

State of the Art of Double Skin Facades in Europe

The results of WP1 of the BESTFACADE Project

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1 Introduction

Innovative faade concepts are today more relevant than ever. The demand for natural ventilation in commercial buildings is increasing due to growing environmental consciousness while at the same time energy consumption for buildings has to be reduced. An advanced faade should allow for a comfortable indoor climate, sound protection and good lighting, while minimising the demand for auxiliary energy input. Double skin faades (DSF) have become an important and increasing architectural element in office buildings over the last 15 years. They can provide a thermal buffer zone, solar preheating of ventilation air, energy saving, sound, wind and pollutant protection with open windows, night cooling, protection of shading devices, space for energy gaining devices like PV cells and – which is often the main argument – aesthetics.

Commercial and office buildings with integrated DSF can be very energy efficient buildings with all the good qualities listed above. However not all double skin façades built in the last years perform well. Far from it, 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.

The project BESTFACADE, sponsored by the Energy Intelligent Europe Program of the European Union, and led by MCE-Anlagenbau, Austria, put together the state of the art of double skin facades in seven European countries (Austria, Belgium, France, Germany, Greece, Portugal and Sweden). 27 facades of different buildings in all partner countries of Bestfacade have been studied by means of a standardized questionnaire. The questionnaire comprises data on location, information about the building and the facade, construction and route of air flow in the façade as well as maintenance and costs.

The analysis is been drawn for the aspects, types of façade in different countries, DSF in different climatic regions of Europe, existing simulations and measurements, thermal behaviour, indoor air quality, comfort, user acceptance, energy demand and consumptions, control strategies, integrated building technology, costs (investment, maintenance, operation), resource conservation, environmental impact, comparison to conventional glass facades (CGFs), integration of renewable energy sources into DSF, and non-energy related issues: acoustics, aesthetics, fire protection, moisture, corrosion, durability, maintenance, repair.

The main results of this work are shown in the following.

2 Definition

“A double skin façade can be defined as a traditional single façade doubled inside or outside by a second, essentially glazed façade. Each of these two façades is commonly called a skin. A ventilated cavity - having a width which can range from several centimetres to several metres - is located between these two skins. Automated equipment, such as shading devices, motorized openings or fans, are most often integrated into the façade. The main difference between a ventilated double façade and an airtight multiple glazing, whether or not integrating a shading device in the cavity separating the glazing, lies in the intentional and possibly controlled ventilation of the cavity of the double façade” (BBRI, 2004).

“Essentially a pair of glass “skins” separated by an air corridor. The main layer of glass is usually insulating. The air space between the layers of glass acts as insulation against temperature extremes, winds, and sound. Sun-shading devices are often located between the two skins. All elements can be arranged differently into numbers of permutations and combinations of both solid and diaphanous membranes” (Harrison, Meyer-Boake, 2003).

“The Double Skin Façade is a system consisting of two glass skins placed in such a way that air flows in the intermediate cavity. The ventilation of the cavity can be natural, fan supported or mechanical. Apart from the type of the ventilation inside the cavity, the origin and destination of the air can differ depending mostly on

climatic conditions, the use, the location, the occupational hours of the building and the HVAC strategy. The glass skins can be single or double glazing units with a distance from 20 cm up to 2 meters. Often, for protection and heat extraction reasons during the cooling period, solar shading devices are placed inside the cavity”.

Poirazis (2004).

3 History

The history of Double Skin Façades is described in several books, reports and articles. Saelens mentions that “in 1849, Jean-Baptiste Jobard, at that time director of the industrial Museum in Brussels, described an early version of a mechanically ventilated multiple skin façade. He mentions how in winter hot air should be circulated between two glazings, while in summer it should be cold air” (Saelens, D., 2002).

Crespo and Neubert (1999) claim that, the first instance of a Double Skin Curtain Wall appears in 1903 in the Steiff Factory in Giengen / Brenz near Ulm, Germany (see Figure 3.1). According to them, the priorities were to maximize day lighting while taking into account the cold weather and the strong winds of the region. The solution was a three storey structure with a ground floor for storage space and two upper floors used for work areas. The building was a success and two additions were built in 1904 and 1908 with the same Double Skin system, but using timber instead of steel in the structure for budget reasons. All buildings are still in use.

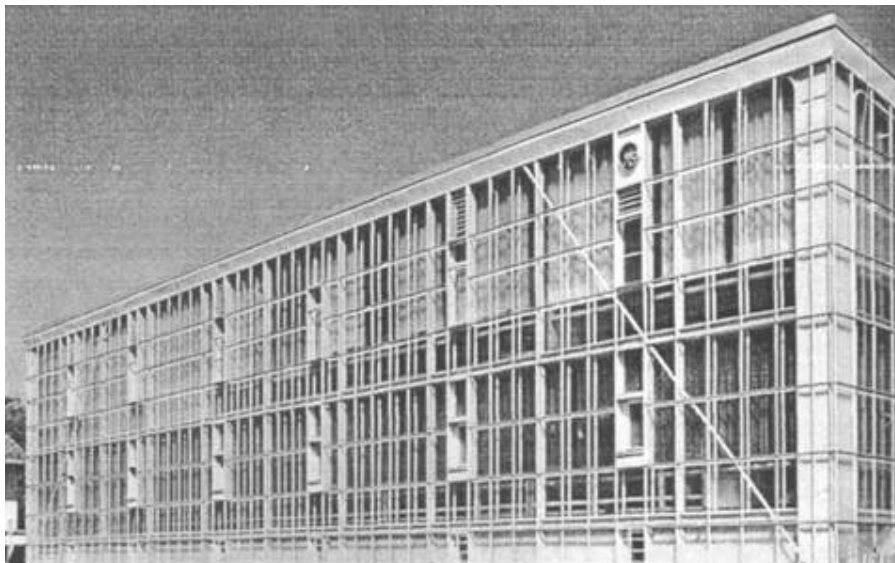


Figure 3.1 Steiff Factory, Giengen / Brenz, Germany (Neubert, 1999)

In 1903 Otto Wagner won the competition for the Post Office Savings Bank in Vienna / Austria. The building, built in two phases from 1904 to 1912 has a double skin skylight in the main hall. At the end of the 1920’s double skins were being developed with other priorities in mind. Two cases can be clearly identified. In Russia, Moisei Ginzburg experimented with double skin stripes in the communal housing blocks of his Narkomfin building (1928). Le Corbusier was designing the Centrosoyus, also in Moscow. A year later he would start the design for the Cite de Refuge (1929) and the Immeuble Clarte (1930) in Paris and stated „la respiration exacte“

(„...an exactly regulated mechanical ventilation system...“) and „le mur neutralisant“ („...neutralising walls are made of glass or stone or both of them. They consist of two membranes which form a gap of a few centimetres. Through this gap which is enveloping the whole building in Moscow hot and in Dakar cold air is conducted. By that the inner surface maintains a constant temperature of 18° C. The building is tightened hermetically! In the future no dust will find its way into the rooms. No flies, no gnats will enter. And no noise!...“) (Le Corbusier, 1964).

Little or no progress was made in double skin glass construction until the late 70's, early 80's of the past century. During the 80's this type of façades started gaining momentum. Most of these façades are designed using environmental concerns as an argument, like the offices of Leslie and Godwin. In other cases the aesthetic effect of the multiple layers of glass is the principal concern.

In the 90's two factors strongly influence the proliferation of double skin façades. The increasing environmental concerns start influencing architectural design both from a technical standpoint but also as a political influence that makes “green buildings” a good image for corporate architecture (Poirazis, 2004).

4 Technical description

4.1 The Facade construction

The choice of the glass type for the interior and exterior panes depends on the typology of the façade. In case of a façade ventilated with outdoor air, an insulating pane (= thermal break) is usually placed at the interior side and a single glazing at the exterior side. In case of a façade ventilated with indoor air, the insulating pane is usually placed at the exterior side, the single glazing at the interior side. For some specific types of façade, the interior window can be opened by the user to allow natural ventilation of the building.

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

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 radiation 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 and has a high impact on the daylight situation within the rooms behind.

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 Façade system. Different panes can influence the air temperature and thus the flow in case of a naturally ventilated cavity.

The geometry (mainly width and height of the cavity) and the properties of the blinds (absorbance, reflection and transmission) may also affect the type of air flow in the cavity. When designing a Double Skin Façade 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 Façade system by studying the physics of the cavity. The geometry of the façade, the choice of the glass panes and shading devices and the size and position of the interior and exterior openings determine the use of the Double Skin Façade 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 façade design and the proper façade integration is the key to a high building performance. Potential advantages with office buildings with double skin facades can be (compared with traditional office buildings, but mainly compared with corresponding office buildings with large windows/glazed facades):

- Individual window ventilation is almost independent of wind and weather conditions, mainly during sunny winter days and the intermediate season (spring and autumn)
- 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
- Improved burglary protection thanks to two glazed skins
- Better sound proofing towards the outside e.g. at locations with heavy traffic, mainly during window ventilation
- More efficient exterior (intermediate) solar shading, as the shading can be used also during windy days

Potential problems with office buildings with double skin facades can be:

- 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
- Higher investment costs
- The office floor area can be reduced
- Risk of cross talk via façade from one office to another with open windows
- Cleaning can result in additional costs
- The energy saving potential has often been overestimated
- Fire protection can be more difficult depending on the type of façade.

