

# BESTFACADE

# **Best Practice for Double Skin Façades**

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# 1. INTRODUCTION

Innovative façade 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 façade should allow for a comfortable indoor climate, sound protection and good lighting, while minimising the demand for auxiliary energy input. Double skin façades (DSF) have become an important and increasing architectural element in office buildings over the last 15 years.

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 EU IEE project BESTFACADE promotes the concept of well-performing double skin façades both in the field of legislation and of construction thus increasing investor's confidence in operating performance, investment and maintenance costs.



Figure 1-1: Example for a double skin façade building: The central library in Ulm, Germany.

# 1.1 Definitions

• "A ventilated double 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 (Whence the widely-used name "ventilated double-skin façade"). A ventilated cavity having a width which can range from several centimetres at the narrowest to several metres for the widest accessible cavities - is located between these two skins.

There exist façade concepts where the ventilation of the cavity is controllable, by fans and/or openings, and other façade concepts where this ventilation is not controllable (the ventilation is produced in this case via fixed permanent ventilation openings). The indoor and outdoor skins are not necessarily airtight (see, for example, the "louver" type façades). Automated equipment, such as shading devices, motorised 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 glazings, lies in the intentional and possibly controlled ventilation of the cavity of the double façade".<sup>1</sup>

- "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".<sup>2</sup>
- "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 20cm up to 2 meters. Often, for protection and heat extraction reasons during the cooling period, solar shading devices are placed inside the cavity."

#### 1.2 History

The history of Double Skin Façades is described in several books, reports and articles. Saelens, (2002) 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".

Crespo, claims that, the first instance of a Double Skin Curtain Wall appears in 1903 in the Steiff Factory in Giengen, Germany. According to her, the priorities were to maximize daylighting 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.

In 1903 Otto Wagner won the competition for the Post Office Savings Bank in Vienna in 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). Also Le Corbusieur was designing the Centrosoyus, also in Moschow. A year later he would start the design for the Cite de Refuge (1929) and the Immeuble Clarte (1930) in Paris.

Little or no progress is made in double skin glass construction until the late 70's, early 80's. During 80's this type of façades they 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 esthetic 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.

# 1.3 Technical description

The Double Skin Façade system consists of:

• The exterior and interior glazing

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 façades, the interior window can be opened by the user to allow natural ventilation of the building.

• The air cavity between the exterior and interior glazing

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

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.



• 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 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.

# 1.4 Typology

There are many different principles of how to construct ventilated double skin façades. These 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



Figure 1-2: Typology overview.

#### 1.4.1 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 façades. Each ventilated double skin façade 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).

#### 1.4.2 Partitioning of the façade

The partitioning of the cavity gives the information on how the cavity situated between the two glazed façades is physically divided. The partitioning solutions implemented in practice can be classified as follows:

#### Ventilated double window

A façade 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 filling element in a wall. Some concepts of naturally ventilated double windows are also called 'Box-window' in the literature.



Figure 1-3: Example of a ventilated double window

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# Façade partitioned per storey with juxtaposed modules

The ventilated double façade partitioned per storey with juxtaposed modules. In this type of façade, the cavity is physically delimited (horizontally and vertically) by the module of the façade which imposes its dimensions on the cavity. The façade module has a height limited to one storey.



'Corridor' type ventilated double façades partitioned per storey are characterised by a large cavity in which it is generally possible to walk. 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 (see figure below) or even an entire floor.

#### The 'Shaft-box' ventilated double façade

The objective of this partitioning concept is to encourage natural ventilation by adapting the partitioning of the façade so as to create an increased stack effect (compared to the naturally ventilated façades which are partitioned by storey). Thus it is logical that this type of façade and partitioning is applied only in naturally ventilated double façades. This type of façade is in fact composed of an alternation of juxtaposed façade modules partitioned by storey and vertical ventilation ducts set up in the cavity which extends over several floors. Each façade module is connected to one of these vertical ducts, which encourages the stack effect, thus supplying air via the façade modules. This air is naturally drawn into



Figure 1-4: View of different juxtaposed modules; 'Greensquare' building; Architect : Archi+I, Atelier de Genval



Figure 1-5: Corridor-type ventilated double façade partitioned per storey



Figure 1-6: Shaft-box ventilated double façade - front view

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the ventilation duct and evacuated via the outlet located several floors above.



Figure 1-7: Shaft-box ventilated double façade – cross section



Figure 1-8: Multi-storey ventilated double façade

#### The multi-storey ventilated double façade

Multi-storey ventilated double façades are characterised by a cavity which is not partitioned either horizontally or vertically, the space between the two glazed façade layers therefore forming one large volume. Generally, in this type of façade, the cavity is wide 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 façades with this type of partitioning are naturally ventilated; however, there are also examples of façades of this type which are mechanically ventilated. It should be noted that the façades 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 façade.

# The multi-storey louver naturally ventilated double façade

The multi-storey louver naturally ventilated double façade is very similar to a multi-storey ventilated double façade. 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 façade and the multi-storey façade is that the outdoor façade is composed exclusively of pivoting louvers rather than a traditional monolithic façade equipped (or not) with openings. This outside façade 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 façades are generally comparable to those encountered in the other ventilated double skin façades.





Figure 1-9: View of the large cavity and the louvers in horizontal/vertical position; Ventilated double façade with louvers; Berlaymont 'building'; Architect : Berlaymont 2000 s.a., P. Lallemand, S. Beckers

#### 1.4.3 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 façades are capable of adopting all of the ventilation modes described here. At a given moment, a façade is characterised by only a single ventilation mode. However, a façade can adopt several ventilation modes at different moments, depending on whether or not certain components integrated into the façade permit it (for example operable openings).

One must distinguish between the following 5 main ventilation modes (see Figure 1-10 below):

1. Outdoor air curtain

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

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 façade.

3. Air supply

The ventilation of the façade 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 façade 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 façade 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 façade 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 1-10: Ventilation modes of the cavity

# 2. OPPORTUNITIES AND RISKS OF DSF

Compared to traditional office buildings, especially with large glazed façades, office buildings with double skin façades can have the following potential advantages:

- 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 security thanks to the two glazed skins



- Better sound proofing from external noise sources 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 façades 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 cost
- The office floor area can be reduced
- Risk of sound transmission via the façade cavity from one office to another with open windows
- Cleaning can result in additional cost
- The energy saving potential has often been overestimated
- Fire protection can be more difficult depending on the type of façade.

# 3. **STATE OF ART – WP 1** (ву IWT)

The project BESTFACADE, sponsored by the Energy Intelligent Europe Program of the European Union, and led by MCE-Anlagenbau, Austria, accumulated the state of the art of 28 double skin façades in seven European countries.

# 3.1 Literature Database

As a basis for the further research work a general literature database was established with contributions from all partners of the project.

The aim of this literature database is to give all partners an overview about the state of the art concerning the published and relevant literature in the field of double skin façades.

The database contains references of articles, books, proceedings, diploma thesis and PhD thesis about double skin façades. These documents may be sorted and evaluated by their authors, keywords, language, and publication type, with the objective to make it as easy as possible to find a special document or documents about a special aspect of double skin façades.

The main function and advantage of this database is the possibility to get an efficient overview about the literature, ranked by keywords and their relevance in this document.

The literature database, based on a national research project, financed by the Belgian Federal Public Service Economy [LIT source BBRI], was created by BBRI. In June 2005, the adoption of an existing BBRI database of double skin façades to the Bestfaçade needs by BBRI and IWT was finished. A new

article interface accrues in this version, including all the necessary information's about the relevant documents.

Each partner of the Bestfaçade project has provided his own literature references. There is one responsible person for the literature database per country. The database has been sent around and stayed for two weeks in each country to input the data. The check of the database (e.g. doubling, correct input ...) has been done by IWT.

After this first round more than 360 articles are available within the literature database. A second upgrading of the literature database is planned for the last year of the Bestfaçade project.

A special four-language keyword list (English, French, Dutch and German) was developed to classify the literature by reducing and completing an existing list from BBRI. This keyword list is the main feature for finding and using the literature database.

#### **General items**

The main languages within the collected literature entries in the field of double skin façades are English (48%), German (26%), Dutch (14%) and French (11%). The PDF-Articles are not translated and so the articles are only in the original language available.

An important aspect for the quality of the literature database is the distribution of the publication types within the literature database. The main part are common articles (38%), proceedings (32%) followed by books (6%), presentations (5%), PHD Thesis (4%) and so on.

English	French	Dutch	German
acoustics	acoustique	akoestiek	Akustik
cavity climate	climat dans la cavité	klimaat in the spouw	Klima Fass.zwischenraum
classification	classification	classificatie	Klassifikation / Gliederung
comfort	confort	comfort	Komfort
construction details	details de construction	bouwdetails	Konstruktionsdetails
control systems	systèmes de contrôle	regelsysteem	Regelungssystem
cooling	refroidissement	koeling	Kühlung
design	conception	ontwerp	Konzeption
economical aspects	aspects économiques	economische aspecten	wirtschaftliche Aspekte
energy	énergie	energie	Energie
field test	essai sur terrain	test te velde	Feldversuche
fire safety	protection incendie	brandveiligheid	Feuer / Brandschutz
glazing	vitrage	beglazing	Verglasung
heating	chauffage	verwarming	Heizung
history	histoire	geschiedenis	Geschichtliches
in situ measurement	mesures in situ	in situ metingen	'in situ' Messungen
indoor climate	climat intérieur	binnenklimaat	Raumklima
labtest	essai laboratoire	labtest	Labortest
lighting	éclairage	verlichting	Licht
maintenance	maintenance	onderhoud	Instandhaltung
material	matériau	materiaal	Material
motivation	motivation	motivatie	Motivation
pathology	pathologie	pathologie	Bauschaeden
performance	performance	prestatie	Leistungsfähigkeit
regulation / standardization	réglementation / norme	regelgeving / norm	Reglementierung / Normung
renovation	renovation	renovatie	Sanierung
shading / glare	eblouissement	zonnewering / verblinding	Sonnen- / Blendschutz
simulation	simulation	simulatie	Simulation
ventilation	ventilation	ventilatie	Lüftung

Figure 3-1: 29 defined keywords for the field of research on double skin façades listed in four languages

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Figure 3-2: Apportionment of publication types within the literature database

The keywords 'simulation' and 'classification' have the best average relevance values. These investigated subject areas contain useable scientific results. The keywords 'design' and 'ventilation' are with a large number of articles but with less relevance value. In this subject areas further research seems necessary. The keywords 'material' and 'glazing' are with a low number of articles and with a bad relevance value. In this subject areas further research seems urgent necessary.

#### Age of the literature database

The age of the articles, included into the literature database can be seen in the figure below. The average age of the articles is about four years, the oldest article is about 22 years old and the newest article is about three month old. The actuality of the database literature is fine and thus a well starting point for the further working packages.

