered and are not damaged
- visual inspection of glazing, profiles, weatherstrips and joints, to determine quality of workmanship
- visual inspection of mounting, dampers, walking grids (floor grating), blinds, sheet metal work to determine quality of workmanship.
- testing the bolts with which the façade is attached to the structure of the building using a torque indicator.

Before commissioning careful adjustment of the building with its installations and control system is necessary.

4.8 Commissioning

Written by Åke Blomsterberg

Certain performance checks are necessary, in order to ensure that the performance is satisfying:

- the operation of dampers and movable solar shading of double skin facade
- the control system of the double skin façade including dampers and movable solar shading
- the operation of the building energy management system

Other performance checks are of great interest e.g. the airtightness of the façade using pressurization testing and thermography.

4.9 Operation and maintenance

Written by Sabrina Prieus and Gilles Flamant

To ensure optimal operation of a building with a double skin facade, the following is crucial:

- An intelligent control system for the double skin facade and the installations of building
- A usable and user friendly building energy management system (BEMS)
- Proper maintenance procedures including a maintenance plan, which is continuously updated
- The continuous operation of the building and its systems by a trained and motivated operating staff.

4.9.1 Control systems and strategies

A façade forms the contour of a building, admits daylight, protects the occupants against noise and guarantees a certain thermal comfort and air quality. The desired the performance of a façade is a function of the exterior climate and the type of use of the building. Generally the façade solely can not ensure an interior climate that is comfortable during the whole year. Therefore installations are foreseen to maintain the climate within acceptable boundaries. A good functioning of the installations requires a control system that needs to respond to a series of demands. Finally the aim of these systems is to have an interior climate within acceptable boundaries, while realizing economical rationalisation of energy use.

The performance of a façade ideally can vary as a function of the interior climate, the exterior climate and the activity in the building. This can be illustrated by considering 3 parameters: the solar factor (g-value or total solar energy transmittance), the light transmittance and the U-value.

A lower g-value of the glazing in summer and during the transitional seasons is advantageous and helps to prevent the overheating of a building and/or to reduce the cooling consumption. A lower g-value can, however, reduce the use of passive solar energy in winter.

The light transmittance (τ_V) represents the proportion of visible solar radiation that passes through the considered component. A high value often indicates a good availability of daylight.

The thermal transmittance U-value is the measure of the rate of heat loss through a component (in W/m²K).

The ideal façade should be able to adapt these parameters as a function of the season and possibly also during the course of the day, depending on the climate conditions and the conditions of exploitation as illustrated in table 4.2.

Table 4.2 Ideal façade interaction with the climate conditions.

Criterion	Heat demand	Cooling demand
g	↑	↓
τ_V	↑	↑
U	(Text > Tint) ↑ (Text < Tint) ↓	(Text > Tint) ↓ (Text < Tint) ↑

In the case of heat demand in a room, a high g-value permits to limit the need for heating in that room, by admitting solar gains. For a cooling demand the opposite is valid; a low g-value permits to limit the solar gains.

A low U-value of the whole façade contributes to limit the transmission losses to the exterior, so less heat will be wasted. In case of a cooling demand, the difference between the inside and the outside temperature can be taken into account, to determine if the U-value needs to be high or low. The cooling needs can be reduced by a low U-value, if the interior temperature is higher than the outside temperature.

A high light transmittance is generally desired, for the visual comfort of the occupants. However too much daylight can impair the visual comfort e.g. glare making it difficult to read on the PC screen.

While the aim is to provide a sense of comfort to the occupant, there is a maximum of occupants that can be satisfied, while always at least 10% of the people stay unsatisfied.

The control systems have to take this aspect in consideration and have to establish systems active on 2 levels:

- A global or central control that assures the conditions of the environment to be comfortable for the majority, limiting the use of energy;
- Means to regulate locally, easy accessible to the users, permitting them to influence their own comfort conditions.

Energy issues have to be reckoned with as well; generally the occupants of an office building do not pay the energy bill themselves and are not likely to pay attention to this aspect. The algorithms of the control system for the whole building should therefore take in consideration the aspects of energy consumption, assuring the comfort of the occupants and decreasing the energy bill.

Double skin facades generally integrate different motorized components, which permit to adapt them to variable conditions of operation (the interior climate, the exterior climate, occupation, interaction with heating and cooling systems, ventilation, etc.). The type of motorized components depends on the concept of the façade. Components which can often be found in double skin façades are: shading devices, ventilation openings and ventilators. An efficient management system involves the different techniques considered and also the interaction between the double skin facade and the HVAC system.
The importance of having an optimal control and the difficulties to establish such a control is obvious.

Depending on the typology criteria (see 3.3.2 Typology) of double skin facade different control strategies can be discussed.

1. The type of ventilation

The type of ventilation can be natural, mechanic or hybrid. In case of natural ventilation the ventilation airflow is realised in the façade cavity and is not directly controllable like it is for mechanical ventilation. The airflow is indirectly regulated by the ventilation openings, the placing of the shading device in the cavity and in the case of hybrid ventilation the control of the assisting ventilators. The variable weather conditions (speed and direction of the wind, solar radiation, etc.) can bring about a high variability in airflow in the cavity.

In the case of mechanical ventilation, the control strategies are also very important, but less important to the performance, because the control of the airflow in principle does not pose any problem.

2. The partitioning of the façade

The partitioning of the facade has an influence on its thermal performances. This influence has to be known to determine an efficient control strategy. It will influence among other things the stack effect, which depends on the vertical height of the cavity. After the building is realized, it is not really possible to have control over the aspect of partitioning; therefore it is not a criterion necessary to examine in determining the control strategy.

3. The ventilation mode of the cavity

The ventilation mode and the direction of the airflow can lead to several variants; the 5 modes as described in the previous chapter (3.3.2), their variants when inversing the airflow direction and one extra mode for a double skin facade with openings in both skins (see figure 4.1).

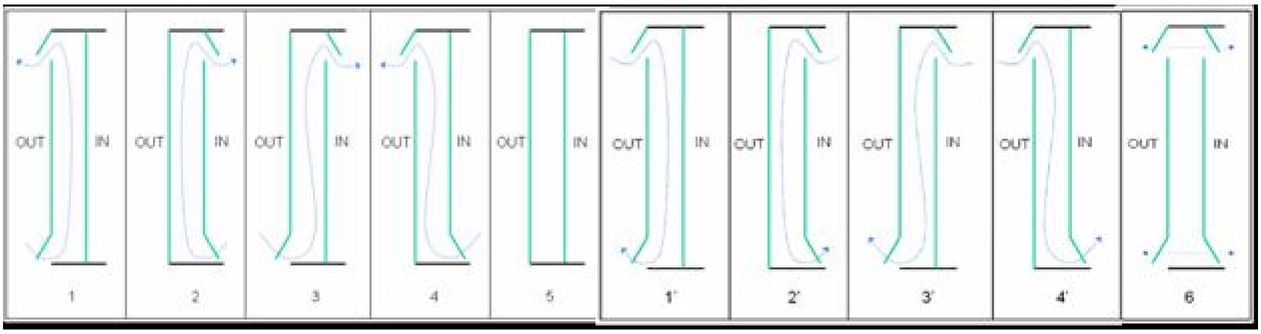

Figure 4.1 Ventilation mode variant for double skin façades.

The control strategy has to be conceived so it can work with one selected mode, but also changing from one mode to another. As already mentioned, the natural ventilated double skin facade are prone to adopt several ventilation modes. Mechanically ventilated double skin facade are typically characterized by only one ventilation mode.

It is quite obvious that the development of a control adequate for a ventilated double skin facade is complex; there are the parameters of the façade (shading, airflow in the cavity, openings, etc.), the weather conditions (temperature, solar radiation, wind, etc.), the conditions inside the building and the individual control by the occupant. The façade should therefore not be considered as an isolated element, but the interaction between the façade, the building and the HVAC systems needs to be considered in the overall control strategy, the Building Management System (BMS).

The current situation is that the control systems of buildings with double skin facade often have not been studied much, which can be vested to the complexity of the systems. Not many systems are specifically developed for double skin facade as well; they usually seem to be the same systems as produced for a traditional building. This although there are many different BMS on the market, controlling the whole of the installations (heating, cooling, electricity, ventilation, lighting, air quality) and even aspects linked to safety (fire safety, protection against burglary, etc).

There are several difficulties to establish an optimal control for a ventilated double skin facade. By ‘optimal control’ the following concept is intended: a model of physical behaviour of the façade that is available for different ventilation modes.

- The demands to attain are multiple and sometimes contradictory:
  Maximising the indoor climate (daylight, thermal and acoustic comfort, air quality) and minimising the energy use of the building. Examples of contradictions are: for acoustic comfort it is advisable to keep the ventilation openings closed, while it is recommended for the air quality and thermal comfort to open them. A complex compromise thus needs to be established and additionally the individual preferences of the occupant should be taken into account.
- The complexity of the modelling of phenomena’s like heat transfer and mass in the cavity.
  The nature of the physical phenomena in a ventilated double skin facade can require a 3D modelling where the turbulent air flux and the components of the façade are the object of heat transfer via conduction, convection and radiation. Therefore it is not easy to precisely predict the response of such a system through simulation.

The principal components of control systems are:

- Sensors (measurement of temperature, presence, pressure, CO_2, airflow, humidity, wind speed, wind direction, solar radiation, rain, etc.);
- Activators (taps, motors, thermostatic taps, contacts, etc.);
- Control and regulating components (thermostat, switches and other controllers).

Figure 4.2 illustrates the different components used for the control for shading devices.

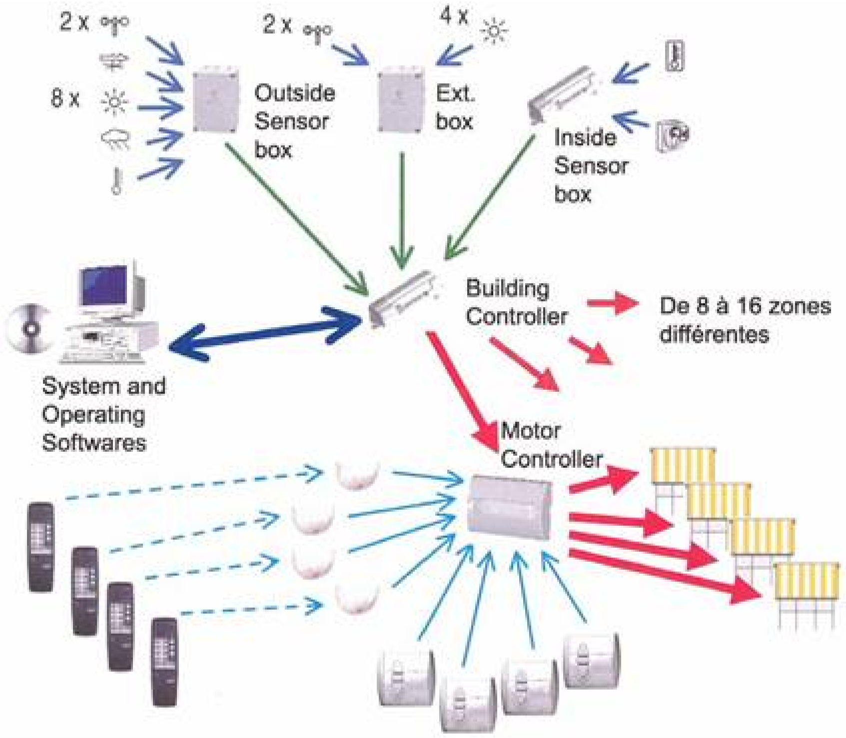

Figure 4.2 The different components for the control of shading devices (source: SOMFY)

Depending on the orientation of the building, the number of occupants, the type of room, etc. the need for cooling or heating can be very different from one zone to another. For this reason, buildings are generally divided into different climatic zones where rooms have similar characteristics, e.g. in orientation and environmental shading (by other buildings).

The control of the different motorized components is based on a series of parameters. The main parameters are:

- Temperatures
- Solar radiation
- Wind speed
- Wind direction
- Time

Other important parameters are:

- Alarm
- Control by the operator
- Snow

- Frost
- Rain
- Manual command at the level of the building
- Manual command at the level of the considered zone
- Clock at the level of the zone
- Manual command at the level of the motor group
- Manual command at the level of a particular motor

In the case of alarm it could be a fire or the interruption of the mechanical ventilation of the double skin facade.

The integration of a control strategy for a double skin facade can usually not be done in a systematic way. Each concept requires a strategy adapted to its particularities, e.g. for a building with a naturally ventilated double skin facade with motorized ventilation openings or a double skin facade with louvers which can rotate in a certain angle to diffuse the light towards the interior.

Double skin facades have the possibility to adapt their performance to evolving conditions. A good integration with the BMS (building management system) will ensure an optimal use of the systems. The control strategy needs to be thought through adapted to the type of façade and its characteristics. Careful fine-tuning and continuous performance monitoring are required to have a well performing façade resulting in an energy efficient operation of the building and a high degree of comfort for the occupants.

4.9.2 Maintenance and durability

It is evident that a double skin façade has two more surfaces to be cleaned than a traditional curtain wall. The cavity surfaces, air in- and outlets may be difficult to reach, increasing the maintenance time.

The frequency of the cleaning of the glazing and the shading device will influence the costs of the double skin façade comparing with a traditional curtain wall. The frequency of maintenance depends on the ventilation type of the double skin (ventilation with air coming from inside or outside) and the environment (polluted or not) in case of ventilation with outside air.

Some concepts of double skin façade are ventilated with indoor air. This air is coming, via the room, from the ventilation system of the building. This ventilator system filters the air for dust particles, by which less particles enter the cavity. As a result the cavity gets less filthy and needs less maintenance. The filters of the ventilation system however need to be cleaned on a regularly basis.

A double skin façade, naturally ventilated with outside air, needs more maintenance in comparison with a façade ventilated with indoor air, because of the outside air is more polluted with dust particles. In this case an easy access for maintenance is necessary. Also the ventilation openings need maintenance and need to be durable.

The possibility to place the shading device inside the cavity is usually a favourable argument for choosing a double skin facade. Since it is protected from outside weather conditions, like wind and rain, this is a more durable solution and thus a cost reducing factor.

Buildings with double skin facades, with a good control strategy, require less heating and cooling energy than a highly single glazed facade. The HVAC-plant capacity can thus be lowered and the maintenance and inspection can be lowered as well. Chilled ceilings or concrete core activation are often used together with double skin facades and need less maintenance than e.g. ventilo-convectors (window mounted air conditioner).

4.10 Costs

Written by Reinhard Waldner

The methods of calculating the life cycle costs are described in chapter 3.6. Below are given some advice regarding double skin facade buildings and examples.

4.10.1 Life cycle costs factors for double skin facade buildings

For each of the following cost factors it has to be proven if and when, and to what extent they apply to the analyzed double skin facade project.

Construction

A double skin façade is a significant capital investment and an estimate of construction cost is necessary in order to make a calculation as to the likely LCC. There are wide variations depending on the level of sophistication of the façade, location and construction method as well as the contractors' experience.

Reduced Mechanical Plant Capital Costs

With a well designed double skin façade the peak loads may be reduced and this may allow smaller chillers, boilers, air handlers, ducts, or even different HVAC systems.

Increased planning costs

The double skin façade technique is still a rather new technology which causes some uncertainty. This has to be compensated for by an increased level of planning effort.

Energy costs
Double skin façades must be assessed specifically on their individual merit considering climate, orientation, complexity, construction cost and energy price. Potential advantages/problems which will change the energy costs are:

- Individual window ventilation is almost independent of wind and weather conditions, mainly during sunny winter days and the intermediate season (spring and autumn). This is only true for juxtabox facades which does not allow an air flow from one room to another in the cavity and if the U-value of the outer glazing is low to prevent condensation of the warm and humid air leaving the room at the outer skin.
- Reduced heating demand thanks to preheating of outdoor air
- Night cooling of the building by opening the inner windows is possible if the façade is well ventilated. In the case of mechanical ventilation, this, of course, increases the electricity demand for the ventilation system.
- Poorer cross ventilation and insufficient removal of heat from the offices rooms during windless periods, when ventilation is mainly provided for by natural ventilation
- Hot summer/spring/autumn days can lead to high temperatures in office rooms as a result of window ventilation
- Reduced heating and cooling as a result of low g- (summer) and U-values (winter).

Maintenance cost
Double skin façades cause additional maintenance costs due to cleaning of additional windows and maintenance for pivoting louvers.

4.10.2 Life cycle revenue factors for double skin facade buildings

The following points could influence future economic benefits of the double skin facade building.

Reduced net building area
For a building with the same outside dimensions, the double skin façade reduces the net building area compared with a single skin façade. This applies especially for buildings with a small base area.

Aesthetic Purity
The exterior skin requires no thermal breaks, structural mullions or spandrel glass providing a visually aesthetic façade. External blinds provide shading, so clear glass can be acceptable.

Reduced Emissions
Greenhouse gases, SO_x, NO_x and other pollutants are reduced, if the energy consumption is reduced.

Comfort

- In many ways the comfort is improved in the building. Not all are exclusive for double skin façades:
- *Moderated glass surface temperatures:* Blinds prevent direct solar radiation from striking the inner glass preventing it from heating up to 60°C. In winter, the warm space between heats the inner glass reducing drafts and cold radiant exchange.
- *Glare control:* Operable blinds block direct solar glare.
- *Operable windows in high-rise buildings:* The air cavity between the exterior and interior glazing buffers wind pressure which otherwise make operable windows impossible in tall buildings.
- *Sound reduction:* The exterior skin reduces noise improving acoustics near noisy roads, airports, factories or rail lines.
- *Increased daylighting:* Operable blinds with light redirection parts direct light deeper into occupied space.

Estimating comfort costs

Increased comfort may increase future revenues, but how should the comfort be converted into money equivalents? Several studies (Fisk 2000) have analyzed the relationship between room temperatures, lightning, air quality and work efficiency. Combining this information with the results of building energy simulation softwares can produce comfort cost estimates e.g. the software *VisualEnergy* (Ployer 2006), which uses the following equations:

$$K_{Komfort,i,t} = \left(\left\| PMV_{i,t} \right\| \cdot g_{K\lim a} + \left\| B_{i,t} \right\| \cdot g_{Blendung} \right) \cdot N_{Pers,i,t} \cdot g_{Komfort} \cdot k_{Komfort}$$

$$K_{Komfort,t} = \sum_{Zone\ i} K_{Komfort,i,t}$$

$$K_{Komfort} = \sum_{t} K_{Komfort,t} \tag{4.1}$$

$K_{Komfort,i,t}$ Comfort costs at timestep t of zone i

$K_{Komfort,t}$ Comfort costs for all zones at timestep t

$K_{Komfort}$ Annual comfort costs

$PMV_{i,t}$	Predicted Mean Vote of Zone i at timestep t
$g_{K\lim a}$	Weighting factor room environment
$B_{i,t}$	Daylight Glare Index at timestep t
$g_{Blendung}$	Weighting factor glare
$N_{Pers,i,t}$	Number of persons in Zone i at timestep t
$g_{Komfort}$	Weighting factor comfort
$k_{Komfort}$	specific comfort costs

$$\left\|PMV_{i,t}\right\| = \begin{cases} 0{,}2 \cdot \left(1 - e^{0{,}2 \cdot PMV_{i,t}^{\ 2}}\right) + 0{,}007 \cdot \left|PMV_{i,t}\right| & PMV_{i,t} > 0{,}5 \\ 0 & PMV_{i,t} \le 0{,}5 \end{cases} \tag{4.2}$$

$$\left\|B_{i,t}\right\| = \begin{cases} 0{,}035 \cdot \left(1 - e^{-0{,}004 \cdot \left(B_{i,t} - 15\right)^2}\right) & B_{i,t} > 20 \\ 0 & B_{i,t} \le 20 \end{cases} \tag{4.3}$$

The calculation of the annual comfort costs consists of following steps:
- Calculate $PMV_{i,t}$ and $B_{i,t}$ at time step *t* for zone *i*
- Calculate $K_{Komfort,i,t}$ at time step *t* with the actual number of persons in zone *i*
- Sum over all zones to calculate $K_{Komfort,t}$ at time step *t;*
- Sum over all time steps of one year to calculate the annual comfort costs $K_{Komfort}$

A decrease in comfort will decrease the productivity. The annual comfort costs $K_{Komfort}$ specifies the cost due to the decrease of the productivity and not due to increased rental income. Therefore, the comfort costs as described above may only be used directly, if the builder is at the same time the user of the building. If this is not true the increased rental income may be estimated with the help of the calculated comfort data.

