Double Skin Façades for Office Buildings

Literature Review

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Division of Energy and Building Design
Department of Construction and Architecture
Lund Institute of Technology
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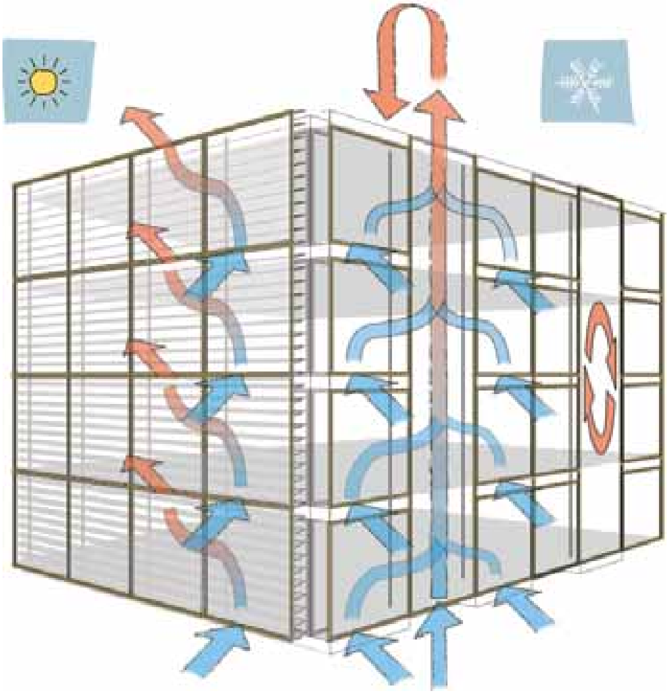

Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 101 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 5 530 employees and 34 000 students attending 60 degree programmes and 850 subject courses offered by 89 departments.

Department of Construction and Architecture

The Department of Construction & Architecture is part of Lund Institute of Technology, the technical faculty of Lund University. The main mission of the Department of Construction & Architecture is to pursue research and education on topics related to the built environment. Some of the topics of interest are: restoration and maintenance of buildings, construction management, design processes, construction, energy efficiency, climatization and design of ventilation and heating systems, demolition, disposal and re-use of building materials.

These topics are treated from both a Swedish and an international perspective and collaboration between actors from mutidisciplinary fields of competence forms a particularly important aspect of research and education at the Department. The Department is divided into 6 sub-departments or divisions: Architectural Conservation & Restoration, Building Services, Computer Aided Architectural Design, Construction Management, Energy & Building Design, and Housing Development & Management.

Division of Energy and Building Design

Reducing environmental effects of construction and facility management is a central aim of society. Minimising the energy use is an important aspect of this aim. The recently established division of Energy and Building Design belongs to the department of Construction and Architecture at the Lund Institute of Technology in Sweden. The division has a focus on research in the fields of energy use, passive and active solar design, daylight utilisation and shading of buildings. Effects and requirements of occupants on thermal and visual comfort are an essential part of this work. Energy and Building Design also develops guidelines and methods for the planning process.

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Key words

Double Skin Facade, Active Facade, Passive Facade, Double Envelope, Double Skin Curtain Wall, Supply Air Window, Ventilated Facade, Multiple-Skin Facade, Office Building.

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Abstract

The aim of this report is to describe the concept of Double Skin Façades based on different sources of literature. Although the concept is not new, there is a growing tendency from the architects to put it into practice. Its complexity and adaptability to different climatic conditions increase the need for careful design. Since the construction types can differ from one location to another, it is obvious that the comparison of different literature sources is not always relevant.

Since the concept of Double Skin Facades is complicated and its use and function affects different parameters of the building, the literature studied is from different fields. It is clear that the design of the system is crucial for the performance of the building. It is the opinion of the author that the Double Skin Facades can provide both improved indoor climate and reduced use of energy in the same time if designed properly. If the approach is overall and the goals to be achieved are clear, then the mentioned system is flexible enough to meet climatic changes for most types of building use.

The classification of the Double Skin Facades is important since the initial approach can influence the design stage. After selecting the type of Double Façade appropriate for the building, it is necessary to define the design and the technical parameters (such as the materials used) that can influence the function and the performance of the system and the physical properties of the cavity. The accuracy of calculations of the façade performance in the design stage will lead to more precise predictions. It is clear that by prioritizing the main goals of the double façade system in different ways, the building design and construction can differ adapting to the performance requirements of the designers, and the needs of the users. The advantages and disadvantages of double skin façades found in different literature sources are mentioned and described. Furthermore, examples of office buildings with Double Skin Façades are presented. Finally a discussion and conclusions section follows in which the point of view of the author is given and comments are made. Fields of further research an development needed are presented.

Contents

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1 Introduction

The main purpose of the present literature review is to give an overview of work done and ongoing research related to Glazed Office Buildings with Double Skin Facades. Thus, it will serve as a basis for a PhD study within the framework of a research project "Glazed Office Buildings" at the Division of Energy and Building Design, Lund University. At this point, it is important to clarify the difference between a "Literature Review" and a "State of the Art" report.

- In the literature review (present) report the main purpose is to inform the reader about the main sources and results of research done in the field of interest and the possible field that can be developed in the future. Often it is more important to describe the work done and to categorize different approaches for every aspect than to give our point of view. Thus, comments were made only when necessary and in some parts, the opinions of the authors were used exactly as they were initially written. In this way, the reader may have the opportunity to develop his own view of the aspects mentioned. On the other hand, it is unavoidable to describe all the individual parts that were considered and constitute the basic structure of the report, without showing the author's point of view. In the discussion and conclusions chapter the main approach of the author is described and comments are given concerning fields of further research and development of the Double Skin Façade System.

- Generally, in a state of the art report, the purpose is to establish the current level of knowledge and technology, phase/stage of development based on literature, interviews, study tours, etc. The first step in order to meet the main goal is to make clear the approach and to define the framework of interest. In this case, the existing literature is used as necessary background knowledge in order to develop our own point of view. Thus, it is more important to show how the work done is considered comparing and scrutinizing the point of view of different authors. An introductive report to the project “Glazed Office Building” will follow in the spring of 2004.

The present literature review report is divided in the main parts:

- Introduction
- Classification of Double Skin Facades
- Technical Description of the Double Skin Façade System
- Building Physics of the Double Skin Façade Cavity
- Advantages and Disadvantages of Double Skin Facades
- Measurements – Test Rooms and Real Buildings
- Cost and Investments
- Examples of Office Buildings with Double Skin Facades
- Important Literature Sources
- Discussion and Conclusions

1.1 Double Skin Facades - General

The Double Skin Façade is a European architectural trend driven mostly by:

- the aesthetic desire for an all glass façade that leads to increased transparency
- the practical need for improved indoor environment
- the need for improving the acoustics in buildings located in noise polluted areas
- the reduction of energy use during the occupation stage of a building

Although that the concept of Double Skin Facades is not new, there is a growing tendency by architects and engineers to use them. Since the function of this façade type is not yet completely investigated, in the existing literature, one can find reports that prioritise the main goals of this system in different ways.

Previous research has been made focusing mostly in the following areas:

- Architecture:
    - ¤ Architecture of the façade in general
    - ¤ Fully glazed façades
    - ¤ Office floor plan layout – better utilization of perimeter area.
    - ¤ Improvement of the environmental profile of the building

- Indoor climate
  - Thermal comfort
    - Possibility to use solar control all year
    - Avoidance of overheating the offices
    - Acceptable internal surface temperatures during the winter and summer
  - Visual comfort
    - Possibility to use solar control all-the-year-round
    - Improved visual comfort (such as avoiding glare)
  - Acoustic comfort
    - Improved acoustical performance of the envelope
  - Ventilation
    - Use of natural instead of mechanical ventilation when possible, using the Double Skin Façade cavity

- Energy Use
  - Reduction of heating demand during winter
  - Reduction of cooling demand during summer
  - Reduction of peak heating/cooling loads
  - Use of natural daylight instead of artificial as much as possible

- Other
  - Construction costs
  - Fire regulations
  - Maintenance of the façade

Since the concept of Double Skin Facades is complicated and its use and function affects different parameters of the building (that often may interact with each other, i.e. daylight, natural ventilation, indoor air quality, acoustics, thermal and visual comfort, energy use, environmental profile, etc) the literature studied is from different fields. It is also important to mention that in this first step it was considered important to present the function and the impacts of the mentioned system from different point of views.

1.2 Keywords

The gathering of data concerning the Double Skin Façade systems revealed that according to both texts and web sites, these types of systems are named in different ways. These include:

- Double-Skin Façade
- Active Façade (usually when the air cavity ventilation is mechanical)
- Passive Façade (usually when the air cavity ventilation is natural)
- Double Façade
- Double Envelope (Façade)
- Dual-Layered Glass Façade
- Dynamic Façade
- Wall-Filter Façade
- Environmental Second Skin System
- Energy Saving Façade
- Ventilated Façade
- Double-Leaf Façade
- Energy Saving Façade
- Environmental Façade
- Multiple-Skin Façades
- Intelligent Glass Façade
- Second Skin Façade/System
- Airflow Window
- Supply Air Window
- Exhaust Window/Façade
- Double Skin Curtain Wall
- Twin Skin Facade

1.3 Definition of Double Skin Façade System

In this part, different definitions were given in order introduce some of the most important authors and to describe briefly how they defined the Double Skin Façade System.

According to the Source book of the Belgian Building Research Institute [BBRI], (2002), "*An active façade is a façade covering one or several storeys constructed with multiple glazed skins. The skins can be air tighten or not. In this kind of façade, the air cavity situated between the skins is naturally or mechanically ventilated. The air cavity ventilation strategy may vary with the time. Devices and systems are generally integrated in order to improve the indoor climate with active or passive techniques. Most of the time such systems are managed in semi automatic way via control systems.*"

Harrison and Boake, (2003) in the Tectonics of the Environmental Skin, described the Double Skin Facade system as *"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".*

Arons, (2001) defines the Double Skin Façade as *"a façade that consists of two distinct planar elements that allows interior or exterior air to move through the system. This is sometimes referred to as a twin skin."*

Uuttu, (2001) describes the Double Skin Facade as "*a pair of glass skins separated by an air corridor (also called cavity or intermediate space) ranging in width from 20 cm to several meters. The glass skins may stretch over an entire structure or a portion of it. The main layer of glass, usually insulating, serves as part of a conventional structural wall or a curtain wall, while the additional layer, usually single glazing, is placed either in front of or behind the main glazing. The layers make the air space between them work to the building's advantage primarily as insulation against temperature extremes and sound.*"

Saelens, (2002) defines the multiple – skin facade as "*an envelope construction, which consists of two transparent surfaces separated by a cavity, which is used as an air channel. This definition includes three main elements: (1) the envelope construction, (2) the transparency of the bounding surfaces and (3) the cavity airflow.*"

According to Claessens and DeHerde "*a second skin façade is an additional building envelope installed over the existing façade. This additional façade is mainly transparent. The new space between the second skin and the original façade is a buffer zone that serves to insulate the building. This buffer space may also be heated by solar radiation, depending on the orientation of the façade. For south oriented systems, this solar heated air is used for heating purposes in the winter time. It must be vented in order to prevent overheating in other periods.*"

Compagno, (2002) describes the Double Skin Façade as *"an arrangement with a glass skin in front of the actual building façade. Solar control devices are placed in the cavity between these two skins, which protects them from the influences of the weather and air pollution a factor of particular importance in high rise buildings or ones situated in the vincity of busy roads."*

1.4 The Double Skin Façade Concept

In this part the Double Skin Façade concept is described more detailed providing additional general information concerning the structure, the function and the use of the mentioned system.