#### 3.2 Evaluation of existing buildings with DSF

Besides the establishment of the literature database the collection of implemented Double Skin Façades in the member countries of the project was the main goal of WP 1. In order to collect data on a comparable basis two questionnaires (a short and a detailed one) were developed by IWT and ISQ supported by all other participants as standard protocol of information (photographs, diagrams, performance data and graphs etc.). This information includes the basic resources for the following WPs and on the other hand gives an overview of DSF in Europe on the web site.

As a first step a short questionnaire which gathers information about the building (address, involved institutions and companies, the room heating and cooling system including its energy demand, the room ventilation and the local energy tariff) and information of the façade system (geometry, type and costs) was send to all participants in order to have a high number of double skin façades described.

A more detailed questionnaire, taking into account also measured data about temperatures in the façade gap and indoors, the detailed control of ventilation, shading, and other features was sent out in a second round. It comprised items such as: detailed questions on the specific climate, existing simulations and measurements, thermal behaviour, indoor air quality, comfort, user acceptance,



energy demand and consumptions (heating, ventilation, cooling, lighting), control strategies, integrated building technology, costs (investment, maintenance, operation), resource conservation, environmental impact, comparison to conventional façades, renewable energy sources, integration into DSF, non-energy related issues like acoustics, aesthetics, fire protection, moisture, corrosion, durability, maintenance, repair. Both questionnaires can be found in the appendix.

Included is a coherent typology of double skin façades merged by several information sources (BBRI and others), where the façade type can be defined by click boxes. Though DSF might be classified by at least three methods as mentioned in the following it was decided to use the classification according to the partitioning of the gap.

#### 3.3 Location and type of the DSF buildings

Figure 3-3 shows the locations the 28 façades of different buildings in all partner countries of BESTFACADE, which have been studied by means of a standardized questionnaire. The questionnaire comprises data on location, information about the building and the façade, construction and route of air flow in the façade, as well as maintenance and cost.

In Austria, the aim was to cover as many as possible different sizes, types and utilizations of buildings with DSFs, for example, newly built DSFs as well as retrofitted ones, offices as well as schools and museums. But unfortunately the smallest, the largest and the most extraordinary DSFs could not be researched, although the managers of these buildings showed high interest in joining the project at the beginning. The example of the small DSF is just two stories high and is the retrofitting is of three façades of the control room of the fire station in Graz. The main purposes were to improve noise protection and thermal efficiency, and both aims are said to have been achieved by the attached single pane facade with venetian blinds inside the gap. The building that would have been one of the largest researched buildings in the project, the 24-storey Uniqa Tower in Vienna, is said to be one of the most interesting towers among the aspiring high rises in the city because of its HVAC concept and the good performance of its DSF. The third interesting building that should have been covered is the 'Kunsthaus Bregenz', which is well known for its architecture. Since the walls of this museum have to be opaque for presentation reasons, the DSF is used to provide daylight for special light ceilings in each storey. Besides the buildings described above, a special type was covered in the analysis too. In the facade of BiSoP, Baden, the operable windows are bypassing the gap. This seems to be a good compromise for using the interesting aesthetics of the DSF and at the same time avoid many disadvantages such as overheating, condensation and sound transmission. However, natural ventilation by opening of windows is limited by the height of the building because of the increasing wind pressure on the façade.



Figure 3-3: Analysed buildings within the BESTFACADE project

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

Examples from **Germany** are two office buildings in Munich: a major public library in Ulm in the extraordinary shape of a pyramid, and the VERU test facility at the Fraunhofer Institute of Building Physics in Holzkirchen near Munich. Data for the buildings are based on the energy performance certification according to the new standard DIN 18599. During the planning phase of the library in Ulm, scientific support was given including energy performance calculations according to the former 'Wärmeschutzverordnung' and thermal simulations. For the library detailed energy consumption data are not available, but the total energy consumptions levels are known. However, data for the VERU test facility are detailed and calculated with the DIN 18599. However this building is not occupied by users, therefore a user investigation is not possible.

In **Portugal** DSF buildings are located mainly in Lisbon, where different architects have designed several that are high-rise. These are mainly privately owned office buildings, some of them belonging to important Portuguese financial institutions. In fact, DSFs were already being designed in Portugal in the 1980s (Caixa Geral de Depósitos, Av. da República), and currently different typologies coexist in the city of Lisbon. These buildings usually have more than five storeys and the most common typologies are corridor façades and multi-storey façades. Aesthetics and energy conservation are

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some of the main reasons that architects use to support the use of DSFs. Despite the significant number of DSF buildings in Lisbon, and according to the information gathered, until now no comprehensive energetic, acoustic, lighting and user acceptance study of Portuguese DSFs 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 over recent years. Such buildings have been built primarily in the Stockholm area, for example, the Kista Science Tower, the ABB-house, the new police house, Glashusett and the Arlanda Terminal F, but there are also examples in other Scandinavian countries. In total there are about ten modern glazed office buildings with DSFs in Sweden. In these cases the purpose of the double skin has been to reduce high indoor temperatures with protected efficient exterior solar shading during summer, reduce transmission losses during winter, and, in some cases, also to reduce noise from motor traffic. The DSF in Scandinavia has rarely 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, by contrast, they often have a higher use of electricity than older office buildings. Why are offices with fully glazed façades 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 and Åqvist<sup>4</sup>, 2001). Technically it is possible to have protected 'exterior' movable efficient solar shading to reduce noise from motor traffic and to open windows for ventilation during part of the year Carlsson<sup>5</sup> (2003). Swedish buildings with DSFs share many of the characteristics of DSFs in Germany that is, they are mainly for high-profile, high-quality office buildings (new constructions) and used when building envelopes with transparency and lightness are wanted and daylight and aesthetics are important.

DSF examples from **Greece** are three office buildings, a hotel that is under renovation and a retail building that is currently under construction. The majority of the DSF buildings are located in Athens apart from one office building that is located in Kilkis, a northern area of Greece. Different DSF typologies are used in these buildings: the corridor type, the double window, the multi-storey façade and the multi-storey louver façade. The double window façade was used for acoustic reasons in the hotel building, which is located in a densely built up area of central Athens with high traffic and noise levels. The other types of DSFs were chosen mainly for aesthetics and energy conservation reasons. However, in Greece where the climatic conditions encourage the use of natural ventilation and necessitate the control of solar gains in order to prevent overheating, the preferred types of DSF are the multi-storey façade and the multi-storey louver façade that combine external shading systems and natural ventilation.

Figure 3-4 show some details of the façades evaluated.

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

Figure 3-4: Analysed buildings with DSF within Bestfaçade

Most of the buildings analyzed were non-public office buildings followed by public schools and services (Figure 3-5). 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 3-6).



Figure 3-5: Utilisation of BESTFACADE buildings

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Figure 3-6: Implementation and orientation of façades within BESTFACADE

# 3.4 Energy related aspects

The types of façades are mainly multi-storey and corridor types, 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) (Figure 3-7). Most of the façades have bottom and top openings in the outer shell of the façade which can be closed during winter and opened in summer (Figure 3-8). For the inner shell only half of the analyzed façades have openings (mainly windows, sometimes the windows are bypassing the gap). If present, they are, of course, closable. 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.



Figure 3-7: Type of ventilation and partitioning of the gap

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. Nearly all of the buildings use mechanical ventilation systems for the building and

both heating and cooling are performed mostly by air heating/cooling systems (see Figure 3-9). As heat source district heating followed by electricity and gas/oil is mainly used.



Figure 3-8: Ventilation openings in outer shell of analysed façades

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.





# 3.5 Integrated building technology

DSFs allow, to a certain 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, apart from the room conditioning, lighting systems and PV elements within the façade.

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In Belgium, usually, for the majority of buildings equipped with DSFs, the whole concept including the façade is similar to the HVAC system. 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 returned 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.

Integrated building technology exists in DSF buildings in Portugal. The oldest of these buildings, designed in the 1980, already included a system to recover the heated gap air and use it to heat offices located far from the DSF. Figure 3-10shows elements of building technology integrated in the façades analysed. Fire protection and active solar systems were used about in about one third of the façades. Only a few buildings include PV, sound absorbers or pluvial protection devices.



Figure 3-10: Integration of different devices into the façades (besides shading systems)

# 3.6 Cost (Investment, Maintenance, Operation)

The cost of DSF are about 20 - 80% higher compared to single glazed façades and about 100 to 150% higher compared to opaque façades with windows. Therefore there have to be significant benefits in the HVAC system cost or the operating cost of DSF to make them more attractive compared to conventional façades.

The initial investment in the DSF bears an extra cost that can be very high for some specific types of DSF. For the most common used DSF in Belgium (mechanical ventilated façade with juxtaposed modules), total cost ranges from  $500-700 \notin m^2$ , including solar shading. With some types of DSF, heating appliances can be avoided or the capacity of the heating appliances can be reduced, both of which reduce the installation cost. 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 façade. The change in operation cost is proportional to energy (heating and cooling) reduction or increase for the whole building equipped with a DSF compared to a traditional building.

The maintenance cost specific to the glass skins is of course higher because of the presence of four surfaces to be cleaned. The source of the ventilation air passing through the cavity also plays a role: more cleaning is needed in case of a cavity ventilated with outside air. The environment (pollution or 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 energy consumption, the building owner and/or users in Germany do not aim at disseminating the cost for the erection of their buildings, with or without DSFs. Construction management companies and façade manufacturers should have more insight into the investment cost. In the case of the German BESTFACADE project, participant Fraunhofer Institute of Building Physics is usually not party to the financial side of projects, but deals with energy-efficiency and energy economy. A DSF means two façades (inner and outer shell, which does not necessarily have to add up to the price of two façades, but will lead to a higher cost than most of the usual façades with only one skin). Additionally the DSFs are mainly glazed on both shells, glazing and especially the necessary safety glass, is more expensive than insulated panels. The investment cost of the DSF applied at the VERU test facility amounted to  $1255 \notin/m^2$  of façade area (though it should be mentioned that this façade has a very small total area of  $40 \text{ m}^2$ ).

Figure 3-11 and Figure 3-12 show absolute and additional costs that were collected from different publications on DSFs. Due to the wide range of technical possibilities and economic boundary conditions, a wide range of costs is reported.



Figure 3-11: Cost of DSF compared to conventional façades. The blue and white fields show the range of cost mentioned in Blum<sup>6</sup> (1998), Daniels<sup>7</sup> (1997), Kornadt<sup>8</sup> (1999), Schuler<sup>9</sup> (2003) and own data.