A simpler approach of accounting for loss in productivity, is where the perception of the indoor environment is directly connected with the efficiency of the occupants. Too high or too low air temperatures in a room result in production losses from workers. For mean air temperatures between 20 and 25 °C no work is regarded as lost. Above and below these limits experiments show that the average loss in performance can be estimated to be 2% in performance per degree (Wyon 2000).

4.10.3 Example

To reduce the calculation effort it is possible to take only a look at the differences between several façade constructions. The resulting annuity is then a difference to a common base line. If the calculation includes the revenues, also only the differences to the base line have to be used. This will be outlined in the following example.

Given a hypothetic office building project with an already planned conventional glass façade, it should be analyzed if an alternative double skin facade is cost-effective. Table 4.3 gives the main differences of the double skin facades to the base line.

Table 4.3 Cost estimate for a hypothetic office building with a double skin facade, compared with a base line.

Cost factor	Costs	Relation type	
additional Erection	+840 000 €	Capital	ΔA_0
additional planning	+30 000 €	Capital	ΔA_0
reduced mechanical plant	-120 000 €	Capital	ΔA_0
additional annual cleaning	+9 000 €/year	Operation	ΔA_B
reduced annual energy	-20 000 €/year	Consumption	ΔA_V
reduced building area	+15 000 €/year	Other	ΔA_S
increased annual revenue due to comfort	+25 000 €/year	Incoming	ΔE

Because there are no replacements which are different to the baseline in this example ΔA_1 … ΔA_n according to equation (3.2) are 0. With an observation period T of 70 years which is assumed identical to the building life span T_N also the net book value given in equation (3.3) is 0. Using an interest rate of 4%, i.e. q=1+0.04=1.04, and equation (3.4) results in an annuity factor:

$$a = \frac{1.04 - 1}{1 - 1.04^{-70}} = 0.0427$$

There is no difference in the factor for repairs so the annuity of capital related costs is

$$\Delta A_{N,K} = (840000 + 30000 - 120000) \cdot 0.0427 = 32025 € / year$$

The cash value factor for a price change factor of 3% for consumption-related, operation-related, other costs and incoming payments calculated with equation (3.6) is

$$b_V = b_B = b_S = b_E = \frac{1 - \left(\frac{1.03}{1.04}\right)^{70}}{1.04 - 0.03} = 49.15$$

With equation (3.5) results in the price-dynamic annuity factor

$$ba_V = ba_B = ba_S = 49.15 \cdot 0.0427 = 2.0987$$

Equations (3.7), (3.9) and (3.10) resulting in

$$\Delta A_{N,B} = 9000 \cdot 2.0987 = 18888 \text{ €}/\ year$$

$$\Delta A_{N,V} = -20000 \cdot 2.0987 = -41974 \text{ €}/\ year$$

$$\Delta A_{N,S} = 15000 \cdot 2.0987 = 31480 \text{ €}/\ year$$

and with equation (3.11)

$$\Delta A_{N} = -(32025 - 41974 + 18888 + 31480) = -40419 \text{ €}/\ year$$

The average additional annual cost is 40419 € without considering the increased revenue.

With equation (3.12) and equation (3.13)

$$\Delta A_{N,E} = 25000 \cdot 2.0987 = 52467 \text{ €}/\ year$$

$$\Delta A_{N} = 52467 - 40419 = 12048 \text{ €}/\ year$$

Total difference in LCC: $\Delta A_{N,Total} = 12048 \cdot 70 = 843360$ €

The result of this hypothetic example calculation with these specific assumptions is that the alternative double skin facades is economical because ΔA_N. is greater 0.

4.11 Case studies

Written by Rogério Duarte

The best performers among the case study double skin façade buildings were selected from the initial sample of 30 buildings after a benchmark analysis. This analysis is presented in WP3 Report (Matos, 2007).

The characteristics of these buildings are presented in the following subsections, grouped according to climate region.

4.11.1 Nordic climate

Building E		
Generic characteristics	Year of construction	-2004
	Number of storeys	n.a.
	Gross floor area	30000 m^2
Façade	Type	Ventilated double window
	Area	3032 m^2
	Ventilation	Natural
	Shading	Venetian blinds, mechanical controlled without overrule by occupants
	Daylight control	No daylight control
HVAC	Type	Heating with radiators, cooling with cooled ceilings
	Setpoints	n.a.
Energy use	Supplied energy	District heating and cooling
	Year of data gathered	City design day
	Data source	Simulation (all cases)
	Annual consumption	44 kWh/(m^2 a) for heating; 44 kWh/(m^2 a) for cooling; 107 kWh/(m^2 a) total electricity consumption.
Office manager opinion		n.a.
User opinion	Generic	Very good comfort (summer); unaware of DSF concept; HVAC is essential for prestige
	Winter	n.a.
	Autumn	n.a.
	Summer	Very dissatisfied; feeling uncomfortably cold
	Spring	Dissatisfied; would prefer cooler
Remark		Energy performance is based on simulation results. Contradictory users opinion suggests indoor thermal environment problems. These problems should be related to HVAC system and possibly the façade. The user opinions are from the first year of operation, which means that the HVAC and facade systems were still being adjusted to the actual needs.

Building D

Generic characteristics	Year of construction	2002-2003
	Number of storeys	32
	Gross floor area	22000 m^2
Façade	Type	Corridor; partitioned per storey; two of the three facades are double skin facades, the third (to the north) is a single skin facade. The double skin facades are of the type corridor façade with diagonal ventilation. In the cavity there are gangways on each floor; windows are non-openable; cavity width 0.70 m
	Area	6656 m^2
	Ventilation	Natural
	Shading	Venetian blinds, mechanical controlled without overrule by occupants
	Daylight control	No daylight control
HVAC	Type	Heating with radiators, cooling with active cooling beams; balanced ventilation with heat recovery
	Setpoints	22ºC winter; 24ºC summer
Energy use	Supplied energy	District heating and cooling
	Year of data gathered	2004
	Data source	Measured (energy bills)
	Annual consumption	107 kWh/(m^2 a) for heating; 49 kWh/(m^2 a) for cooling; 93 kWh/(m^2 a) total electricity consumption.
Office manager opinion		Energy conscious building management; DSF has lower maintenance costs; window cleaning is the main maintenance issue
User opinion	Generic	n.a.
	Winter	n.a.
	Autumn	n.a.
	Summer	n.a.
	Spring	n.a.
Remark		

Building A

Generic characteristics	Year of construction	-2002
	Number of storeys	n.a.
	Gross floor area	n.a.
Façade	Type	Multi-storey; cavity width 0.80 m; air flows in through grids in the outer skin at bottom level and flows out through grids in the outer skin at top level: outside air inflow and gap air outflow can be controlled by closing the grids above; there are no openable windows
	Area	3200 m^2
	Ventilation	Natural
	Shading	Venetian blinds placed in the gap near the inner skin, slat angle mechanical controlled via solar radiation; no overrule by occupants
	Daylight control	Interior (in the office room) canvas screens enable daylight control. These screens are manually operated
HVAC	Type	Heating with radiators, cooling with cooled ceilings; mechanically ventilated with a system that enables heat recovery; this ventilation system pre-heats
	Setpoints	21ºC winter; 25ºC summer
Energy use	Supplied energy	District heating and cooling
	Year of data gathered	2004
	Data source	Measured (energy bills)
	Annual consumption	143 kWh/(m^2 a) for heating; 32 kWh/(m^2 a) for cooling; 89 kWh/(m^2 a) total electricity consumption.
Office manager opinion		Energy conscious building management; DSF has higher maintenance costs; window cleaning is the main maintenance issue
User opinion	Generic	Good comfort (summer); aware of DSF concept; HVAC is essential for comfort
	Winter	n.a.
	Autumn	n.a.
	Summer	Satisfied; sometimes feeling uncomfortably cold, but generally felling slightly warm; undesired sunlight

		reflections
	Spring	Dissatisfied; less comfortable than summer, would prefer warmer
Remark		

4.11.2 Moderate climate

Building R

Generic characteristics	Year of construction	-2002
	Number of storeys	n.a.
	Gross floor area	20705 m^2
Façade	Type	Corridor; partitioned per storey; natural ventilation through window opening or special openings on both inner and outer skins; double and triple glazing in the outer skin; single glazing on the inner skin; air cavity width: 0.55m
	Area	3941 m^2
	Ventilation	Natural
	Shading	Canvas screen in the gap near the inner skin; manual operated
	Daylight control	No daylight control
HVAC	Type	HAVC system that humidifies, pre-heats and pre-cools the air
	Setpoints	21ºC (winter); 26ºC (summer)
Energy use	Supplied energy	District heating and electricity for cooling
	Year of data gathered	2003 (winter); City design day (summer and electricity)
	Data source	Measured (winter; energy bills); simulation (summer cooling and total electricity)
	Annual consumption	57 kWh/(m^2 a) for heating; 18 kWh/(m^2 a) for cooling; 94 kWh/(m^2 a) total electricity consumption.
Office manager opinion		n.a.
User opinion	Generic	n.a.
	Winter	n.a.
	Autumn	n.a.
	Summer	n.a.
	Spring	n.a.
Remark		Energy performance is partly (cooling and electricity) based on simulation results.

Building Q

Generic characteristics	Year of construction	-2004
	Number of storeys	n.a.
	Gross floor area	55000 m^2
Façade	Type	Juxtaposed modules; partitioned per storey; except for half of the SE façade, DSF in the perimeter of the building; inner skin windows openable; per storey, the outer skin has a lower half made of a perforated metal sheet (26% perforation) and a glazed upper half; this solution enables the flow of air between outside and gap
	Area	10512 m^2
	Ventilation	Natural
	Shading	Venetian blinds in the gap near the outer skin, mechanical controlled with overrule by occupants; daylighting sensor inside the gap controlling the slat angle of the Venetian blinds
	Daylight control	Segments, mechanical controlled with overrule by occupants
HVAC	Type	Ventilation via openings in the windows that separate inside air from gap air and a mechanical ventilation system that allows preheating or pre-cooling of inflow air; HVAC system dehumidifies
	Setpoints	21°C (winter); n.a. (summer)
Energy use	Supplied energy	District heating and electricity for cooling
	Year of data gathered	2004 (winter and electricity); City design day (summer)
	Data source	Measured (winter and electricity; energy bills); design (summer cooling)
	Annual consumption	72 kWh/(m^2 a) for heating; 20 kWh/(m^2 a) for cooling; 103 kWh/(m^2 a) total electricity consumption.
Office manager opinion		n.a.
User opinion		n.a.
Remark		Energy performance is partly (cooling) based on design results.

Building G		
Generic characteristics	Year of construction	-2004
	Number of storeys	4 (behind the DSF)
	Gross floor area	227 m^2
Façade	Type	Multi-storey; openable windows; air cavity width: 0.28m
	Area	222 m^2
	Ventilation	Natural
	Shading	Canvas screen in the gap near the inner skin, mechanical controlled with overrule by occupants
	Daylight control	No daylight control
HVAC	Type	n.a.
	Setpoints	22ºC (winter); 25ºC (summer)
Energy use	Supplied energy	n.a.
	Year of data gathered	City design day (all cases)
	Data source	Design (all cases)
	Annual consumption	50 kWh/(m^2 a) for heating; 62 kWh/(m^2 a) for cooling; 115 kWh/(m^2 a) total electricity consumption.
Office manager opinion		Energy conscious building management; ventilation system is the main maintenance issue
User opinion	Generic	Regular comfort (summer); poor comfort (winter); aware of DSF concept; HVAC is essential for comfort
	Winter	Satisfied; undesired sunlight reflections
	Autumn	Satisfied; as comfortable as in winter
	Summer	Very satisfied; undesired sunlight reflections
	Spring	Satisfied; more comfortable than summer
Remark		Energy performance is based on design results.

4.11.3 Mediterranean climate

Building W

Generic characteristics	Year of construction	-1998
	Number of storeys	n.a.
	Gross floor area	3050 m^2
Façade	Type	Multi-storey louver (openable outer skin); cavity width: 0.80 m; In the inner skin openable windows can be used for inflow and outflow of room air. the outer skin has permanent openings to the outside and is composed of shading devices that control the incoming solar radiation; these vertical panels are mechanically operated to rotate on a central axis and are responsible for reducing daylighting in approximately 70%; Inside the office rooms manually operated Venetian blinds enable further daylighting control; permanent openings are placed above and below the outer skin panels occupying approximately 1/5 of the panel area, enabling abundant gap ventilation.
	Area	410 m^2
	Ventilation	Natural
	Shading	Venetian blinds, mechanical controlled without overrule by occupants
	Daylight control	Yes (n.a.), mechanical controlled without overrule by occupants
HVAC	Type	Convective system for heating and cooling
	Setpoints	20ºC (winter); 26ºC (summer)
Energy use	Supplied energy	Electricity for heating and cooling
	Year of data gathered	2000
	Data source	Measured
	Annual consumption	17 kWh/(m^2 a) for heating; 28 kWh/(m^2 a) for cooling; 80 kWh/(m^2 a) total electricity consumption.
Office manager opinion		n.a.
User opinion		n.a.

Building AB

Generic characteristics	Year of construction	-1998
	Number of storeys	11
	Gross floor area	8411 m^2
Façade	Type	Corridor; partitioned per storey; cavity gap 0.50 m (approximately)
	Area	2520 m^2
	Ventilation	Mechanical
	Shading	Venetian blinds in the gap near the inner skin, mechanical controlled with overrule by occupants
	Daylight control	No daylight control
HVAC	Type	Convective 4-pipes fan-coil system for heating and cooling
	Setpoints	23ºC (winter); 22ºC (summer)
Energy use	Supplied energy	District heating and cooling
	Year of data gathered	2004
	Data source	Measured (energy bills and monitoring)
	Annual consumption	33 kWh/(m^2 a) for heating; 156 kWh/(m^2 a) for cooling; 130 kWh/(m^2 a) total electricity consumption.
Office manager opinion		Energy conscious building management; window cleaning is the main maintenance issue; maintenance cost identical to SSF buildings.
User opinion	Generic	Regular comfort; unaware of DSF concept; a more natural alternative to the HVAC system would be preferred
	Winter	Satisfied; undesired sunlight reflections
	Autumn	Satisfied; identical to winter
	Summer	n.a.
	Spring	n.a.
Remark		

Building AD

Generic characteristics	Year of construction	-2003
	Number of storeys	n.a.
	Gross floor area	8158 m^2
Façade	Type	Shaft-box – "*façade pareclosée respirante*" with only a few centimetres air cavity width where the pressure balance between the air gap and the outside is maintained.
	Area	4153 m^2
	Ventilation	Natural
	Shading	Venetian blinds in the air cavity, mechanical controlled with overrule by occupants
	Daylight control	No daylight control
HVAC	Type	Convective system for heating and cooling
	Setpoints	25ºC (winter); 20ºC (summer)
Energy use	Supplied energy	District heating and cooling
	Year of data gathered	2005-2006
	Data source	Measured (energy bills)
	Annual consumption	16 kWh/(m^2 a) for heating; 140 kWh/(m^2 a) for cooling; 197 kWh/(m^2 a) total electricity consumption.
Office manager opinion		Energy conscious building management; maintenance costs identical to SSF; ventilation system is the main maintenance issue
User opinion	Generic	n.a.
	Winter	n.a.
	Autumn	n.a.
	Summer	n.a.
	Spring	n.a.
Remark		Building only partially occupied; problems (due to overheating) with the shading device Although not a double glazed window - since outside and cavity air communicate - the façade typology is uncommon

4.11.4 Comments

On typology
An overall analysis of the case studies presented in this section leads to the conclusion that the corridor façade typology (partitioned per storey) is present in all European climates and can have good energy performance. The corridor façade in the Mediterranean climate was mechanically ventilated.

On ventilation
The ventilation of the cavity of the façade seems to be a decisive factor in the success of the design. As cases D, A, R, Q and W show, several strategies are possible, from the more conventional outer skin bottom and top slits to the possibility of mechanically rotating (and opening) the outer skin.

On shading
In all case studies solar shading devices were used. The most common device is Venetian blinds located in the gap near the inner skin. In some cases solar shading is mechanically operated and controlled using a light sensor.

On daylight control
Separate daylight control is seldom used (however, the above mentioned light sensors for shading control can also be used for daylight control, and this is not unusual). When separate daylight control is used, it usually consists of manually operated canvas screens located inside the inner skin.

4.12 Predicted performance – examples

Written by Ake Blomsterberg

Due to the difficulties of determining the influence of a double skin facade 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 and office building. A comparison is also made with single skin facades. This kind of predictions should be made each time a glazed office building is to be designed (see chapter 4.5).

This section presents and discusses simulation results for double skin façades. Section 4.12.1 uses a single zone modelling tool — Parasol-DSF — to perform parametric studies on energy use and study indoor climate for one typical cell office located in Lisbon, Paris and Stockholm. Section 4.12.2 uses a multi-zone building energy simulation tool — EnergyPlus

— to model a reference building in the same locations as above, and study changes in energy use due to changes in specific building and façade characteristics.

4.12.1 Predicted performance of a cell office with double skin façade

Written by Ake Blomsterberg, Gérard Guarracino, Bassam Moujalled

The aim was to determine the energy use and thermal comfort for a single cell office with a double skin facade for a warm, mild and cold climate. This in order to estimate for a given type of double skin facade, which type of glazing and shading is suitable for different climates i.e. resulting 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 (see chapter 5.4).

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 and 3.5 m x 2.4 m facing south

The building envelope has the following characteristics:
Single skin facade: the U-value (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), which were chosen from commercially available products and glazing which are commonly used in office buildings (see tables 4.4 – 4.6). The U-value of the profiles was assumed to be 1.6 W/m²K.
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 idea is that 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), which were chosen from commercially available products and glazing which are common in office buildings (see tables 4.4 – 4.6). The glazing were also chosen to allow a reasonable amount of daylight, the light transmittance is for all windows higher than 0.55 (see chapter 4.4.1). The U-value of the profiles was assumed to be 1.6 W/m²K.
Internal walls: adiabatic and light construction
Floor: adiabatic and medium construction
Ceiling: adiabatic and medium construction

The solar shading consists of Venetian blinds and for some alternatives also solar control glazing. The control of the Venetian blinds is 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 are intermediate (placed in outer cavity) for triple-glazed windows, interior for double-glazed windows and for the double skin façade alternatives located in the 800 mm deep cavity. There is no adjacent building shading the cell office. The ground reflectance was assumed to be asphalt.

The HVAC system has the following characteristics:
Ventilation: balanced ventilation with heat recovery, 10 l/s
Heating: district heating
Cooling: district cooling
Infiltration: 0.1 air changes per hour
Supply air temperature: 18 °C
Air-to-air heat recovery efficiency: 60 %
Operating time ventilation: weekdays 5:00 – 18:00
Set points indoor air temperature: heating 21 °C and cooling 26 °C

Three different climates were used, warm (Lisbon in Portugal), mild (Paris in France), cold (Stockholm in Sweden).