4.2 Double Skin Façades buildings and HVAC

There are two different approaches:

1. A building with its own separate heating, cooling and ventilating system, where a second skin is added to the façade. The cavity of the double skin façade is only ventilated to the outside and is built to reduce noise, contain solar shading and light redirection devices.
2. A building, where the heating, cooling and ventilating system of the building is integrated into the double skin façade e.g. by ventilating the building using the cavity of the double skin façade.

Alternative 2 is often the most cost effective alternative. The risk of alternative 1. being a building with a complete conventional HVAC system, with the added cost of an expensive façade. Most of the above described HVAC systems can be applied to buildings with double skin facades. According to different investigations and technical reports there are some technical benefits with a DSF, benefits which have an impact on the HVAC system.

- All types of Double Skin Façade offer a protected place within the air gap to mount solar shading and daylight enhancing devices, which then can be used whenever necessary and thereby reducing the cooling load
- One of the main advantages of the Double Skin Façade systems is that they may allow natural (or fan supported) ventilation, which will reduce the use of electricity for ventilation.
- In winter the cavity forms a thermal buffer zone which reduces heat losses and enables passive thermal gain from solar radiation, which will reduce the heating load.
- May enable natural ventilation and night time cooling of the building's thermal mass, which will reduce the use of electricity for ventilation and the cooling load.
- Noise reduction from motor traffic, enabling natural ventilation without noise problems.

5 Evaluation of WP1 of the BESTFACADE project

5.1 Location of the DSF buildings and typology in different countries

Table 5.1 lists Figure 5.1 shows the locations the 27 facades of different buildings in all partner countries of Bestfacade have been studied by means of a standardized questionnaire. The questionnaire comprises data on location, information about the building and the facade, construction and route of air flow in the façade as well as maintenance and costs.

Table 5.1 Analysed buildings with DSF within the BESTFACADE project

Nr.	Country	Partner	Long Version			
			name	city	orientation	utilisation
1	Austria	IWT	BiSoP	Baden	S / N	school
2			Felbermayr	Salzburg	S	office - n.p.
3			Fachhochschule	Kufstein	NW	school / office - n.p.
4			Justizzentrum	Leoben	SE	office - p.
5			Schubertstrasse	Graz	SE	office - n.p.
6	Belgium	BBRI	Aula Magna	Louvain-La-Neuve	SE	other
7			Sony	Zaventem	NE / SW	office - n.p.
8			UCB Center	Brussels	NE / SW	office - n.p.
9	France	LASH-DGCB	Cité	Lyon	NE	office - n.p.
10			EAL	Vaulx en Velin	NE	school
11			Thiers	Lyon	E	office - n.p.
12	Germany	IBP	Münchner Tor	Munich	N / S / E / W	office - n.p.
13			Geschäftsgeb. Süd 1+4	Munich	N / S / E / W	office - n.p.
14			Zentralbibliothek	Ulm	N / S / E / W	library
15	Greece	NKUA	A-A Holdings	Athens	E	office - n.p.
16			Alumil M5	Kilkis-Stavrochori	E	office - n.p.
17			AVAX	Athens	E	office - n.p.
18	Portugal	ISQ	CGD	Lisboa	S	office - n.p.
19			Atrium Saldanha	Lisboa	SW	office - n.p. / services
20			ES Viagens / expo 98	Lisboa	SE	office - n.p. / school / services
21			Palacio Sotto Mayor	Lisboa	SE	school / services
22			Torre Zen	Lisboa	S	office - n.p. / school / services
23	Sweden	WSP	ABB	Sollentuna/ Stockholm	W	office - n.p.
24			Arlanda	Stockholm	N / S / E / W	other (airport terminal)
25			Glashuset	Stockholm	S	office - p. / school
26			Kista	Kista / Sockholm	S / W	office - n.p.
27			Polishuset	Stockholm	S / W	office - n.p.

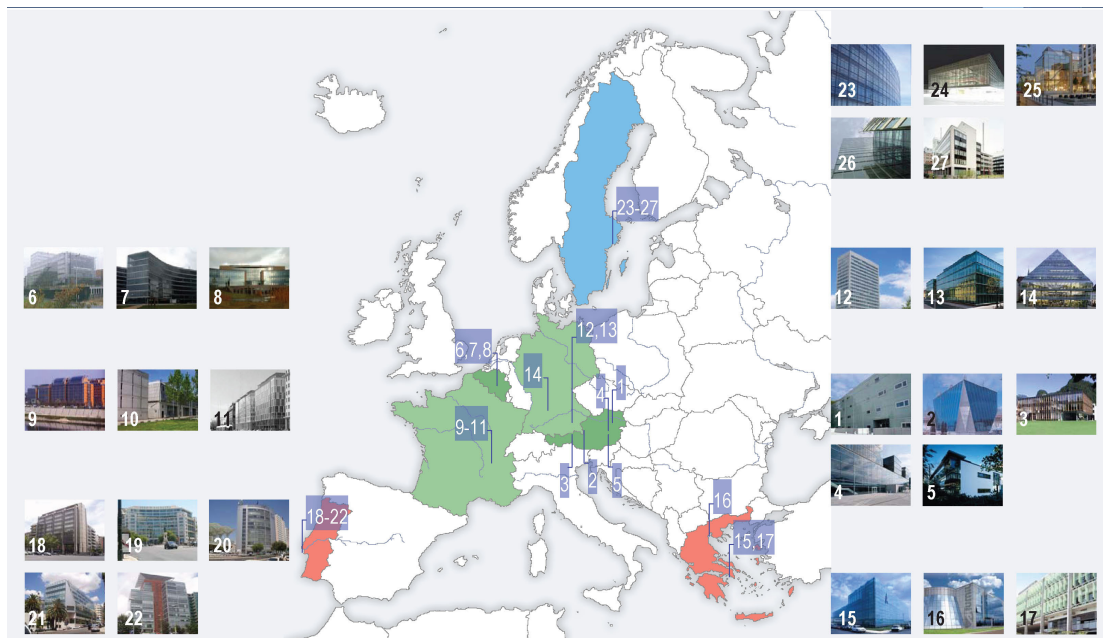


Figure 5.1 Analysed buildings within the BESTFACADE project

For **Austria** the aim was to cover as many as possible different sizes, types and utilisations of buildings with DSF e.g. newly built DSF as well as retrofitted ones, offices as well as schools and museums. But unfortunately the smallest as well as the biggest examples as well as the most extraordinary one couldn't be researched at the end - although managers of all of them showed high interest in joining the project at the beginning.

The small one is just two stories high and retrofitting the three facades of the control room of the fire brigade in Graz. The main purpose was to improve noise protection and thermal efficiency. Both aims are said to be achieved by the attached single pane façade with ventian blinds inside the gap.



Fig. 1 Control room fire brigade Graz. The old wooden windows have been left as they were

The large building would have been one of the largest researched building in the project: the Uniqa Tower in Vienna which consists of 24 stories and is said to be one of the most interesting towers among the aspiring high rises in Vienna for it's HVAC concept and the good performance of it's DSF. Probably there will be a chance to get data from this tower in coming spring.



Fig. 2 Uniqa Tower, Vienna

The third interesting building which should have been covered is the “Kunsthaus Bregenz” which is well known for it's architecture. Since the walls of this museum have to be opaque due to presentation reasons in this case the DSF is used to provide daylight for special light ceilings in each story.

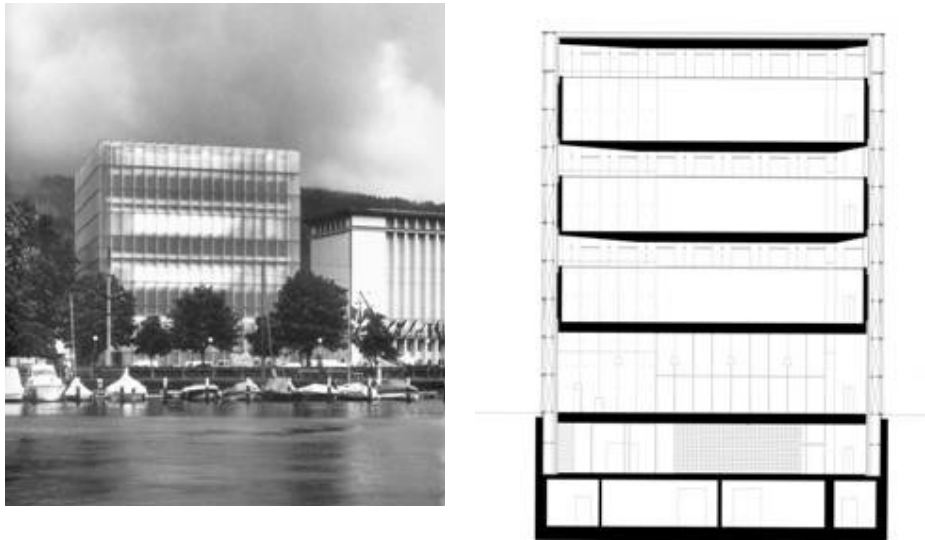


Fig. 3 Kunsthaus Bregenz

Besides the buildings described above a special type could be covered in the analysis too. In the façade of BiSoP / Baden the open able windows are bypassing the gap - which might to be a good compromise to use the interesting aesthetics of DSF and at the same time avoids many disadvantages such as overheating, condensation and sound transmission. Of course this limits the height of the building if natural window opening should be possible, and may cause constructional disadvantages if very many windows are to be opened.