Figure 3-12: Additional cost of DSF according to different authors. The blue and white fields show the range of cost mentioned in Blum<sup>6</sup> (1998), Kallinich<sup>10</sup> (1994), Kornadt<sup>8</sup> (1999), Oesterle<sup>11</sup> (2003), Schuler<sup>9</sup> (2003).

For Sweden up to date estimated investment costs for the new WSP office building in Malmö are shown. The builder/developer is Midroc Projects, with costs according to WSP and Schüco. Approximate investment costs for different glazed façade alternatives are:

- Single skin façade without exterior solar shading, 370 €/m<sup>2</sup>;
- Single skin façade with fixed exterior solar shading (catwalk not included, simple control of solar shading included), 580 €/m<sup>2</sup>;
- Single skin façade including daylight redirection (catwalk not included, simple control of solar shading included), 680–790 €/m<sup>2</sup>;
- SF, including venetian blinds, such as the Kista Science Tower, 920–1000 €/m<sup>2</sup>;
- DSF box window type (cavity width 0.2m) with venetian blinds, 560 €/m<sup>2</sup>;
- DSF box window type (cavity width 0.2m) with venetian blinds, including daylight redirection, 610 €/m<sup>2</sup>

# 3.7 Other Aspects

**Acoustics** can be one of the main reasons to apply DSF - e.g. with traffic noise. In many cases DSF can reduce sound transmission from the outside due to additional shell. 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 for the application of DSF. They give depth and a kind 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 the case where the gap is separated between the storeys the problem is smaller than in conventional façades. Some types of DSF such as "multi storey DSF" must not be applied to high buildings.

**Durability** - Due to the fact that most DSF are kind of prototypes, difficulties have been reported with unproved durability - especially with pane fixtures (those problems may refer to Conventional Glazed Façades, 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 façades. 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 façades has 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 façades. However additional cleaning cost has 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 façade fixtures whether the need for maintenance is higher or not compared to CGFs.

# 4. CUT BACK OF NON-TECHNOLOGICAL BARRIERS – WP 2 (BY NKUA)

This report includes the project results of deliverable 6 (D6) of work package 2 of the "Best Practice for Double Skin Façades" project. The aim of deliverable 6 is to describe the cut back of non-technological barriers to the application of Double Skin Façades (DSF). These non-technological barriers are more difficult to overcome than technological barriers due to the fact that the factors which govern them are not objective and differ from country to country.

The research within work package 2 comprises two parts:

In the first part the non technological barriers are identified and analysed. These concern legislation issues, financial, institutional, sociological-behavioural and educational aspects. As part of this action a questionnaire was completed by each partner describing the above factors that hinder or, in some cases, promote the development of double skin façades in their countries respectively. The analysis aimed at a broad approach, however, there is not always easy to summarize the advantages and disadvantages of DSF in a questionnaire. This is due to the high number of different DSF concepts, some elements can be positive in a specific DSF design, and not for other.

This report includes a summary of the answers from the partners to the WP2 questionnaire, the detailed answers can be found in the WP2 report: 'Cut back of the non-technological barriers'.

In the second part of the report strategies to overcome these barriers are suggested. The proposed strategies are based on the answers of the questionnaires. It is suggested to follow a policy that will be



distinguished into two stages: the pre-assessment and post-assessment stage in order to cover all issues that are defined in the first part of the analysis.

### 4.1 Non technological barriers

In the first part of the research the non technological barriers are identified and analyzed. These concern aspects as legislation, financial, institutional, sociological-behavioral aspects, and educational aspects. As part of this action a questionnaire was completed by each partner describing the above factors that hinder or, in some cases, promote the development of double skin façades in their countries respectively.

#### 4.1.1 Methodology

A questionnaire was developed within the first part of work package 2 identifying the non-technological barriers to DSF<sup>12</sup>. The questionnaire forms the basis for a 'SWOT' analysis. 'SWOT' analysis is a methodology that analyses the barriers and limitations of a product in the market. It is a means to identify the advantages and disadvantages of the product and thus the range of its applicability.

'SWOT' is an abbreviation of 'Strengths', 'Weakness', 'Opportunities' and 'Threats'.

The issues 'Strengths' and 'Weaknesses' study *internal* resources of the product (in this case double skin façade systems) by comparing it with other products of the same type ( in this case with conventional façade systems)<sup>13</sup>. Therefore the key questions of this group investigate the main advantages/disadvantages of double skin façades compared to conventional façade systems.

The issues 'Opportunities' and 'Threats' analyze *external* resources that have an impact on the applicability and use of the product like as sociological and behavioral aspects, legislation etc. The key questions of this group investigate the major opportunities/threats posed by the outside world for double skin façade systems.

The WP2 questionnaire investigates the following non technological barriers:

- Legislation
- Knowledge
- Financial aspects
- Sociological and behavioural aspects
- Institutional aspects

Following all questions of each category are described along with a summary of the answers regarding the status of the double skin façade in the participating countries.

#### 4.1.2 Legislation

The first factor to be studied is the legislation on double skin façades in each country. The legislation is divided into 13 sub-categories concerning:

1. Basic legislation on double skin façades (whether this is an opportunity or threat to double skin façades)

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- 2. Existence of legislation on fire protection (opportunity or threat)
- 3. Existence of legislation on sound protection (opportunity or threat)
- 4. Existence of legislation on energy issues savings (opportunity or threat)
- 5. Existence of legislation on environmental issues (lighting, glare, indoor comfort, air quality)-(opportunity or threat)
- 6. Existence of legislation on ventilation requirements (opportunity or threat)
- 7. Current legislation on the percentage of glazing (opportunity or threat)
- 8. Current legislation on thermal insulation achieved U-values (opportunity or threat)
- 9. Requirements for the integration of renewable energy PV cells (opportunity or threat)
- 10. Requirements on thermal and energy modeling of buildings (opportunity or threat)
- 11. Requirements on thermal and energy modeling of double skin façade performance (opportunity or threat)
- 12. Safety regulations influencing double skin façades (opportunity or threat)
- 13. Other legislation with an impact on double skin façades (opportunity or threat)

Table 4-1 summarizes the answers of the WP2 questionnaire regarding the legal aspects.

Currently the EN Standards 13830 and CE marking of curtain walling is the official document that specifies the characteristics of curtain walling and provides technical information on the varying performance requirements which apply throughout Europe. Also, the document provides guidance to the curtain wall manufacturer on how to meet the requirements of the European Construction Products Directive (CPD). The CE marking is in force since 2005.

However, in all countries that completed the questionnaire, apart from one, there is no awareness of any specific legislation on double skin façades. All existing legislations applicable to conventional façades (legislation on fire and sound protection, legislation on environmental issues etc) are also applied to the case of double skin façades, since there is no awareness of any specific one for this type of façade.

In general legislation on fire protection exists in all countries but this does not concern specifically double skin façades. Legislation on fire protection may be a threat to DSF since the fire transfer between the rooms and levels has to be reduced.

In all countries apart from Greece there is legislation on sound protection but not specific for double skin façades. Sound legislation can be a threat when considering sound transfer between adjacent spaces through the DSF cavity. On the other hand, sound legislation can also be an opportunity to DSF as this type of façade provides better sound insulation than single skin systems. Also the sound propagation between adjacent spaces through the DSF cavity due to the telephony effect is a possible threat.

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Legislation	Austria	Belgium	France	Germany	Greece	Portugal	Sweden
Any legislation on DSF	YES & NO	YES & NO	NO	YES & NO	NO	NO	YES & NO
Existence of legislation on fire protection	YES legislation	YES legislation	YES legislation	YES legislation- THREAT	YES legislation may be a THREAT	YES legislation	YES legislation
Existence of legislation on sound protection	YES legislation can be an OPPORTUNITY	YES legislation	YES legislation	YES legislation OPPORTUNITY& THREAT	NO legislation NO THREAT	YES legislation	YES legislation
Existence of legislation on energy issues - savings	YES legislation	YES legislation	YES legislation	YES legislation THREAT&OPPO RTUNITY	NO legislation	YES legislation no threat	YES legislation
Existence of legislation on environmental issues	YES legislation	YES & NO legislation	YES legislation	YES & NO legislation THREAT OPPORTUNITY	NO legislation	YES legislation NO THREAT	YES & NO legislation
Existence of legislation on ventilation requirements	YES legislation	YES legislation	YES legislation	YES & NO legislation	YES legislation	YES legislation - NO THREAT	YES legislation NO THREAT NO OPPORTUNITY
Current legislation on percentage of glazing	YES legislation	NO legislation	YES legislation	YES legislation OPPORTUNITY THREAT	NO legislation	YES legislation NO THREAT	NO legislation
Current legislation on thermal insulation - U- Values	YES legislation	YES legislation	YES legislation	YES legislation OPPORTUNITY	YES legislation some THREAT	YES legislation NO threat	YES legislation THREAT
Requirements for integration of renewable energy - PV cells	No obligation	NO	YES	YES & NO - OPPORTUNITY	NO	NO	NO
Requirements on thermal and energy modeling of buildings	YES	YES & NO	YES	YES some THREAT	NO requirement s THREAT	NO	YES requirements THREAT
Requirements on thermal and energy modeling of DSF	NO requirements	NO requirements	NO requirements	YES & NO requirements	NO requirement s THREAT	NO requiremen t some threats	NO requirements
Safety regulations influencing DSF	Possible OPPORTUNITY	NO regulation	NO regulation	YES & NO regulations	NO regulation	YES regulations NO THREAT	YES regulations
Other legislation with an impact on DSF	On air traffic						

#### Table 4-1: Summary of answers regarding the legal aspects

All countries except Greece have legislation on energy issues. In the majority of the countries the regulations are under revision to fulfill the requirements of the EPBD and since January 2006, requirements about the energy performance at the building level (primary energy consumption of



buildings) have been entered into force. The current legislation on energy at national level can be a threat or an opportunity to the application of DSF depending on the design achievement on the final thermal transmittance and U-values of the façade.

Legislation for lighting exists only in Germany, in the majority of the other countries efficient lighting is suggested but no regulated by Law. The energy impact of the lighting is also included in the new regulation about the energy performance of the buildings. Legislation on lighting issues could pose a threat to DSF since the inner layer of glazing in conjunction with the internal blinds can lower significantly the daylight factors in the occupied spaces; however, the legislation on lighting can be seen as an opportunity since buildings with double skin façades can usually achieve desirable visual comfort conditions.

No quantitative specifications about glare exist today; also in the majority of the countries there are no requirements on air quality. Some guidelines that exist usually concern smoking areas.

In the case of ventilation requirements all countries have legislation and airflow recommendations in the building code. This legislation does not seem to pose any threat or opportunity to the application of double skin façades.