Table 4.4 Glazing combinations for the single skin façade. The U- (thermal transmittance) and g-values (solar energy transmittance) were calculated by Parasol. The g-values are given with and without Venetian blinds and are average values for the three cities and for the period May - August. System is glazing and solar shading. The light transmittance is higher than 0.7 for all cases. 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 4.5 Glazing combinations for single skin façade retrofitted to a double skin façade, which is naturally ventilated with an opening area of half the depth of the gap at the top and the bottom. The U- and g-values were calculated by Parasol. The g-values are given with and without Venetian blinds and are average values for the three cities and for the period May - August. System is glazing and solar shading. The light transmittance is approximately 0.65 for all cases. Optitherm is a pane with low emissivity coating.

Case	External pane	Gap 800mm	Intermediate pane	Gap	Internal pane	Gap	Internal pan	U-value glazing closed gap W/m²K	g-value glazing, opened gap	g-value system, opened 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 4.6 Glazing combinations for the double skin façade, which is naturally ventilated with an opening area of half the depth of the gap at the top and the bottom. The U- and g-values were calculated by Parasol. The g-values are given with and without Venetian blinds and are average values for the three cities and for the period May - August. The light transmittance is approximately 0.7 for G3A and G3B, and approximately 0.55 for the other cases.

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	

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. This means no compensation for the amount of daylight, which varies with glazing area and type of glazing.
- PC, 125 W, with an average use of 111 W between 8:00 – 17:00

The total internal gains are for the cell office during office hours = 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 4.3 – 4.5). For Lisbon, with the warm climate, the cooling demand is dominating and there is hardly any heating need. 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 energy use for cooling and heating was chosen for each type of facade. 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.

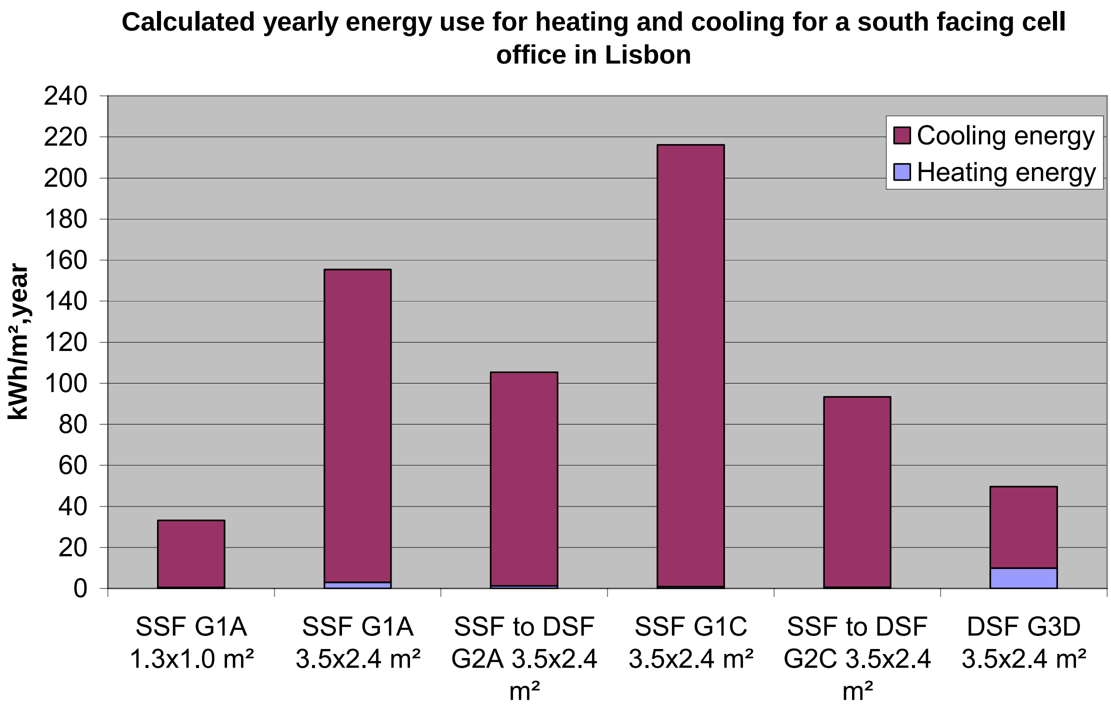

Figure 4.3 Calculated yearly energy use for heating and cooling for a cell office in Lisbon. The glazing types can be found in table 4.4 for SSF, table 4.5 for SSF to DSF and table 4.6 for DSF. SSF = single skin façade and DSF = double skin façade. SSF to DSF means retrofit of a single skin façade to a double skin facade.

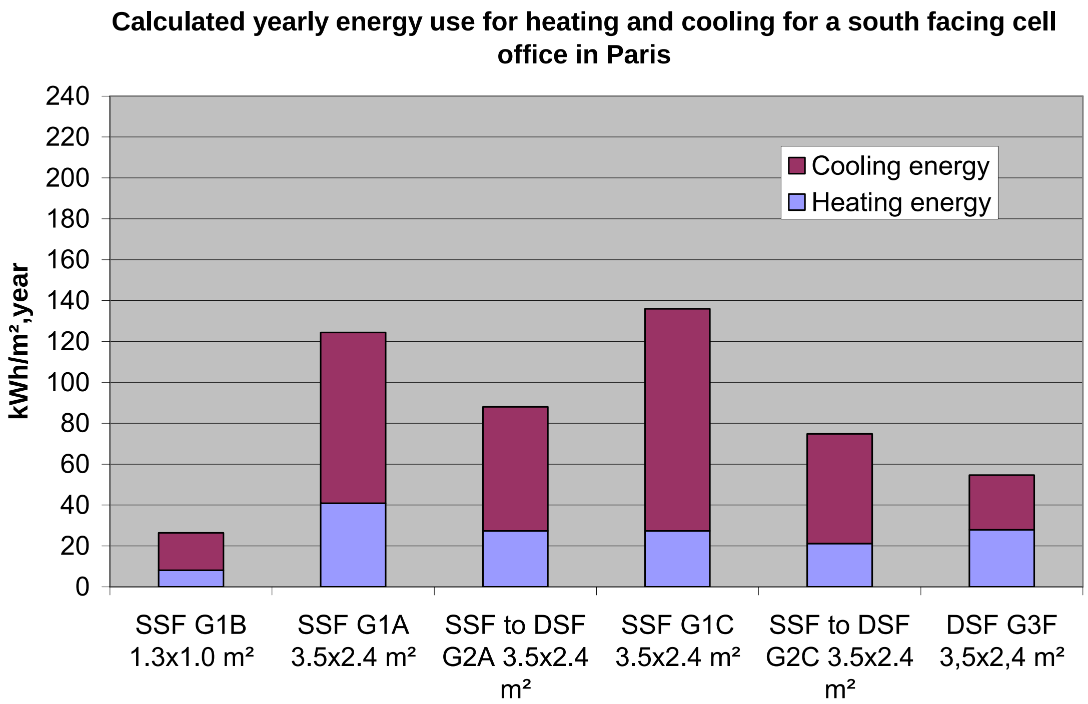

Figure 4.4 Calculated yearly energy use for heating and cooling for a cell office in Paris. The glazing types can be found in table 4.4 for SSF, table 4.5 for SSF to DSF and table 4.6 for DSF. SSF = single skin façade and DSF = double skin façade. SSF to DSF means retrofit of a single skin façade to a double skin facade.

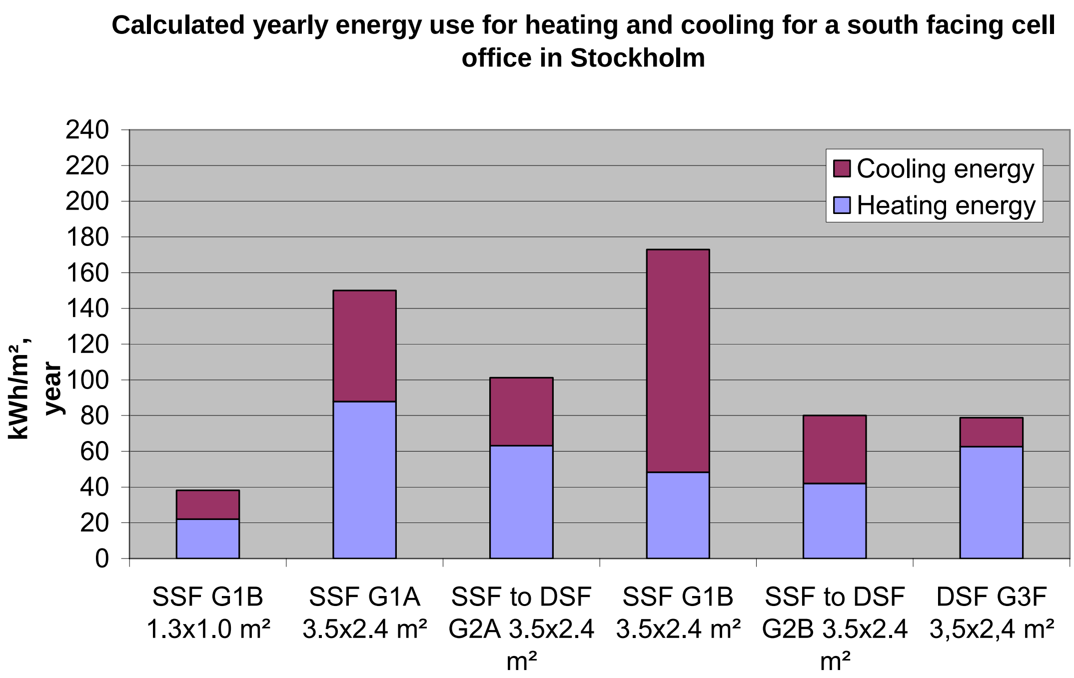

Figure 4.5 Calculated yearly energy use for heating and cooling for a cell office in Stockholm. The glazing types can be found in table 4.4 for SSF, table 4.5 for SSF to DSF and table 4.6 for DSF. SSF = single skin façade and DSF = double skin façade. SSF to DSF means retrofit of a single skin façade to a double skin facade.

For the three cities the case with the lowest total energy use is the case with a single skin façade and 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 chose an alternative with a low g-value including Venetian blinds, to reduce the solar gains and thereby the cooling demand. The heating demand is low and a normal level of internal gains is sufficient for most of the heating during winter.

A fully glazed single skin façade means 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 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. converting to a double skin façade, the total energy use is reduced a fair amount. This is thanks to the fact that the U- and g-value is 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 explanation 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 when a double skin façade is designed from the beginning. The total energy use is lowest for the office in Lisbon, which is for solar control glazing combined with "exterior" Venetian blinds resulting in a very low g-value, 0.10, but not a very low U-value. Some architects might not like the alternative, as the exterior glazing is tinted. An alternative would then be G3F, which would increase the total energy use about 25 %. For the office in Stockholm it is mostly heating and not very much cooling, 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 figure 4.6 – 4.8). The ratio for the different alternatives is similar to the ratios between the different use 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 access to daylight.

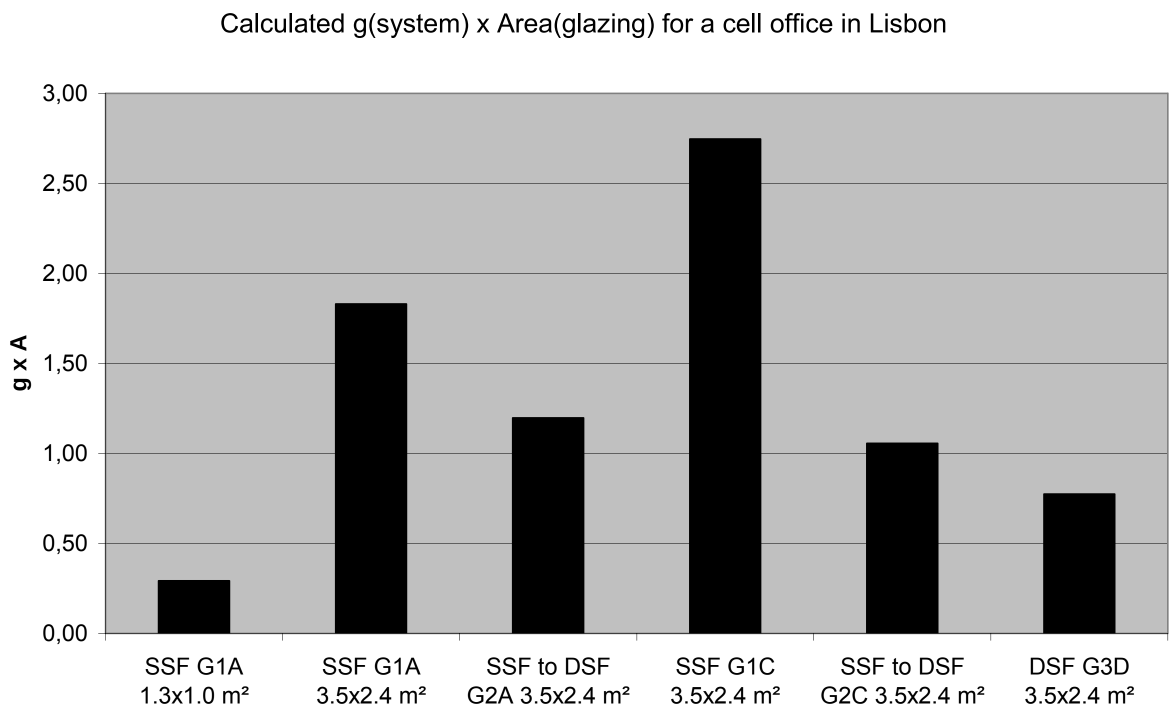

Figure 4.5 Calculated g_{system} x $Area_{glazing}$ for a south facing cell office in Lisbon.

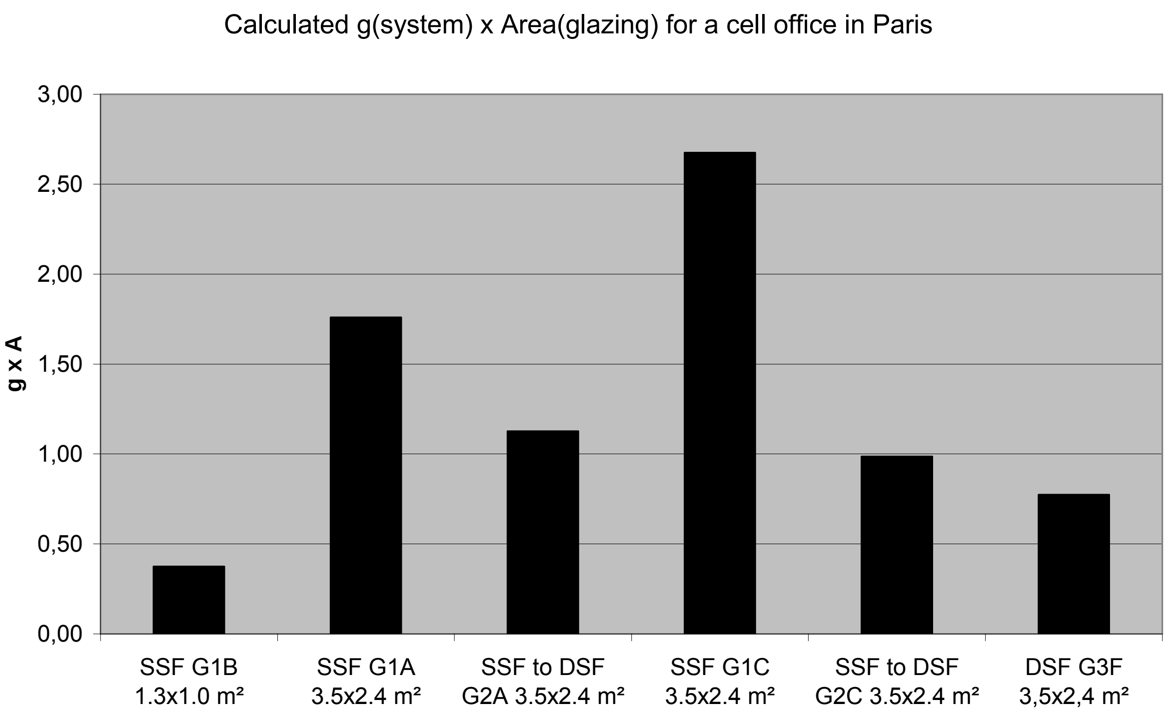

Figure 4.7 Calculated g_{system} x $Area_{glazing}$ for a south facing cell office in Paris.

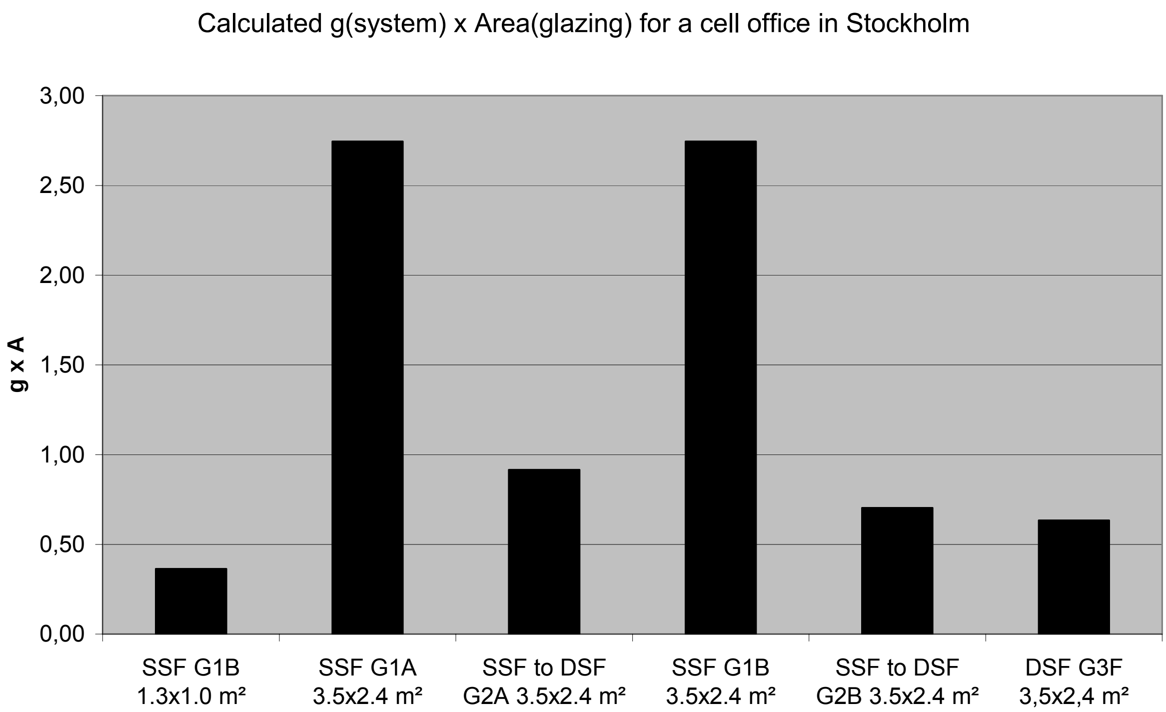

Figure 4.8 Calculated g_{system} x $Area_{glazing}$ for a south facing cell office in Stockholm.

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 figure 4.9 – 4.11). 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 facade, 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 100 %.