The BBRI, (2002) includes in the Source book a satisfactory description of the structure of a Double Skin Façade System. The layers of the façade are described below:

- Exterior Glazing: Usually it is a hardened single glazing. This exterior façade can be fully glazed.
- Interior glazing: Insulating double glazing unit (clear, low E coating, solar control glazing, etc can be used). Almost always this layer is not completely glazed.
- The air cavity between the two panes. It can be totally natural, fan supported or mechanically ventilated. The width of the cavity can vary as a function of the applied concept between 200 mm to more than 2m. This width influence the way that the façade is maintained.
- The interior window can be opened by the user. This may allow natural ventilation of the offices.
- Automatically controlled solar shading is integrated inside the air cavity.
- As a function of the façade concept and of the glazing type, heating radiators can be installed next to the façade.

Kragh, (2000) describes the Double Skin Façade as "*a system that consists of an external screen, a ventilated cavity and an internal screen. Solar shading is positioned in the ventilated cavity. The external and internal screens can be single glass or double glazed units, the depth of the cavity and the type of ventilation depend on environmental conditions, the desired envelope performance and the overall design of the building including environmental systems*".

Saelens, (2002) explains in his PhD thesis the concept of the Double Skin Façade. According to him, "*a multiple-skin facade is an envelope construction, which consists of two transparent surfaces separated by a cavity, which is used as an air channel*". The three main elements which are included in this definition are described below:

- The envelope construction, (atria, ventilated greenhouses and glazed corridors are excluded)
- The transparency of the bounding surfaces (cavity walls and Trombe walls are excluded) and

- The cavity airflow (double window constructions and airtight transparent constructions are excluded) It should be noted that in certain adaptable solutions the cavity may be closed to avoid ventilation.

The exterior cavity surface is made up by a cladding system. Usually, it is fully glazed (single glazing). The interior surface of a naturally ventilated facade is composed of an opaque wall and an operable window. Fully glazed interior surfaces are popular as well.

As Saelens mentioned in the definition, "*multiple-skin facades are characterized by a ventilated cavity. This intermediate space is an excellent zone to locate devices sheltered from weathering and soiling. Usually, the shading device is positioned in the cavity. Sometimes it is suggested to install day lighting equipment in the cavity as well.*"

Uuttu, (2001) describes the Double Skin Façade concept as *"a pair of glass skins separated by an air corridor ranging in width from 20 cm to several meters"* According to the author *"the cavity is connected with the outside air so that the windows of the interior façade can be opened, even in the case of tall buildings subject to wind pressures; this enables natural ventilation and night time cooling of the building's thermal mass. In winter the cavity forms a thermal buffer zone which reduces heat losses and enables passive thermal gain from solar radiation. All types of double-skin façades offer a protected place within the air gap to mount shading and daylight-enhancing devices such as venetian blinds and louvers. Sheltered from wind, rain and snow, these shading devices are less expensive than systems mounted on the exterior.*

When solar radiation is high, the façade cavity has to be well ventilated, to prevent overheating. The key criteria here are the width of the cavity and the size of the ventilation openings in the outer skin. The air change between the environment and the cavity is dependent on the wind pressure conditions on the building's skin, the stack effect and the discharge coefficient of the openings. These vents can either be left open all the time (passive systems), or opened by hand or by machine (active system). Active systems are very complicated and therefore expensive in terms of construction and maintenance. Further criteria in designing a double-skin façade are regulations concerning fire and noise protection. Using these factors as a basis, various solutions have been developed for double-skin façades."

According to Compagno, (2002), *"the term of Double Skin Façade refers to an arrangement with a glass skin in front of the actual building façade. Solar control devices are placed in the cavity between these two skins, which protects them from the influences of the weather and air pollution, a factor of particular importance in high rise buildings or ones situated in the vicinity of* *busy roads"*. As the author claims, one of the biggest advantages of the Double Skin Façade System is the intermediate placed shading devices combined with ventilation inside the cavity. As the solar radiation is being absorbed by the shading devices the temperature inside the cavity is increased. Due to the stack effect approximately 25% of this heat can be removed by natural air circulation. Apart from that, the Double Skin Façade also reduces heat losses since inside the cavity the air velocity is reduced (compared to the case without intermediate placed blinds) and the temperature is higher. The higher temperatures inside the cavity during heating periods lead to increased temperatures close to the windows, and as a result improved thermal comfort for the occupants.

Lee, Selkowitz, Bazjanac, Inkarojrit and Kohler, (2002) comment on the use of the Double Skin Façade System as follows: *"The foremost benefit cited by design engineers of EU double-skin facades is acoustics. A second layer of glass placed in front of a conventional façade reduces sound levels at particularly loud locations, such as airports or high traffic urban areas. Operable windows behind this all-glass layer compromise this acoustic benefit, particularly if openings in the exterior layer are sufficiently large to enable sufficient natural ventilation"*. The authors mention another benefit of this system. As they claim, *"double-skin facades allow renovation of historical buildings or the renovation of buildings where new zoning ordinances would not allow a new building to replace the old with the same size due to more stringent height or volume restrictions"*.

The authors focus on the heat extraction of the Double Skin Facades. As they describe, *"Heat extraction double-skin facades rely on sun shading located in the intermediate or interstitial space between the exterior glass façade and interior façade to control solar loads. The concept is similar to exterior shading systems in that solar radiation loads are blocked before entering the building, except that heat absorbed by the between-pane shading system is released within the intermediate space, then drawn off through the exterior skin by natural or mechanical ventilative means. Cooling load demands on the mechanical plant are diminished with this strategy.*

This concept is manifested with a single exterior layer of heat-strengthened safety glass or laminated safety glass, with exterior air inlet and outlet openings controlled with manual or automatic throttling flaps. The second interior façade layer consists of fixed or operable, double or single-pane, casement or hopper windows. Within the intermediate space are retractable or fixed Venetian blinds or roller shades, whose operation can be manual or automated. During cooling conditions, the Venetian blinds (or roller shades) cover the full height of the façade and are tilted to block direct sun. Absorbed solar radiation is either convected within the intermediate space or re-radi-

ated to the interior and exterior. Low-emittance coatings on the interior glass façade reduce radiative heat gains to the interior. If operable, the interior windows are closed. Convection within the intermediate cavity occurs either through thermal buoyancy or is wind driven. In some cases, mechanical ventilation is used to extract heat".

Hendriksen, Sørensen, Svensson and Aaqvist support that "*the transparency is often seen as the main architectural reason for a double skin facade, because it creates close contact to the surroundings. This in fact is also derived from a client's point of view saying that physical transparency of a company gives a signal of a transparent organization with a large degree of openness.*

Double skin facades affect a lot of aspects of indoor climate and to some extend energy consumption. Transparency, view to the outside and daylight levels are increased when double skin facades are used compared to the use of traditional window facades. An increased glazing area will also lead to increased glare problems and this is crucial for open plan offices, where disability glare might occur in depth of the rooms".

1.5 History of the Double Skin Façade

The history of Double Skin Facades 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 facades they started gaining momentum. Most of these facades 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 facades. 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."

Historical reviews Double Skin Facades are also made by Uuttu (2001), Wigginton & Battle McCarthy (2001) and Kragh, (2000).

2 Classification of Double Skin Façades

Different ways to classify Double Skin Façade Systems are mentioned in the literature. The systems can be categorized by the type of construction, the origin, destination and type of the air flow in the cavity, etc.

The Environmental Engineering firm of Battle McCarthy in Great Britain created a categorization of five primary types (plus sub-classifications) based on commonalities of façade configuration and the manner of operation. These are:

- Category A: Sealed Inner Skin: subdivided into mechanically ventilated cavity with controlled flue intake versus a ventilated and serviced thermal flue.
- Category B: Openable Inner and Outer Skins: subdivided into single story cavity height versus full building cavity height.
- Category C: Openable Inner Skin with mechanically ventilated cavity with controlled flue intake
- Category D: Sealed Cavity, either zoned floor by floor or with a full height cavity.
- Category E: Acoustic Barrier with either a massive exterior envelope or a lightweight exterior envelope.

Oesterle et al., (2001) categorize the Double Skin Facades mostly by considering the type (geometry) of the cavity. Very similar is the approach of Saelens (2002) and E. Lee et al. (2002) in "*High Performance Commercial Building Facades*". The types are described below:

- Box window type: In this case horizontal and vertical partitioning divide the façade in smaller and independent boxes
- Shaft box type: In this case a set of box window elements are placed in the façade. These elements are connected via vertical shafts situated in the façade. These shafts ensure an increased stack effect.
- Corridor façade: Horizontal partitioning is realized for acoustical, fire security or ventilation reasons.

- Multi storey Double Skin Façade: In this case no horizontal or vertical partitioning exists between the two skins. The air cavity ventilation is realized via large openings near the floor and the roof of the building.

The BBRI, (2002) adds also another type of façade, the Louvers Facades. As it is described, *"with this kind of façade, the exterior skin is composed of motorized transparent rotating louvers. In closed position, these louvers constitute a relatively airtight façade. In open position, they allow an increased ventilation of the air cavity"*.