Concerning the percentage of glazing, Belgium, Greece and Sweden have no legislation. However, in Belgium and Sweden, indirect requirements are set by imposing a maximal average U-value to the building and indirect minimum requirements exist by imposing daylight availability into the office areas. In Austria national standards dictate the minimal account of glazing for living spaces to guarantee enough sunlight, while there is no regulation for the maximum. In Germany and Portugal legislation on the percentage of glazing exists. A possible threat of extended glazed areas is the development of overheating problems and thus large glazed areas and DSF without good shading may have problems to meet the requirements.

All countries have legislation on thermal insulation and achieved U-values; this is considered from most countries as an opportunity for double skin façades since the U-value is usually lower than for other glazed façade types. However, maximum indoor temperatures could pose a threat to DSF if limits of indoor temperature are to be observed.

The EPBD implementation could be an opportunity if the designed DSF is performing well (due to the presence of the two glazed skins), but it could be a threat if the system is badly designed and cannot meet the thermal and energy requirements (for example if overheating is observed during summer).

All countries apart from Belgium, Greece and Portugal have requirements on thermal and energy modeling of buildings. Threats for double skin façades will then depend on their actual performance. In Belgium there are no requirements except that reference is made to the existing Belgian standards however, none of these standards are giving satisfactory answers on how to handle double skin façades. In Austria heat demand calculations are requested by all provinces according to a simplified EN 832 approach. In Germany the new DIN V 18599 gives a conservative approach for double skin

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façades and could pose a threat for good double skin façades that might provide better results than calculated with the DIN.

Concerning the requirements on thermal and energy modeling of double skin façade performance, these do not exist in any of the participant countries.

In Portugal and Sweden safety regulations exist but pose no threat to the double skin façade, while in France and Greece no relevant regulations exist. In Austria the safety regulations can prove as an opportunity for double skin façades since the cavity can be used as a fire escape route and night ventilation is possible without safety risk. In Belgium and Germany in terms of stability and occupant's or pedestrians' safety, the same criteria as those applicable to traditional single façades are applicable to DSF.

#### 4.1.3 Knowledge

The second aspect to be studied from this questionnaire is the level of knowledge that each country has on double skin façades. The questions are addressed at: scientific–educational institutions, the building industry–construction, architects and others such as building owners and investors.

Subsequently, the level of knowledge in each country is analyzed according to 5 factors:

- 1. The level of knowledge on the typology and performance of double skin façades (high or low level of knowledge)
- 2. The level of knowledge on the design, construction and technology of double skin façades (high or low level)
- 3. The dissemination of knowledge on double skin façades (through University, Internet, Seminars, Other Methods)
- 4. The level of knowledge on the advantages and disadvantages of the double skin façade compared to a conventional façade (high or low level)
- 5. The availability of double skin façade built examples in each country

In general the level of knowledge concerning the typology, performance, design and construction of DSF, is high in educational /research institutions and big constructions companies that usually work at an international level. The level of knowledge on the typology and performance of DSF is high especially in research institutions of Austria, Germany and Belgium (i.e. IBP and BBRI) where extensive simulations, measurements and literature research have been performed. In France, Greece, Portugal and Sweden there is a low level of knowledge on the typology and performance of double skin façades, however at the educational institutions of the participating countries (i.e. University of Lund) there are several ongoing research projects on glazed office buildings.

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Knowledge	Target Group	Austria	Belgium	France	Germany	Greece	Portugal	Sweden
Intowicage		HIGH/LOW	HIGH/LOW	HIGH/LOW	HIGH/LOW	HIGH/LOW	HIGH/LOW	HIGH/LOW
	Scientific - educational institutions	HIGH - in a small range of institutions LOW - in educational institutions	HIGH: BBRI &Universities LOW concerning performance	LOW	IBP: HIGH	LOW		LOW
Level of knowledge on the typology and performance of DSF	Building Industry - Construction	HIGH-big construction companies Low -big facility management firms	HIGH		Façade Industry: HIGH	LOW	LOW	LOW
	Architects	LOW	LOW		LOW -majority of architects	Extremely LOW	HIGH - typology LOW - performance of DSF	LOW
	Other (optional)				Building owners: LOW Investors:LOW			
	Scientific - educational institutions	Relatively HIGH	relatively HIGH		IBP:HIGH	LOW		LOW
Level of knowledge on the design,	Building Industry - Construction	HIGH -Only in a small range of companies	HIGH		Facade Industry: HIGH	LOW	LOW	LOW, among clients and engineers
construction and technology of DSF	Architects	LOW	LOW	LOW	HIGH	LOW	HIGH- architects who have designed DSF buildings	LOW
	Other (optional)				Building owners: LOW Investors: LOW			
Dissemination of knov (through Universit Seminars, Other	wledge on DSF y, Internet, Methods)	internet	University, Internet, Seminars	University, Internet and Seminars	University, Internet, Seminars	Internet and Seminars	University	Web site of University of Lund
	Scientific - educational institutions	LOW Reliable comparative studies are missing	Quite HIGH - BBRI	LOW	IBP:HIGH	LOW	LOW	LOVV, apart from University of Lund
Level of knowledge on the advantages and disadvantages of the DSE compared to a	Building Industry - Construction	The facade industry mostly knows	HIGH for the main facade constructor of DSF		Facade Industry: HIGH	LOW		LOW
DSF compared to a conventional façade	Architects	Low - Architects often do only see the design advantages	LOW except for some specialised architects		HIGH some specialised architects LOW-majority of architects	LOW	LOW	LOW
	Other (optional)				Building owners: LOW Investors: LOW			
Availability of DSF bu your cour	ilt examples in htry	YES, several examples exist	YES built examples	YES built examples	YES built examples	∨ery few built examples	YES built examples	YES built examples

Table 4-2: Summary of answers regarding the knowledge aspects

On the other hand, low level of knowledge concerning the typology, performance, design and construction of DSF is noted in the group of architects, building owners and investors. It seems that

the knowledge is high between a few architects who have been involved in the design of DSF buildings.

In the case of the advantages and disadvantages of the double skin façades compared to the conventional systems, it seems that the knowledge is low in all target groups apart from several educational/research institutions that are working in relevant projects.

Four methods are considered for the dissemination of knowledge of DSF: university level, internet, seminars and any other method. The answers to this question vary: In Austria the internet could be considered the best source to get information but the quantity of high quality information is rather small. In Belgium, France and Germany the dissemination comes through universities, the internet and seminars. In Greece the dissemination comes through the internet, seminars and indirectly through educational institutions. In Portugal dissemination comes mainly through universities (graduate students) and scientific papers

The analysis showed that in all countries there are built examples; the majority of them have been constructed recently. However there is no documentation of their energy and environmental performance and the availability of reliable data is low.

Table 4-2 summarizes the answers of the WP2 questionnaire regarding the knowledge aspects.

#### 4.1.4 Sociological – Behavioral aspects

Sociological and behavioral barriers to double skin façades were studied in each country.

Specifically, the following aspects were investigated:

- 1. Local climatic conditions (if these are appropriate or not appropriate to DSF)
- 2. Local architecture and the aesthetics for full transparency (if this is a problem or not for the use of DSF)
- Aspects on the double skin façade cavity, concerning the calculation of its area in the total net floor area of the building and the reduction of rentable Office space (a problem or not a problem to the use of DSF)
- 4. The appropriateness of double skin façades in each country and the non-appropriateness of buildings in each country (a problem or not a problem to the use of DSF)
- 5. The importance, under specific climatic conditions, of occupant control for ventilation and the possibility that such controls could pose a problem the operation of double skin façades (a problem or not a problem to the use of DSF)
- The reputation of double skin façades according to different target groups such as scientific educational institutions, the building industry – construction, architects and others such as building owners and investors. (if there is a good reputation or bad reputation)

Climatic conditions do not seem to pose any obstacle in the application of DSF in any of the participating countries; however this always depends on the building usage and type of façade.



Various systems can be applied in the different climatic regions; however it seems that naturally ventilated double skin façades are not very appropriate for warm climates, in which mechanical ventilation could be adapted. In Austria the climatic conditions usually can be controlled by DSF related technical equipment. However, it is not proven yet if this justifies enormous additional investment. In Belgium several concepts of façades exist. Each of them is more appropriate for a specific type of climate. In France the climate is also appropriate for double skin façades, as well as in Germany depending on the building usage and type of DSF. In Greece, if the double skin façade is not well designed and shaded, an overheating problem could arise in the summer because of the high temperatures inside the air cavity. In Portugal the architects that design DSF buildings state that double skin façades are appropriate for the climatic conditions.

Also, in Sweden according to some architects the local climatic conditions are appropriate for double skin façades. Local architecture and aesthetics for full transparency do not seem to pose any threat to the application of DSF. The outward looking transparency is usually not a problem, while the inward looking transparency is disputed and causes opposition by the users as often architects desire full transparency while users might not like it. The selection of the DSF system always depends on the clientele. Also, for many of the participating countries it could be argued that double skin façades have become an architectural trend in high-level, high-rise buildings in the last 15 years.

In many countries the calculation of building area is not clearly specified, however, the reduction of the net floor area by the double skin façade may be a problem because this results in smaller rented net floor area.

Although DSF can be applied in all type of buildings, until now they have been used mainly in office buildings and not so much in residential and other type of buildings because of their increased construction and capital cost.

Studies have shown the significance for occupants to have a certain control of their environment, such as the control of the solar shading, the temperature levels or opening of the windows. Therefore, if a façade (ventilation system) does not allow at least a small range of user control it will not be accepted and if the technical concept is not able to handle this, it will be considered as the wrong concept.

Regarding the reputation of DSF in all countries, it seems there is skepticism in the scientific field concerning the energy efficiency, the indoor air quality and thermal comfort levels that this type of façade can provide. The reputation is good in the building industry that tries to promote this type of façade but there is also concern because of the high investment cost. Among the majority of the architects in many participating countries, the reputation is good mainly because of aesthetics reasons and because it seems this type of façade could be the solution to most problems for high rise buildings. However, there is rather low level of knowledge on the energy performance of DSF among all target groups.