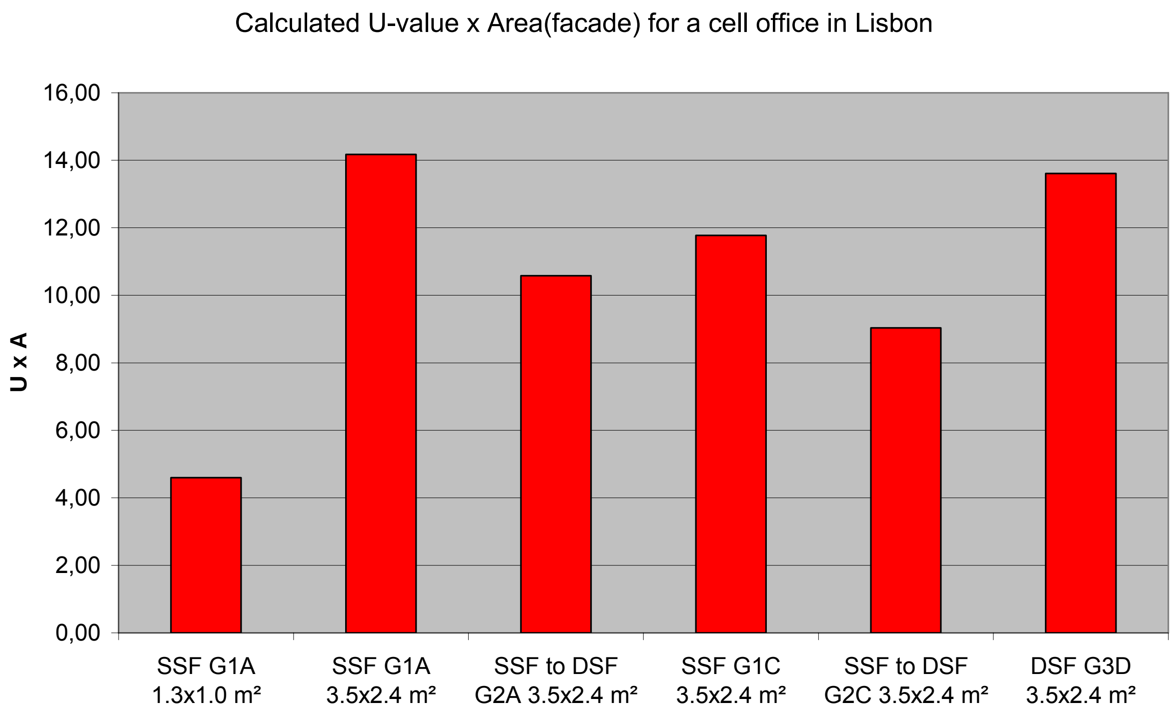

Figure 4.9 Calculated U_{facade} x $Area_{facade}$, W/K, for a south facing cell office in Lisbon.

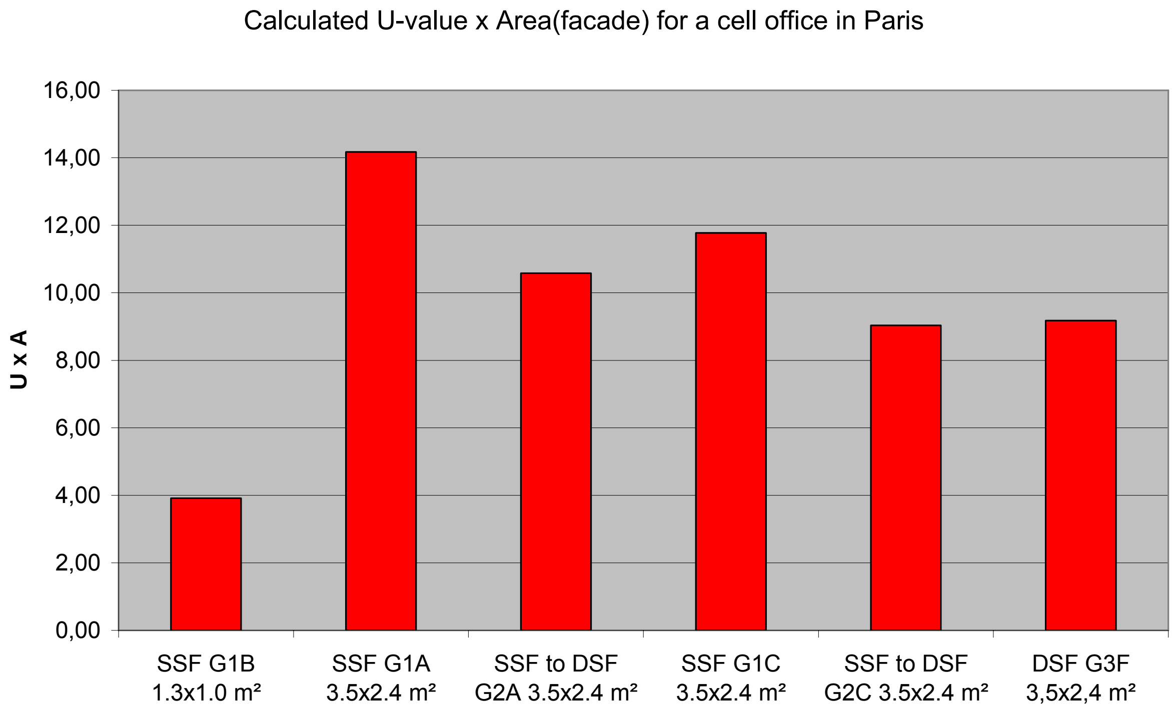

Figure 4.10 Calculated U_{facade} x $Area_{facade}$, W/K, for a south facing cell office in Paris.

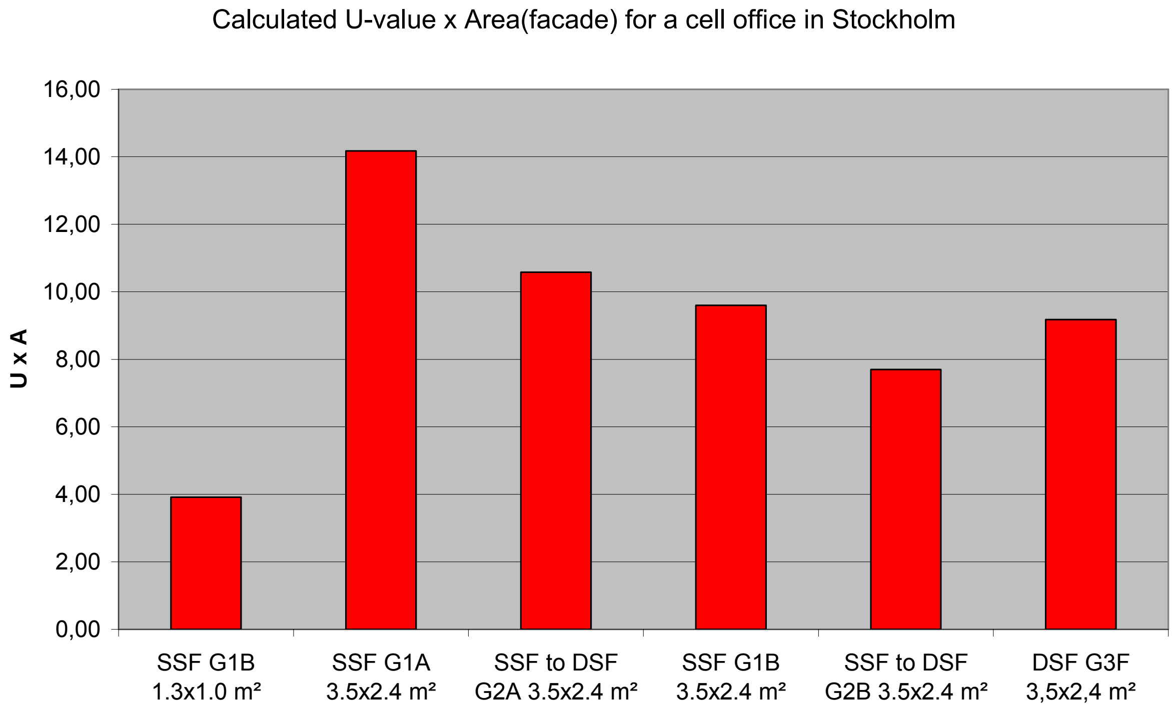

Figure 4.11 Calculated U_{facade} x $Area_{facade}$, W/K, for a south facing cell office in Stockholm.

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 (see figure 4.12 – 4.14). The set points 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 by far 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.

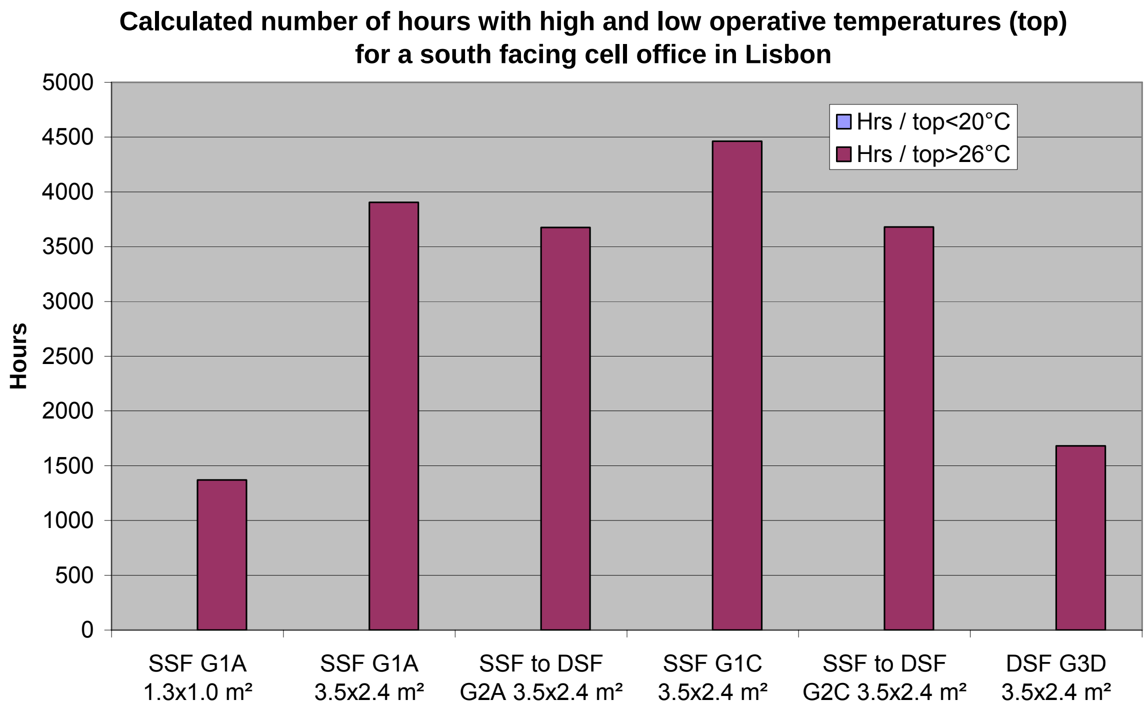

Figure 4.12 Calculated number of hours/year with high and low operative temperatures (top) for south facing cell office in Lisbon.

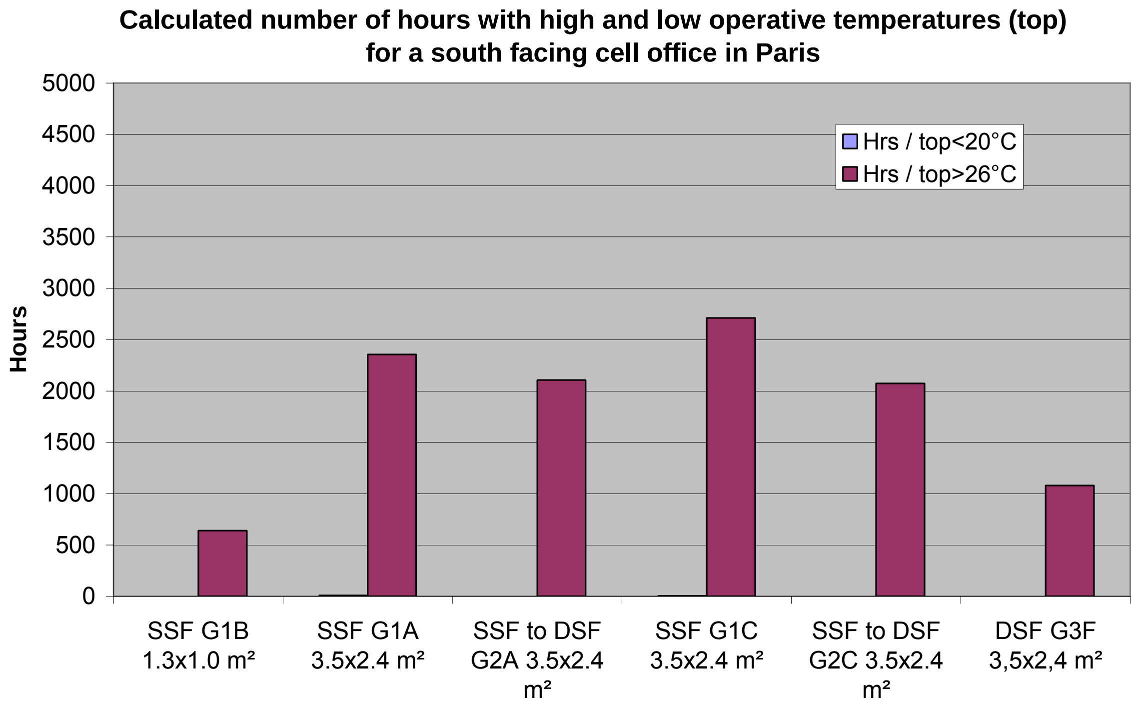

Figure 4.13 Calculated number of hours/year with high and low operative temperatures (top) for south facing cell office in Paris.

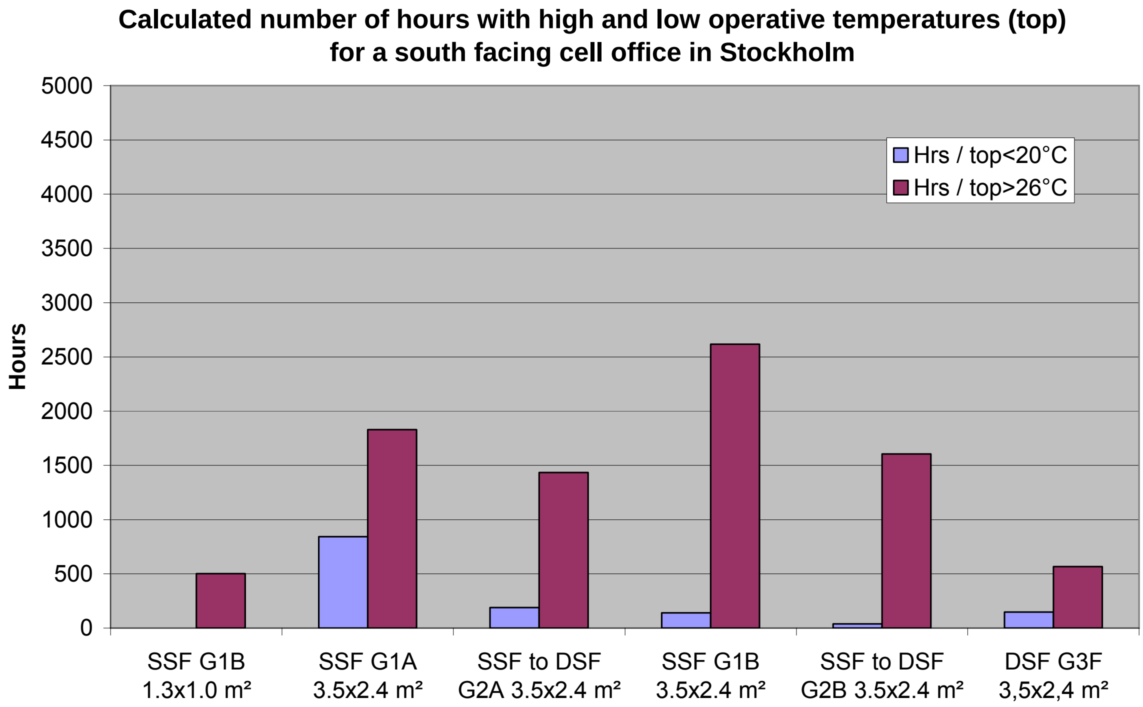

Figure 4.14 Calculated number of hours/year with high and low operative temperatures (top) for south facing cell office in Stockholm.

4.12.2 Predicted performance of a double skin façade office building

Written by Rogério Duarte

The aim was to determine the energy use for an office building for a warm, mild and cold climate and to assess the importance of changes in building orientation, position of shading devices and double skin façade air gap ventilation strategy. The multizone building energy simulation tool EnergyPlus (see chapter 5.3) was used in this study.

Description of the building

The reference building used is described by Poirazis (2005), was developed at the Division of Energy and Building Design (LTH) of Lund University and included the participation of architects and engineers from WSP and Skanska.

The 100% glazed, cell-type offices version of Poirazis' building was considered. This is a 6 storey high building with 6177 m^2 floor area, with a total height of 21 m, length of 66 m and a width of 15,4 m (see figure 4.15).

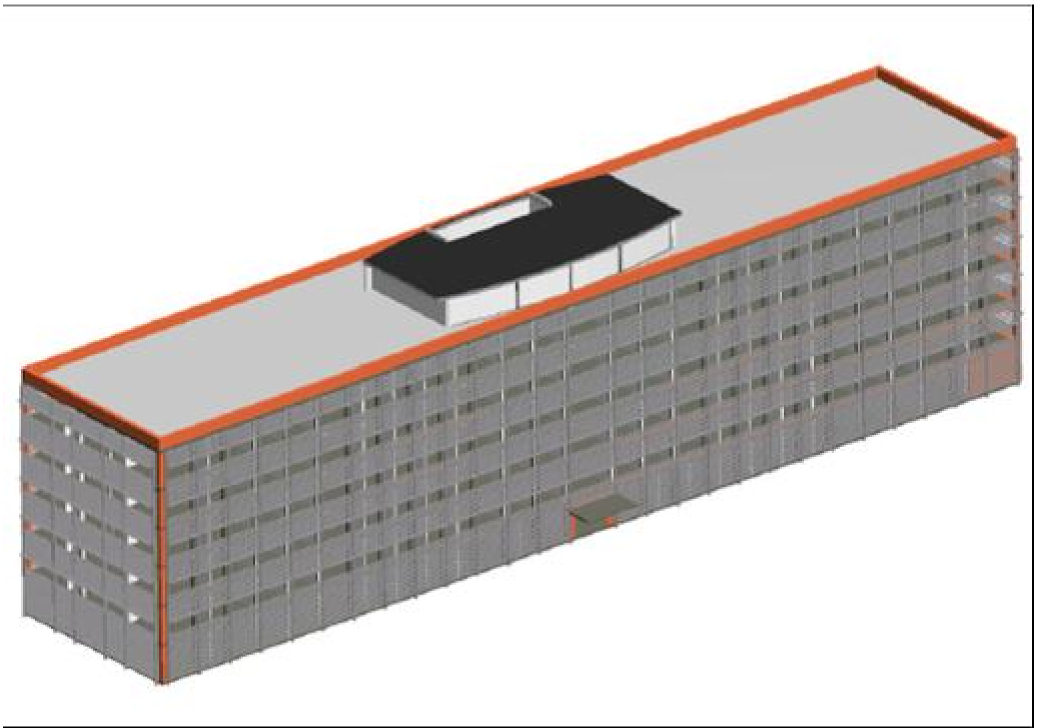

Figure 4.15. Representation of the reference building (Poirazis, 2005).

The thermal zone model of the reference building used in the EnergyPlus simulations is presented in figure 4.16.