Uuttu, (2001) classifies the Double Skin Façade systems in a similar way described below:

- Building-high double-skin façade: According to her, *"a building-high double-skin façade, the cavity is not separated at each storey; instead it extends over the whole height of the building. The basic idea of a building-high cavity is the following: air that accumulates at the top of the air space between the two layers is likely to get hot on sunny days. Openings in the outer skin and at the roof edge siphon out the warm air, while cooler replacement air is drawn from near the base of the building."*

- Storey-High Double-Skin Façades: *"The storey high double-skin façades consists of air channels separated horizontally at each intermediate floor."*

- Box Double-Skin Façades: *"Box double-skin façades are stockwise ventilated façades with horizontal partitions on each floor and vertical partition on each window. The inlet and outlet vents are placed at each floor. Hence the lowest degree of air heating and therefore the most effective level of natural ventilation is to be expected."*

  A type of "Diagonal Streaming of Air" ventilation configuration inside this type of cavity is described both by Uttu and the journal "Space Modulator", (1999). *"In box double-skin façades, a special sash called a "fish-mouth" designed to admit and exhaust outside air is often built in between storeys. This "fish mouth" has air inlets and outlets. The outside air from the intake "fish-mouth" is warmed inside the double-skin and diagonally ascends to be exhausted from the outtake "fish mouth" at the neighbouring sash. If both the "fish mouths" are laid out vertically, a large part of the exhausted air would have been reabsorbed. This system also prevents fire from spreading to other levels"*.

- Shaft Façades: *"A shaft façade is a combination of a double skin façade with a building-high cavity and a double-skin façade with a storey-high cavity. The full-height cavity forms a central vertical shaft for exhaust air.*

On both sides of this vertical shaft and connected to it via overflow openings are storey-high cavities. The warmed, exhaust air flows from the storey high cavity into the central vertical shaft. There it rises, due to the stack effect and escapes into the open at the top. The buoyancy in the shaft supports this flow at the level of the lower floors in that as the trapped air is warmed it is drawn upwards".

Arons, (2000) describes two types of facades:

- *Airflow facades: a double façade that is continuous for at least one storey with its inlet at or below the floor level of one storey and its exhaust at or above the floor level above.*
- *Airflow window: a double leaf façade that has an inlet and outlet spaced less than the vertical spacing between floor and ceiling.*

More detailed, the author describes crucial parameters of the design the function and thus the classification of this system separating them to:

- primary identifiers
  - ¤ airflow patterns
  - ¤ building height
- secondary identifiers
  - ¤ layering composition,
  - ¤ depth of the cavity,
  - ¤ horizontal extend of cavity
  - ¤ vertical extend of cavity
  - ¤ operability
  - ¤ materials

Magali, (2001) divides the double skinned façades in two categories: A) Double Skinned Façade on several floors and B) Double skinned façade per floor. As she mentions, *"The difference between the categories (A) and (B) is that there is a horizontal partitioning into the air cavity, at each floor".*

According to the author, each of these categories is divided into subcategories. The distinction has been made between airtight or non-airtight façades *"the tightness of the façade is related with the possibility to open the windows".*

Category A: Double skinned façade on several floors
Sub-classification: A1: the 2 façades are airtight
A2: non-airtight internal façade - airtight external façade
A3: non-airtight external façade - airtight internal façade
A4: non-airtight internal and external façade

Category B: Double skinned façade per floor
Sub-classification: B1: the 2 façades are airtight
B2: non-airtight internal façade - airtight external façade
B3: non-airtight external façade - airtight internal façade
B4: non-airtight internal and external façade

Kragh, (2000) categorizes the Double Skin Facades according to the function (ventilation type) of the cavity in three types:

- Naturally Ventilated Wall: "*An extra skin is added to the outside of the building envelope. In periods with no solar radiation, the extra skin provides additional thermal insulation. In periods with solar irradiation, the skin is naturally ventilated from/to the outside by buoyancy (stack) effects - i.e. the air in the cavity rises when heated by the sun (the solar radiation must be absorbed by blinds in the cavity). Solar heat gains are reduced as the warm air is expelled to the outside. The temperature difference between the outside air and the heated air in the cavity must be significant for the system to work. Thus, this type of façade cannot be recommended for hot climates*".

- Active Wall: "*An extra skin is applied to the inside of the building envelope; inside return air is passing through the cavity of the façade and returning to the ventilation system. In periods with solar radiation the energy, which is absorbed by the blinds, is removed by ventilation. In periods with heating loads, solar energy can be recovered by means of heat exchangers. Both during cold periods with no or little solar irradiation and during periods with solar gains or cooling loads, the surface temperature of the inner glass is kept close to room temperature, leading to increased occupant comfort in the perimeter zone, near the façade. This type of façade is recommended for cold climates, because of the increased comfort during the cold season and the possible recovery of solar energy*".

- Interactive Wall: *"The principle of the interactive is much like that of the naturally ventilated wall with the significant difference that the ventilation is forced. This means that the system works in situations with high ambient temperatures, as it does not depend on the stack effect alone. The system is thus ideal for hot climates with high cooling loads. During cold periods with no solar irradiation (e.g. during night-time) the ventilation can be minimized for increased thermal insulation. Apart from the advantages in terms of solar and thermal performance the system allows the use of operable windows for natural ventilation, even in highrise buildings".*

The BBRI, (2002) suggests a more detailed way to classify the active facades according to the:

- Type of ventilation
  - ¤ Natural
  - ¤ Mechanical
- Origin of the airflow
  - ¤ From inside
  - ¤ From outside
- Destination of the airflow
  - ¤ Towards inside
  - ¤ Towards outside
- Airflow direction
  - ¤ To the top
  - ¤ To the bottom (only in case of mechanical ventilation)
- Width of the air cavity
  - ¤ Narrow (10 - 20 cm)
  - ¤ Wide (0.5 – 1m)
- Partitioning
  - ¤ Horizontal (at the level of each storey)
  - ¤ No horizontal partitioning

In this way, 48 different cases can be considered. Even more cases could be created if the different categories would be refined (for instance cavity width). Although this way of categorizing can be very precise, the increased number of categories can be confusing.

3 Technical Description

3.1 Double Skin Façade Construction

A MSc thesis was written at Helsinki University of Technology in 2001 by Uuttu. Apart from a short historical description and classification of double skin façades, the thesis focuses mostly on the structural systems in double-skin façades. According to the author, "*a complete structure can be broken down into a hierarchy of substructures:*

- *Primary structure: Loadbearing core, all columns, walls, floors and bracing required to carry horizontal and vertical loads.*
- *Secondary structure: Floors, which are not part of the primary system; built-in items, partitions, roof structures and annexes; façade elements.*
- *Tertiary structures: All constructions which are part of the secondary structures and whose stability is not critical to the stability of those secondary structures, e.g. a window within a façade element".*

The main parts that are discussed in this thesis are the secondary and the tertiary structures. More detailed, the secondary structure can be divided into three main types:

- cantilever bracket structure
- suspended structure and
- frame structure.

The author mentiones that *"cantilever bracket structures and suspended structures are most commonly used in Finland".* Comparing case studies of buildings located in Finland and in Germany the author concludes that *"Further double-skin façades constructed in Finland differ greatly from the ones constructed in Germany. In Finland, the cavities in double-skin façades are building-high, while in Germany they are partitioned horizontally at each intermediate floor and vertically on each window. This difference results in the fact, that the double-skin façades in Germany enable natural window ventilation, while in Finland their main purpose is to act as a raincoat for the inner façade".*

Another MSc thesis written in Helsinki University of Technology in 1999 by Kallioniemi, presents information on research, design and codes about joints and fastenings in steel glass facades. According to the author *"the use of glass in facades causes many problems due to the material properties of glass. Glass differs from other building materials in aspect of being an extremely brittle material and breaking without a forewarning. This material property of brittleness has to be taken into account when designing large glass facades. The requirements of designing load-bearing structures are normally gotten from either the glass supplier or the producer of glass pane elements, who both are thereby responsible for the strength and functionality of the fastening.*

The connection types of steel-glass facades are putty glazing (old), glass holder list, pressed fastening, point supported glass panes and structural silicone glazing (SSG). The new invention, point support, is used very little in Finland, although it nowadays can be applied in Finnish climatic conditions. Point supports are mainly constructed of stainless steel. The main requirements of supports are functionality with glass and very small tolerances. The requirement of small tolerances concerns also the load-bearing structures. Point supported glass panes are affected by high stresses in drilling area, restraint loads caused by temperature and in insulation glass panes, especially in Finland, even additional stresses caused by many-sheet-glazing".

3.2 Opening principles

The air velocity and the type of flow inside the cavity depend on:

- The depth of the cavity (both for mechanical and natural ventilation)
- The type of the interior openings (both for mechanical and natural ventilation)
- The type of the exterior openings (for natural ventilation)

3.2.1 Cavity

According to Compagno, (2002) *"the air exchange between the environment and the cavity is depending on the wind pressure conditions on the building's skin, the stack effect and the discharge coefficient of the openings. These vents can either be left open all the time (passive systems), or opened by hand or by machine (active systems). Active systems are very complicated and therefore expensive in terms of construction and maintenance".*

Faist, (1998) compared an airtight façade and a Double Skin Façade that provides natural room ventilation. After this comparison, he concluded the following:

- In an air tight façade:
  - ¤ the depth of the façade is not really critical for the temperatures inside the cavity
  - ¤ the windows are usually closed; opening the window does not guarantee good room ventilation
  - ¤ the canal is open at the bottom and may be closed (by a valve) at the top
  - ¤ the double-skin has virtually no noise-insulating effect (comparing to a convectional wall)
  - ¤ owing to the air temperature rise in the canal (with solar radiation), the canal height is limited to 3 to 4 levels

- In a ventilated façade:
  - ¤ the depth of the façade has to be determined precisely
  - ¤ ventilation of the rooms is obtained by opening appropriate valves (sized floor by floor)
  - ¤ the canal closed at its base, extends above the last floor level.
  - ¤ Noise insulation can be improved when the double-skin screen is installed as the outer layer
  - ¤ the allowed height depends on the canal sizing. An upper limit is nevertheless given by the allowed air temperature rise in the canal (10 to 15 storeys)

Oesterle et al., (2001) presents an extensive description of the function and the air flow of the cavity in relation with constructional parameters. The authors mention that only when the cavity between the façade skins is relatively shallow (less than 40 cm) significant pressure losses are likely to occur. Otherwise, the intermediate space offers no major resistance to the air flow.

3.2.2 Interior façade openings

Oesterle et al., (2001) mention that the effectiveness of the inner façade in terms of its ventilating function will depend on the opening movement of the windows. The authors make a comparison between various casement opening types in the inner façade skin and their relative ventilating effectiveness in relation to the elevational area of the opening light. The following cases of inner openings are described:

Table 3.1 Relative Ventilating Effectiveness in relation to the Elevational Area of Opening Light for different types of inner openings

Type of inner opening	Relative Ventilating Effectiveness in relation to the Elevational Area of Opening Light
Bottom hung tipped casement	Up to 25%
Horizontally sliding casement	Up to 70%
Slide down, top hung casement	Up to 80%
Vertically sliding casement	Up to 90%
Side-hung casement	Up to 100%
Vertically pivoting casement	Up to 100%
Horizontally pivoting casement	Up to 100%

Jager presented in 2003 different design configurations of the air inlet and outlet. He gave results of different opening types of the interior façade and their relative air change efficiency related to the visible area of the opening sash.