Fig. 4 BiSoP baden, north elevation

In **Belgium** there is a specific situation concerning the concepts of ventilated double skin façades. Indeed, a national project has shown that the big majority of VDSF - as DSF are called there - are of the same concept. This is an industrialised façade concept; the façade is partitioned per storey with juxtaposed modules and characterised by a single ventilation mode: the indoor air curtain. The facade is used to extract the air from the room with which it is in contact (indoor air curtain). Usually, for the big majority of buildings, not only the ventilated double skin façade but also the HVAC equipment is of the same kind.

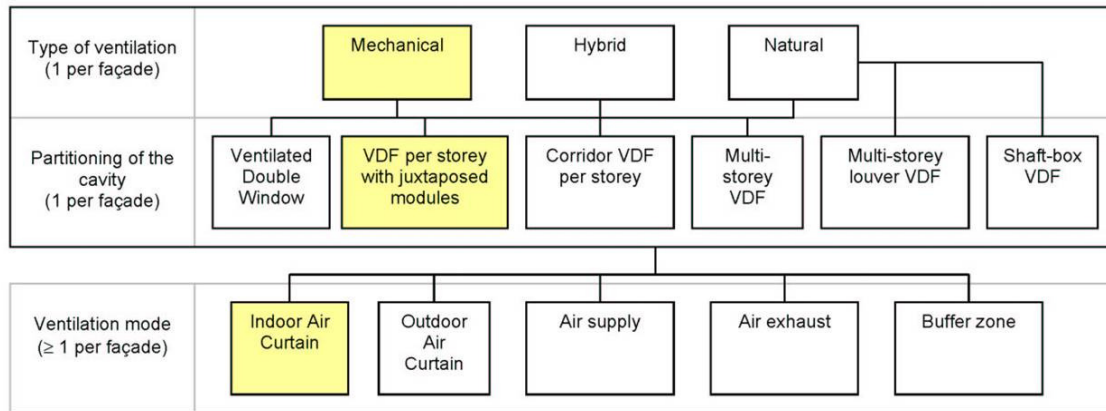


Fig. 5 The typical Belgium DSF type within the multitude of varieties (VDF means DSF)

In **Portugal** DSF buildings are located mainly in Lisbon, where different architects have designed several high rise DSF buildings. These are mainly privately owned office buildings, some of them belonging to important Portuguese financial institutions. In fact, DSF were already being designed in Portugal in the 1980 – Caixa Geral de Depósitos, Av. da República -, currently, different typologies coexist in the city of Lisbon. These buildings have usually more than five storeys and the most common typologies are corridor façades and multi-storey façades. Aesthetical and energy conservation reasons are some of the main reasons that architects use to support the use of DSF. Despite the significant number of DSF buildings in Lisbon, and according to the information gathered, until now no comprehensive energetic/acoustic/lighting/user acceptance study of Portuguese DSF has been made.

In **Sweden** the interest among architects in applying the technique of double skin glass facades mainly in new construction of office buildings has increased during the last years. Such buildings have been built primarily in the Stockholm area e.g. Kista Science Tower, the ABB-house, the new police house, Glashuset and the Arlanda Terminal F, but also in the other Scandinavian countries. All in all there are about ten modern glazed office buildings with double skin facades in Sweden. The purpose of the double skin has in these cases been to reduce high indoor temperatures with protected efficient exterior solar shading during summer and reduce transmission losses during winter, and in some cases also to reduce noise from motor traffic. The double skin façade in Scandinavia has very seldom been used for ventilation of the building behind. Modern office buildings in Sweden have high energy savings potential and potential for indoor climate improvements. They may have a lower energy use for heating, but does on the other hand often have a higher use of electricity than older office buildings.

Why are offices with fully glazed facades being built in Sweden? Architecturally an airy, transparent and light building is created, with more access to daylight than in a more traditional office building (Svensson, Åqvist, 2001). Technically it is possible to have a protected “exterior” movable efficient solar shading, to reduce noise from motor traffic and to open windows for ventilation during part of the year Carlsson (2003).

For Swedish conditions buildings with double skin facades are of interest for the same cases as in Germany i.e. mainly for high-profile-quality office buildings (new construction) and when a building envelope with transparency and lightness with regard to use of daylight and aesthetics is desired.

5.2 Climatic regions type of facades

As buildings with DSF are mostly erected in the bigger cities, which have a special “city-climate” nearly the same conditions apply for all the buildings per country. Though **Austria** covers different climates, thinking e.g. of the pannonian and the alpine climate, DSF concentrate in the capital town of Vienna. But in smaller towns there can be found DSF too - e.g. in Graz, Leoben, Salzburg and Bregenz. But those cities have similar climates too. Other countries like **Belgium** are too small to have distinctive regions. In some countries like **Sweden** and **Portugal** all researched buildings are situated in the capital town – so they have to be representative for their country. Therefore it is not easy to identify special types of DSF in a certain region of a country or one can say that this has no impact on the choice of the concept of DSF applied. However there are of course small differences concerning the solar radiation and temperature (e.g. in **Germany** with the Freiburg region and the Rhine area having more sunshine and higher temperature in summer than for example the regions near the North Sea).

To structure the results according to climatic circumstances three main regions covering the researched countries within Bestfaçade are proposed:

- “The Nordic Region” with it’s only representative **Sweden**
- “The Moderate Region” with **Austria, Belgium, France** and **Germany**
- “The Mediterranean Region” with **Greece** and **Portugal**

The benchmarking system and the guideline will take into account those three regions and their special circumstances for their analysis. For example **Greece** is located in the south-eastern part of Europe between the 34° and 42° parallel N., with a meridian extent from 19° to 28° E. The climate in Greece is typical of the Mediterranean climate: mild and rainy winters, relatively warm and dry summers and, generally, extended periods of sunshine throughout most of the year. The year can be subdivided into two main seasons:

- The cold and rainy period lasts from mid-October until the end of March. The coldest months are January and February, with, a mean minimum temperature of 5 -10 °C near the coasts and 0–5 °C over the mainland, and lower values over the northern part of the country.
- The warm and dry season lasts from April until September.

During this period the weather is usually stable, the sky is clear, the sun is bright and there is generally no rainfall. The warmest period occurs during the last ten days of July and the first ten days of August, with a mean maximum temperature of 29 – 35 °C.

For the climate of Greece, control of solar gains in the building design is important during the summer periods. Therefore double skin facades may lead to overheating during the summer months if there is no appropriate façade design, ventilation technique building orientation and provision of shading. The climate of Greece encourages the use of natural ventilation in office buildings. However, in the last decades, it is noted an increased use of air-conditioning due to high ambient air temperatures and high internal gains in large office buildings.

Many of the above mentioned potential advantages of office buildings with double skin facades are likely to be valid for **Sweden** as well. In addition there are other potential problems. The following potential problems are being studied for Swedish conditions (Blomsterberg, 2003):

- Warm summer/spring/autumn days high temperatures in office rooms can occur as a result of window ventilation
- Low altitude of the sun, which result in fairly high cooling demands during spring and autumn
- Possible risk of high energy use
- Risk of low daylight levels in the central parts of the building, mainly for deep buildings
- High operating and maintenance costs

Many modern Swedish office buildings have large glazed facades. As mentioned above some of them have an additional façade i.e. double skin facades. The simplest and most common system solutions in Sweden entail that the façade is only ventilated to the outside. Most of the time this means that the office building behind has a traditional heating, cooling and ventilation system. Window ventilation is usually not possible, apart from French doors, which purpose is to gain access to the double skin façade cavity for maintenance.

Most of the buildings analyzed were non-public office buildings followed by public schools and services (Figure 5.2). None of the buildings were equipped with a DSF in a renovation process and there is no clear main orientation of the façade, as it is mainly an architectural element (Figure 5.3). Most of the façade use a natural ventilation followed by hybrid ventilation. The façade type mainly the multi storey approach is used, followed by the corridor type and juxtaposte modules (Figure 5.4).