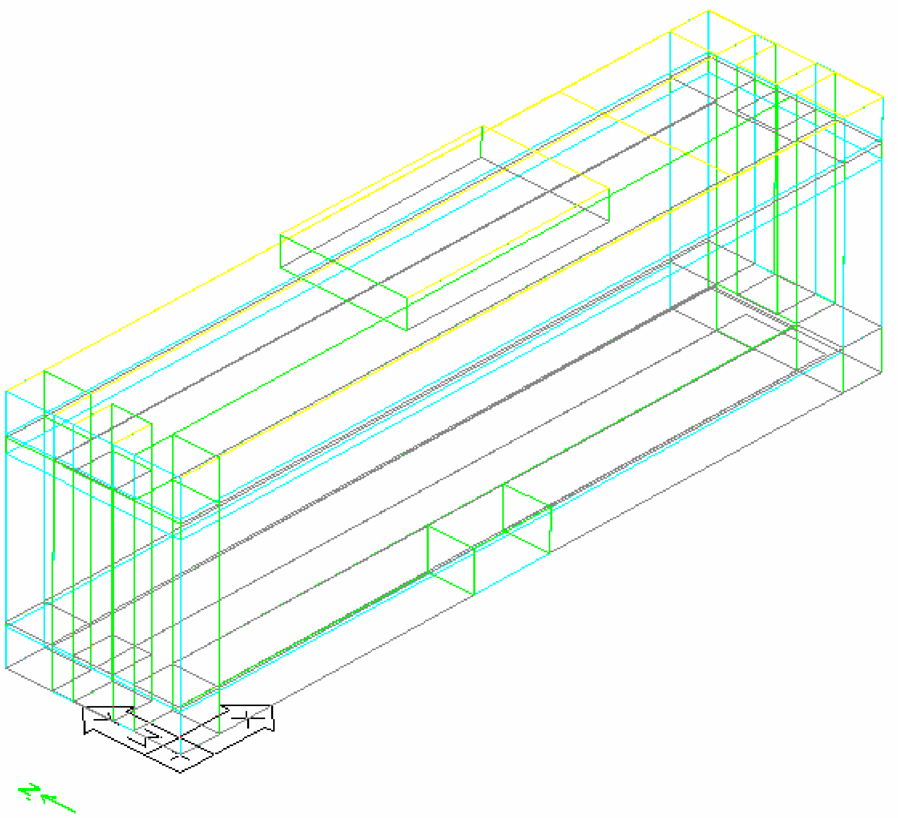

Figure 4.16 Model of the reference building and the thermal zones considered.

Offices layout, constructions and internal gains were those presented by Poirazis (2005). A 4 pipe fan-coil HVAC system operating according to specifications identical to those used by Poirazis (2005) was also considered.

Regarding the glazed windows, triple glazing identical to case G1A in table 4.4 was considered. Venetian blinds with a default slat angle of 45º were used. These blinds were 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). Different positions for the shading devices were studied: (i) inside the office; (ii) intermediate position, between the glazing panes; (iii) outside the building.

Glazed windows with construction identical to case G1A but with the possibility of ventilating the inside air gap between the two innermost glazings were also considered. The ventilation modes considered are the ones presented in figure 4.17.

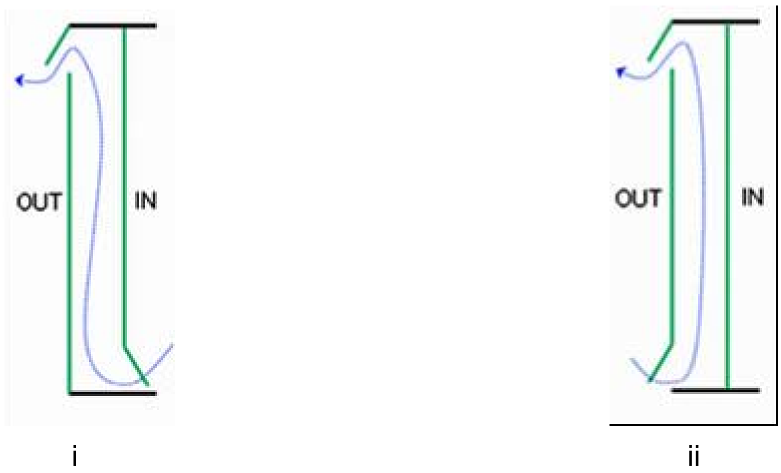

Figure 4.17 Ventilation of the air gap (i) Inside to Outside; (ii) Outside to Outside.

Results

When the reference building changes its orientation (see North direction in figure 4.16) from North-South to East-West in Lisbon, a 15% increase in energy use for cooling is obtained. In Stockholm, the same orientation change increases by approximately 5% both energy use for heating and cooling. In France changing the buildings orientation from North-South to East-West causes a 10% increase in energy use for cooling and only a small 2% increase in energy use for heating.

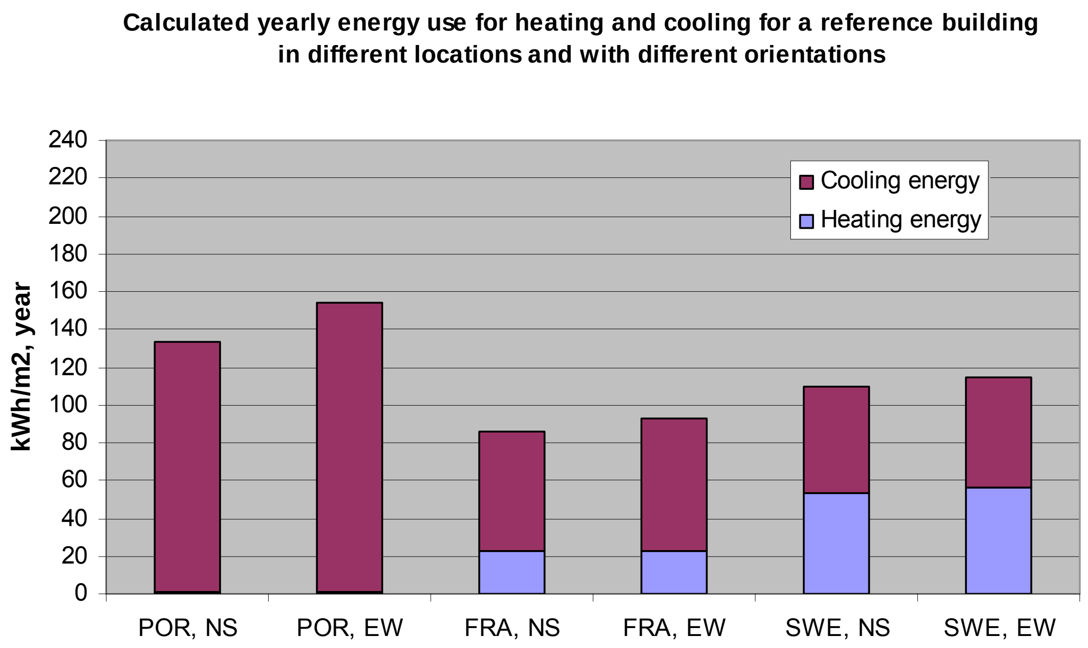

Figure 4.18 Calculated yearly energy use for heating and cooling for a fully glazed reference building located in Lisbon (POR), Paris (FRA) and Stockholm (SWE) with orientation North-South and East-West.

Despite the modelling simplifications made by the single zone simulation tool, it is important to notice that the energy use results for the building and for the cell office oriented South (case SSF G1A 3,5×2.4 m^2, figure 4.3 – 4.5) are not very different, and that the cooling and heating energy use patterns in Lisbon, Paris and Stockholm are similar for both the single and the multi-zone tools.

For the reference building and the North-South orientation figures 4.19 – 4.21 show the influence of the position of the shading device in the building yearly energy use.

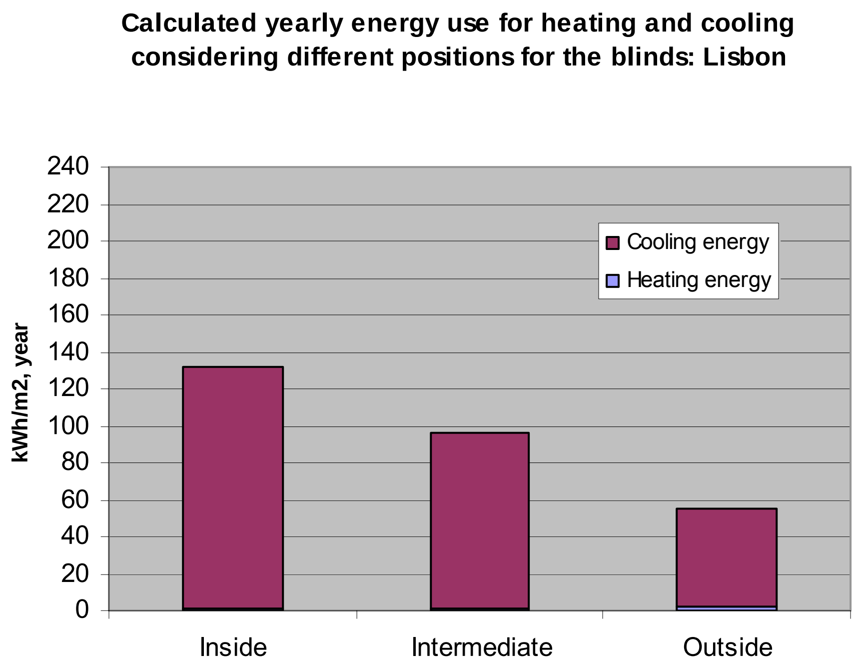

Figure 4.19 Calculated yearly energy use for heating and cooling for a reference building in Lisbon: Results for different positions of the shading devices (Venetian blinds). (i) inside the building; (ii) in an intermediate position between the glazed window panes; (iii) outside the building.

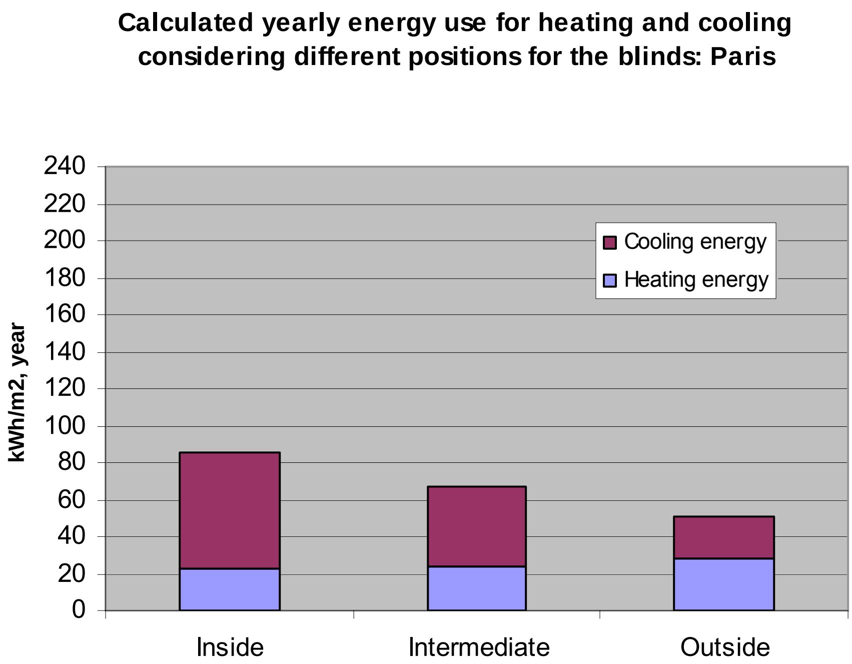

Figure 4.20 Calculated yearly energy use for heating and cooling for a reference building in Paris: Results for different positions of the shading devices (Venetian blinds). (i) inside the building; (ii) in an intermediate position between the glazed window panes; (iii) outside the building.

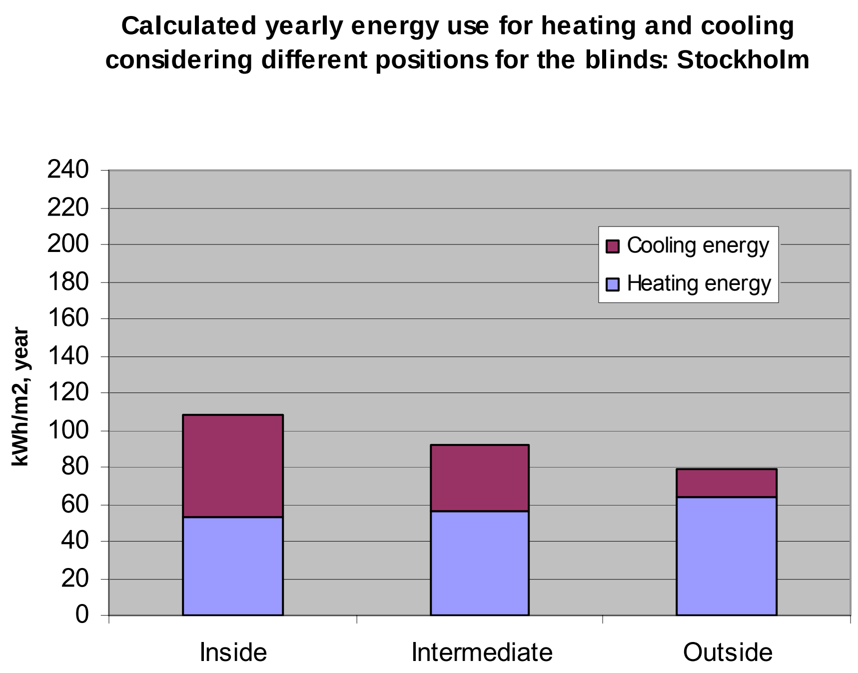

Figure 4.21 Calculated yearly energy use for heating and cooling for a reference building in Stockholm: Results for different positions of the shading devices (Venetian blinds). (i) inside the building; (ii) in an intermediate position between the glazed window panes; (iii) outside the building.

As expected, the results show that the outside shading device position is the best one, since it more effectively prevents solar radiation from entering the offices. Intermediate shading position, as commonly used in double skin façades, is also to be preferred whenever outside shading is not possible.

For the reference building in the two most extreme climates of Lisbon and Stockholm (North-South oriented), considering a glazing window construction identical to case G1A but with a ventilated air gap (0,008 $m^3/(s\ m)$), figure 4.22 presents the influence of different air gap ventilation strategies (see figure 4.17) in the building yearly energy use.

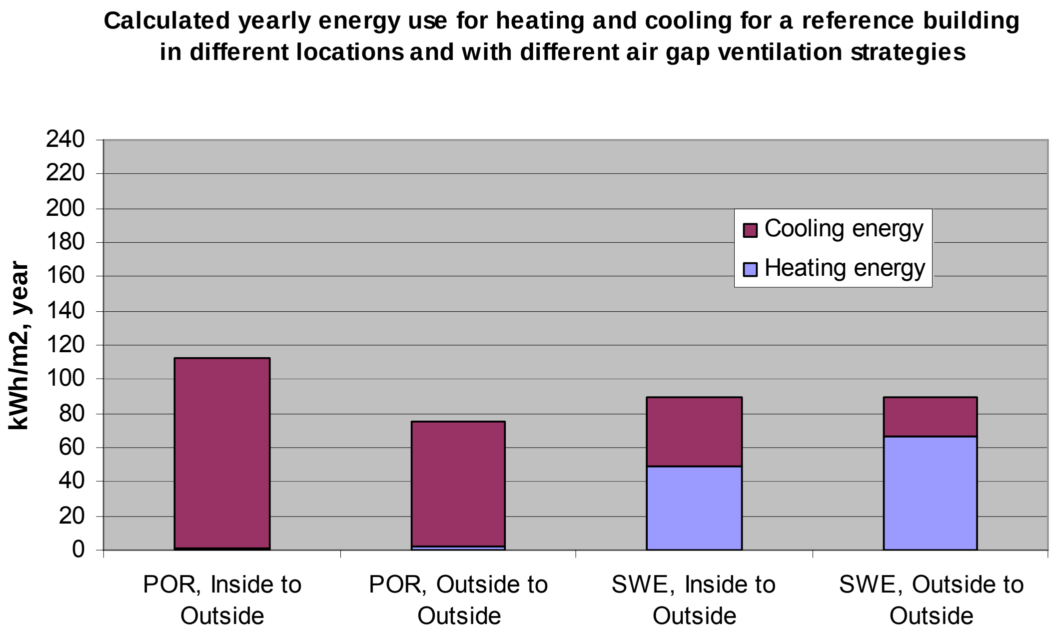

Figure 4.22 Calculated yearly energy use for heating and cooling for a reference building with a double skin façade in Lisbon (POR) and Stockholm (SWE): Results for different air gap ventilation strategies. Inside air to outside air and outside air to outside air.

Comparing 4.22 and 4.18 it can be concluded that air gap ventilation reduces energy use. For Lisbon, ventilating with outside air is the most efficient strategy since it reduces significantly energy use for cooling. For Stockholm, both ventilation strategies seem to have equivalent overall performance. However, ventilating with outside air increases significantly the energy use for heating. Therefore in Stockholm the air gap should be closed in winter.

4.12.3 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 the energy and indoor climate performance in an office. In particular for a double skin façade also the choice of control strategy for ventilation of the cavity and operation of solar shading is crucial. The above choices are very dependant 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 a validated tool. Different façade alternatives may have to be chosen for different orientations. The most energy efficient office seems to be with a façade with modest window areas, which will also have a good indoor climate. From an energy and indoor climate point of view a highly glazed office with a double skin façade is often preferable to a single skin façade. A well designed highly glazed façade with double skin facades can result in an office with almost as low energy use and good thermal comfort as for an office with a traditional single skin façade with a modest window area. Besides a highly glazed double skin façade has other advantages, which is mentioned elsewhere in this report.

5 Energy and indoor climate tools

Written by Heike Erhorn-Kluttig

As explained in the previous chapters, double skin facades as also other types of facades influence the building in many ways. The focus of this chapter is however the energy performance of the double skin façade system and its influence on the energy use and indoor climate of the building. The tools that are listed and described here can be used for the calculation of the energy performance of the building including the double skin façade (chapter 5.3 and 5.4) and the façade itself (chapter 5.5). Other areas such as acoustics or statics are not covered.

The name "tool" covers a wide range of instruments, starting with rules of thumb, to national and international calculation standards and guidelines up to more or less detailed and complicated computer simulation tools including fluid dynamic calculations. Additionally the chapter focuses on the work of the BESTFACADE with a "Simple Calculation Method", which developed or further developed such a method for double skin facades, that can be used in the national standards (Erhorn 2007). For a complex system like the double skin façade rules of thumbs are not available, therefore the following sub-headers were used:

- international and national calculation standards
- simple calculation method for double skin facades developed in the IEE BESTFACADE project
- simulation tools for the energy performance of buildings incl. buildings with double skin facades (multi-zone models)
- simulation tools for the energy performance of a single zone coupled to a double skin facade
- simulation tools for the (energy) performance of double skin facades

Tools can be used during various phases of a building project: brief, design, construction and operation. The project can be new construction or retrofit. During the design phase of buildings, tools are used at different stages:

- the pre-design, where rather simple to use instruments like standards and guidelines should be used and decisions concerning the type of façade (double skin or single skin, totally glazed or partly glazed) are made.
- the phase at which the owner has to apply for the building permit. In some countries like Germany there is an energy performance certificate calculation already needed, which includes double skin facades. This has then to be updated with the final design details. Other countries will only need one energy performance certificate at the end of the construction phase. This has become even more of current interest with the European Energy Performance of Building Directive (EPBD). Figure 5.1 shows an

example of such a certificate that was made for an office building with a double skin façade in Munich, Germany.

- the detailed design, where the façade is developed into detail with the help of partly rather complex simulation tools and decisions are made like what type of glazings, how many openings with which size, what kind of shading system, how to control the shading and the openings, etc.