3.2.3 Exterior façade openings

Oesterle et al., (2001) claims that in a Double Skin Façade the principles applying to inbuilt elements in air –intake openings, also apply to air extract openings. According to the authors *"vortices may occur along the path of the airstream, with eddies spinning off along the edges and at tight curves. Once these turbulences have formed, they can considerably reduce the effective area of an opening. The cross-section available for the airflow will then be the residual area free of turbulence, the dimensions of which are the only ones that should be used in calculations"*. The authors provide an example and a detailed description of a CFD Simulation.

3.3 Material Choice

3.3.1 General

When choosing the materials used for the construction of the Double Skin Façade, caution should be paid to the pane type and the shading device.

Uuttu, (2001) describes the support structure materials used for the mentioned facades. According to her *"Designers should take care when choosing materials to be used together with glass. This is not simply because of possible incompatibilities in natural properties of the base material, such as coefficient of thermal expansion. It is also because the coatings used with materials may be incompatible or may need maintenance that is difficult to carry out without harming the glass or its coatings in some way"*.

3.3.2 Selection of Glass

In most of the literature, one can read that the most common pane types used for Double Skin Facades are:

- For the internal skin (façade): Usually, it consists of a thermal insulating double or triple pane. The panes are usually toughened or unhardened float glass. The gaps between the panes are filled with air, argon or krypton.
- For the external skin (façade): Usually it is a toughened (tempered) single pane. Sometimes it can be a laminated glass instead.

Lee et al., (2002) claim that the most common exterior layer is a heat-strengthened safety glass or laminated safety glass. The second interior façade layer consists of fixed or operable, double or single-pane, casement or hopper windows. Low-emittance coatings on the interior glass façade reduce radiative heat gains to the interior.

Oesterle et al., (2001) suggest that for higher degree of transparency, flint glass can be used as the exterior layer. Since the number of the layers and the thickness of the panes are greater than in single skin construction, it is really important to maintain a "clear" façade. The main disadvantage in this case is the higher construction costs since the flint glass is more expensive than the normal one.

If specific safety reasons occur (i.e. bending of the glass or regulations requiring protection against falling glass), then the toughened, partially toughened or laminated safety glass can be used.

Similar description of the panes used can be found in the existing literature. However, there is no literature connecting the pane types and the shading devices with the construction type (i.e. box window, corridor façade, etc) and the use of the Double Skin Façade (origin and destination of the air flow, etc).

Poirazis and Rosenfeld, (2003) compared 4 different Double Skin Facade cases where different panes were applied in order to calculate the airflow, the temperatures in different heights of the cavity and other properties. The pane types used are shown below:

Table 3.2 Description of panes applied for different types of Double Skin Facades

Case	1	2	3	4
Outer Pane	8 mm clear float glass	8 mm clear float glass	8 mm clear float glass	6 mm solar control glass
Intermediate Pane	4 mm clear float glass	4 mm clear float glass	6 mm solar control glass	4 mm clear float glass
Inner Pane	4 mm clear float glass	4 mm low-e glass	4 mm clear float glass	4 mm low-e glass

As the authors concluded, the case 1 gives the highest U-Values. The 3rd gives slightly lower U-Values. The case 2 and 4 have approximately the same U-Values, lower than the cases mentioned above. The average increase of the mentioned value compared with the cases 2 and 4 is approximately 39.6% for the 1st and 34,3% for the 3rd case correspondently. Concerning the heat losses, (Q_{loss}) the 1st and 3rd case lead to higher losses than the 2nd and the 4th.

3.3.3 Selection of shading device

According to Oesterle et al., (2001) *"Determining the effective characteristics of the sunshading in each case poses a special problem at the planning stage since the properties can vary considerably, according to the type of glazing and the ventilation of the sunshading system. The sunshading provides either a complete screening of the area behind it or, in the case of the louvers it may be in a so-called "cut-off" position".*

As the authors conclude *"for large-scale projects it is worth investigating the precise characteristics of the combination of glass and sunshading, as well as the proposed ventilation of the intermediate space in relation to the angle of the louvers".*

3.3.4 Construction types common in Nordic Climates

Tenhunen, Lintula, Lehtinen, Lehtovaara, Viljanen, Kesti and Mäkeläinen carried out a research project at the Helsinki University of Technology, during the years 2000-2002. The purpose of the project was to develop design and product development bases for metal-glass double-skin facade systems in order to ensure their satisfactory performance in Nordic climate conditions. The parameters considered for the suggestion of appropriate Double Skin Facades were:

- Architectural
- Lighting
- Building Physics and
- Structural Performance

The project was named "Metal-Glass Structures in Double Facades: Architecture, Lighting, Building Physics and Structural Performance". Five functionally different double-skin alternatives have been found and chosen as a basis for further research. Furthermore, based on building physics, three different types of systems have been detected. Classification is based on the utilization degree of the double facade in the ventilation system. Some temperature and humidity measurements have been done and wide variations in the intermediate space have been shown. After studying integrated double skin facades, three different supporting structure types have been found. Furthermore, many kinds of glass systems have been used. Tolerances between the main frame and the facades are usually the most demanding challenges. According to the authors "*The further research will be based on the above mentioned models and types. The purpose is to produce guidelines for design and development of a high quality technical standard to get a structural system that faultlessly fulfils relevant functional requirements*".

Uuttu, (2001) describes the current structures in double skin façades after studying fourteen double-skin façades in Finland and five in Germany. The research work was carried out by means of site visits and interviews among architects, structural designers, façade designers, contractors and manufacturers.

According to the author, the most common façade types built in Finland are box-window. However both in Denmark and Sweden, most of the façades are multi storey (see building examples, chapter 8).

4 Building Physics of the Double Skin Façade Cavity

4.1 Introduction

The modelling and simulation of the Double Skin Façade Cavity is a complicated task, since different elements interact with each other influencing the function of the cavity. Efforts to model the cavity are focused mostly on:

- Air flow simulations
- Calculation of the temperature at different heights (Thermal Performance)
- Daylight simulations

Different studies and approaches in order to model the cavity are mentioned.

4.2 Air flow

4.2.1 General

Air flow simulations of the Double Skin Façade cavity are necessary if one wants to calculate the temperatures at different heights in the cavity. Additionally, the temperatures can be critical when deciding the:

- Façade design
  - ¤ Type of the Double Skin Façade (box window, corridor, multi-storey façade, etc)
  - ¤ Geometry of the façade (width of the openings, height and width of the cavity, etc)

- Façade glazing

  - ¤ Type of glazing units (single/double glazing for the interior and exterior layers)
  - ¤ Type of panes (clear glass, solar control glass, low E coating, etc)

- Shading devices
  - ¤ Type of shading devices (venetian blinds, louvers, etc)
  - ¤ Positioning of shading devices (external/internal/intermediate)
  - ¤ If placed inside the cavity, exact positioning

- Proper combination of pane type and shading device for each orientation and type of façade.

- HVAC Strategy
  - ¤ Origin and destination of the air inside the cavity
  - ¤ Natural/mechanical/fan supported ventilation
  - ¤ Night cooling/venting

Before describing more detailed each of the air flow simulation methods that different authors have used, it is important to describe briefly the two possible ways of ventilating the Double Skin Façade cavity.

As Shiou Li, (2001) describes, "*The cavity in double skin facades is either naturally or mechanically ventilated. Natural ventilation can provide an environmental friendly atmosphere and reduce the requirement for mechanical ventilation. On the other hand, natural ventilation is not without risk. It may create a door-opening problem due to pressurization. Besides, if the air path is not appropriately designed, the solar heat gain within the façade cavity will not be removed efficiently and will increase the cavity temperature.*

For the naturally ventilated double façade system, the air is brought into the cavity and exhausted by two means: wind pressure and/or the stack effect. Wind pressure typically dominates the airflow rate. If properly designed, wind flowing over the façade can create pressure differences between the inlet and outlet inducing air movement. Without wind, the cavity can still be ventilated due to the stack effect. As air flows into the lower inlet, it is heated and becomes less dense and thermally buoyant. As a result, air will flow into the inlet and out the outlet while removing heat. Because there is the potential for stack-driven and wind-driven pressures to be counteractive, the air path and exterior openings need to be correctly sized and configured to insure the stack effect pressures and wind-driven forces are additive. Otherwise, the preheated airflow in the cavity will tend to radiate to the interior, and opening the inner layer window in summer will introduce a burst of hot air.

In urban environments, natural ventilation systems may also experience significant problems of noise transmission and pollution and may result in uncomfortable indoor environments in extreme weather conditions. Therefore, a natural ventilation system is more suitable in suburban areas with temperate weather where the airflow in the cavity will be close to the indoor air condition.

The mechanically assisted ventilation systems usually use an underfloor or overhead ventilation system to supply or exhaust the cavity air to ensure good distribution of the fresh air. Air is forced into the cavity by mechanical devices. This air rises and removes heat from the cavity and continues upwards to be expelled or re-circulated. Because air is not pumped in directly from the outdoors, there is potentially less risk of condensation and pollution in the cavity (Barreneche, 1995). Also because the mechanically assisted ventilation systems allow the building to be sealed, they provide more protection from traffic noise than naturally ventilated systems. In areas with severe weather conditions or poor air quality, the mechanically assisted ventilation system can keep conditions in the buffer zone nearly constant to reduce the influence of the outdoor air to the indoor environment".

4.2.2 Air flow simulations of the cavity

The approaches for calculating the air flow inside the cavity differ in the existing literature. Djunaedy, Hensen and Loomans, (2002) categorize the main airflow modelling levels of resolution and complexity as described below:

- *Building energy balance (BEB) models that basically rely on airflow guesstimates.*
- *Zonal airflow network (AFN) models that are based on (macroscopic) zone mass balance and inter-zone flow-pressure relationships; typically for a whole building.*
- *CFD that is based on energy, mass and momentum conservation in all (minuscule) cells that make up the flow domain; typically a single building zone.*

Hensen, Bartak and Drkal, (2002) explain that *"although airflow is demonstrably an important aspect of building/plant performance assessment, the sophistication of its treatment in many modelling systems has tended to lag behind the treatment applied to the other important energy flow paths. The principal reason for this would appear to be the inherent computational* *difficulties and the lack of sufficient data. In recent times more emphasis has been placed on airflow simulation mostly focused on the following two approaches:*

A. Computational fluid dynamics (CFD) in which the conservation equations for mass, momentum and thermal energy are solved for all nodes of a two- or three-dimensional grid inside or around the object under investigation. In theory, the CFD approach is applicable to any thermo-fluid phenomenon. However, in practice, and in the building physics domain in particular, there are several problematic issues, of which the amount of necessary computing power, the nature of the flow fields and the assessment of the complex, occupant-dependent boundary conditions are the most problematic. This has often led to CFD applications being restricted to steady-state cases or very short simulation periods.