#### "Best Practice for Double Skin Facades"



Sociologica asp	ll-Behavioral Jects	Austria	Belgium	France	Germany	Greece	Portugal	Sweden
Local climat	tic conditions	APPROPIATE for DSF	Concepts of DSF are APPROPRIATE	APPROPIATE for DSF	APPROPIATE for DSF	APPROPRIATE If not well designed and shaded, maybe a problem of overheating during summer	APPROPIATE for DSF - answer from architects that design DSF buildings.	APPROPIATE for DSF, according to some architects
Local arc aestheti transp	chitecture- ics for full parency	YES a problem. Depends on clentele, many architects like full transparency, many users don't.	NOT a problem Tendency to adopt more and more transparent buildings	NOT a problem	NOT a problemDSF became an architectural trend in high-level high-rise buildings in the last 15 years.	NOT a problem	NOT a problem	NOT a problem
Is the area c DSF cavity thetotal net the building? rentable C	overed by the calculated in floor area of Reduction of Office space	YES a problem. Ecological impact, need for energy and cost to be compared to the usefulness of a building, in this comparison space for cavity cannot been seen equal as floor space.			YES a problem smaller rented floor area (net floor area).	YES a problem, possible reduction of office space	NOT a problem	YES, it is often a problem.
ls in your o appropiate fo buildings? state what l not ap	country DSF or all types of If not please buildings are propiate	Not common for multi storey residental buildings. due to the costs the main field of application is office buildings	applicable to all kind of buildings excepted for residential buildings	NOT a problem	used mostly in high- level office buildings because of high investment costs.	Mostly in offices and public buildings (because of high cost). Not in residential buildings	mainly office buildings and shopping malls.	Until now DSF buildings are mainly new office buildings.
ls occupar ventilation im specific conditions problem for of D	nt control for nportant under climatic s? Is this a the operation DSF?	Conclusion: if a facade (ventilation system) does not allow at least a small range of user control it will not be accepted and if the technical concept is not able to handle thisit is the wrong concept	YES a problem - occupant needs to have a certain control on his environment. Adapted concepts of DSF could take advantage of this	NOT a problem	YES a problem Most people prefer an indoor comfort that they can influence themselves. Most of the times not possible with DSF and the linked technical systems like ac	YES a problem if DSF design does not permit flexibility	YES a problem Occupant control is a problem for occupants	NO, as most office buildings have openable windows. It is not unusual that occupants want to be able to open windows. In most DSF office buildings in Sweden windows cant be opened.
	Scientific - educational institutions	rather sceptic but never the less interested	GOOD for acoustical performances, transparency, etc. BAD due to higher costs and sometimes higher energy consumption.		GOOD - for architects BAD - energy consumption in DSF buildings can be higher than in conventional buildings	NO reputation currently- Investigation on DSF reputation through research work	GOOD - mainly due to aesthetics	BAD i.e. scepticism concerning energy efficiency and quality of indoor climate.
	Building Industry - Construction	Mixed	Good for the main company which is designing DSF		Façade Industry:GOOD	GOOD in a few companies that try to promote DSF and improve their performance		BAD - high investment cost
Reputation of DSF	Architects	GOOD regarding aesthetics because it gives new possibility to design the building envelope.	GOOD for acoustical performances, transparency, etc. BAD due to higher costs and sometimes higher energy consumption.		GOOD architectural papers praise the designs of DSF buildings BAD Engineers exchange informations on technology related symposia Every consultant tries to develop a more efficient system	NO reputation in the group of architects since the majority of them are not aware of DSF		GOOD, among many architects
	Other (optional)				Building owners:GOOD - if reading architectural papers BAD-if reading publication on real consumptions and partly also comfort Investors:GOOD-for high-level office buildings-BAD			GOOD, among investors in high profile office building

#### Table 4-3: Summary of answers regarding the sociological-behavioral aspects

It can be concluded that for many actors, the reputation of DSF is a confused subject due to the lack of knowledge about the energy and environmental performance of buildings equipped with DSF



#### 4.1.5 Financial aspects

For the financial aspects of double skin façades three main factors were examined:

- 1. The cost of double skin façade buildings compared to buildings with traditional façades (high or low cost)
- The level of knowledge on the cost of double skin façades (investment, operational, maintenance), depending on target groups such as scientific – educational institutions, the building industry – construction, architects and others. (high or low level of knowledge)
- 3. The availability of funding grants for double skin façades (available or not available grants)

Table 4-4 summarizes the answers to the WP2 questionnaire regarding the financial aspects.

inancial aspects	s	Austria	Belgium	France	Germany	Greece	Portugal	Sweden
Cost of DSF built to traditione	dings compared al facades	Mostly higher but very few comparable data available	BBRI High cost / Low cost are subjective concepts. As general rule, it can be said that DSF should cost more than traditional facade and that the operational costs should be reduced.	HIGH	HIGH	HIGH	HIGH - but identical to that of common single skin buildings with identical typology . Since DSF technology is imported, the cost depends very much on the contract	HIGH investment cost
	Scientific - educational institutions	LOW - Investment , LOW - Operational , LOW - Maintenance Extremely difficult to get data, reasons for economics and the fear of bad reputation seems to block dissemination	LOW - Investment LOW - Operational LOW - Maintenance	LOW - Investment LOW - Operational LOW - Maintenance	IBP :HIGH - Investment HIGH - Operational LOW - Maintenance	LOW , knowledge acquired through research programmes and study of built examples	LOW - Investment LOW - Operational LOW - Maintenance	LOW - Investment, operational, maintenance due to lack of data
Level of knowledge on the cost of DSF (Investment, Operational, Maintenace)	Building Industry - Construction	Investment - high Operational and maintainance - low	Quite HIGH for the main facade constructor of DSF		Façade Industry: HIGH Investment: HIGH & LOW - Operational, HIGH - Maintenance	In general LOW , HIGH for the companies that have participated in the construction of DSF		HIGH - Investment LOW - Operational and Maintenance, due to lack of data
	Architects	LOW			HIGH & LOW - Investment LOW - Operational LOW - Maintenance	LOW		LOW - Investment LOW - Operational LOW - Maintenance
	Others (optional)				Investors: HIGH & LOW- Investment, LOW- Operational, LOW- Maintenance Building owners: LOW- Investment, HIGH & LOW- Operational, HIGH & LOW- Maintenance			
Funding/gra	nts on DSF	Not available	Not available	Not available	Not available	Not available	Not available Low level of incentives for energy efficient buildings.	Not available

#### Table 4-4: Summary of answers regarding the financial aspects

In all countries taking part in this questionnaire the cost of double skin façade buildings compared to buildings with traditional façades is considered higher. Although based on very few data available, as a general rule, it can be said that DSF should cost more than traditional façades and that the operational costs should be reduced.

In all countries apart from Germany the level of knowledge on the cost of double skin façades concerning the investment, operational and maintenance cost is low in scientific and educational



institutions, as well as in architects, due to the difficulty of getting data and the fear of bad reputation, which blocks dissemination. In Germany on the other hand, there is high level of knowledge for investment and operational cost and low on maintenance cost among scientific and educational institutions, and a high level of knowledge in all fields of the façade industry. Among architects and investors the level of knowledge on investment cost could be high, but in all other fields it is low.

The level of knowledge on the cost of DSF is low on all fields among building owners as well. In Greece, while the level of knowledge is mainly low, companies that have participated in the construction of DSF have a high knowledge on investment cost. In Sweden the level of knowledge on the cost of the façade –investment, operational, maintenance- is low mainly due to the lack of data as the few existing buildings are recently constructed. However, among architects and building industry there is high level of knowledge on the investment costs.

Finally, in all countries there are no available grants for double skin façades.

#### 4.1.6 Institutional aspects

The study of institutional barriers to the application of double skin façades concerns the possible support that this kind of technology could have, as well as institutional drawbacks, such as bureaucracy. Thus, the questionnaire was divided into three sub-categories, namely:

- 1. Support from the Government or Professional institutions
- 2. Regional Support-Planning policy
- 3. Required bureaucracy-authorization for the new technology (increased or decreased bureaucracy)

Table 4-5 summarizes the answers to the WP2 questionnaire regarding the institutional aspects. Concerning the institutional aspects, nearly all the countries that filled in the questionnaire replied that there is no sufficient support by the government or professional institutions either. It is noticeable, though, that on Belgium's part there is indirect support via the financing of research projects like a national project (2000-2004) on DSF coordinated by the BBRI. In the case of Germany, also, support is provided only for integrated PV glass systems. In Greece also there is indirect support through the financing of research programs. As for Austria, France and Portugal support in these countries does not exist. In Sweden there is at least one research project supporting the building design funded mainly by the Swedish Energy Agency.

No specific planning policy is reported in any of the participating countries and regional support is apparently non-existent.

#### "Best Practice for Double Skin Facades"



Institutional aspects	Austria	Belgium	France	Germany	Greece	Portugal	Sweden
Support from the Government or Professional institutions	NO support	YES & NO support. Indirect support via the financing of research projects like the DSF project coordinated by BBRI.	NO support	YES & NO support Support only for intergrated PV glass systems	NO support. lindirect support through the financing of research programmes	NO support	NO support
Regional Support-Planning policy	NO support	NO support	NO support	NO support	NO support	NO support	NO support
Required bureaucracy- authorisation for the new technology	Yes increased	YES increased With the future energy performance regulation, technology not covered by the standard calculation procedure will have to be assessed by the so-called principle of equivalence. The exact way to fill in this is not know yet	YES - increased bureaucracy	YES increased Same as for other facades	YES - increased bureaucracy	YES increased - Fire protection is the main cause of problem for DSF buildings	YES - increased, especially with the new building code stating the energy performance, but not any recommendation as to how to take into account DSF

#### Table 4-5: Summary of answers regarding the institutional aspects

Bureaucracy is shown to have increased to a great extent in the countries mentioned. In Belgium, specifically, the future energy regulation implies that technology not covered by the standard calculation procedure will have to be assessed by the so-called principle of equivalence. Unfortunately, the exact way to fill in this remains unknown and this eventually leads to the quest of complementary studies in order to be able to evaluate the energy performance of this kind of technology (as DSF). In France, Greece and Portugal there are high levels of bureaucracy. In Portugal, due to the huge bureaucracy, new technologies such as DSF are used without specific authorization. Fire protection, in particular, is the main cause of problem for DSF buildings in this country. Germany retains an increased level of bureaucracy, especially with the new building code stating the energy performance but not any recommendation is given on how to take into account DSF.

#### 4.2 Strategies to overcome the non-technological barriers

The analysis on the non-technological barriers to DSF, based on the WP2 questionnaire, showed the significance of the following issues:

- Lack of specific legislation and standardised schemes on DSF
- Lack of knowledge on DSF (advantages/disadvantages, inconveniences, real performances at the level of the façade and also at the level of the building, cost of DSF)
- Lack of knowledge on the most appropriate applicable concept of DSF and on the best control system and strategy (for example different concepts are possible in function of the type and/or the use of the building),
- Not documentation of reliable best practice examples of DSF
- Not available funding

In order to overcome the non-technological barriers it is suggested to follow a policy that will be distinguished into two stages: the pre-assessment and post-assessment stage.