Tools can also be applied at existing buildings for several reasons:

- for the design of a planned retrofit of a building
- for the application of the EPBD requirement (energy performance certificate) in case the building is sold or rented
- for the application of the EPBD requirement (energy performance certificate) in case of public buildings that need to display the certificate
- in special cases like the Portuguese implementation of the EPBD: here a building can be certified with measured data of the energy performance. However if the measured values are too high in comparison with the reference values, there has to be made a simulation of the building adapted to the real user behaviour etc. in order to define energy efficiency measures that improve the energy quality up to the required level.
- in general the energy performance certificates have to be renewed every 10 years

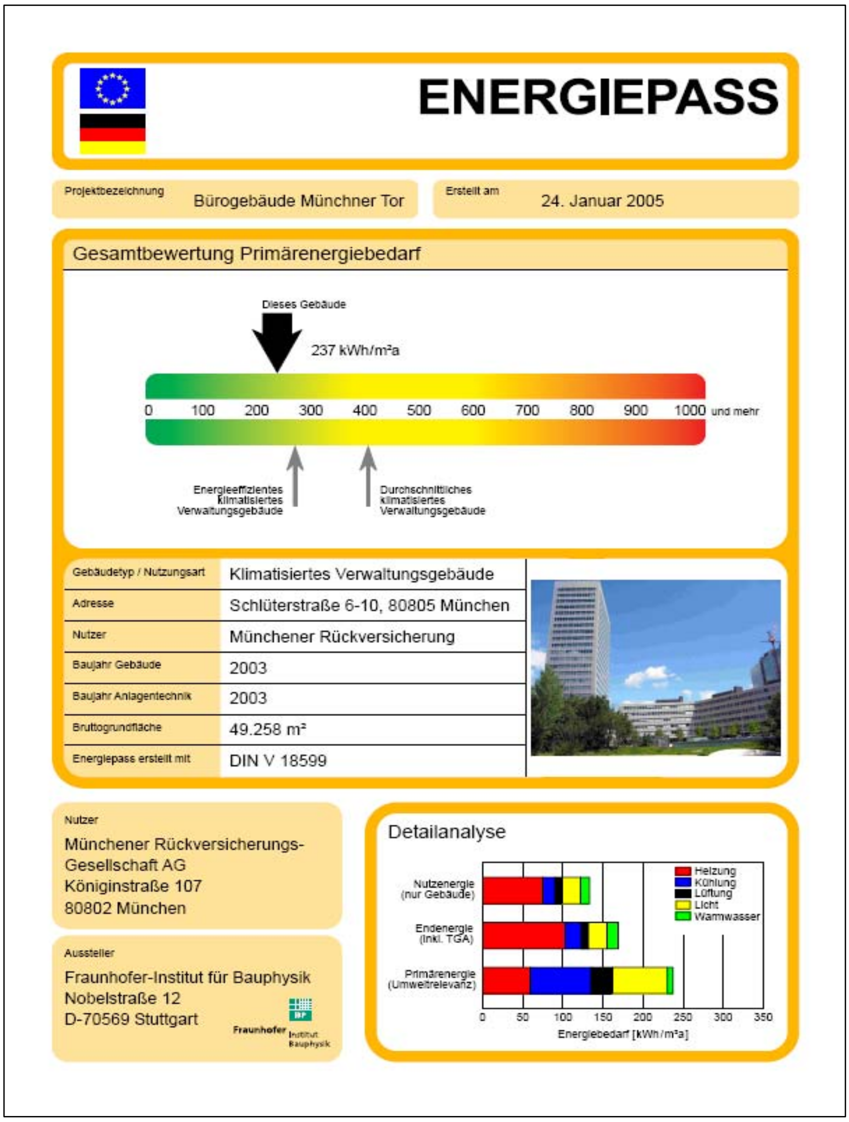

Figure 5.1 Energy performance certificate for a German double skin façade office building situated in Munich.

With the help of tools architects and engineers can show the clients the functions of the façade, the detailed and correct simulation can help to convince the clients that the façade will function and contribute to an energy efficient building. However care has to be taken that the simulation corresponds to reality such like the correct user behaviour, the correct solar reduction due to shading and the correct control of the façade openings etc. are used as input to the tool. Examples of the output of simulation tools are given in figure 5.2.

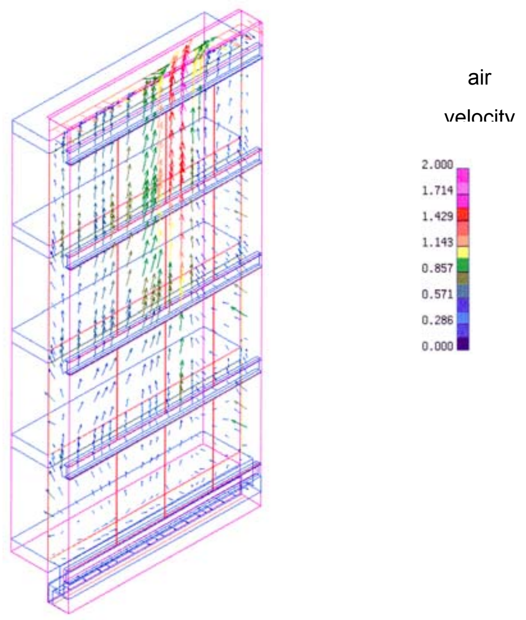	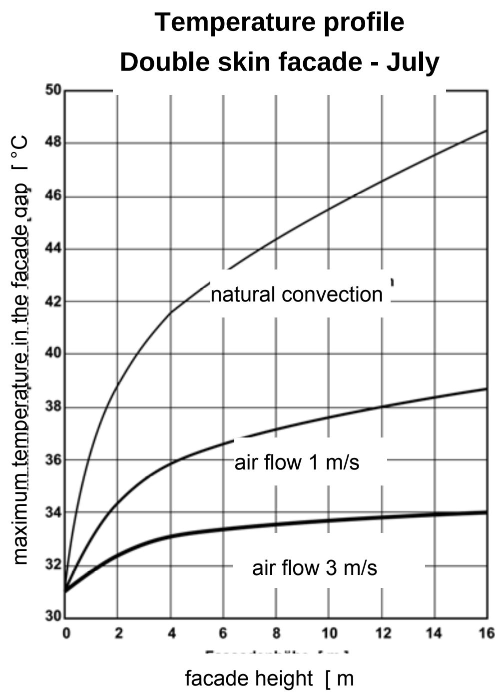
Simulation of the air velocity in a natural ventilated double skin façade.	Temperature profile of a façade gap in July dependent on the air flow.

Figure 5.2 Examples for outputs of simulation tools for the energy performance of double skin facades.

Figure 5.3 presents a simulation of the air flow velocity in the double skin façade of the Baden case study of BESTFACADE WP1.

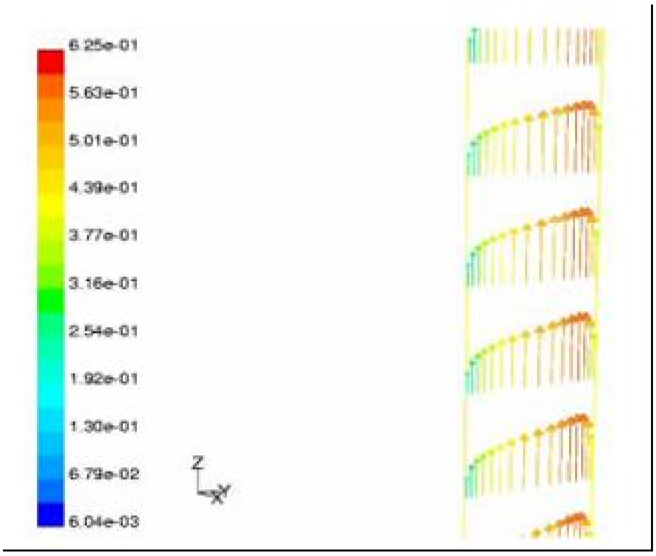

Figure 5.3 Simulated air flow velocity [m/s] in the double skin façade gap of the BiSop building in Baden in summer. [Kautsch et ali: Thermisch hygrisches Verhalten von Glasdoppelfassaden unter solarer Einwirkung. Theorieevaluierung durch Vorort-Messung. [http://www.nachhaltigwirtschaften.at]

Nowadays, building simulation software and developed mathematical models vary in a wide range of complexity. The simplest model is described by a few equations and the most complex one is a CFD (computational fluid dynamics) model solving the conservation equations for mass, momentum and thermal energy.

5.1 International and national calculation standards

The review of existing approaches to cover façade systems including double skin facades in different national energy performance standards or guidelines has resulted in the following list:

- prEN/ISO 13790: Thermal performance of buildings – Calculation of energy use for space heating
- ISO/FDIS 13789: Thermal performance of buildings - Transmission and ventilation heat transfer coefficients - Calculation method
- DIN V 18599: Energy efficiency of buildings — Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting
- modified prEN/ISO 13790 by Dr. Platzer, which is referred to as the Platzer approach

- EU project WinDat: Windows as renewable energy sources for Europe – Window energy data network. The project developed a calculation tool called WIS, will be later refered to as the WIS approach
- EN 13830: Curtain walling - Product standard
- EN 13947: Thermal performance of curtain walling – calculation of thermal transmittance
- ISO 15099: Thermal performance of windows, doors and shading devices - Detailed calculations
- ISO 18292 - Energy performance of fenestration systems - Calculation procedure

prEN/ISO 13790

The prEN/ISO 13790: Thermal performance of buildings – Calculation of energy use for space heating does not yet foresee the calculation of double skin facades. It is still listed here and was analysed within the project since it will be the ISO standard for the calculation of the energy performance of buildings. Therefore the developed simple calculation approach of BESTFACADE will have to be adaptable to this standard. For further information go to the national standard committee or standard publication websites.

ISO/FDIS 13789

The ISO/FDIS 13789: Thermal performance of buildings - Transmission and ventilation heat transfer coefficients - Calculation method is not considering the solar radiation that is transferred from the double skin façade to the room.

DIN V 18599

The German standard DIN V 18599: Energy efficiency of buildings – Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting is foreseen for the national implementation of the Energy Performance of Buildings Directive (EPBD) in Germany. Using the standard calculations of the energy performance of buildings, sub-divided in zones is possible, including zones for double skin facades (DSF). The calculation method for double skin facades is based on the calculation for unheated glazed annexes (conservatories) and the standard foresees an air change rate in the façade gap of 10 h^{-1} that has to be used for the calculation throughout the year. The standard committee decided for this ventilation rate as there were no detailed rates available and by using this factor the energy performance calculation for summer and winter is on the safe side (no underestimation of the energy consumption for heating and cooling). For further information on the DIN V 18599 go to www.din.de or to http://www.beuth.de. The calculation method for the double skin facades is explained in more detail in the BESTFACADE report on the Simple Calculation Method (Erhorn, 2007)

EU project WinDat

The EU project WinDat: Windows as renewable energy sources for Europe – Window energy data network sponsored by DG TREN developed a calculation tool called WIS. The tool is available for download at http://www.windat.org. The calculation procedure was analyzed and the conclusion was that the WIS approach was developed for a stationary calculation, requires a computer tool, is based on many characteristics of the façade system and would be too complicated for a simple calculation method. However it was used for the evaluation of the BESTFACADE simple calculation method (see also 5.5).

EN 13830

The EN 13830: Curtain walling - Product standard contains only definitions no calculation method. For further information go to the national standard committee or standard publication websites.

The Platzer approach

The Platzer approach is a modification of the prEN/ISO 13790. However the the solar radiation includes some weaknesses as it does not foresee reduction factors for dirt, obstructions, frames and solar shading of the exterior façade.

EN/ISO 13947

The EN/ISO 13947: Thermal performance of curtain walling with ventilated and unventilated air spaces calculates the reduced transmission losses due to the buffer effect of the second façade of the double skin facade but considers no influences on the solar gains. For further information go to the national standard committee or standard publication websites.

ISO 15099

The ISO 15099: Thermal performance of windows, doors and shading devices - Detailed calculations specifies detailed calculation procedures to determine the thermal and optical transmission properties (e.g. thermal transmittance, total solar energy transmittance) of window and door systems based on the most up-to-date algorithms and methods, and the relevant solar and thermal properties of all components. This is a complex standard, a lot of input data are needed (some of them are difficult to determine) to perform the calculations. The WIS simulation software (see chapter 5.5.1) has implemented a part of the calculation routines of this standard. For further information go to the national standard committee or standard publication websites.

ISO 18292

The ISO 18292: Energy performance of fenestration systems - Calculation procedure. This standard provides a method for façade rating that can also be applied to double skin facades, yet is no calculation method for the energy performance of such a façade. For further information go to the national standard committee or standard publication websites.

5.2 Simple calculation method developed in the BESTFACADE project

The scope of the work in the BESTFACADE project foresaw the development of a simple calculation method that is able to model (estimate) the energy performance of different types of double skin façades and their influence on the building energy performance and can be integrated in different existing national and international calculation standards. The decision was made to use the calculation method of the German DIN V 18599, which is an extended approach of prEN/ISO 13790 and define more specific ventilation rates in dependence of the various systems of double skin facades. Figure 5.4 shows a scheme of the simple calculation method. For more detailed information go to the BESTFACADE report (Erhorn 2007). Based on an analysis of existing monitoring of double skin facades default values for ventilation rates in winter and summer for open and closed gaps were developed that can be used for monthly calculation in middle European climates. As there were no monitoring results available from Northern and Southern European double skin façade buildings additional default values for these climate zones were not possible. The method was validated by using simulation tools such as Energy Plus.

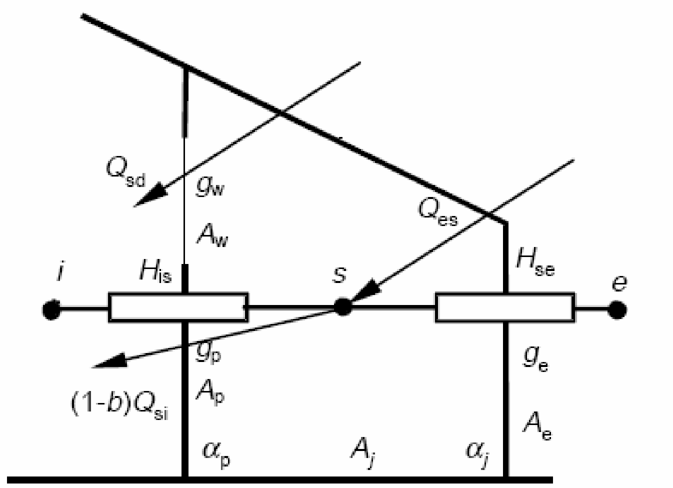

Figure 5.4 Scheme of the simple calculation method. The double skin façade is regarded as an attached sunspace. The scheme includes gains and heat loss coefficients and an equivalent circuit.

The default values for the mean ventilation rates and also the mean excess temperature for middle European climate are summarised in table 5.1.

Table 5.1 Default values for the mean air change rate and the mean excess temperature in the naturally ventilated façade gap for the calculation of the energy performance with the simple calculation method of BESTFACADE.

Façade control strategy	Air change rate [h^{-1}]		Excess temperature in the gap [K]	
	Summer (April–October)	Winter (November–March)	Summer	Winter
Open at all times	25	25	6	4
Adjustable flaps	25	4	6	8

A detailed calculation method for the ventilation rate was also developed in BESTFACADE. This method is however dependent on various characteristics of the façade, which are not known in most situations. For more information on this calculation method read the report (Erhorn 2007).

The simple calculation method developed in the BESTFACADE project is the basis for the BESTFACADE tool for the yearly energy need and lighting autonomy in office rooms with different façade types. The simple to use tool is not thought for detailed calculation assessments but for giving first indications on the impact of different façade types on the heating, cooling and lighting energy demand. It is based on a lighting information and decision tool developed at Fraunhofer Institute of Building Physics for assessing the daylight availability and the electrical lighting demand for different façade types and was extended to heating and cooling energy demands in the participating European regions within the BESTFACADE project.

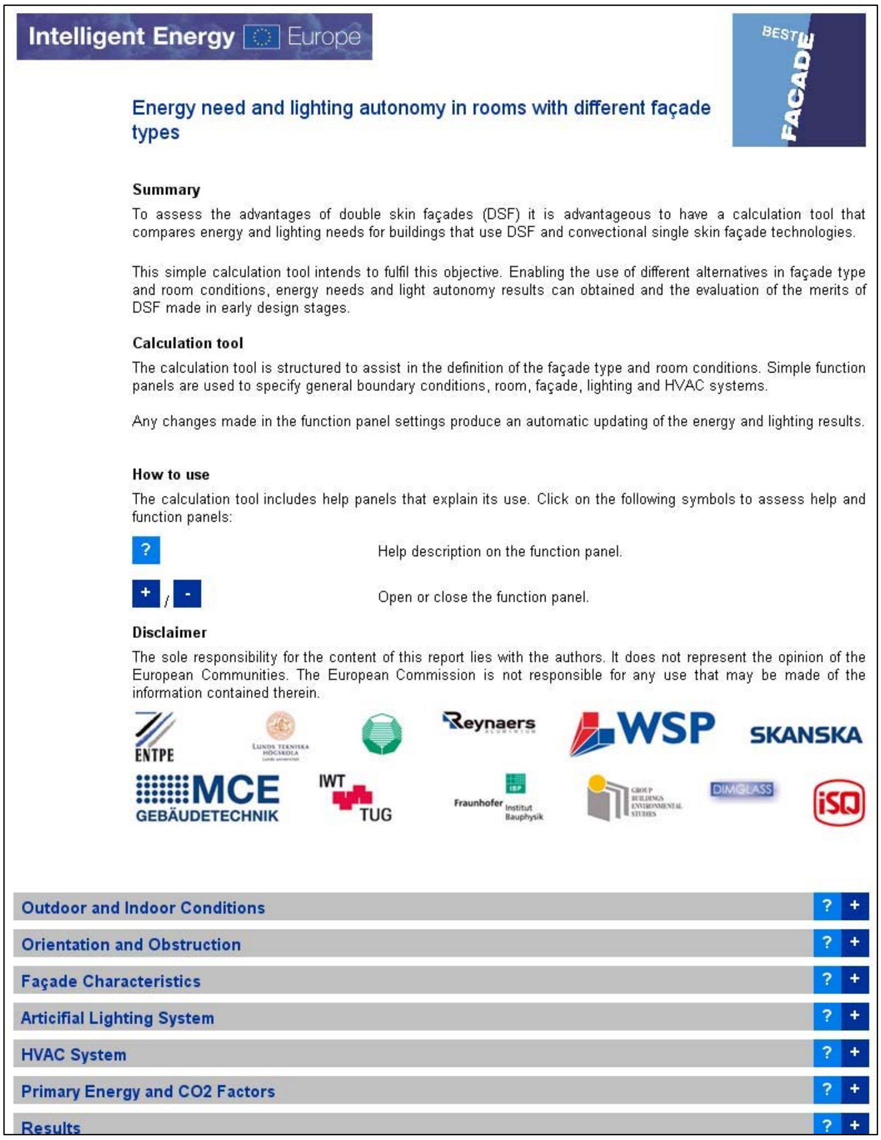

Figure 5.5 Screenshot of the start page of the BESTFACADE tool on the energy need and lighting autonomy in rooms with different façade types.

After choosing the European region (North, Central, South), the internal gains (standard, extended), the façade orientation and the possible linear obstruction, the user has to define the façade characteristics. This includes the façade types (single façade, double skin façade naturally ventilated and double skin façade mechanically ventilated), different types of glazings, different window wall ratios and various shading systems. The next step is the choice of the artificial lighting system (direct, indirect or direct/indirect, task lighting) and the lighting control (manual, daylight dependent, dimming, independent control near and far from the window). The offered HVAC systems include district heating with radiators or fan coils, mechanical or natural ventilation only and district cooling with fan coils or with cooling ceiling.