B. The network method, in which a building and the relevant (HVAC) fluid flow systems are treated as a network of nodes representing rooms, parts of rooms and system components, with inter-nodal connections representing the distributed flow paths associated with cracks, doors, pipes, pumps, ducts, fans and the like. The assumption is made that for each type of connection there exists an unambiguous relationship between the flow through the component and the pressure difference across it. Conservation of mass for the flows into and out of each node leads to a set of simultaneous, non-linear equations, which can be integrated over time to characterize the flow domain.

The network method is of course much faster but will only provide information about bulk flows. CFD on the other hand will provide details about the nature of the flow field. It depends on the problem at hand, which of these aspects is the more important one".

According to Champagne, (2002), "*in the HVAC field, there is a need to validate a proposed design to ensure proper performance. One of two methods is typically used: experimental or numerical. Although experimental values are very reliable when performed in a controlled environment, there are several major drawbacks to this approach. It is expensive and time consuming. Computational Fluid Dynamics (CFD) is a numerical approach that is informative while also saving time and money".*

In some documents experimental measurements are made in order to develop a numerical model for the calculation of the airflow and the temperatures inside the Double Skin Façade cavity. Saelens, (2002) mentions that, *"most researchers provide models to simulate specific multiple-skin facade typologies. Only few models for naturally ventilated multiple-skin facades are available. Most multiple-skin facade models have been developed for mechanically ventilated types. The existing models can be ar-*

ranged in order of complexity. Starting from single node energy balance models over analytical models and network models to very complex and detailed numerical models".

The CFD modelling of passive solar space heating is not an easy matter. Jaroš, Charvát, Švorèík and Gorný, presented a paper in the Sustainable and Solar Energy Conference in 2001, which deals with critical aspects of these problems, touches possibilities and drawbacks of some CFD codes in this area and, on basis of several solved cases, presents outcomes which can be obtained by this method.

According to the authors *"simulation methods are a very useful tool for the optimization of the solar building performance, since they enable to predict performance parameters still in the stage of the design. The CFD simulation has become very popular, because of its capability to model particular details of the temperature fields and airflow patterns. These features are essential just in the case of solar-heated rooms with the intense heat fluxes and natural convection.*

The CFD simulation of the performance of solar air systems can significantly improve their operation parameters and effectiveness. Moreover, new structures or systems can be evaluated still in the stage of their design. However, the applicability of the CFD simulation is still restricted to the relatively simple cases. The simulation of airflow and heat transfer inside the whole building is still difficult due to the computer performance. The capabilities of CFD simulation will grow with the increasing capabilities of hardware and software".

Gan, (2001) presented in an article a numerical method that he developed for the prediction of thermal transmittance of multiple glazing based on Computational Fluid Dynamics. As he describes *"the predicted thermal resistance of glazing agrees with reference data for double glazing unit. The results confirm that the heat transfer coefficient, thermal resistance and thermal transmittance vary with the width of air space between glazing panes up to about 25 mm. As the width of air space increases, the thermal resistance increases while the thermal transmittance decreases. It is shown that both the convective heat transfer coefficient and thermal transmittance increase linearly with the temperature difference between the hot and cold panes of glass. The effect of the temperature difference across an air space on the convective heat transfer coefficient is significant. For moderate climate conditions the effect of the temperature difference on the thermal transmittance may be considered negligible*". According to the author *"one of the advantages of the CFD technique over the analytical method is that it can easily be applied to performance evaluation of novel flow devices such as air flow windows*".

Manz presented in 2003 an article concerning the development numerical simulation model of heat transfer by natural convection in cavities of façade elements. The present study sets out to compare the results obtained by means of a CFD code with empirical correlations in relation to heat transfer by natural convection in rectangular, gas-filled cavities. It mostly focuses on tall, vertical cavities in building elements such as insulating glazing units, double-skin facades, doors, façade integrated solar collectors, transparent insulation panels etc.

More detailed, *"heat transfer by the natural convection of air layers within vertical, rectangular cavities with aspect ratios (A) of 20, 40 and 80 was investigated in relation to applications in building facade elements, such as insulating glazing units, double-skin facades, doors, etc. using a computational fluid dynamics (CFD) code. Boundary conditions were assumed to be isothermal hot and cold wall, and zero heat flux at bottom and top cavity surfaces. Rayleigh numbers were between 1000 and 106, i.e. flow was either laminar or turbulent, and a conduction, transition or boundary layer regime was applied. The study focuses on overall convective heat flow through the air layer. This study improves the starting position for future applications of the code to more complex cases of facade elements, where less or even no experimental data are available in literature".*

Manz and Simmler, (2003) presented at the "Building Physics" recurrent conference (in Belgium) an experimental and numerical study of a mechanically ventilated glass double façade with integrated shading device. In this article the procedure for modeling glass double façades is described. Optical properties are calculated and a transient 2D computational fluid dynamic model is developed. The computing program used for the CFD simulations is FLOVENT. Simulated results are compared with data derived from an experimental investigation of a mechanically ventilated glass double façade built in an outdoor test facility.

The authors concluded that *"A total solar energy transmittance of 7% means that solar energy absorbed in the façade is removed efficiently by mechanical ventilation. In addition, thermal comfort problems due to infrared radiation between people and the inner pane are unlikely because the pane temperature did not rise more than 6 K above mean room air temperature. However, an overall analysis of the façade concept should take into account that the fans used for mechanical ventilation consume electrical energy.*

It would be still possible to decrease total solar energy transmission, e.g. by increasing the outside solar reflectance of the shading screen (here ñ = 0.48). In other words, very low values can be obtained in a carefully designed glass double façade with mechanical ventilation in comparison with the total solar energy transmittance values that are often recommended, e.g. < 15%, as in SIA 180 (1999).

Furthermore, it was found that

- *air flow pattern depends on boundary conditions, in particular absorbed solar radiation,*

and can substantially change over 24 hours

- *air flow pattern can be much more complex than the piston-flows assumed in simple analytical models such as that to be found in ISO/DIS 15099 (2001)*
- *detailed analysis of air flow patterns (e.g. recirculation / counter flow), energy flows and temperature distribution is only possible with CFD*
- *boundary conditions, e.g. external heat transfer coefficient, have to be carefully set because they can have a substantial effect on results*
- *we have to bear in mind that if the shading screen is open or not fully closed, solar energy flow into the room increases substantially (e.g. present case: shading screen closed* $\tau_{sol,tot} = 0.03$*, shading screen open* $\tau_{sol,tot} = 0.28$*)".*

Results from CFD calculations are also available from McCarthy and Wigginton, (2002). The results are mainly illustrative, there are no validations available and wind effects are not taken into account.

Hensen, et al. (2002) give an overview of the methodology of a design study in order to calculate the physics inside the Double Skin Façade Cavity (temperatures, airflow, etc). As the author describes it was decided to use the network approach fully integrated in a building thermal energy model. The model comprises a typical 7.5 m wide section of the south side of the building, consisting of a stack of 8 zones representing the office zones up to a depth of 5 m behind the façade, and another 7 stacked zones representing the double-skin façade itself. These 7 zones are coupled by an airflow network which also includes the inlet opening (modelled by a connection between the bottom cavity zone and outside, i.e. the air temperature and wind pressure in front of the façade) and the outlet opening (a connection between the upper cavity zone and outside, i.e. the air temperature and wind pressure on the roof).

As the authors describe, *"In the current case the thermal side of the problem is very important. Given the extent of the model and the issues involved, this can only be predicted with building energy simulation. Both CFD and the network method can be integrated with building energy simulation. In case of CFD this is still very much in development although enormous progress has been made in recent times. Integration of the network method with building energy simulation is much more mature and more commonly used in practice. The reasons for this are threefold. Firstly, there is a strong relationship* *between the nodal networks that represent the airflow regime and the corresponding networks that represent its thermal counterpart. This means that the information demands of the energy conservation formulations can be directly satisfied. Secondly, the technique can be readily applied to combined multi-zone buildings and multi-component, multi-fluid (e.g. water and air) systems. Finally, the number of nodes involved will be considerably less than that required in a CFD approach and so the additional CPU burden is minimized".*

A two-dimensional numerical model for single storey multiple-skin facades with mechanical as well as natural ventilation was developed by Saelens, (2002) in his PhD thesis. As he describes, *"The model is based on a cell centred control volume method. The cavity layers are only vertically subdivided and the temperature of the cavity control volume is represented by a bulk temperature. It is assumed that enthalpy flows only occur in the vertical direction. This restricts the use of the model to multiple-skin facades with roller blinds.*

To estimate the convective heat transfer coefficient, existing relations obtained from experimental research and numerical simulations are implemented. Distinction is made between natural, forced and mixed convection regimes. In most cases, the flow in one storey high multiple-skin can be regarded as a developing flow. For the naturally ventilated as well as the mechanically ventilated multiple-skin facade heat transfer correlations for flow over a single vertical plate are then suggested. During night time and during situations with low solar radiation, uniform wall temperature expressions are used. For all other situations, uniform heat flux correlations are implemented. A limited experimental evaluation of the correlations is presented. The spread on the results, however, shows that obtaining a reliable expression for the heat transfer coefficient is difficult.

The solar radiation absorbed in the different layers depends on the angle of incidence, takes into account multiple reflections and deals with vertical shadowing. The long-wave radiation is calculated by the net-radiation method".

Arons, (2000) has developed a simplified numerical model of a typical Double Skin Façade. The purpose of the model is to predict the energy performance of multiple types of Double Skin Facades. As the author describes, *"the platform for development has been spreadsheet utilizing iterative calculation methods. The basic configuration for the window under study has a layer of insulating glass on the exterior, an air cavity and a single interior layer of glass. An inlet is assumed at the bottom and an outlet at the top.*

Two-dimensional heat transfer, neglecting edge effects are considered. The system is considered in a steady state condition, with constant temperatures throughout. Conduction and radiation are considered in the horizontal plane (one dimensional) and convection is considered in the vertical direction (also one dimensional)".