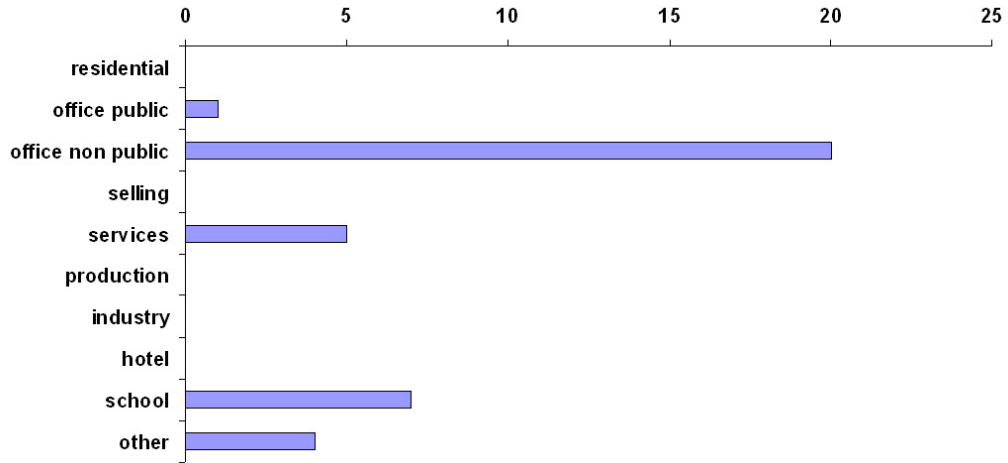


Figure 5.2 Utilisation of Bestfaçade buildings

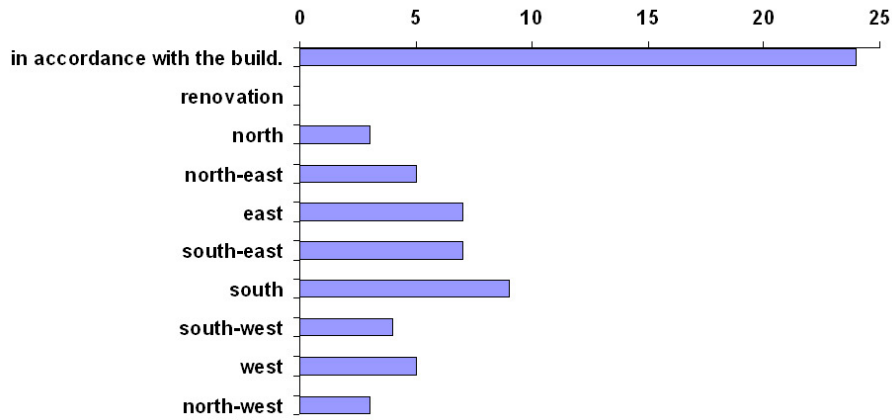


Figure 5.3 Implementation and orientation of façades within Bestfaçade

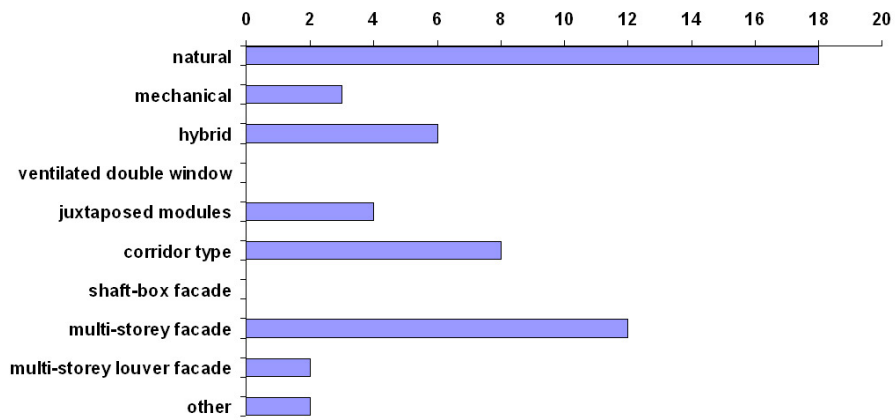


Figure 5.4 Type of ventilation and partitioning of the gap

5.3 Existing simulations and measurements

In **Austria** not many measurements have been done from which data is disposable. From BiSoP / Baden south façade intensive measurement data compared to simulation data is available. In this case the aim was to research the physical behaviour of the façade and not primarily their influence on the rooms behind. FH Kufstein has done some simulations and measurements as well. From Felbermayr / Salzburg some single measurement data is available while Uniqa has done much work on this but until now it hasn't been possible to get those data.

In **Belgium** BBRI has carried out several measurements on DSF: some in situ, some in outdoor test cells and some in laboratory. Different fields were examined: energy, ventilation, acoustics and daylight. A detailed monitoring of the most common concept of DSF applied in Belgium has been performed during the year 2005 in order to determine the thermal and solar properties (in winter & summer) of this kind of façades. Some universities have also performed measurements in laboratory or in situ. All these measurements have been realized at the level of the façade component (and not at the level of the building). BBRI has also performed simulations on different kinds of DSF, also in different fields: energy, acoustics and daylight. In the design phase of a building equipped with a ventilated double facade, it is essential to be able to predict the energy performances of the facade in the building and this for different design possibilities of the facade. The possibility of modelling the facade (and the building) with simulation programs can play an important role from that point of view and allows to compare different possible design concepts.

The prediction of the energy performances of a ventilated double facade 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 ventilated double facade.

BBRI has written a document, which explains how the thermal and solar performances of ventilated double facades and of buildings equipped with this kind of facades can be predicted by simulation. The control aspects are considered too. In some cases, measurements and simulations have been compared (Flamant, Heijmans, Guiot , 2004).

The objectives of this document were the following:

- to consider not only the modelling of the ventilated double facade alone, but also the modelling of the whole building equipped with the facade, the HVAC systems and the control aspects. Simulation programs (only software which are available on the market) are analysed. Studying the interaction between the facade, the building and the installations is important for a good assessment of the performances of ventilated double facades. Until now, practically no research study has assessed the impact of the control systems and the integration of ventilated double facade with the HVAC systems
- to analyse the capability to simulate control systems and control strategies
- to assess the various simulation programs on basis of their modelling possibilities, user-friendliness, advantages, disadvantages, etc.

- to explain how a ventilated double facade can be modelled with the various software. Sometimes, ‘tips’ are needed. This is the reason why the knowledge of experts in simulation has been collected.

In **Germany** DSF are applied mostly at high-level office buildings. The building owner or user is normally not interested to publicize the planning information in detail. Technical journals like architectural journals often show high-quality photos of the facades and describe the usefulness of the façade with many words, but the simulation results and even more the measured energy consumptions or occurring temperatures are rarely presented. Additionally detailed measurements are mostly initiated after occurring problems with the indoor comfort or high energy consumptions. This leads partly to bad reputation of DSF between specialists in this field. It is necessary that good examples, that means buildings with DSF and low energy consumption as well as good indoor comfort have to be more documented, monitored in detail and publicized. With simulations it has to be checked if the boundary conditions dependent on the user, the weather, the HVAC influence, etc. are represented in a correct way so that the reality after the erection of the building does not deviate too much from the simulated results. The experience at Fraunhofer-IBP concerning DSF buildings, include the following buildings:

- Fraunhofer Central Administration, Munich (owner: Fraunhofer Gesellschaft, 2000, simulation)
- Neubau Katharinenhospital, Stuttgart (owner: city of Stuttgart, 2002, simulation)
- Neubau Bibliothek Ulm (owner: city of Ulm, 2003/2004, simulation, control strategy)
- Münchner Tor, München (owner: Münchner Rück, 2005, energy performance certificate)
- Sued 1, München (owner: Münchner Rück, 2005, energy performance certificate)
- Berlaymont Building, Brussels (owner: European Union, 2005, energy performance certificate)
- VERU test facility for entire building concepts (owner: Fraunhofer-IBP, 2004, measurements, performance assessment calculations)

The only known simulation in **Greece** was made for the new headquarters building (currently under construction) of ALUMIL S.A. in Kilkis in northern Greece, as part of an international architectural competition where the building got the 2nd prize in the professional category. This simulation focused on the comparison of the double skin façade being constructed to a typical single skin façade building, a base case building following the Greek building regulations and a typical brick building. This comparison was made on energy consumption, lighting needs in daytime, visual comfort, shading flexibility and the possibilities for views from the interior spaces of the buildings. On all accounts the proposed double skin façade was better than the buildings simulated, apart from the comparison on lighting needs during daytime, where the single skin building was better.

Measurements of the environmental performance of the existing Alumil DSF have been carried out by NKUA within the frames of the research programme ‘BESTFACADE’. The measurements include:

Dry bulb temperature [°C] of external shell, façade gap and internal shell using a thermometer. Relative humidity [%] of external shell, façade gap and internal shell using a humidity sensor. Air change rates [ach] of the façade gap using a tracer gas system according to the decay method. Wind speeds [m/sec] externally and in

the façade gap using a hot wire anemometer. Global solar radiation [W/m^2] perpendicular to the external shell, façade gap and internal shell using a pyranometer. Levels of day lighting [lux] externally, in the façade gap, internally and on task levels using a luxometer. Additionally, the energy (electricity, air conditioning, heat pumps, lighting) and environmental performance (thermal comfort, temperatures and relative humidity) of the AVAX SA Headquarters office building has been monitored by an electronic digital system for central monitoring and control (BMS). The monitoring was carried out for the period 1/07/2000 to 30/06/2001.

Despite the interest that **Portuguese** architects show towards DSF technology, until recently this interest was not accompanied by the Portuguese scientific energy-related community. This situation was reversed recently (in 2005) with the inclusion of Portuguese research institutions in scientific projects related to the evaluation of DSF technology (e.g., Bestfaçade). Doctorate and Master students and researchers from ISQ, LNEC and INETI (Portuguese research institutions) are currently studying different aspects of Portuguese DSF buildings, both through the use of simulation tools (Energy-Plus and DOE-2), laboratory tests (air flow field details) and gap and indoor monitoring (acoustic, thermal, lighting and energy parameters). One DSF building is currently being thoroughly monitored and more than 5 scientific papers were submitted for presentation at international conferences. Recently, in the context of the design of a new DSF building to be located in the Expo98 area – Lisbon –, a prototype of a DSF has been built and monitored for thermal conditions in the air gap.