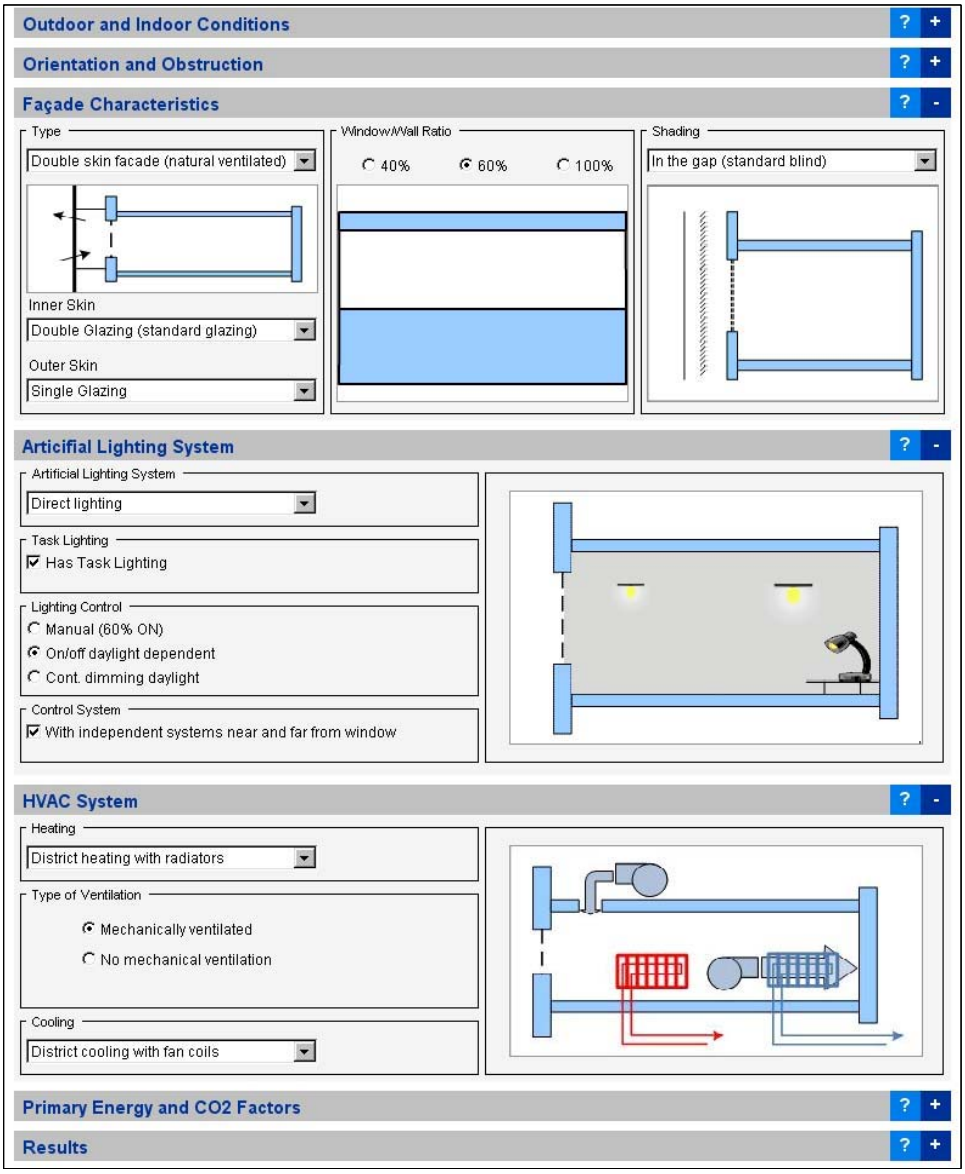

Figure 5.6 Screenshot of the BESTFACADE tool part deifnition of facades, lighting and HVAC systems.

The results given are based on the simple calculation method developed within the BESTFACADE project and include net energy, final energy and primary energy demands for heating, cooling, lighting, ventilation and appliances as well as the CO_2 emissions. The lighting results are further elaborated by giving the relative annual luminous efficiency at each point of the room plus the minimum and the maximum and the daylight autonomy of the office.

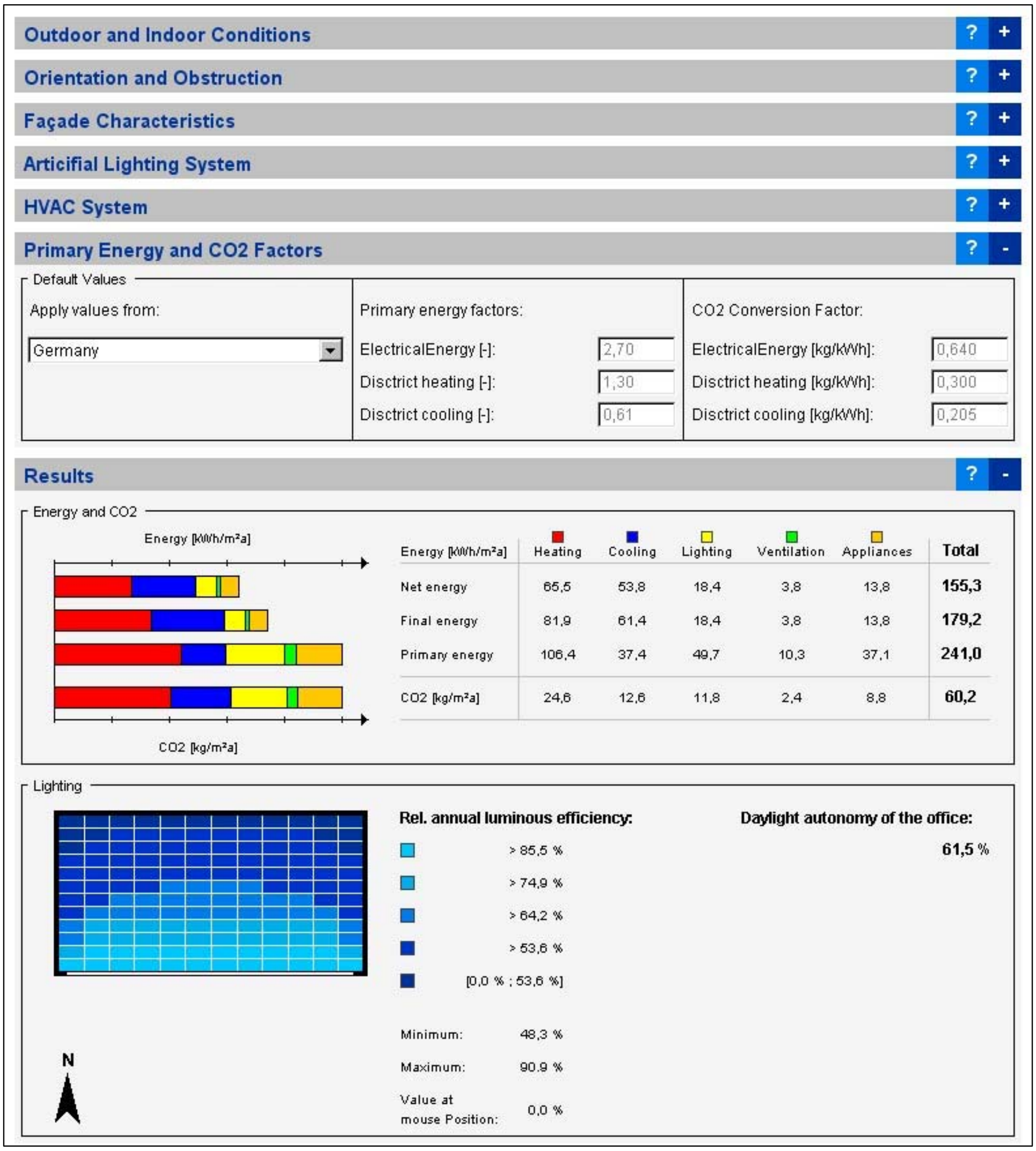

Figure. 5.7 Screenshot of the BESTFACADE tool part definition of the primary energy and CO_2 factors and results for energy, CO_2 and luminous efficiency and daylight autonomy.

5.3 Building energy simulation tools including double skin facades (multi-zone model)

Double skin facade modelling aspects and the applicability of different building simulation software have been investigated at the Belgian Building Research Institute (Flamant 2004).

Recognized are different options of double skin facade functions. Modelling ventilated double skin façades can be difficult, especially when the air flow in a cavity is naturally driven. The report comprises information on modelling of the double skin facade together with a whole building system. Different building simulation softwares are investigated depending on: the possibility to model double façade cavity, its influence on the building energy performance, possibility for the double skin facade control and incorporation of double skin facades into the building systems. The document can be helpful when the simulation tool has to be chosen. Detailed information on the modelling procedure with different software tools is provided in the report, some "tips" are given, which are necessary when the double skin facade is to be modelled, etc. The building simulation tools are described with their limitations, advantages, disadvantages, and sometimes, they are rated after their user-friendliness.

The following list of energy performance software tools starts with those that are known and used for the energy performance simulation of buildings including double skin facades at the different participating organisations within the BESTFACADE consortium. Additional there are listed tools from a database owned by the AIVC - Air Infiltration and Ventilation Centre (http://www.aivc.org/frameset/frameset.html?../airbase/Database-intro-001.html). As the authors do not work with these latter tools, there might be tools included that may only be able to be used for some types of double skin facades or can only roughly determine the influence of the double skin façade on the building energy performance.

5.3.1 Simulation tools used at the organisation of the BESTFACADE consortium

- *TRNSYS (by Wolfgang Streicher)*

TRNSYS (Transient System Simulation Program) is a program package for the calculation of the thermal behavior of a building including active as well as passive components for energy supply (e.g. boilers, heat distribution systems, solar collector, cooling equipment, ...) where a balance of all time-dependent energy flows in the system is provided. TRNSYS has originally been developed for the detailed analysis of buildings with active solar thermal systems. Currently also passive solar components as well as models for conventional heating and cooling equipment are available. The advantage of TRNSYS lies in its modular structure resulting in a high degree of flexibility and the possibility to model a system in a very detailed way. There is a large number of standard components available – so called TYPES – which can be combined for the simulation of a real system. TRNSYS currently boasts a graphical interface, a library of 80 standard components, add on libraries offering over 300 other components, a world wide user base and distributors in France, Germany, Spain, Sweden, Luxembourg, the US and Japan. The open structure of the problem allows the user to include user-written components or modified standard types.
Main distributors of TRNSYS are http://www.trnsys.com in the US,
http://www.transsolar.com in Germany and
http://software.cstb.fr/soft/present.asp?context=Trnsys&langue=us&cd=&search= in France.

Two software packages (at least) that can be coupled to TRNSYS are available for the computation of air flow between pressure nodes based on temperature relative height differences, and the nature of the air link between the two. COMIS was developed by an international group based at Lawrence Berkeley Labs while CONTAM was developed at the National Institute of Standards and Technology. Links to both COMIS and CONTAM's main development sites are given below. Both COMIS and CONTAM rely on what is called the "bulk air flow" method for calculating air flow. In this method, isothermal pressure nodes (akin to isothermal temperature zones in a thermal building model) are defined and are linked by various types of flow paths, each of which is described by a power law equation of the form: Flow = C (Dp)^n. COMIS can be downloaded for free at http://epb1.lbl.gov/comis .

Double skin facade capabilities: Double skin facades can be calculated using COMIS and defining the cavity as a separate zone with boundary conditions that have to be defined (flow resistance of inlet/outlet grills etc.) or coupling a CFD tool to TRNSYS. For double skin facades with an opaque inner skin a TROMBE-Wall model (standard type in TRNSYS) can be used (need slight adaptation). See report (Flamant 2004) for detailed information about the modelling of double skin facades with this software.

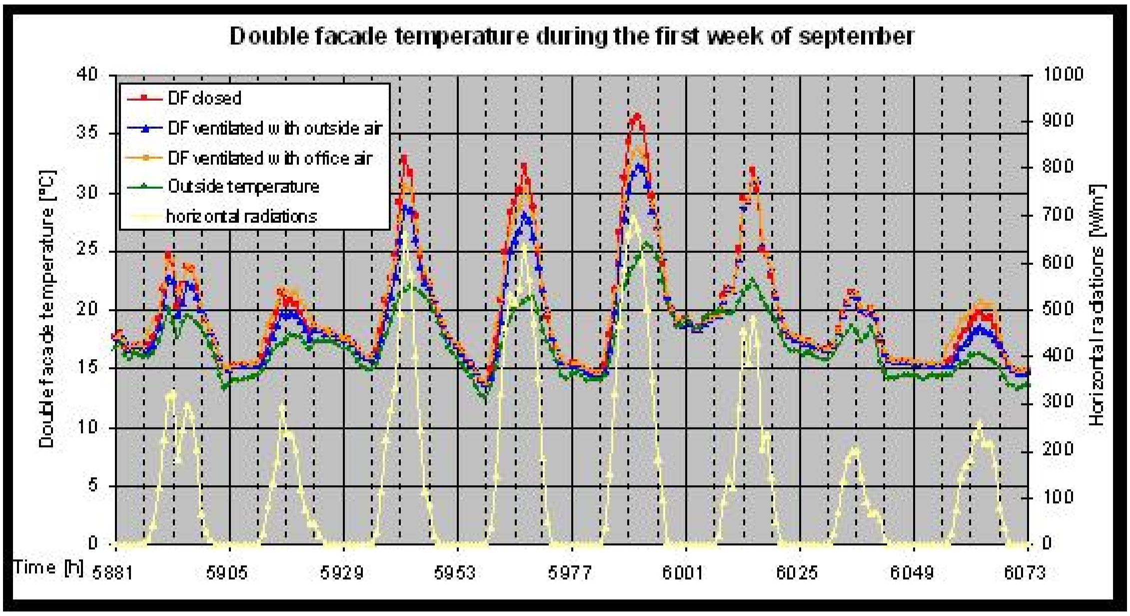

Figure 5.8 Example of results obtained by TRNSYS (see Flamant 2004).

Comments by the author: As TRNSYS can simulate many details, the correct use requires long experience of the users.

- *IDA ICE (by Ake Blomsterberg)*

IDA ICE is a building energy simulation program for the simulation of energy use for heating, cooling, lighting etc., thermal comfort and indoor air quality in buildings. The tool is a multi-zone dynamic energy simulation program, which in a detailed manner takes into account HVAC equipment, which is simulated as well. There are close to 400 users of the program, mainly in Sweden and Finland. The target groups for the program are building owners and managers, HVAC designers, product manufacturers, researchers.
The program can be used at three different levels: room wizard, standard or advanced level. At the room wizard level a one-zone model with default characteristics is given, which then can be modified. At the standard level a multi-zone model can be created. The mathematical models in IDA ICE are described in terms of equations in a formal language, NMF. This makes it easy to customize the models for the needs of a particular project. At the advanced level advanced users can do this themselves by using the IDA Simulation Environment (IDA SE). Validation tests have shown the program to give reasonable results and to be applicable to detailed buildings physics and HVAC simulations.

The main inputs to the program are thermal characteristics, internal loads and schedules, heating and cooling equipment and system characteristics, building geometry and hourly weather data. Controls for heating, cooling, lighting etc. are specified.

A single zone IDA ICE model with default primary and secondary systems, comprises a total of about 600 time dependent variables, any of which may be plotted, such as: zone heat balance, including specific contributions from: sun, occupants, equipment, lights, ventilation, heating and cooling devices, surface transmissions, air leakage, thermal bridges and furniture. Solar influx through windows with full 3D account for local shading devices is included. Air CO2 and moisture levels can be simulated as well as air and surface temperatures. Comfort indices, PPD and PMV, can be calculated.

IDA ICE has been requested, specified and partly financed by a group of thirty leading Scandinavian companies. The mathematical models have been developed at the Royal Institute of Technology in Stockholm (KTH) and at Helsinki University of Technology. The models seek to capture the international state-of-the-art in building performance modelling. Whenever appropriate, models recommended by ASHRAE have been used. The program has a user friendly graphical interface. The program can be downloaded from the website of Equa Simulation http://www.equa.se/.

Double skin facade capabilities: In the present version (3.0), the input data for the window model is given as values of U for the glazing and the frame, and as values of solar T and g at normal incidence. In a new version (4.0) of IDA ICE, which is planned to be released this year (2007), a detailed, pane by pane, window model, will be available. Also a new double façade model is then planned to be available. Today, it is only possible to model a double façade in the advanced level of the program by creating models of your own.

- *Energy Plus (by Reinhard Waldner and Rogério Duarte)*

EnergyPlus is a building energy simulation program for modelling building heating, cooling, lighting, ventilating, and other energy flows. While it is based on the most popular features and capabilities of its parent programs BLAST and DOE-2, it includes many innovative simulation capabilities such as time steps of less than an hour, modular systems integrated with heat balance-based zone simulation, multi-zone air flow, thermal comfort, and photovoltaic systems.
Based on a description of the building with its geometric and physical properties and the associated HVAC and lighting system EnergyPlus will calculate the heating and cooling loads necessary to maintain the thermal control setpoints, conditions throughout a secondary HVAC system and coil loads, and the energy consumption of primary plant equipment as well as many other simulation details that are necessary to verify that the simulation is performing as the actual building would.

Some important features of EnergyPlus are listed below:

- Integrated simultaneous solution where the building response and the primary and secondary systems are tightly coupled and iterations are performed when necessary
- Sub-hourly, user definable time steps for the interaction between the thermal zones and the environment, variable and when necessary automatically varied time steps for the interactions between the thermal zones and the HVAC system
- Thermal comfort models based on activity, inside dry bulb, humidity, etc.
- Advanced fenestration calculations including controllable window blinds, layer-by-layer heat balances that allow proper assignment of the solar energy absorbed by window panes
- Daylight controls including interior illuminance calculations, glare simulation and control, luminaire controls, and the effect of reduced artificial lighting on heating and cooling
- Loop based configurable modular HVAC systems that allow users to model typical systems

EnergyPlus is a stand-alone simulation program without a 'user friendly' graphical interface. The EnergyPlus inputs are text files and also the output is in form of text files without post-processing. There are several commercial graphical user-interfaces available.
The program may be downloaded free of charge from the website of the US Department of Energy – Office of Energy Efficiency and Renewable Energy
http://www.eere.energy.gov/buildings/energyplus

Double skin facade capabilities: Most types of double skin facades can be simulated as an integral part of the building. Airflow windows, defined as windows where forced air flows in the gap between adjacent layers of glass are readily modelled by EnergyPlus. Allowed combinations of airflow source and airflow destination can be selected among inside air, outside air and return air. For these windows mechanical ventilation of the gap is assumed. More general modelling of double skin façades can be achieved using the Airflow Network System. This model enables the simulation of multi-zone airflows driven by HVAC systems (custom HVAC systems can be used), by wind pressure and by buoyancy effects (natural convection; well stirred model, no air stratification). The modelling of different types of shading devices and the connection between the control of these devices, daylighting, solar radiation and air temperature is also a possibility.

Comments by the author: As for most detailed building energy simulation tools, EnergyPlus can simulate many details, however, understanding the consequences of choosing among different available models and identifying the correctness of the results requires long experience of the users. Preliminary validation of the models against experimental results is always a good practice. The work carried out within IEA ECBCS Annex43/SHC Task 34 — Validation of Building Energy Simulation Tools can be useful for airflow in the gap validation. However, many important modelling aspects are still subject of research: the influence of the inside-the-gap shading device in the gap natural convection airflow is one example.

- *SUNCODE (SERI-RES (by Heike Erhorn-Kluttig)*

SUNCODE provides insights into the impact of various design strategies on overall energy consumption, and is capable of modeling relatively complex buildings. The program has been extensively tested by the Solar Energy Research Institute and others using measured building data and has been compared with programs such as DOE 2 and BLAST. A large empirical validation study of the most common international dynamic simulation programs conducted by the IEA confirms that SUNCODE is one of the most reliable energy prediction tools. SUNCODE is an hourly simulation model designed for use in multi- zone structures which incorporates detailed solar algorithms and is appropriate for most residential and small commercial buildings.SUNCODE performs hourly modeling for accurate thermal analysis to arrive at heating, cooling, venting loads, volumetric air flows between zones, heat flows, balance point temperatures, surface temperatures, temperatures at nodes inside walls and air temperatures at different points throughout the building. SUNCODE allows for flexible, interactive development of building components phrased in common terms (windows, walls, etc.) Ground reflectance, ground temperature, internal or appliance gains, infiltration rates, latent gains, heat transfer between zones, movable insulation or shading, heating , venting and cooling setpoints can all be scheduled on hourly , daily or monthly basis. Detailed modeling of direct gain, phase change materials, Trombe walls, attached sunspaces, and rockbins are possible. User specified output (hourly, daily, monthly, and annual) is easy to read and presentable to clients. Suncode can be purchased through Ecotope Inc. http://www.ecotope.com/toolsframe.html.

Double skin facade capabilities: The use for double skin facades is however limited to facades that are not or only with a rather static ventilation rate open to the rooms behind.