4.2.3 Integration of Double Skin Facades–HVAC Strategies of the Building

4.2.3.1 General

The integration of the Double Skin Façade systems in office buildings is crucial for the thermal performance and the energy use during the occupation phase. Stec & Paasen, (2003) presented a paper in which they describe different HVAC strategies for different Double Skin Façade types. According to the authors, *"the designing procedure of the building should include the following tasks:*

- *Defining the functions of the double skin façade in the building. The requirements concerning the airflow, thermal, noise reduction performance should be described as well as control possibilities.*
- *Selecting the type of the double skin façade, its components, materials and dimensions of the façade that fulfill the requirements.*
- *Optimizing the design of the HVAC system to couple it with the double skin façade.*
- *Selecting the control strategy to supervise the whole system".*

The authors introduce briefly the concept of different cavity depths and describe its influence on the air temperatures inside the cavity. According to them, *"Dimensions of the façade together with the openings determine the flow through the façade. The thinner cavity the higher flow resistance and the smaller flow through the cavity. On the other hand the thinner cavity the more intensive convection heat transfer and higher growth of air temperature in the cavity. These lead to the following conclusions:*

1. *In the cold period it is more suitable to use thin cavities to limit the flow and increase the cavity temperature.*
2. *In the hot period the double skin façade should work as a screen for the heat gains from radiation and conduction. It is difficult to claim in general if the thin or deep cavities will perform better because in one case the cavity temperature and in other case temperature of the blinds will be higher".*

Example concerning how different depths influence the properties of the cavity are shown in "Second Skin Façade Simulation with Simulink Code" by Di Maio and van Paassen in (2000).

In "Modeling the Air Infiltrations in the Second Skin Façade" in (2001) the same authors conclude that "*thin cavities are more useful, because they can deliver a higher and hotter air flow compared to the air flow delivered by thick ones*".

4.2.3.2 Contribution of the Double Skin Façades to the HVAC Strategy

As Stec et al., (2003) describe, an HVAC system can be used in the three following ways in a Double Skin Façade office building:

- Full HVAC system (the Double Façade is not a part of the HVAC) which can result in high energy use. On the other hand, the user can select whenever he prefers a controlled mechanically conditions inside or natural ventilation with the use of the Double Skin Façade).
- Limited HVAC system (the Double Façade contributes partly to the HVAC system or is playing the major role in creating the right indoor climate). In this way the Double Façade can play the role of
    - the pre-heater for the ventilation air
    - ventilation duct
    - pre-cooler (mostly for night cooling)
- No HVAC. The Double Facade fulfills all the requirements of an HVAC system. This is the ideal case that can lead to low energy use.

During the heating periods the outdoor air can be inserted from the lower part of the façade and be preheated in the cavity (figure 4.1). The exterior openings control the air flow and thus the temperatures. Then, through the central ventilation system the air can enter the building at a proper temperature. During the summer, the air can be extracted through the openings from the upper part of the façade. This strategy is applied usually to multi storey high Double Skin Facades. This type provides better air temperatures during the winter but during the summer the possibility of overheating is increased.

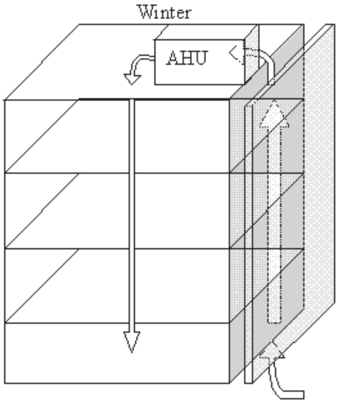


Figure 4.1 Double Skin Façade as a central direct pre-heater of the supply air.

During the whole year, the double skin façade cavity can be used only as an exhaust duct without possibility of heat recovery for the HVAC system (figure 4.2). It can be applied both during winter and summer to the same extent. The main aim of this configuration is to improve the insulation properties in the winter and to reduce the solar radiation heat gains during the summer. There are no limitations in individual control of the windows' openings.

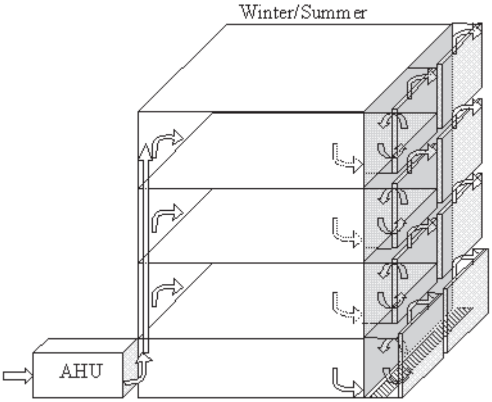


Figure 4.2 Double Skin Façade as an exhaust duct.

The possibility to use the Double Skin Façade as an individual supply of the preheated air also exists (figure 4.3). This strategy can be applied both in multi-storey and box window type. An exhaust ventilation system improves the flow from the cavity to the room and to exhaust duct. Extra conditioning of air is needed in every room by means of VRV system or radiators. This solution is not applicable for the summer conditions since the air temperature inside the cavity is higher than the thermal comfort levels. Also in this case there are no limitations in individual control of the windows' openings.

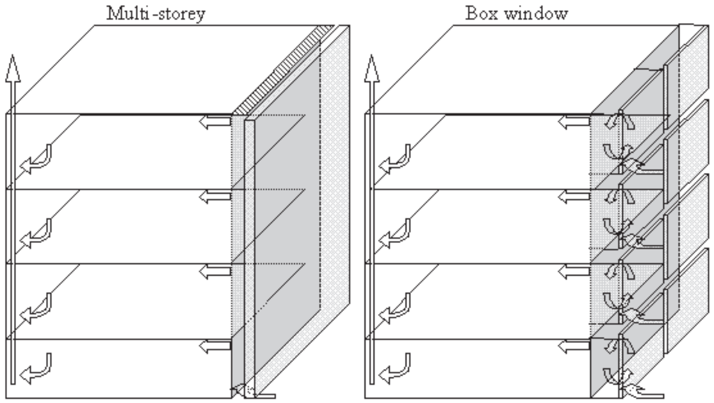


Figure 4.3 Double Skin Façade as an individual supply of the preheated air.

Finally, the Double Skin Façade cavity can be used as a central exhaust duct for the ventilation system (figure 4.4). The air enters through the lower part of the cavity and from each floor. Supply ventilation system stimulates the flow through the room to the cavity. The recovery of air is possible by means of heat pump or heat regenerator on the top of the cavity. The windows cannot be operable due to the not fresh air in the cavity.

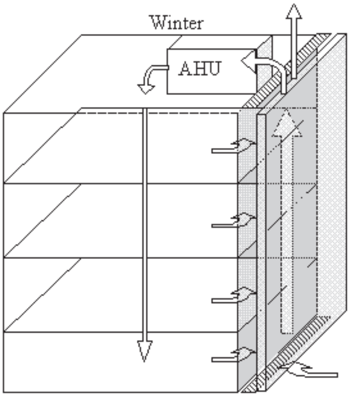


Figure 4.4 *Double Skin Façade as a central exhaust duct for the ventilation system.*

As Stec et al., (2003) describe, *"Generally supply facades couple better with the winter systems in which their preheating properties can be used. The exhaust façade is more efficient to cool the cavity in the summer. Problem arise one façade need to couple both of the periods what cause that the construction need to be adjusted for summer and winter conditions".*

4.2.3.3 Coupling Double Skin Facades and HVAC-Examples

Stec and van Paassen in "Controlled Double Facades and HVAC" in 2000 wrote a paper that deals with the preheating aspects of Double Skin Facades. The authors claim that for the winter period the most significant parameter should be the heat recovery efficiency. The main aim of the paper was to show the usability of the cavity air for ventilation purposes. According to the authors, *"With the simulation one can define how the heat recovery efficiency depends on:*

- *Outside conditions*
- *Dimension of the cavity, (width of the cavity is taken into account)*
- *Area of inlets and outlet of outside air*
- *Height of the building (number of floors)"*

For the simulations, the authors chose the following four different Double Skin Façade types.

1. Double Skin Façade with controlled airflow through the cavities (Figure 4.5). The façade is a multi-storey with no opening junctions that allow the air to be extracted out. There is only one inlet for the ventilation airflow at the bottom of the façade. It is controlled by an air damper such that the air supply to the cavity is just enough for ventilating all the rooms above. The controlled trickle ventilator delivers the desired airflow to each room (80 m^3/h)

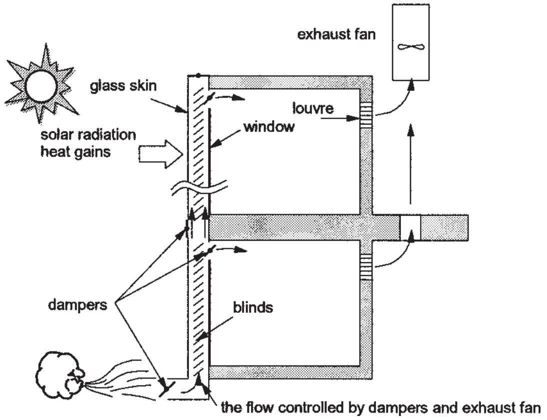


Figure 4.5 Controlled air flow in the cavity (Stec et al, 2000).

2. There are no open junctions on each floor, no controlled airflow in the cavity and no dampers at all in this system (Figure 4.6). Additionally, the upper part of the façade is open allowing the air to be extracted.

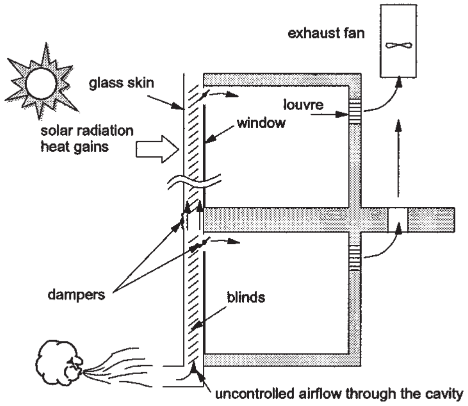


Figure 4.6 Uncontrolled air flow in the cavity (Stec et al, 2000).

3. There are open junctions between the outside and the cavity on each floor, which cause heat exchange between air inside the cavity and outside air. The main airflow is the same as in the second system (Figure 4.7). The authors claim that *"This should be the best system for summer time when cooling is required, but due to the open junctions preheating of the cavity air will be much lower than in the other systems with closed junctions".*

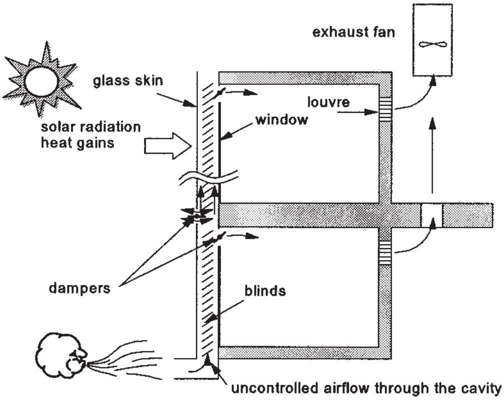


Figure 4.7 Open junctions in each floor (Stec et al, 2000).