In **Sweden** simulations have been made of energy use and indoor climate of buildings with DSF, using multicell dynamic simulation tools. However, there is not yet any commercial simulation tool available, that actually simulates the DSF. The knowledge is insufficient on the actual energy performance, indoor climate performance etc. of the buildings with DSF. Partly due to the fact that most of these buildings have only been in operation for a couple of years.

In many projects with double skin facades simulations of temperatures, air and energy flows have been carried out before and during the design, with more or less success. Often the simulations have deviated from the result in the finished building. Often this depends upon difficulties in defining and accurately determine the boundary conditions. To succeed with calculations not only good experience of the used simulation models is required, but also good knowledge in thermodynamics, fluid dynamics and building physics, and general shrewdness and experience of building services engineering. Increased knowledge concerning and improvement of simulation and calculation methods are needed.

5.4 HVAC systems, thermal behaviour, indoor air quality, comfort, user acceptance

The main heating delivery systems found in the analyzed buildings of the BESTFACADE project use air heating followed by radiators, the main heat sources are district heating, electricity, and gas/oil (Figure 5.5). For space cooling cold air distribution dominates and is partly assisted by other appliances like cooling ceilings, floor cooling, and activated concrete cooling (Figure 5.6).

The ventilation is mainly performed by mechanical ventilation, but also windows into the gap and bypassing the gap have been realized (Figure 5.7). Most of the façades have bottom and top openings in the outer shell of the façade which can be closed during the winter and opened in summer (Figure 5.8). For the inner shell only half of the analyzed façades have openings (mainly windows, Figure 5.9). If present, they are, of course, closable.

The air flow in the façade is mainly vertical, but also diagonal and horizontal flows have been built. Whereas most of the façades allow an air flow in summer (to avoid too high temperatures in the gap), only about half of the façades close the façade in winter to use the air gap as unheated sun space (Figure 5.10).

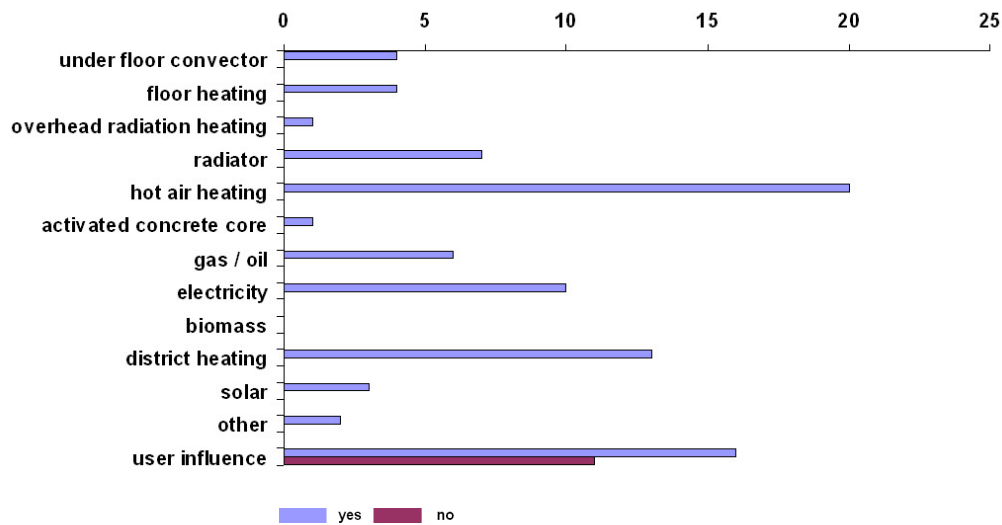


Figure 5.5 Types of room heating devices and used energy source of Bestfaçade buildings

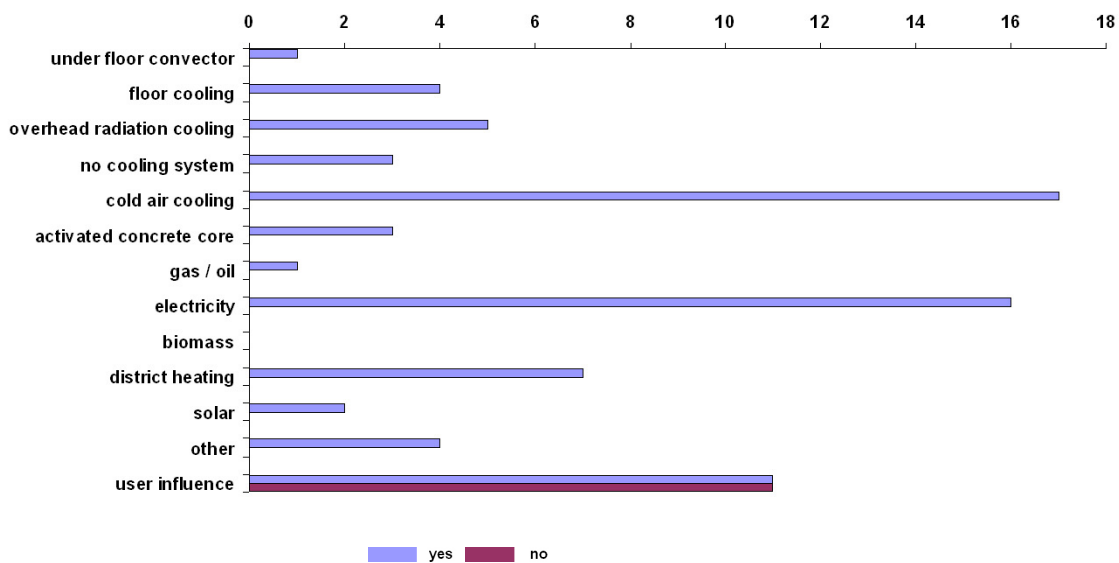


Figure 5.6 Types of room cooling devices and used energy source of Bestfaçade buildings