#### 4.2.1 Pre – assessment stage

The pre-assessment stage aims to provide the target group with all necessary information on DSF to be able to check the performance of the suggested technology. Specifically, the following actions are suggested:

- Provide information on DSF legislation by introducing the EN standards and homogenous calculation methods, marking and predictive tools
- Enhance harmonisation of the market and the calculation methods to meet national legislation and local climatic conditions
- Increase dissemination of DSF regarding the characteristics of DSF, its advantages/disadvantages, the cost of the façade system and dissemination of good documented examples

Currently the legal regulation for DSF in use is covered by the EN- standards, EN 13830 'Product Standard - Curtain Walling'. According to EN 13830: 2003-11 **a curtain walling** is defined as: '*external building façade produced with framing made mainly of metal, timber or PVC-U, usually consisting of vertical and horizontal structural members, connected together and anchored to the supporting structure of the building, which provides by itself or in conjunction with the building construction all the normal functions of an external wall but does not contribute to the load bearing characteristics of the building structure<sup>14</sup>.* 

According to prEN 13119:2004, **a double skin façade** is defined as: *'a curtain wall construction comprising an outer skin of glass and an inner wall constructed as a curtain wall that together with the outer skin provide the full function of a wall'*. The EN standards list the façade specifications according to the requirements of the Construction Products Directive (CPD) leading to the CE marking for curtain walling, that is in enforcement since the year 2005.

The standards cover the thermal resistance, acoustic, air tightness, water permeability and wind protection issues for DSF systems. However, only in one of the participating countries there was awareness of these specific standards.

A homogenous procedure for the U-value calculation and performance of DSF is necessary as a means to compare projects in different countries; this could be covered by the procedure suggested by prEN 13947:2005 in conjunction with the calculation method that is developed within work package 4 of the 'BEST FAÇADE' project. A simple calculation method is developed in accordance with the CEN standards to be used by all European countries for the thermal and visual performance of DSF at the design stage.

Harmonization of the EN standards and calculation methods to meet all national legislations is important to meet different climatic conditions and market needs. It should be noted that the participating countries in the 'BESTFACADE' project belong in 3 different climatic regions all over Europe: the 'Nordic region' represented by Sweden, the 'temperate region' represented by Austria,



Belgium, France and Germany, and the 'Mediterranean' region with Greece and Portugal ('BESTFACADE' WP1 report<sup>15</sup>). This climatic variation results in various ventilation concepts and energy demand thus different façade concepts. Additionally, variation in knowledge and needs on simulation methodologies and legal requirements are noted among the participating countries.

Dissemination of DSF is important. A broad dissemination of the 'BEST FAÇADE' project can be performed in various ways through seminars on national and international level, training of architects and engineers at university level. Also, the use of complementary methods like internet and journals would support the promotion of the training process.

Within the dissemination procedure, a best practice guideline including good examples already built in the participating countries is prepared within work package 5 of the 'BEST FAÇADE' project addressed at a broad target group consisting of engineers, architects, building owners and construction industry. The guideline includes common basic scientific, technical and economic knowledge of the DSF projects that are published.

#### 4.2.2 Post – assessment stage

The post assessment stage includes all actions that have to be taken into consideration after the DSF dissemination in order to support the product in the market. The following actions are suggested:

- Appropriate marketing from involved associations
- Better definition of targets by the façade industry
- Increased and reliable documentation of best practice
- Provision of funding

The advertisement of DSF depends on the company level policy: the national markets and involved associations should follow an appropriate policy for the support of the product. They could make public the advantages of the system as well as the fact that funding is important to enhance the spread of its use. Political pressure should be applied both on national and EU level. Additionally, companies could play an active role on legislation issues, for example by promoting DSF products as 'green' products that are adequate to comply with the EPBD, thus to reduce emissions, especially CO<sub>2</sub>, and the building energy consumption.

Additionally, the analysis showed the lack of specific targets/standards of DSF. It is essential to establish a clear set of specific objectives: nowadays, with the implementation of new regulations, science should be considered to deal with construction and particularly with the façade performance and energy conservation issues. A society of façade engineering on national and EU level in conjunction with the façade industry could play a driving force for the development of the glazing systems and the support of the DSF products. Proposed actions of the society should include the preparation on 'technical' and 'physics' aspects of high-technology façades, the organization of regular technical meetings aiming at informing technicians and engineers on the update of the legislation and market.



The publication of the good DSF examples along with the documentation of their energy and environmental performance including operational and investment costs in engineering and architectural journals can increase reliability of the product and awareness among the target group. The provision of real data (i.e. monitoring data on energy and indoor comfort along with the users' satisfaction after the building construction and occupancy) and publication of the results would encourage the use of DSF and the public confidence in the product. On the other hand, the lack of documentation on the real performance of DSF, i.e. lack of energy data and thermal comfort could be considered and as an indication of the negative aspects and malfunction of the product.

'Demonstration' projects could also be used to demonstrate the best technology, such as DSF, document the whole procedure from the pre-design stage until the occupancy of the building to indicate the performance of the technology.

The main competitor to the DSF is the conventional glazed systems due to their simpler technology and their reduced investment and lower construction costs. The reduction of the cost of the façade would promote the use of the product in the market. However, because of the high initial construction cost of DSF and integrated shading systems, the DSF buildings could be assessed as cost-effective through the life-cycle cost method, assessing the total building cost over time.

The analysis showed that currently there are no financial incentive schemes for DSF. On national and EU level, there should be established short and long term funding to support both research and construction.

# 5. BENCHMARKS AND CERTIFICATION - WP 3 (BY ISQ)

In the scope of the Bestfaçade work package 3 a methodology for the energy benchmarking of double skin façade (DSF) buildings was presented and main results of the use of this methodology for a group of buildings located in Europe were given. Best performing double skin façade office buildings were identified and their main characteristics highlighted. Energy benchmarks for double skin façade office buildings and a certification method for façades were also proposed.

As a result of the work package the Bestfaçade target group has had the opportunity during the workshops - and can still use the website for this purpose – to obtain information on DSF buildings case studies that represent, for different climatic regions, the best energy performers from the set of buildings that was studied. Using this data it is possible to compare the target group "own projects versus state of the art double skin façades."

#### 5.1 Analysis of energy performance data

A combination of data collection tools, which comprises questionnaires, documentation research, interviews and technical visits, was used to gather sufficient data to interpret building's energy performance and critical success factors. Data was verified as far as possible by identifying any anomalies outside the expected range of results.



In general, results have shown good energy performance of DSF buildings. For purposes of comparing energy needs, annual data for energy delivered per floor area was obtained for each DSF building (from energy bills or monitoring). Clusters of DSF office buildings with similar energy behaviour were then established.

To further study the energy behaviour of the DSF buildings, values of heating and of cooling energy needs for each DSF building were compared. No climatic distinction between buildings was made. Three non-office buildings were removed from the analysis because their use is different from that of all the other ones.

Figure 5-1 presents the energy needs for heating and for cooling for the DSF sample office buildings. Energy type normalization was performed when necessary.



Figure 5-1: Heating and cooling energy needs for DSF sample office buildings (with energy type normalization when necessary).

Buildings AE and V can be clearly distinguished from the rest of the sample for having significantly higher heating and cooling energy needs. These are obvious non-candidates to good performing DSF buildings. The remaining sample of the DSF office buildings have heating and cooling energy needs lower than 200 kWh/( $m^2$  a).

A preliminary principal component analysis (PCA) was used to further understand the relative performance of the buildings. PCA is a statistical technique often used to interpret existing mutual relationships within complex sets of data and to explain the characteristics and/or the behaviour of a



given set of entities (in this case, buildings). In the present analysis no data reduction benefits were gained, for only two energy performance indexes were used. The reduced statistical significance of the available data also affects the analysis, since comparisons to an average sample data energy performance are made. PCA analysis enabled however further insight into the building energy performance.



Figure 5-2: PCA graphical representation of the positions of the buildings on the rotated space.

The first axis (or component) in figure 2 is strongly related to the buildings heating needs and the second to the cooling needs. Buildings in the upper left corner have low heating and high cooling needs. Buildings in the lower right corner have high heating and low cooling needs.

Figure 2 distinguishes buildings with "expected" behaviour (given their climatic region) from those that have "unexpected" behaviour. Nordic climate buildings should probably occupy the lower right side of the graph, since they should have higher heating and lower cooling energy needs. On the other hand, Mediterranean climate buildings should probably occupy the higher left side of the graph, since they should have lower heating and higher cooling energy needs. Moderate climate buildings should occupy positions intermediate between those of Nordic and Mediterranean climates.

Analysing the Nordic climate buildings, it can be concluded that building E is the best performing, approaching a heating need behaviour similar to that of Moderate climate buildings. Building A is the worst performing. Building D has an intermediate performance.

For the Mediterranean climate buildings, it is clearly noticeable that building W exhibits a heating behaviour that is closer to Moderate climate buildings than to the Mediterranean ones. The other two Mediterranean climate buildings, AD and AB, possess lower heating needs than building W.

Regarding the cooling behaviour, building W is only marginally better than building AD, and slightly better than building AB.

Regarding the Moderate climate buildings, building G can be clearly distinguished from the others. Having very low heating and very high cooling needs, it behaves as if it was located in a Mediterranean climate. For the remaining two buildings, Q and R, both have similar heating needs behaviour and R has slightly lower cooling needs.

When a cluster analysis using the Mahalanobis distance is performed, figure 3 is produced.





Figure 5-3 confirms the analysis of Figure 5-2 identifying: a "Moderate Cluster", composed of Moderate climate buildings R and Q, to which buildings E and W, respectively, Nordic and Mediterranean, also belong; a "Nordic Cluster", composed of buildings D and A; and a "Mediterranean Cluster", with buildings AD and AB, joined by the Moderate climate building G.

From the previous results, candidates for the search of best practices in DSF buildings are:

- Nordic climate: buildings E and D;
- Moderate climate: buildings R and Q;
- Mediterranean climate: buildings W and AD.

These buildings were used as case studies of best practices of double skin façade buildings and were completed characterised. Most significant features are the following:

#### 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.

#### 5.2 Energy benchmarks

To compare the energy performance of the DSF sample buildings with that of the existing European building stock, energy benchmarks from different European countries were gathered.

Based on the values presented in the work carried out, comparing the best performing DSF buildings and the most demanding benchmarks, Table 5-1 proposes energy benchmarks for DSF office buildings in the three climatic regions used in the project: Nordic, Moderate and Mediterranean.

An upper limit of 150 kWh/(m<sup>2</sup> a) for the total delivered energy (fossil fuel plus total electricity) is proposed. Upper limits for heating, cooling and electricity (except cooling) are also proposed. Since buildings may use heating energy expressed as kWh fossil fuel (mostly in Nordic and Moderate climates that produce heat with boilers) or kWh electricity (mostly in Mediterranean climate where heat-pumps are increasingly used), benchmarks expressed in annual tonnes oil equivalent per square meter are presented. Also presented are benchmarks expressed in units of annual emissions of tonnes CO<sub>2</sub> equivalent per square meter (see WP3 Report for conversion coefficients used).