4. There are open junctions on each level, but each storey is separated from each other (Figure 4.8). Consequently each storey creates its own system. The authors claim that *"In practice this will be the most convenient system because the same module can be used on each storey. Also the problems due to large temperature gradients in different height of the cavity can be avoided (on each storey there is more or less the same temperature in the cavity)".*

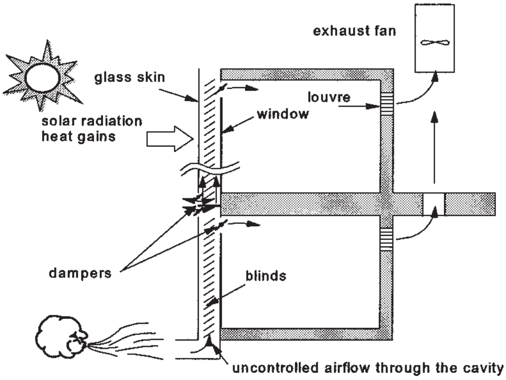


Figure 4.8 Each storey is separated (Stec et al, 2000).

Some of the conclusions that the authors made are:

- *"The most important parameters in designing the double skin façade are dimensions of the cavity, its height and width. Dimensions have the greatest influence on the heat and flow performance in the double skin façade.*
- *A high-rise building with a very thin cavity may not ensure the airflow in the cavity needed for ventilation purposes.*
- *In general double facades with airtight junctions and properly airflow control in the cavity is an interesting pre-heater for ventilation air. In a four storeys building and a cavity width of 0.2 m an overall heat recovery efficiency of 40% can be obtained. This efficiency can be increased to 72% if the ventilation flow inside the cavity is properly controlled. In that case the second skin can compete with a mechanical ventilation system with heat recovery. A disadvantage is the vertical temperature gradient inside the double façade. It gives less comfort or higher cooling capacities at higher floors.*
- *From the previous conclusion and simulation results it can be concluded to split cavities of high rise buildings in separated parts by combining for example four storeys with their own inlets and outlets. If this is done for each floor the efficiency will drop to 35%.*
- *In order to use the double façade as well as for night cooling, as for heat recovery controlled dampers in the open junctions are necessary. In summer they should be fully open.*
- *The asymmetric behaviour of the double façade gives less comfort or higher cooling capacities at higher floors".*

4.2.3.4 Control Strategy

A crucial point when integrating Double Skin Façade systems in buildings is to define a control strategy that allows the use of solar gains during the heating period and provides acceptable thermal comfort conditions during the whole year. The risk of overheating the offices during the summer months is high when the design of the Double Skin Façade is not coupled properly with the strategy of the HVAC system. According to Stec et al., (2003) this system allows the outside conditions influence the indoor climate. As the authors describe, *"Efficient control system needs to be applied to manage rapidly changing outside conditions. A successful application can only be achieved when the contributions of all the devices can be synchronized by an integral control system"*.

According to the authors, *"The control system of the "Passive climate system" of the building should be done according to the following principles:*

- *The occupants must be able to influence everything, even if their intervention spoils energy. (A.H.C. van Paassen, 1995).*
- *In order to save energy, the control system must take the maximum advantage from the outside conditions before switches over to the air conditioning system. (A.H.C. van Paassen, 1995).*
- *All the control system must be focused on the realization of the comfort with the lowest energy consumption.*
- *During the unoccupied period the control system is focused only on the energy saving, while during the occupied period must be focused on the comfort as well.*

The control system has three tasks to fulfill with the use of the passive and active components. These tasks are following:

- *keep the right level of the temperature inside the building*
- *supply sufficient amount of the ventilation air to the building*
- *ensure the right amount of light inside the building".*

4.3 Thermal Performance

According to Barták, Dunovská and Hensen, (2001), "*inside a double-skin façade, the air temperature will mainly depend on heat gains and on the amount of air flow. However, in a naturally ventilated double-skin façade the air flow itself is mainly governed by the temperature difference with outside and possibly, also by wind induced pressure differences; the air flow is typically highly erratic".*

Todorovic and Maric, (1998) developed a model for the thermal performance of a Double Skin Façade system. According to the authors "*The paper presents methods for estimating the inter-space air temperature and the associated cooling/heating load per hour. Calculations are made for specific double-façade constructions designed for the climatic conditions of mid-latitude Europe (45° N). The used outdoor air temperatures and solar radiation are typical for Belgrade. Results for each of the double façade cases are compared with those for a traditional, single façade building".*

Grabe, (2002) presented a paper which deals with the development and validation of a simulation algorithm for the temperature behaviour and the flow characteristics of double facades. According to the author, "*It has been developed in order to obtain a tool which enables the energy consultant to make quick design decisions without being required to use fairly complicated CFD tools. In order to determine the degree of accuracy of the* *algorithm, a double facade has been monitored under controlled conditions and the results have been compared against the predicted values for several design situations. The resulting inaccuracy in some cases can be traced back to how the flow resistance of various geometries is modeled".*

Poirazis et al., (2003) studied 4 different types (panes) of Double Skin Facades and calculated the temperatures at different heights of the cavity and for each layer. The calculations were made partly using two computing programs (WIS and MathCAD) and partly implementing their own numerical model. Each type was simulated for daytime and night time, during the winter and summer, with and without blinds, for mechanical and natural ventilation with openings (air inlet-outlet) of 50 and 8000 mm. The 104 case studies were simulated and results were concluded in order to gain knowledge of the performance and flexibility of Double Skin Facades. The variation of each construction type is shown below:

Table 4.1 Variation of construction types for different Double Skin Façade cases.

Case	Venetian blinds	Air flow rate (Natural - Mechanical) (dm^3/s)	Inlet/Outlet gap (mm)	T_{in} (°C)	T_{out} (°C)	Q_{sol} (W/m^2)
1	No	Mechanical (50 dm^3/s)	Not relevant	20	0	0
2	No	Natural - Calculated	800	20	0	0
3	No	Natural - Calculated	50	20	0	0
4	Yes	Mechanical (50 dm^3/s)	Not relevant	20	0	0
5	Yes	Natural - Calculated	800	20	0	0
6	Yes	Natural - Calculated	50	20	0	0
7	No	Mechanical (50 dm^3/s)	Not relevant	20	25	0
8	No	Natural - Calculated	800	20	25	0
9	No	Natural - Calculated	50	20	25	0
10	Yes	Mechanical (50 dm^3/s)	Not relevant	20	25	0
11	Yes	Natural - Calculated	800	20	25	0
12	Yes	Natural - Calculated	50	20	25	0
13	No	Mechanical (50 dm^3/s)	Not relevant	20	0	500
14	No	Natural - Calculated	800	20	0	500
15	No	Natural - Calculated	50	20	0	500
16	Yes	Mechanical (50 dm^3/s)	Not relevant	20	0	500
17	Yes	Natural - Calculated	800	20	0	500
18	Yes	Natural - Calculated	50	20	0	500
19	No	Mechanical (50 dm^3/s)	Not relevant	20	25	500
20	No	Natural - Calculated	800	20	25	500
21	No	Natural - Calculated	50	20	25	500
22	Yes	Mechanical (50 dm^3/s)	Not relevant	20	25	500
23	Yes	Natural - Calculated	800	20	25	500
24	Yes	Natural - Calculated	50	20	25	500

The authors concluded that *“both U-value and* U_{vent} *(*U_{vent} *is the energy transmitted to the ventilation air) decrease when blinds are placed in the cavity, both for winter and summer. Both values increase slightly during the summer period. The highest* U_{vent} *values are when the gap is 800 mm and the lowest when the gap is 50 mm. In the summer when the outdoor and the indoor temperature differ by 5°C, the stack effect is not so intense and* U_{vent} *decreases in a similar way for the cases with and without the blinds.* Q_{loss} *and* Q_{vent} *decrease slightly when blinds are placed in the cavity, for winter. On the other hand in summer time there is no difference. The highest* Q_{vent} *values are when the gap is 800 mm and the lowest when the gap is 50 mm”*.

In the “Modelling the air infiltrations in the second skin facades” in 2001, Di Maio and van Paassen carried out different simulations in order to show the possibility of the system to deliver hot air to the roof of the building. As the authors claim, *“the main propose of this work is to find out if the openings positioned toward the external part of the building can affect this possibility”*. The models were simulated for opening junction area of 0.072 m^2 and 0.144 $m^{2.}$

Saelens and Hens, (2001a) presented a paper in which a numerical model that evaluates the thermal behaviour of active envelopes is discussed and compared with in situ measurements. As they found, *“the agreement between the measurements and the simulations is good for the mechanical flow active envelope, but less so for the natural flow variant.*

The numerical model has been implemented in an energy simulation program, and an annual energy simulation has been performed on a select number of active envelope typologies. The results were compared to those of a traditional cladding system. Compared to the traditional cladding solution, active envelopes proved to have lower transmission losses but higher transmission gains. These results cannot, however, be extrapolated to the office heating and cooling load.

The naturally ventilated envelope has a somewhat higher heating load but a slightly lower cooling load than the traditional envelope. However, some reservations have to be made because of the uncertainty about the airflow rate in the cavity. Regarding mechanically ventilated active envelopes, the lower transmission gains of the mechanically ventilated active envelopes are offset by the enthalpy change of the cavity return air for airflow rates that surpass the ventilation airflow rate. In summer, we have to conclude that free cooling is an important measure in preventing overheating rather than that active envelopes reduce the cooling load.

The energy demand analysis shows that the energy performance strongly depends on the way the return cavity air is used. In order to correctly evaluate the energy efficiency of active envelopes, it is imperative to take into account the enthalpy change of the cavity air”.

A dynamic simulation of a four-floor building was carried out by Di Maio and van Paaseen, (2001) in order to reduce the energy use for heating and cooling by coupling properly the integration of Double Skin Facades and HVAC systems. As the authors describe, *"the model used in this simulation has been built up step by step, but the main framework can be regarded as an interaction of two main subsystems: The ventilation model and the thermal model"*. The ventilation model that the authors developed calculates the flows through the inlet and cavities of the second skin based on the outputs of the thermal model, the stack effect generator, the pressure generator, the wind generator and on the weather data coming from the Matlab Workspace. According to the authors, the thermal model is able to compute the temperatures of all points in the thermal network. The authors concluded that *"a simple simulation of the Double Skin Façade can be delivered from the heat balances and airflow models"*. Additionally in this paper as an example the effect of the depths of the cavity has been shown.

Shiou Li, (2001) presented a protocol for experimentally determining the performance of a south facing double glass envelope system. As the author describes, *"Two modular full-scale double glazed window models with naturally or mechanically assisted ventilation were constructed and monitored for a range of weather conditions. The goals of this investigation were to develop and apply the test protocol and to monitor and analyze the thermal performance of these two systems and to improve our understanding of the double façade system"*.