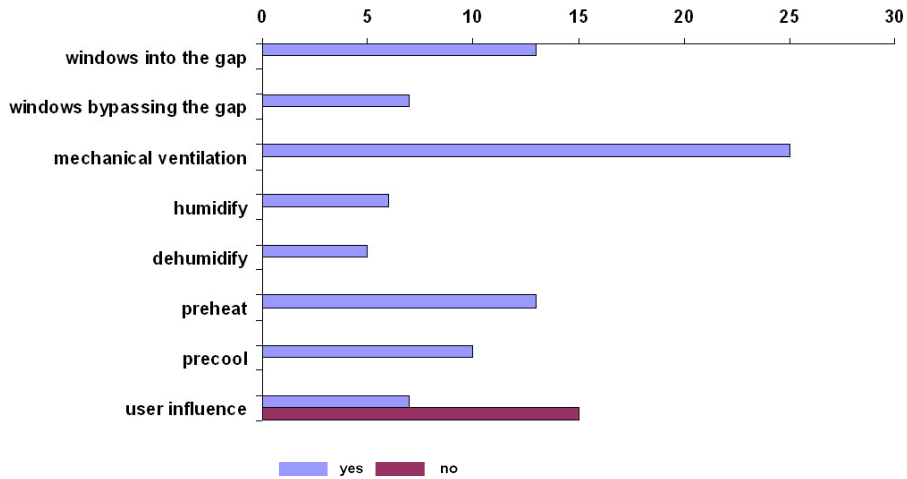


Figure 5.7 Ventilation and air conditioning of Bestfaçade buildings

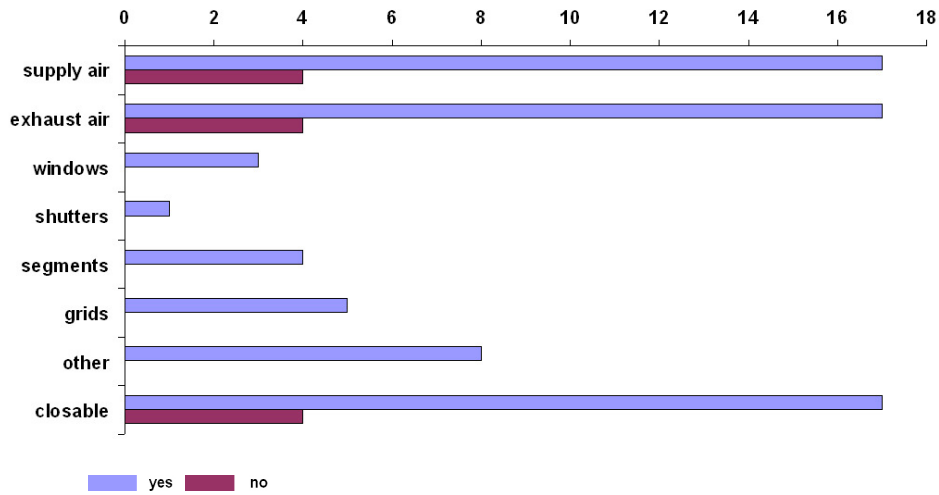


Figure 5.8 Ventilation openings in outer shell of analysed façades

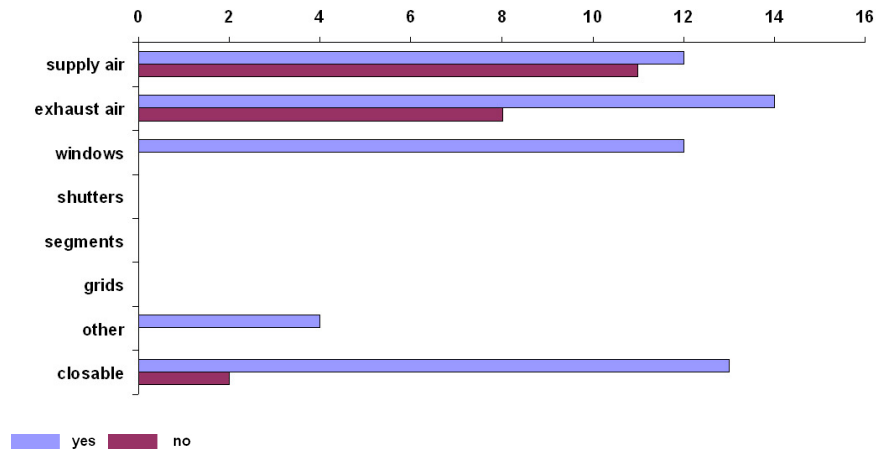


Figure 5.9 Ventilation openings in inner shell

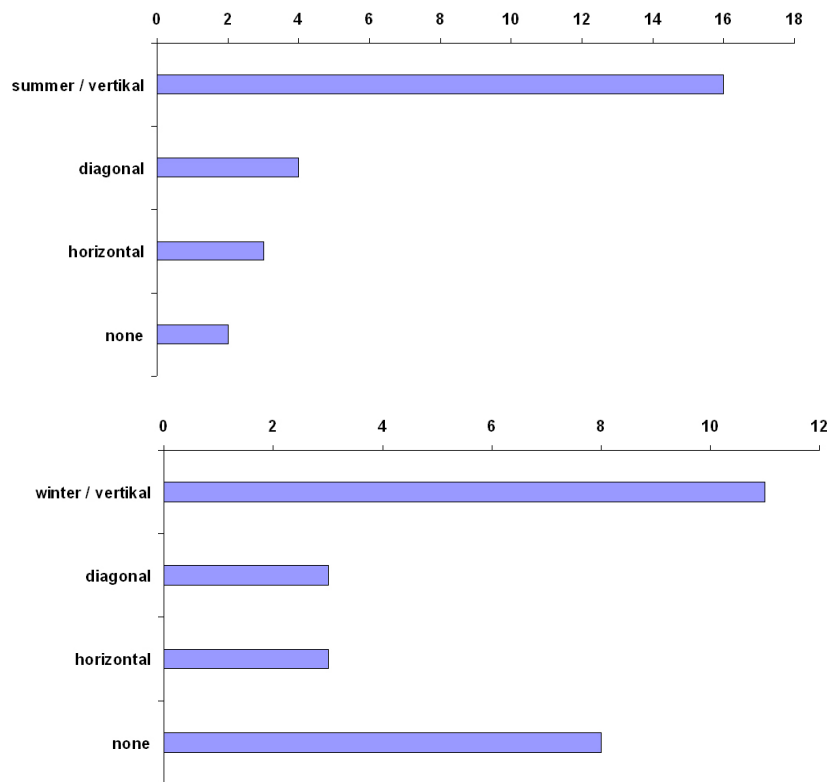


Figure 5.10 Air flow in the gap in summer (above) and in winter (below)

The thermal comfort encountered in a building equipped with a DSF can be improved compared to a single glazed façade, especially during winter where the temperature of the inner glazing will be usually higher than for a traditional façade. That reduces the thermal radiation of the cold surface of the glazing. In summer, the air temperature in the cavity of the DSF can be high (>50°C), depending on the concept of DSF. The temperature of the inner glazing can reach in these cases high levels (>30°C), which can create a thermal discomfort and overheating (or higher energy consumption for cooling). A proper choice of the shading device and of the air ventilation rate is important.

For some encountered concepts of DSF in **Belgium**, there is no direct influence of the façade on the air quality in the adjacent room since the air of the room is extracted via the façade (no air supply).

In some former published articles on **German** DSF buildings the applied technology leads to high temperature in the façade gap in summer that partly causes overheating problems in the adjacent rooms. This is mostly solved by big air-conditioning plants and therefore high operation costs. However some buildings and especially those buildings mentioned in detail in the attached building typology show that with considerate planning DSF do not necessarily lead to critical thermal situations and comfort problems. In any case the planning also in the region of Germany has to be based on the summer conditions. First the overheating problem has to be solved and secondly

the façade should be adapted to possible gains during the winter. The indoor air quality may be influenced by the façade in several ways if there are openings from the rooms to the façade gap:

- positively, because in the high-tower office buildings a natural or hybrid ventilation might not be possible without the DSF
- positively if the air taken from the gap into the rooms in winter is warmer than the room temperature (possibility of reduction of the heating demand).
- negatively as the façade may lead to bad air quality being transferred from one room to the other (e.g. with smokers)
- negatively if the air taken from the gap into the rooms in summer is hotter than the room temperature (increase of cooling demand).

The user acceptance is dependent on these influences (thermal behaviour, indoor air quality and comfort) but also on the possibility to control his environment as well as other things like acoustics, aesthetics, etc.

The published results regarding the thermal behaviour, indoor air quality and comfort of DSF buildings in **Greece** apply to the AVAX Headquarters offices that were monitored via the Building Management System. Additionally, questionnaires on thermal comfort were distributed to the users. The results show that:

- Due to the design, orientation and building façade good visual comfort was achieved in the office areas provided mainly by natural day light
- Thermal comfort was mainly described as ‘neutral’ with little request to changes
- Energy consumption was reduced and almost half compared to similar buildings with conventional lighting and air-conditioning systems.

The users’ acceptance to DSF is evaluated within the ‘BESTFAÇADE’ project. Currently DSF examples have no reputation in Greece because of their limited application. Initial results of the analysis show that the users are positive with the idea of the DSF systems if the façade design does not lead to overheating.

Due to the lack of scientific and field studies it is difficult to report on the thermal behaviour, indoor climate, comfort and user acceptance of DSF buildings in **Portugal**, and to conclude a better or poorer performance of DSF when compared to single-glazed façade. A preliminary analysis of some of the existing buildings (type of glazing, shading) suggests that problems of overheating could occur. Information gathered from conversations with architects, maintenance personnel also points to this possibility/reality. Studies currently ongoing in Portuguese DSF buildings (within the frame of Bestfaçade project, for example) will contribute to clarify these very important aspects.

As in all countries a comprehensive view because of the complexity of building and HVAC system is required. Energy, comfort and costs must be analysed. The long, cold and dark winters in **Sweden** can cause thermal

comfort problems. The low altitudes of the sun can result in fairly high cooling demand during spring and autumn. The visual comfort can be problematic due to glare in the boundary zone. For deep buildings the daylight level can be low in the core of a building, although the façade is fully glazed.

Obviously there is an uncertainty in the building trade as to the design of buildings with highly glazed facades and how to calculate the use of energy, the comfort and the influence on these buildings of different technical solutions.

5.5 Energy demand and consumptions

There are very few data available on energy demand and consumptions of buildings equipped with DSF, as they are not easy to get.

There are publications showing very high energy consumptions in some well-known DSF-office towers in **Germany**. Two of the projects analysed within BESTFACADE include the comparison between the final energy demand calculated with DIN V 18599 according to the new EPBD (Energy Performance of Buildings Directive) requirements and the final energy consumption. In these cases both calculation of demands and monitoring of consumption by the energy provider result in values that are in the range of usual office buildings or better.

The published results regarding the energy consumption of DSF buildings in **Greece** refer to the AVAX SA Headquarter offices. The results, show that the façade design in conjunction with the use of natural ventilation, night mechanical cooling, and energy efficient lighting results in significant energy savings and operational costs.

The level of knowledge on double skin facades among most scientists, builders/developers, consulting engineers and architects in **Sweden** is fairly limited especially concerning the actual energy and indoor climate performance of the building behind the façade apart from some major property owners/developers, engineers and architects. A situation similar to this also happens in **Portugal**.

5.6 Control strategies

In **Belgium** the control systems and strategies have been studied during the national project on DSF managed by BBRI. This study has shown that the control systems and strategies applied in buildings equipped with DSF are, most of the time, very similar to these applied for single glazed building. An efficient working of the façade is only possible when the control of motorized components that are integrated in the DSF is efficient. This can be realized via the BMS (Building Management System), which allows an optimal working of the different systems of the building.

In Belgium the use of BMS systems is currently not yet generalized. Very often, no major differences in the control strategy applied exist between a traditional building and a building equipped with DSF.

Control strategies for the façade and/or the building and plants behind the façade are various and very dependent on the type of façade (self operating/passive up to actively influencing the climate in the building). The façade control may cover the following parts: openings of the façade (ventilation of the gap), support of the ventilation behind the outer façade, solar shading and day lighting.

The control strategy of the building that means mostly the heating/ventilation/cooling/lighting systems should be adapted / linked to the control of the façade (if there exists one) and to the user boundary conditions. In high-level office buildings the controls are mostly realized by the BEMS (Building Energy Management System), which can at the same time monitor the energy consumption of the building. By this it is easier to refine the control strategy towards the most suitable and energy efficient one and discover unnecessary energy consumption because of false control strategies or mistakes in the programming. A commissioning of the building and the plants is indispensable.

In **Portugal** the more recent DSF buildings include façade related control strategies, mainly for cooling and lighting systems. This control is made automatically through the Building Energy Management System.