		Climate	
-	Nordic	Moderate	Mediterranean
Heating with fossil fuel [kWh/(m <sup>2</sup> a)]	90	65	
Heating with electricity [kWh/(m <sup>2</sup> a)]			20
Cooling with electricity [kWh/(m <sup>2</sup> a)]	20	45	90
Electricity (except cooling) [kWh/(m <sup>2</sup> a)]	40	40	40
Total delivered (sum of the above)	150	150	150
Total (fossil fuel+electricity) [toe/(m <sup>2</sup> a)]	25x10 <sup>-3</sup>	30x10 <sup>-3</sup>	44x10 <sup>-3</sup>
Total CO <sub>2</sub> emissions [tCO <sub>2</sub> e/(m <sup>2</sup> a)]	30x10 <sup>-3</sup>	36x10 <sup>-3</sup>	52x10 <sup>-3</sup>

Table 5-1: Proposed benchmarks for DSF office buildings.

#### 5.3 Certification method for façades

The energy certification of office buildings — including buildings with double skin façades — is defined by each European Member State based on the EPBD. To certify façades a method similar to the energy certification of buildings already implemented in some European countries is proposed. This method considers the existence of designers and building owners on one side; experts responsible for the rating of the façade on the other side; and finally, at Member-State level, an overall supervision entity. The rating is based on a *Reference Façade Method*, which consists of the comparison of *numerical* energy performance results for the actual building, with the actual façade and HVAC system, and *numerical* energy performance results for the same building but considering a *reference façade and HVAC system*. The reference (or typical) façade and HVAC system is defined at Member State level.

Figure 5-4 presents the envisioned certification method. The two-step approach considers the use of the following two expressions.

$$1^{\text{st}} \text{ Step ratio} = \frac{\text{Building energy need}|_{\text{Actual façade}}}{\text{Building energy need}|_{\text{Reference façade}}}$$
(1)





Figure 5-4: Certification method for façades.

The first step equation (1), based on the (room) energy needs, assesses the energy performance of the actual façade against the reference façade, not taking into account the HVAC system used.



The second step equation (2), based on (system) demand energy, differs from the first step because it takes into account not only the actual façade, but also the actual HVAC system, its efficiency, and compares both these systems to reference ones.

The definition of reference façade, reference HVAC system and numerical simulation tools should be established at Member-State level, taking into account the specifics of building architecture and common construction materials in each country.

# 6. A SIMPLE CALCULATION METHOD FOR THE ENERGY PERFORMANCE OF DOUBLE SKIN FAÇADES – WP 4 (BY FRAUENHOFER-IBP)

Presently the assessment of the thermal behaviour and the energy-efficiency of naturally ventilated double skin façades is only possible by using complex simulation tools, which allow interconnections between fluid dynamics, energy balances and optical transport mechanisms. The performance assessment of mechanically ventilated double skin façades is slightly easier but still requires simulation tools. Because of the interaction of separate calculation results, extensive iterations are often necessary. This makes it impossible to have reliable predictions on energy efficiency and impacts on comfort in the early planning phase and to reduce uncertainties at designers and investors.

Therefore the goal of the BESTFACADE work package 4 was to develop an assessment method, which on the one hand can be integrated in the calculation methods of the EPBD (Energy Performance Building Directive) and on the other hand offers sufficient accuracy of the thermal behaviour and the energy performance of the system.

Experience from innovations in the past has shown that it is helpful for the increased implementation of new technologies (to which the double skin façades still can be counted) to be assessable within the national energy performance assessment methods. An assessment method for the very early planning stage contributes to the reliability and therefore also the trust of the architects and clients into the technology.

The work in the BESTFACADE project foresaw the development of a method similar to the standardised approach for the wintergardens, trombe walls and the ventilated building envelope parts of the ISO 13790, annex F, which is a monthly balanced calculation procedure. It had to be evaluated based on sensitivity studies performed in earlier projects of the consortium partners. The calculation procedure had to harmonise with the currently developed CEN standards for the implementation of the EPBD. The results of the developed methods had to be compared to results from simulations.

The method shall then be applied in an energy design guide, an interactive usable internet tool for giving impressions on the influence of different façade types on the energy performance the zone behind the façade.



# 6.1 Analysis of existing approaches

The work started with the analysis of standards<sup>16</sup> or guidelines that are covering certain approaches which may allow to be extended for calculating the energy performance of buildings with DSF systems. The analysis gave the following strengths and weaknesses for the choice of an appropriate standard for the BESTFACADE approach.

- EN/ISO 13790: no DSF approach foreseen so far, but as shown in the German DIN V 18599 the wintergarden approach in Annex F can be sufficient applied to DSF systems. A DSF extension is strongly recommended for this standard.
- ISO/FDIS 13789: this standard is not applicable to energy performance calculation as solar radiation is not considered in the calculation.
- DIN V 18599: the national German application of EN/ISO 13790 with an useful extension for DSF. The approach is recommended to be transferred as general method for DSF to EN/ISO 13790 (DIN Standard Committee, 2007).
- Platzer guideline: Comparable to the DIN V 18599 DSF approach but some physical weaknesses in the calculation of the solar gains through the outer façade. No added value compared to the DIN V 18599 approach. Therefore not recommended.
- WIS approach (EU project WIS): only steady state conditions are foreseen for the calculation, no whole year approach with dynamic characteristics of façade systems. More a tool for calculating product characteristics. Therefore not applicable.
- EN 13830: this standard contains only definitions, no calculation procedures.
- EN 13947: this standard covers only procedures for calculating thermal characteristics; no solar, no energy. Therefore not applicable.
- ISO 15099: this standard covers calculation procedures for thermal, solar and optical characteristics for façade elements, but neither energy nor coupling with building behaviour is foreseen. Therefore not applicable.
- ISO 18292: façade rating system on the base of the EN/ISO 13790 philosophy, but only for façade related parameters of the energy balance. DSF applications can be used in the same way as in EN/ISO 13790.

The analysis made evident, that the BESTFACADE approach should be applied in EN/ISO 13790 in the way as done in DIN V 18599, but extended to all kinds of DSF systems. The façade system is regarded similar to the winter garden model (see Figure 6-1). The influence factors have to be updated by the further work in the BESTFACADE project.







Figure 6-1 Wintergarden model out of EN/ISO 13790 and DIN V 18599

# 6.2 Analysis of existing measurements

The chosen German standard generally uses a constant air change rate of 10 h<sup>-1</sup> for naturally ventilated double skin façades throughout the year in order to be on the safe side for both heating and cooling issues. The next step was to analyse existing measurements and adapt the ventilation rate to different façade types, temperature, etc.

The project partners could provide the following in detail measurements of double skin façade buildings:

- BiSoP Building in Baden, Austria
- VERU test facility in Holzkirchen, Germany
- Postcheque building, Vliet test building, Aula Magna building in Belgium

An example of the analysed data is given in Figure 6-2 for the VERU test facility (see Figure 6-3). Figure 6-4 presents the comparison of the net energy demand for heating, cooling and lighting between the measurement, the calculation with the DIN V 18599 approach with an air change rate of  $10 \text{ h}^{-1}$  and with the measured monthly average air change in the façade gap. The graphic shows that by using correct air change rates, the calculation with the German standard gives results very close to the measurements.



Figure 6-2: Measured monthly average data of the excess temperature and the air change rate in the façade gap at the test facility VERU.





Figure 6-3: Test facility VERU in Holzkirchen, Germany.



Net energy: Measured vs. Calculated for VERU

Figure 6-4: Comparison of the measured and calculated net energy demand according to DIN V 18599 with a standard ventilation rate and with monthly adapted ventilation rates



# 6.3 Default ventilation rates

The developed default values for ventilation rates in winter and summer for open and closed gaps are presented in Table 6-1 and 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 project group has also prepared default values for the excess temperatures in the double skin façades which are included in the BESTFACADE WP4 report (Erhorn, 2007)<sup>17</sup>.

Eacade control strategy	(Default) air change rate [h <sup>-1</sup> ]					
	Summer (April–Oct.)	Winter (NovMarch)				
Open at all times	25	25				
Adjustable flaps	25	4				

Table 6-1: Default air change rates for naturally ventilated façades.

Additionally there was a more detailed approximation of the ventilation heat transfer coefficient developed, which is dependent from various construction parameters like inlet and outlet characteristics and obstacles in the cavity (Hellström, B., 2007)<sup>18</sup>.

The simple method was validated by using simulation tools such as Energy Plus, Parasol and WIS.

# 6.4 APPLICATION OF THE METHOD IN AN INTERNET-BASED INFORMATION TOOL

The simple calculation method developed in the project is the basis for the BESTFACADE tool<sup>19</sup> for the energy need and lighting autonomy in office rooms with different façade types. The simple to use tool is not thought for in detail calculative assessment 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.

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 as presented in figure 7. 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.

#### "Best Practice for Double Skin Facades"





Figure 6-5: Screenshot of the start page of the BESTFACADE information tool.



Figure 6-6: Screenshot of the BESTFACADE tool part definition of façades, lighting and HVAC 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.

The results 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 CO2 emissions. The lighting results are further elaborated by giving the daylight autonomy at each point of the room plus the average daylight autonomy of the office.

BestFacade Best Practice for Double Skin Facades					itelligent	Energy 💽	Europe
About							
Outdoor and Indoor Conditions							?
Orientation and Obstruction							?
Façade Characteristics							? .
Artificial Lighting System							?
HVAC System							?
Primary Energy and CO2 Factors							?
Default Values	Brimany opprøyfact	ore		C02 C0	moreion Ea	stor	
Germany	FlectricalEnergy Lt	ui 5.		Electric	alEnerov (kr	1606.	
	Disctrict heating [-]:			Disctric	t heating [k	g/kWh]:	
	Disctrict cooling [-]:			Disctric	t cooling (k	y/KWh]:	
Results							2
Energy and CO2							
Energy [kWh/m²a]	Energy (KWh/m²a	Heating	Cooling	Lighting	Ventilation	Appliances	Total
	Net energy	104,0	6,8	16,4	3,8	13,8	142,8
	Final energy	130,0	0,0	15,4	3,8	13,8	169,6
	Primary energy	169,0	4,0	41,6	10,3	37,1	262,0
	CO2 [kg/m²a]	39,0	1,4	9,9	2,4	8,8	61,5
CO2 [kg/m²a]							
- Lighting	Dardight auton	00015			hinrago das	dialat autonor	
	Dayiigin auton	> 89.7 %			Avei aye uay	ngnt autonoi	83,3 %
		> 78,5 %					
		> 68,3 %					
		> 58,0 %					
and a second	* 0.0j	; 58,0 %]					
a sur f	Minimum:	52,9 %					
N Å	Maximum:	93.8 %					
A	Value at mouse Position:	0,0 %					

Figure 6-7: Screenshot of the BESTFACADE tool part definition of the primary energy and CO<sub>2</sub> factors and results for energy, CO<sub>2</sub> and daylight autonomy.