- *CAPSOL (by Gilles Flamant)*

CAPSOL is a programme that calculates multi-zone transient heat transfer. In CAPSOL, the building and its environment are considered as a set of zones, between which heat flows occur due to conduction, convection, radiation and ventilation. The behaviour of the system is defined by the boundary conditions, i.e. known temperatures, heat fluxes (such as solar radiation and internal heat gains) and controls (such as heating, cooling, ventilation and sun shading). The program contains a solar processor; building sun obstacles and wall sun obstacles can be defined to simulate e.g. other buildings and overhangs. During the dynamic calculation, a system of energy balance equations is built and solved each calculation time step, using the Crank-Nicolson finite difference method.
The global philosophy is to consider the double skin facade as a set of zones, in order to take into account the thermal stratification in case of ventilation and the control strategy of the shading device.

Double skin facade capabilities: The simulation of some types of double skin facades (e.g. naturally ventilated double skin façades where the impact of the wind has to be considered or facade with more than one air inlet and one outlet) will required to couple CAPSOL with a ventilation model.

For more information about CAPSOL: http://www.physibel.be/
See also (Flamant 2004) for detailed information about the modelling of double skin facades with this software.

Comment by the author: The software allows simulating most types of double skin facades. It shows less functionalities than other powerful software but can be recommended for specific points of interest due to its ease of use.

- *DEROB-LTH (by Bengt Hellström)*

Building energy simulation tool used to explore the complex dynamic behaviour of buildings for different designs. The behaviour is expressed in terms of temperatures, heating- and cooling loads and different comfort indices. The form of the building can be modelled in a flexible way. The model for assessing the solar insolation on building surfaces is detailed and includes the influence of different types of shading devices. The window model has been improved and calculates properties for a window package in an accurate way. The simulation uses a time step of one hour and calculates values in response to hourly values for climatic data, internal loads and airflows.

DEROB-LTH is very good at calculating the energy balance regarding solar energy, taking into account transmittance, absorptance, reflectance in and out from a volume (and to adjacent volumes). Website:

http://www.eere.energy.gov/buildings/tools_directory/software.cfm/ID=211/pagename=alpha_list

Double skin facade capabilities: The present version of DEROB-LTH (2.0) can not handle natural ventilation and is therefore limited to double skin façade systems with an integrated ventilation system etc. However, recently a new ventilation function for the program, which can handle infiltration and natural ventilation, has been developed. This function will be included in the next version of the program.

5.3.2 Simulation tools listed in the AIVC database

- *BSim*

Package of easy to use and flexible programs for evaluating the indoor climate and energy conditions as well as the designing of the heating, cooling and ventilation plants. The BSim package comprises the programs: SimView (user interface and graphic model editor), tsbi5 (simultaneous thermal and moisture building simulation tool), Xsun (dynamic solar and shadow simulation), SimLight (daylight calculation tool), Bv98 (compliance checker), SimDXF (CAD import facility) and SimPV (building integrated PV-system calculation).

BSim permits calculations on complex buildings with several (in principle indefinitely) thermal building zones and rooms simultaneously. It uses data from all structures in the thermal and moisture evaluation. BSim interacts directly with other applications for compliance with building regulation, dynamic (with animated results) solar and shadow distribution, CAD import for model making and daylight calculations. Results from BSim can be exported as boundary conditions for CFD programs. Building models can be exported as input files to Radiance for detailed light analyses.

When it comes to solar shading, BSim has a small problem as it is not possible (but it is under development) to distinguish between internally and externally located shading devices. This option is though under development, including detailed analyses of the light in the room behind the solar shading. Website: http://www.bsim.dk

Double skin facade capabilities: BSim can deal with double skin facades. Mechanical ventilation in double skin facades have always been a possibility. In the latest development a module for simulation of multi-zone natural ventilation have been added, which enables BSim to simulate natural air-flow through openings to the exterior and from one zone to the next.

- *COMFIE*

Performs hourly simulations of buildings, in order to provide mechanical, energy and architectural engineers or architects with accurate estimates of a building's energy needs and temperature profiles. The zone models of COMFIE are based upon a finite volume method on which a modal reduction technique is applied. The output comprises the yearly and hourly heating loads, hourly and mean temperatures in the thermal zones. Graphs and histograms may be obtained.

COMFIE is a multi-zone building simulation tool. A double skin facade can be modelled by considering the air gap as a room (possibly several rooms in case of several orientations). Windows have to be described accounting for the solar energy transmittance of the external skin so that the incoming solar radiation is properly calculated. A mechanical ventilation system can be described by a schedule providing the air flow rate 24h x 7 days. In the case of natural ventilation, the area of air inlet/outlet and the height difference between inlet and outlet have to be given, as well as a possible control (e.g. closing the air inlet/outlet according to the temperature difference between the gap and the building behind). No CFD model is used, but the air flow rate is estimated using a correlation derived from measurements at the University of Poitiers. The tool has been used and compared to measurements in the case of transparent insulation walls (natural internal air circulation) and air collectors on the roof (mechanical ventilation).
Website: http://www-cenerg.ensmp.fr/english/themes/

- *ESP-r*

ESP (ESRU 2005, Clarke 2001) is a general purpose, multi-domain—building thermal, interzone air flow, intra-zone air movement, HVAC systems and electrical power flow—simulation environment which has been under development for more than 25 years. It follows the pattern of simulation follows description where additional technical domain solvers are invoked as the building and system description evolves.

Users have options to increase the geometric, environmental control and operational complexity of models to match the requirements of particular projects. It supports an explicit energy balance in each zone and at each surface and uses message passing between the solvers to support inter-domain interactions (Clarke 2001). It works with third party tools such as Radiance to support higher resolution assessments as well as interacting with supply and demand matching tools. ESP-r is distributed as a suite of tools. A project manager controls the development of models and requests computational services from other modules in the suite as well as 3rd party tools. Support modules include: climate display and analysis, an integrated (all domain) simulation engine, environmental impacts assessment, 2D-3D conduction grid definitions, shading/insolation calculations, viewfactor calculations, short-time-step data definitions, mycotoxin analysis, model conversion (e.g. between CAD and ESP-r) and an interface to the visual simulation suite Radiance. ESP-r is distributed under a GPL license through a web site which also includes an extensive publications list, example models, cross-referenced source code, tutorials and resources for developers. It runs on almost all computing platforms and under most operating systems. Although ESP-r has a

strong research heritage (e.g. it supports simultaneous building fabric/network mass flow and CFD domains), it is being used as a consulting tool by architects, engineers, and multidiscipline practices and as the engine for other simulation environments.
Website: www.esru.strath.ac.uk/Programs/ESP-r.htm

Double skin facade capabilities: The modelling of double skin facades is possible with this software.

- **TAS** *(by Gilles Flamant)*

TAS is a suite of software products, which simulate the dynamic thermal performance of buildings and their systems.

- The main module is Tas Building Designer (A-Tas), which performs dynamic building simulation with integrated natural and forced airflow. It has 3D graphics based geometry input that includes a CAD link.
- Tas Systems is a HVAC systems/controls simulator, which may be directly coupled with the building simulator. It performs automatic airflow and plant sizing and total energy demand.
- The third module, Tas Ambiens, is a robust and simple to use 2D CFD package which produces a cross section of micro climate variation in a space.

A-Tas is a software tool which simulates the thermal performance of buildings. The main applications of the program are in assessment of environmental performance, natural ventilation analysis, prediction of energy consumption, plant sizing, analysis of energy conservation options and energy targeting.

Double skin facade capabilities: Tas is a dynamic multizone model and double skin facade is simulated as an independent zone. Only one temperature per zone is calculated. In order to take into account the stratification of the air in the cavity, the cavity of the double skin facade can be subdivided in several zones. Separations between zones are factitious walls that can be completely open. The factitious walls have a very small thermal resistance and a solar transmission of 1. Vertically and horizontally subdivisions are possible.
For more information about TAS: http://ourworld.compuserve.com/homepages/edsl
See (Flamant 2004) for detailed information about the modelling of double skin facades with this software.

5.4 Energy simulation tools for double skin façades connected to one zone only (single-zone model)

The following list of energy performance software tools are known and used for the energy performance simulation of double skin facades (this time with limited reflection on the building energy performance such as single-zone models) at the different participating organisations within the BESTFACADE consortium.

- *ADELINE (by Hans Erhorn)*

ADELINE is an integrated lighting design computer tool developed by an international research team within the framework of the International Energy Agency (IEA) Solar Heating and Cooling Programme Task 12. ADELINE provides architects and engineers with accurate information about behaviour and the performance of indoor lighting systems. Both natural and electrical lighting problems can be solved, in simple rooms or the most complex spaces. ADELINE produces innovative and reliable lighting design results by processing a variety of data (including: geometric, photometric, climatic, optic and human response) to perform light simulations and to produce comprehensive numeric and graphic information. ADELINE contains SCRIBE-MODELLER as CAD interface, the (day-)lighting tools SUPERLITE and RADIANCE and the link to energy simulation tools using SUPERLINK or RADLINK. ADELINE Version 3 is now available. It runs on PCs under Windows 95/NT. (The version 2.0 for PCs under DOS is still available).
Website: http://www.ibp.fhg.de/wt/adeline/

Comment by the author: The program is worldwide used and continuously updated. Depending on the required type of results the program can produce quick achievable numerous data as well as in detail phototype graphics of the light situation in the rooms and or the double skin façade. Though ADELINE is providing only lighting results there is a possibility to couple the tool to other tools such as TRNSYS or SUNCODE for other energy performance assessments.

- *FLOVENT (by Heike Erhorn-Kluttig)*

FLOVENT is a powerful Computational Fluid Dynamics (CFD) software that predicts 3D airflow, heat transfer and contamination distribution in and around buildings of all types and sizes. A free demo is available at http://www.flomerics.com/flovent/. FLOVENT's fast and easy-to-use menu system is designed specifically for the design and optimization of heating, ventilating and air-conditioning (HVAC) systems. Typical applications include data centres and IT rooms, clean rooms, auditoriums, shopping malls, office buildings, underground car parks, passenger comfort in vehicles, airport terminals, etc, air quality and contaminant control in laboratories, research facilities, and hospitals.

Comment by the authors: As the air flow simulation is complex and the 3-D input for whole buildings with double skin facades rather comprehensive, it is a good tool for static situations, but hardly applicable for yearly runs.

- *ParaSol (by Ake Blomsterberg)*

Parasol is a design tool to study the potential of solar protection for different types of sunshades and glazing systems and their influence on the building energy performance at an early design stage. Parasol is based on dynamic energy simulations using hourly weather data. The results provided are monthly results for the total and direct solar energy transmittance (g- and T- values) of the sunshade and the combination of sunshade and window system and their calculated influence on the building energy performance. The program has post-processors for studies of daylight and thermal comfort. The user can select between external, interpane and internal sunshades. Within each such group, a number of different geometries and material properties can be selected. Internal sunshades are by default modelled as ventilated, but internal screens and roller-blinds can also be simulated with a closed air gap.

A simple geometric model, which can regarded as a rectangular office module, is predefined. All dimensions can be changed. ParaSol is mainly intended for simulations of buildings like offices, schools and hospitals, but rooms in residential buildings can also be simulated.
To use the program requires basic knowledge about solar radiation, solar shading, windows, energy performance indicators. There are some 1400 user of the program. The target groups are architects, building services consultants and other engineers.

Input data is separated into three parts: Room, Window and Sunshade. The room data includes specification of the site, geometry, and wall constructions. The window data includes window specifications (i.e. specification of the glazing system). In the sunshade data part, the type of sunshade is selected. The program includes a database of common awning fabric types on the Swedish market. Some additional input data can be given for the calculation of the building energy performance: Control of sunshades, set-points for the indoor temperatures (heating and cooling), internal loads, inlet air temperatures and flows, and the efficiency of the heat recovery system.

The output from the program consists of monthly average solar energy transmittance (g- and T values). The output also consists of maximum heating and cooling loads, solar irradiation, room air and operative temperatures, design days, and energy demands for pre-heating and pre-cooling the room module.

The advantages of the program are a simple user interface, detailed dynamic simulations, detailed models for shading calculations of direct and diffuse solar radiation and calculations of solar transmittance of window systems. The program can be downloaded free of charge from the website of Lund Institute of Technology www.parasol.se.

Double skin facade capabilities: In the next version of ParaSol a function for ventilation of windows, which is partly based on ISO 15099, will be available. This function could also be used to simulate a glazed double skin façade.

5.5 Energy simulation tools for double skin facades

The following list of energy performance software tools starts with those that are known and used for the energy performance simulation of double skin facades (without reflection on the building energy performance) at the different participating organisations within the BESTFACADE consortium. Additional there is a tool from a database owned by the AIVC - Air Infiltration and Ventilation Centre. As the authors do not work with these latter tools, this tool may only be able to be used for some types of double skin facades.

5.5.1 Simulation tools used at the organisation of the BESTFACADE consortium

- *WIS by (Gilles Flamant)*

WIS 3.0 is a uniform, multi-purpose, European-based software tool designed to assist in determining the thermal and solar characteristics of window systems (glazing, frames, solar shading devices, etc.) and window components. The tool contains databases with component properties and routines for calculation of the thermal/optical interactions of components in a window. One of the unique elements in the software tool is the combination of glazings and shading devices, with the option of free or forced air circulation between both. This makes the tool particularly suited to calculate the thermal and solar performance of complex windows and active facades.

The WIS algorithms are based on international (CEN, ISO) standards, but WIS also contains advanced calculation routines for components or conditions where current standards do not apply.

WIS 1.0 (the first version of WIS), previously developed as a licensed tool under a European Commission-funded research project, has been upgraded to WIS 3.0 during the European WINDAT project (2001-2004), which included 40 leading research and educational organizations, industries, consulting engineers and designers, including a strong representation in relevant international standardization bodies.

This tool is collectively supported and used in research, industry, standardisation, education and design throughout Europe to compare, select and promote innovative windows and window components to maximise energy savings and improve indoor comfort.

WIS 3.0 tool is freely available, and is designed as a user-friendly tool, prepared for a wide variety of users including: consulting engineers, manufacturers, building designers, researchers, those involved in standardisation, building regulation and education.

The WINDAT project and the WIS software were financially supported by the European Commission Directorate General for Energy and Transport.

For more information and free download of the tool: http://www.windat.org. See (Flamant 2004) for detailed information about the modelling of double skin facades with this software.

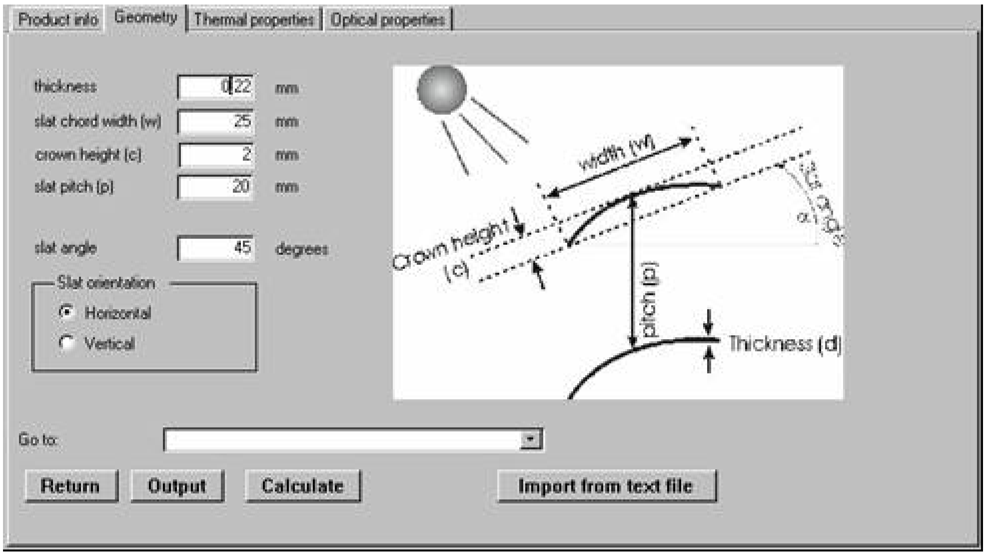

Figure 5.9 Geometrical definition of curved slat type blinds in WIS

Comment by the authors: The WIS software is a user-friendly tool to determine the thermal and solar properties of a double skin façade but it is restricted only to the façade. Control systems and building modelling are not part of this tool.

- **BISCO / TRISCO / VOLTRA** *(by Gilles Flamant)*

The company Physibel has developed a series of software aimed at modeling heat transfer of building details using the energy balance technique.

Where the majority of the simulation programs calculate the ventilated double skin façade as parallel glass and shading layers which does not directly take into account the thermal bridging effect of sub-components with a clear 2D or 3D heat flow, BISCO, TRISCO and VOLTRA have the potential to calculate for both temperature distribution and heat loss, the interaction between the glass and shading layers in combination with the thermal bridging effect of the subcomponents around the double skin facade (e.g. the supporting mullions and transoms, connection with inlet and outlet openings and even the false ceiling).

For more information about BISCO, TRISCO, VOLTRA: http://www.physibel.be/
See (Flamant 2004) for detailed information about the modelling of double skin facades with this software.

5.5.2 Simulation tools listed in the AIVC database

- *Design Advisor*

Web suite of building energy simulators that model energy, comfort, and daylighting performance, and give estimates of the long-term cost of utilities. The simulations restrict flexibility in order to offer users greater ease-of-use and speed. The tool can be quickly mastered by non-technical designers, and runs fast enough to allow them the scope to experiment with many different versions of a design during a single sitting. The immediate feedback that the site provides makes it useful in the conceptual phase of design, when architects cannot afford to invest large amounts of time to rule out any particular idea. Energy-load estimates are based on a library of climate data for 30 different cities around the world. Accuracy within 10-15%, to be used as an approximate tool for comparing early building design concepts. Difficult to fine-tune when a building is beyond early design concepts. Website: http://designadvisor.mit.edu. Freely available as a real-time simulator on the web.

Double skin facade capabilities: The emphasis of the energy model is on the envelope system of the building, and includes simulations of high-technology windows such as double skin facades.

5.6 Conclusions

The prediction of the energy performances of double skin facades is a complex matter. The thermal process and the airflow process interact. These processes depend on the geometric, thermo-physical, optical and aerodynamic properties of the various components of the facade.

The chapter shows that there are various simulation tools available, both, for the energy performance calculation of buildings including double skin façade and for the separate mostly more detailed analysis of the façade itself (effective U-values, air flow, daylighting availability, etc.). As with all simulation tools the results are only as good as the input data given by the user. Most presented programs need therefore experienced users in order to give reliable results. In the particular case of double skin facades, the correct modelling of shading devices such as Venetian blinds or louvers, of the natural ventilation (stack-effect and wind effect) through the cavity and of the different control systems and control strategies is a complex task. It generally makes sense to accompany in detail calculations with simple calculations in order to ensure that the results are in the correct range.

The choice of the most appropriate software for simulating a ventilated double skin façade, itself or integrated with the buildings behind, depends on the objective of the simulation : Design of a new concept for a ventilated double skin facade? Dimensioning of the HVAC systems which are connected to the double skin facade? Determination of the maximum cooling or heating loads during a whole year? Determination of the maximum indoor temperatures in the building during summertime? Determination of the yearly energy use? Condensation risk? Testing of various control alternatives? etc.

The existing simplified calculations for the energy performance of buildings with double skin facades analysed in detail in the report "IEE SAVE BESTFACADE – Final Report of WP4 Simple Calculation Method" (Erhorn 2007) showed that there is a need for further development. This was partly done within the BESTFACADE project, so that there is more knowledge about the major factor for the energy performance of this special façade type: the air flow velocity in naturally ventilated double skin facades. This velocity can be used for calculations with the DIN V 18599 which is CEN conform and currently prepared to become an ISO standard. The BESTFACADE tool informs on the influence of different façade types on the energy performance of a standard office room.

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