The most used shading system in the analyzed facades of BESTFACADE are Venetian blinds followed by canvas screens. The control systems are nearly equally distributed amongst manual control, automatic control with manual overruling and automatic control without manual overruling. A daylight control is used only a few times

5.7 Integrated building technology

In **Belgium** usually, for the big majority of buildings equipped with DSF, the whole concept including the façade as well as the HVAC system are similar. The façade is mechanically ventilated with cooling beams or cooling ceilings with activated concrete. The room air, which is extracted via the double façade, is returning via ventilation ducts to the HVAC system. The control of the shading device situated in the façade cavity can be done manually or centralized at the level of the room or at the level of the building via the BMS.

DSF allow to a special extent the integration of technical systems for the conditioning of the rooms. Local air-conditioning systems disburden the installation ducts in the building core. With newer projects DSF developments have been realized that include besides the room conditioning also lighting systems and PV elements within the façade.

Integrated building technology exists in DSF buildings in **Portugal**. The oldest of this building, designed in the 1980, already included a system to recover the heated gap air and use it to heat offices located far from the double skin façade.

Figure 5.11 shows elements of building technology integrated in the facades analysed. Fire protection and active solar systems were used about 1/3 of the facades. Only a few buildings include photovoltaic, sound absorbers or pluvial protection devices.

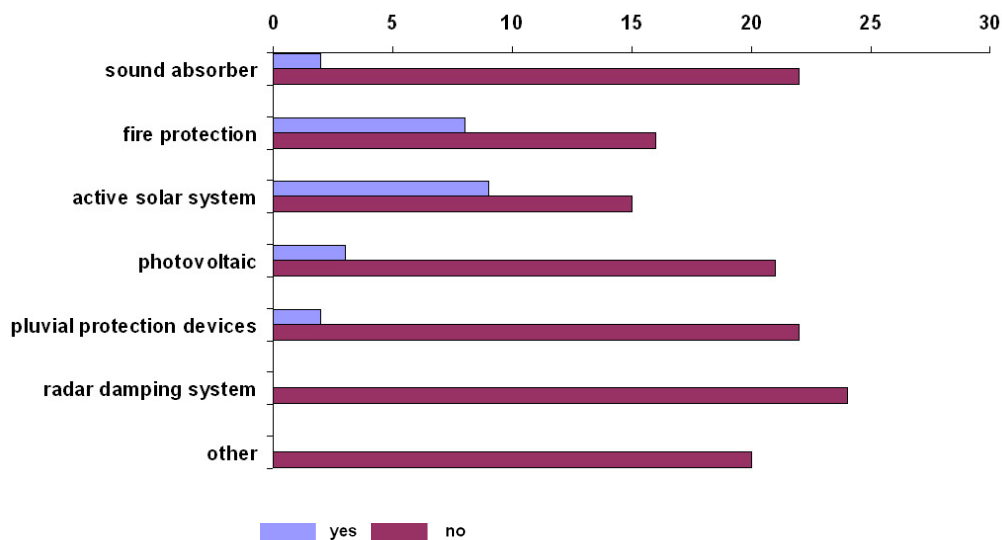


Figure 5.11 Integration of different devices into the façades (besides shading systems)

5.8 Costs (investment, maintenance, operation)

In a national **Belgian** project on DSF, BBRI has not carried out a very detailed analysis of the costs of the buildings equipped with DSF. Nevertheless the different elements having an impact on the cost of DSF were analysed. The initial investment of the DSF constitutes an extra cost that can be very high for some specific concepts of DSF. For the most common used DSF in Belgium (mechanical ventilated façade with juxtaposed modules), total cost ranges from 500 to 700 EUR/m² including solar shading is mentioned. With some concepts of DSF, heating appliances can be avoided, which reduces the installation costs, or the dimensioning of the heating appliances can be reduced. The impact of a DSF on the dimensioning and or the choice of the cooling systems depends on the solar performances (g-value) of the facade. The operation costs are proportional to the energy (heating and cooling) reduction or increase for the whole building equipped with a DSF compared to a traditional building.

The maintenance costs specific to the glass skins is of course higher because of the presence of 4 surfaces to be cleaned. The source of the ventilation air passing through the cavity plays also a role: more cleaning is needed in case of a cavity ventilated with outside air. The environment (pollution / no pollution) also influences the frequency of cleaning. The shading device situated in the cavity of a DSF is protected against the wind and the rain, which is favourable compared to external shading devices.

As with the energy consumption the building owner and/or user in **Germany** do not aim at disseminating the costs for the erection of their buildings, with or without double skin facades. Construction management companies and façade manufacturers should have more insight into the investment costs. In case of the German project participant Fraunhofer Institute of Building Physics is mostly not part of the economical side of projects, but deals with energy-efficiency and energy economy. Anyway, a DSF means two façades (inner and outer shell, which doesn't necessarily have to add up to a price of two facades, but will lead to higher costs than most of the usual facades with only one skin. Additionally the DSF are mainly glazed on both shells, glazing and especially the necessary safety glass is more expensive than insulated panels. The investment costs of the double skin façade applied at the VERU test facility amounted to 1255 €/m² façade area. It has to be mentioned that this façade has a very small total area of 40 m².

Figure 5.12 and Figure 5.13 show absolute and additional costs that were collected from different publications on double skin facades. Due to the wide range of technical possibilities and economic boundary conditions also a wide range of such costs is reported.

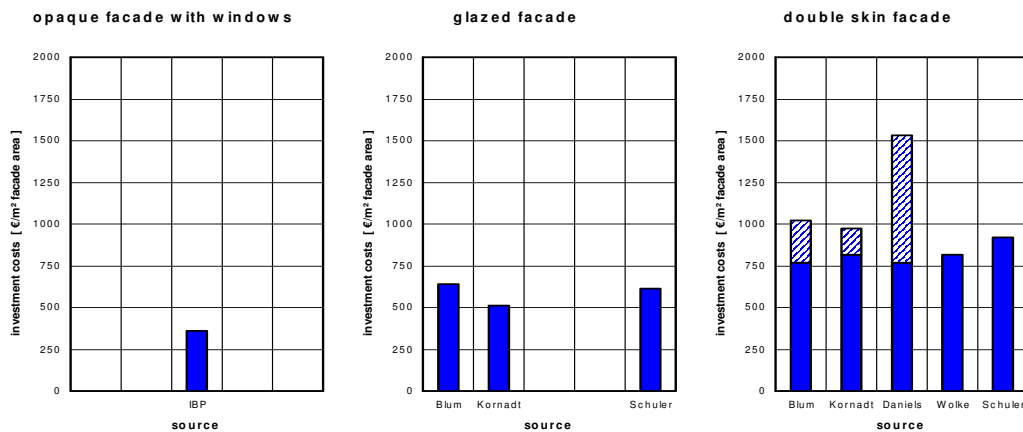


Figure 5.12 Costs of DSF compared to conventional facades. The blue and white fields show the range of cost mentioned in Blum (1998), Daniels (1997), Kornadt (1999, Schuler (2003) and own data.

For Sweden very up to date estimated investment costs for the new WSP office building in Malmö are shown below. Builder/developer is Midroc Projects, costs according to WSP and Schüco. Approximate investment costs for different glazed façade alternatives, €/m² façade area):

- Single skin façade without exterior solar shading = 370,- €/m²
- Single skin façade with fixed exterior solar shading (catwalk is not included, simple control of solar shading included) = 580,- €/m²
- Single skin façade including daylight redirection (catwalk is not included, simple control of solar shading included) = 680 – 790 €/m²
- Double skin façade incl. Venetian blinds like Kista Science Tower = 920 – 1000 €/m²

- DSF box window type (cavity width 0,2 m) with Venetian blinds = 560 €/m²
- DSF box window type (cavity width 0,2 m) with Venetian blinds incl. daylight redirection = 610 €/m²

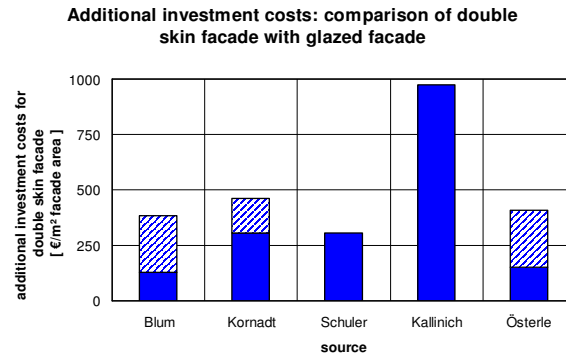


Figure 5.13 Additional costs of DSF according to different authors. The blue and white fields show the range of cost mentioned in Blum (1998), Kallinich (1994), Kornadt (1999), Oesterle (2003), Schuler(2003).

5.9 Ressource conservation and environmental impact

The environment impact of a DSF is influenced by two factors : the additional energy needed to build the DSF (i.e. the second glass skin compared to a single glazed façade) and the reduction/increase of the energy consumption of the building. Very few data are available on this.

The environmental impact can be described in two ways (energy consumption for the operation of the building and the used grey energy for the fabrication of the façade. Here again, two levels of façade will cause more grey energy than one level. Besides the glazing the DSF consists in most times mainly of aluminium frames. Aluminium is a material that consumes a lot of grey energy during the fabrication. However the manufacturers have searched for solutions to decrease in incorporated grey energy in their product and part of them are the production of aluminium in Norway (with hybrid power) and the high recycling rate of the material.