# 7. BEST PRACTICE GUIDELINES- WP 5 (BY ULUND)

The best practice guidelines aim at offering, information supporting in 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 façades is provided.



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

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

# 7.1 Fundamentals

#### 7.1.1 Architecture

No other building material has during the last two decades experienced such an innovative increase 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 façade 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 façades.

#### 7.1.2 Technology

A ventilated double skin façade can be defined as a traditional single façade doubled inside or outside by a second, essentially glazed façade. 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
- Façade partitioned per storey with juxtaposed modules, where the air cavity is delimited horizontally and vertically
- Façade partitioned per storey corridor type, where the air cavity deep enough to 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 façades 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 façade. In case of a façade 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 skin. In case of a façade ventilated with indoor air, the insulating pane is usually placed as the outer skin, 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 façade system.* 

The high daylight access for a building with a highly glazed single or double skin façade, 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 façade 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 façade 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 façade, 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 façade 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.

# 7.2 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 façades 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 façade based on analysis of the entire building, to avoid sub optimisation
- performance checks should be carried out during construction and when the buildings including the double skin façade is finished, in order to check that the performance specifications are fulfilled.

# 7.2.1 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 daylight 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 façade, it is crucial to have an intelligent control system for the double skin façade and the installations of the building, and a usable and user friendly building energy management system (BEMS).

#### 7.2.2 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 façades require special attention, as the risk for poor thermal and visual comfort is high.
- U- (thermal transmittance), g- (the total solar energy transmittance) and τ<sub>V</sub>- (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 façade. 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.

#### 7.2.3 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 façade. 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, such as wind protection with open windows, fire protection, aesthetics, solar preheating of ventilation air, sound protection, night nocturnal cooling and a site for incorporation of PV cells.

# 7.3 Energy and indoor climate tools

The modelling of ventilated double skin façades 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 of 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.

#### 8. SUMMARY

#### 8.1 State of the Art

The project BESTFACADE accumulated the state of the art of double skin façades in seven European countries (Austria, Belgium, France, Germany, Greece, Portugal and Sweden). 28 façades of different buildings in all partner countries of BESTFACADE have been analysed. Most of the buildings are office buildings followed by schools and service buildings. Nearly all of the buildings have mechanical ventilation systems and both heating and cooling are performed mostly by air heating/cooling systems. The types of façades are mainly multi-storey and corridor types, 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.

The cost of DSF are about 20 – 80 % higher compared to single glazed façades and about 100 to 150 % higher compared to opaque façades with windows. Therefore there have to be more work done to develop better technical solutions on integrated systems regarding thermal solutions in buildings with DSF, or to cut down the operating cost of DSF to make them more attractive compared to conventional façades.

#### 8.2 Cut back of non-technological barriers

The analysis on the non-technological barriers to DSF regarding the legislation issues shows that all existing legislations applicable to conventional façades are also applied to double skin façades, since there is no awareness of any specific legislation on DSF in the participating countries. Legislation on fire protection may be a threat to DSF since the fire transfer between the rooms and levels has to be reduced. Additionally sound legislation can be a threat when considering sound transfer between adjacent spaces through the DSF cavity. On the other hand, sound legislation can also be an opportunity to DSF as this type of façade provides better sound insulation than single skin systems. Legislation on lighting issues could pose a threat to DSF since the inner layer of glazing in conjunction with the internal blinds can lower significantly the daylight factors in the occupied spaces; however a

proper design can result in adequate visual comfort; and then the legislation is considered as an opportunity to the use of DSF.

All countries have legislation on thermal insulation and achieved U-values; this is considered from most countries as an opportunity for double skin façades since the U-value is usually lower than for other glazed façade types. However, maximum indoor temperatures could pose a threat to DSF if limits of indoor temperature are to be observed.

The EPBD implementation could be an opportunity if the designed DSF is performing well but it could be a threat if the system is badly designed and cannot meet the thermal and energy requirements. In the case of ventilation requirements, these exist in all countries but do not pose any threat to the application of DSF.

The analysis showed that in all countries there are built examples; however there is no documentation of their energy and environmental performance. In terms of the level of knowledge concerning the typology, performance, design and construction of DSF, educational /research institutions and big constructions companies usually working at an international level have good knowledge of the DSF systems. On the other hand, low level of knowledge is noted in the group of architects, building owners and investors. In the case of the advantages and disadvantages of the double skin façades compared to the conventional systems, it seems that the knowledge is low in all target groups apart from several educational/research institutions that are working in relevant projects.

Climatic conditions do not seem to pose any obstacle in the application of DSF. Also, full transparency do not seem to pose any threat to the application of DSF

Although DSF can be applied in all type of buildings, until now they have been used mainly in office buildings because of their increased construction and capital cost. Also, the occupant control for ventilation may be a threat to DSF if their design does not allow user control.

Regarding the reputation of DSF in all countries, it seems there is skepticism in the scientific field concerning the energy efficiency, the indoor air quality and thermal comfort levels that this type of façade can provide. The reputation is good in the building industry that tries 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 aesthetics reasons. Finally the analysis showed the lack of regional support, support from the government and the lack of a planning policy regarding DSF.

In summary many 'non-technological barriers' prevent the application and development of DSF systems in the EU market mainly because of the lack of legal standardized schemes, the lack of knowledge on the system and the lack of financial support from the government and regional institutions. Although the benefits that DSF could provide in the energy and environmental performance of buildings via an appropriate design, it seems that their use is offset by the use of conventional façade systems.



"Best Practice for Double Skin Facades"

DSF/ASPECTS	THREAT /WEAKNESS/PROBLEM/NOT APPROPIATE	OPPORTUNITY/STRENGTH/NOT A PROBLEM/APPROPIATE			
	fire protection				
Legislation on	sound	sound			
	energy issues	energy issues			
	lighting	lighting			
		U-Values			
	thermal comfort (if overheating is				
	experienced)				
Requirements	on thermal & energy modeling of buildings				
	on thermal & energy modeling of				
	DSF if comfort requirements cannot be met				
Knowledge	low level of knowledge of				
	advantages/disadvantages				
	compared to conventional glazed				
	systems in all target groups				
	low level of knowledge typology- design-construction among architects and building owners	high level of knowledge typology- design-construction among research institutions and big construction companies			
	no available-published data of the				
	built examples (performance,				
	energy)				
Sociological aspects	full transparency	full transparency			
	occupant control for ventilation				
		climatic conditions			
	type of building (mainly for office buildings)				
	reputation - scepticism in the	good reputation in the building			
	scientific field	industry			
Financial	high investment costs				
aspects	high cleaning costs				
Institutional	no support from Government				
aspects	not available funding				

Table 1: Table summarizing the non-technological barriers to DSF based on the 'SWOT' principle

In order to overcome the non-technological barriers to DSF a policy with a pre-assessment and postassessment stage is suggested to cover all issues defined in the first part of the analysis.

In the pre-assessment stage the policy aims at providing the different target groups with all necessary information on DSF to be able to define and check the performance of the system. The pre-assessment policy aims at introducing homogenous legal schemes concerning DSF in all countries based on the EN standards. It is suggested that all countries would comply with the EN standards (EN 13830 'Product Standard - Curtain Walling) and fit these to their market needs. It is also important to have a holistic approach for the calculation of the energy and environmental performance of DSF. 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 that is developed within work package 4 of the 'BESTFACADE' project could be used by all European countries for the thermal and visual assessment of DSF at the design stage.



Dissemination of DSF can be performed in various ways, through seminars on national level, workshops, training at university level, and the use of complementary methods like internet and publication of best practice examples in journals. Also, a best practice guideline with illustrations of DSF built examples is prepared within work package 5 of the 'BESTFACADE' project.

The post-assessment policy includes all actions that have to be taken into consideration after the DSF dissemination in order to support the product in the market. An appropriate marketing from the involved associations is essential as the support of the DSF is dependent on the company level policy. Companies could play a driving force to this on EU level in collaboration with the national markets by creating a functioning market environment for DSF. Additionally, the establishment of a board/institution of façade engineering on EU and national level could define specific standards for DSF and be the link between the designers and the construction industry.

The documentation of DSF best practice examples including real data of their energy and environmental performance along with operational and investment costs is important to increase reliability of the product and awareness among the target group. The main competitor to the DSF is the conventional glazed systems due to their reduced investment and construction costs. It should be noted that the driving force for the application of DSF should not be the cost but the advantages of the technology and the system selected. However, because of the high initial construction cost of the DSF and integrated shading systems, the DSF buildings could be assessed as cost-effective through the life-cycle cost method, assessing the total building cost over time. Finally, public support and support from the government is always important in developing the DSF market; funding also is an essential motive for research and construction.

#### 8.3 Benchmarks and Certification

Benchmarks developed in WP3 allows the users and operators to compare their energy consumption levels with others in the same group, set future targets and identify measures to reduce energy consumption. A façade energy certification method has been proposed.

#### 8.4 Simple calculation method

Presently the assessment of the thermal behavior and the energy efficiency of naturally ventilated double skin façades (DSF) is only possible by using complex simulation tools, which allow interconnections between fluid dynamics, energy balances and optical transport mechanisms. The performance assessment of mechanically ventilated DSF is slightly easier but still requires simulation tools. Because of the interaction of separate calculation results, extensive iterations are often necessary. This makes it impossible to have reliable predictions on energy efficiency and impacts on comfort in the early planning phase and to sizable uncertainties at designers and investors.

Therefore an assessment method was developed in the IEE project BESTFACADE, which on the one hand can be integrated in the assessment methods of the EPBD and on the other hand offers sufficient accuracy of the thermal behavior and the energy performance of the system. Similar to the

standardized approach for the winter gardens, trombe walls and the ventilated building envelope parts of the ISO 13790, annex F, a monthly balanced calculation procedure was developed and evaluated based on sensitivity studies performed in earlier projects of the consortium partners. This calculation procedure harmonizes with the currently developed CEN-Standards for the implementation of the EPBD. The main work consisted of the approximation of the airflow in the façade interspace and the adaptation of the utilization factor of the solar gains to the different façade systems.

All results are described in detail in the BESTFACADE WP4 report (Erhorn, H., 2007) and are available on the project website.

#### 8.5 Best Practice Guideline

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

If the design 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 investment cost for double skin façades are often much higher than for single skin façades. 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 façade.

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 façade and building are necessary. These simulations have to be carried out using a validated tool.

# A. **Appendices**

# 8.6 Table 3: List of contact persons

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