5.10 Comparison to conventional glass facades (CGFs)

The performance of DSF in **Austria** vary intensively: from buildings with good reputation like the Andromeda Tower / Vienna to facades which had severe problems e.g. with fallen down glass panes in Vienna (new buildings as well as retrofitted). On the other hand there are bad energy performing conventional glass facades (CGFs) too. In some cases DSF can be a good choice for retrofitting of buildings from the sixties and seventies. Advantages may be the good storage capacity, new aesthetics and noise reduction.

Different criteria play a role in the comparison between a DSF and a conventional façade. The evaluation depends on the concept of DSF.

- Energy consumption for heating: few data available. A detailed analysis must be performed in order to evaluate the possible energy savings. The DSF with juxtaposed modules is usually characterized by better thermal performances in winter than for a traditional façade.
- Energy consumption for cooling: few data are available. A detailed analysis must be performed in order to evaluate the possible energy savings. For the DSF with juxtaposed modules the cooling consumption can in some cases be higher than for a traditional façade equipped with external shading devices.
- Acoustics: the acoustical insulation (against external noise) of a DSF is better. But for, specific concepts of DSF, problems of indirect transmission of the sound through the cavity can occur (telephony effect).
- Daylight: good penetration of the daylight in the building equipped with DSF. This is also possible with single glazed facades.
- Fire: certain concepts of DSF can be a problem concerning the fire propagation. The second skin does not allow the evacuation of the smokes.
- Shading device : the DSF allows the utilisation of the shading device in all weather conditions due to the protection of the shading device situated in the façade cavity
- Opening of the window : possible with certain concepts of DSF to allow the natural ventilation of offices, even for high buildings
- High-tech image plays a role in the application of DSF.

The chapters above contain parts of the comparison with conventional facades divided into the specific items. It has to be mentioned that DSF may offer possibilities that can't be realized with most conventional facades e.g. natural or hybrid ventilation in high-rise buildings, etc.

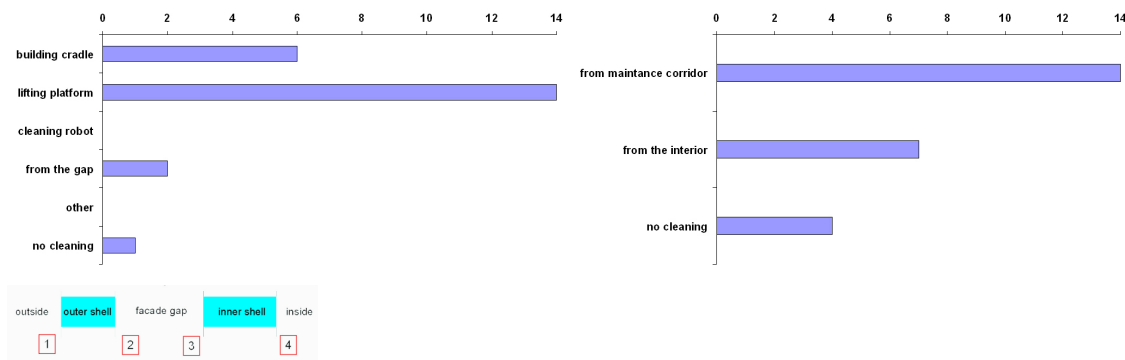


Figure 5.14 How cleaning of surface 1 (outer) and 2 (inner) is done

The maintenance of the façade consists of cleaning and repair. The cleaning has now to be done at four levels (instead of two): inner and outer side of the external façade and inner and outer side of the internal façade. In wide double skin facades (> 60 cm), for the two middle levels most of the time accessible grids are part of the façade gap. This facilitates the work and leaves only the same levels as with conventional facades. However additional cleaning costs have to be taken into account with DSF. Figure 5.14 shows, how cleaning is performed in the analysed facades. The outer surface (1) is mainly cleaned with moving platforms or cradles whereas the inner glazing (2) is mainly cleaned from the corridor. Also for repair two shells might now have defects. On the

other hand a DSF offers some advantages like a protected shading system in the gap, which will less often have defects.

The operation costs (= energy costs + maintenance costs) can't be entirely assigned to the façade system but on the building as a whole. As mentioned above the energy consumption of the building can be negatively influenced by bad planning of the DSF, kept at the same level and also slightly positively influenced by the DSF. Accordingly the energy consumption costs will increase, stay the same or decrease.

Double skin facades are more expensive than conventional facades. However, exact figures regarding the cost of DSF do not yet exist in **Greece**.

Considering the significant number of DSF buildings in Lisbon, the double skin façade technology has certainly acceptance among **Portuguese** architects and promoters. The combination of the aesthetical appearance that this technology enables and its "environmental attributes", often mentioned in Northern and Central European specialized literature, can be one of the main reasons for its use instead of single glazed façades.

5.11 Integration of renewable energy sources into DSF

The only case known among the researched Austrian DSF is the use of the concrete areas behind the south glass façade as solar collectors in BiSoP / Baden which should supply hot water radiators in the north façade to reduce temperature spread.

For **Belgium, Greece** and **Portugal** no applications are known.

Some DSF include photovoltaic implementations. The gained electrical energy can either be fed into the grid (in Germany with high subsidized prices) or used in the building itself. Wind energy, and solar thermal can not easily be linked with DSF, but of course can be an additional feature of the building. Other renewable energies like heat pumps, use of geothermal energy, wood or similar renewable fuels can be integrated into the building concepts, partly also for pre-heating/pre-cooling of the air of the building and maybe also inside the gap but are not specifically coupled to the DSF concept.

5.12 Non-energy related issues: acoustics, aesthetics, fire protection, moisture, corrosion, durability, maintenance, repair

Those issues may even be more important for user acceptance than energy related ones since the energy consumption is mostly not directly experienced by the occupants.

Acoustics can be one of the main reasons to apply DSF - e.g. with traffic noise (control room of the fire brigade / Graz, Austria, Schubertstraße). In many cases DSF by having an additional shell in fact reduce sound transmission from the outside. On the other hand depending on the type of DSF problems of noise transmission

from room to room by the gap is reported. This can be reduced by choosing the appropriate partitioning system or by the implementation of acoustical absorbers in the gap.

Aesthetics are often the main aspect why to apply DSF. They give depth and sort of "crystal image" to the façade.

Fire protection is a serious item with DSF. Fire brigades have to destroy two shells to be able to help the building users in case of fire, also the flashover of a fire from one storey to the next can be facilitated by DSF depending on the partitioning system. The façade manufacturers have found solutions for the second problem and in case of facades where the gap is separated between the storeys the problem is smaller than in conventional facades. Some types of DSF such as "multi storey DSF" must not be applied to high buildings.

Depending on the ventilation concept sometimes problems with condensation are reported when warm and wet exhaust air is ventilated into the gap and meets the cold inner surface of the outer glass pane (e.g. FH Kufstein)

Durability - Due to the fact that DSF sometimes even nowadays are sort of prototypes difficulties have been reported with unproved durability - especially with pane fixtures (those problems may refer to CGFs too) and mechanically driven shutters or lamellae. Since DSF are a rather new development there has been no scientific in-situ long-term analysis of a bigger group of facades. On the other hand problems with the durability of examples of the façade type are not known.

The maintenance of the façade consists of cleaning and repair. The cleaning for double glazed facades has now to be done at four levels (instead of two): inner and outer side of the external façade and inner and outer side of the internal façade. For the two middle levels most of the time accessible grids are part of the façade gap. This facilitates the work and leaves only the same levels as with conventional facades. However additional cleaning costs have to be taken into account with DSF. Also for repair two shells might now have defects. On the other hand a DSF offers some advantages like a protected shading system in the gap, which will less often have defects. So all in all it depends on the amount of facade fixtures whether the need for maintenance is higher or not compared to CGFs.

6 Conclusion:

27 facades of different buildings in all partner countries of the project BESTFACADE have been studied by means of a standardized questionnaire. The questionnaire comprises data on location, information about the building and the facade, construction and route of air flow in the façade as well as maintenance and costs. The analysis is been drawn for the aspects, types of façade in different countries, DSF in different climatic regions of Europe, existing simulations and measurements, thermal behaviour, indoor air quality, comfort, user acceptance, energy demand and consumptions, control strategies, integrated building technology, costs (investment, maintenance, operation), resource conservation, environmental impact, comparison to conventional glass facades (CGFs), integration of renewable energy sources into DSF, and non-energy related issues: acoustics, aesthetics, fire protection, moisture, corrosion, durability, maintenance, repair.

Most of the buildings are office buildings followed by schools and service buildings. Nearly all of the buildings have mechanical ventilation systems and the heating and cooling is performed most often by air heating/cooling systems. The types of façades are mainly multi-storey and corridor type, in Belgium juxtaposed modules are frequently used. The façade gaps are mostly naturally ventilated (except for Belgium, where the indoor air is led by mechanical ventilation via the gap to the centralized air handling unit). The shading is performed mainly with Venetian blinds located in the gap. The cleaning of the outer shell is done via a cradle or a lifting platform, the glazing of the gap is mainly cleaned from the gap or from the interior.

Unfortunately not so much measured data of energy demand and temperatures in the gap and the rooms behind are available, because building managers are not easily willing to give away such sensible data.

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