4.4 Daylight Performance

4.4.1 Daylight Simulations

Viljoen, Dubiel, Wilson and Fontoynont, (1997), presented a study that looks at the daylight implications of several options for the refurbishment of an existing office building in Brussels with a perimeter ceiling height of 2.5 m and a width of 16 m. Each side has a Double Skin Façade, with a 1.4 m wide maintenance walkway in the space between the internal and external glazing. The computing program used was RADIANCE. As the authors describe, *"scale models in an artificial sky and computer simulations, were used to examine the effects of changes to the walkway. Two changes in the building form were also examined, re-entrant slots in the façade and lowering of the central area floor. The results of these experiments are generally applicable to buildings designed with Double Skin Façades, build-*

ings using horizontal solar shading devices, light shelves, or buildings with low floor ceiling heights. If an area of the floor space is considered to be daylit when it receives at least 3000 Lux for over 50% of the working year, it was found that using the walkway options alone, the daylit area can be increased by up to 23%. Re-entrant façade slots produced no increase in the daylit area. Lowering the central floor area produced an increase of up to 14%. None of the walkway options were able to produce daylit area of greater than 53% of the total floor space. Thus, until redirecting glazing becomes commercially viable, it is clear that shallow plan designs are the best option for new buildings".

Hendriksen, Sørensen, Svensson and Aaqvist focus mostly on the heat loss the indoor climate and the energy aspects of Double Skin Facades. Examining four different cases of Double Skin Facades, they provide useful information concerning daylight, climate and energy aspects. The first case is with simple double glazing and the other three with D.S.F. as described below:

- Simple double glazing
- Double inner - single outer glazing
- Single inner – double outer glazing
- Double inner - double outer glazing

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

A report from the University of Waterloo by Straube and Straaten, (2001) provides a critical review, at a general level, of a Double Skin Façade System. The paper refers to the provision of proper daylighting, suggesting glazing types and shading devices. The authors calculate the solar heat gain coefficient and the visual transmittance for the following types of facades:

- Opaque wall
- Double spectrally selective glass
- Double spectrally selective glass with exterior shades
- Double glass reflective coating
- Triple spectrally selective glass
- Double Façade vented outer with shades
- Double Façade exhaust vented with shades

As the authors conclude, *"Daylighting and Double Facades are not tightly connected issues. Most types of facades can be designed to provide an appropriate amount of daylighting. The amount of window area required to provide daylighting depends on a number of factors, but Double Facades are certainly not the only or best way to achieve excellent daylighting in commercial buildings. Properly placed windows (e.g., lightselves and similar) have long been successfully used for daylighting. Double Facades have pros (they can allow lots of light in when it is dull and overcast) and cons (they allow too much light and glare in most of the time and too much heat out during all winter nights)"*.

Oesterle et al., (2001) claim that the daylight properties of Double Skin Facades are the same with all the rest of the glazed facades types. However, the authors focus on the main differences specific to Double Skin Facades and as they describe, *"these include:*

- *the reduction of the quantity of light entering the rooms as a result of the additional external skin;*
- *the additional effective room depth caused by the façade projection;*
- *the compensatory effect of larger areas of glazing and*
- *the scope of installing light reflecting elements in the façade intermediate space where they are protected against the weather"*.

4.4.2 Shading - lighting devices

Both Lee et al., (2002) and Oesterle et al., (2001) insist on the importance of the position of the shading devices inside the Double Skin Façade cavity. The authors claim that in order to protect the sun shading systems from rain, wind etc, it is recommended to place them inside the intermediate cavity. As a result, the cavity will be divided into two sub cavities. The position of the shading within this space therefore plays a major role in the distribution of the heat gains in the intermediate space. As Oesterle et al., (2001) describe, *"the smaller space will heat up to a greater extend than the larger. If the sun shading is situated just in front of the inner façade and if the inner space between the two is not optimally ventilated, the air in front of the window can heat up considerably – an unsatisfactory phenomenon, regardless whether the windows are open or closed. When they are closed, a secondary heat emission occurs; when they are open, the situation is even worse, since there will be a direct inflow of heated air"*.

Thus, the authors agree that the sun shading should be positioned in the outer half of the intermediate space. The ideal position is roughly a third of the façade cavity, with good ventilation to the outer space above and below the sun shading. It should not be too close to the outer pane of glass, either, so as to avoid excessive heating up and thermal loading of this layer. For the mentioned reason and for proper ventilation purposes is recommended a minimum distance of 15 cm between the sun shading and the external skin of the façade.

According to Jager, (2003) the absorbance of the shading device should not exceed 40%, and the proper shading device suggested is the venetian blinds.

Arons, (2000) refers to the way that different materials of the intermediate blinds influence the thermal comfort and the energy consumption during the occupation stage. According to the author *"Heat absorbed by the sun-shading device can be removed by convection if air is moved along the surface of the blinds and then removed from the cavity. The effectiveness of this heat removal is evidenced by a reduced solar heat gain coefficient (SHGC or solar factor, SF). If in addition, the air that passes through the cavity is cooler than the outside air, then the difference in temperature across the inner glazing will be reduced. This results in a lower heat flow across the inner pane as evidenced by a reduced U-value. The SF can be adjusted by adjusting the blinds. During the heating period, the U-value will be improved if the blinds absorb some heat, thereby increasing the cavity temperature and reducing the difference in temperature between the cavity and the interior"*.

Lighting devices can also be placed in double envelope system. Lee et al., (2002) present a case study where exterior prismatic panels were applied. The architect was Herzog and De Meuron and the building is located in Basel, Switzerland. As the authors describe, *"the double-skin façade reduces heat losses in the winter and heat gain in the summer through optical control of sunlight. Within one floor height, the double-skin façade can be divided into three sections. The upper section is made of insulating glass with integrated prismatic panels which automatically adjusts itself as a function of the altitude of the sun. This panel has two functions: reflecting sunlight toward the outside and admitting daylight into the interior space. The vision window is made of clear insulating glass and is manually operated by the occupant during the daytime. The lower level window is automatically controlled to stay closed when solar and thermal insulation are desired"*.

4.5 Energy Performance of Double Skin Façades

A complete study of energy performance was presented by Saelens, Carmeliet and Hens in "Energy performance Assessment of Multiple Skin Facades" in 2003. The authors claim that only few combinations of Multi Storey Façade -modelling and building energy simulation are available. According to the authors, *"most of these papers are restricted to only one MSF-typology. Müller and Balowski [1983] analyse airflow windows, Oesterle et al [2001] give a comprehensive survey of double skin facades and Haddad and Elmahdy [1998] discuss the behaviour of supply air windows"*.

In the above mentioned paper the authors focus on the energy saving objectives of three Multi Storey Façade typologies used in a single office. The MSF-model is coupled with TRNSYS. As they describe, *"to simulate the energy demand of the office, a cell centred control volume model, describing the MSF, is coupled to a dynamic energy simulation program. The results of the energy simulations are compared and confronted with the objectives found in literature"*.

The authors focus on one storey high solutions:

- a conventional facade with an insulated glazing unit (IGU)
- a naturally ventilated double skin facade (DSF)
- a mechanically ventilated airflow window (AFW)
- a mechanically ventilated supply air window (SUP)

The reduction of the transmission losses, the possibility of recovering the transmission losses by the airflow, the position of the shading device sheltered from climatic conditions and the ability to remove the absorbed solar heat are the most commonly mentioned energy advantages.

The authors conclude that: *"It is shown that it is possible to improve the building's energy efficiency in some way by using multiple skin facades. Unfortunately, most typologies are incapable of lowering both the annual heating and cooling demand. Only by combining typologies or changing the system settings according to the particular situation, a substantial overall improvement over the traditional insulated glazing unit with exterior shading is possible. This implies that sophisticated control mechanisms are inevitable to make multiple skin facades work efficiently throughout the year. In order to correctly evaluate the energy efficiency an annual energy simulation focusing on both heating and cooling load is necessary.*

Furthermore, the analysis shows that the energy performance strongly depends on the way the cavity air is used. In order to correctly evaluate the energy efficiency of multiple skin facades, it is imperative not only to study the transmission gains and losses but also to take into account the enthalpy change of the cavity air and to perform a whole building energy analysis".

5 Advantages – Disadvantages of a Double Skin Façade System

Some of the advantages of the Double Skin Façade System are mentioned in the chapter "Concept of Double Skin Facades". However, in order to clarify the desired goals and the weak points of this construction a more detailed description follows presenting the point of view as described by the authors in some of the literature sources:

5.1 Advantages of the Double Skin Façade concept

Lower construction cost compared to solutions that can be provided by the use of electrochromic, thermochromic or photochromic panes (their properties change according to climatic or environmental conditions). Although these panes can be very promising, they are very expensive. On the other hand, Double Skin facades can achieve a quality of variability through a coordinated combination of components which are both known and available.

Acoustic insulation: In view of some authors the sound insulation can be one of the most important reasons to use a Double Skin Façade. Reduced internal noise levels inside an office building can be achieved by reducing both the transmission from room to room (internal noise pollution) and the transmission from outdoor sources i.e. heavy traffic (external noise pollution). The type of the Double Skin Façade and the number of openings can be really critical for the sound insulation concerning the internal and the external noise pollution. Jager, (2003) claims, that for sound insulation, minimum 100 mm has to be proposed. Faist, (1998) wrote a report calculating acoustic aspects of Double Skin Facades. In this report both calculations and real measurements are presented. Finally, there is an extensive description of the acoustic performance in Oesterle et al., (2001).

Thermal Insulation: Many authors claim that the Double Skin Façade System can provide greater thermal insulation due to the outer skin both in winter and in summer.

- **During the winter** the external additional skin provides improved insulation by increasing the external heat transfer resistance. Although the equivalent thermal transmission coefficient U_{eq}- Value for a permanently ventilated façade will be poorer in part, (than with a single skin façade), the results will improve if the intermediate space (cavity) is closed (partially or completely) during the heating period. The reduced speed of the air flow and the increased temperature of the air inside the cavity lower the heat transfer rate on the surface of the glass which leads to reduction of heat losses. This has the effect of maintaining higher temperatures on the inside part of the interior pane. Oesterle et al., (2001) describe which the proportion of the opening area should be, in order to improve the thermal insulation. Additionally, the authors provide the results of measurements in existing buildings when the width of the intermediate cavity is changed.

  Stec and van Paassen in "Controlled Double Facades and HVAC" in 2000 wrote a paper that deals with the preheating aspects of Double Skin Facades. The authors claim that *"The highest values of heat recovery efficiency are found for thinner cavities. Thin cavities have higher air velocity inside and therefore higher heat transfer coefficients"*. Thus, *"during winter, more useful are thin cavities, because they can ensure the desired ventilation airflow in the cavity and has the highest efficiency for preheating the ventilation air"*.

- **During the summer** the warm air inside the cavity can be extracted when it is ventilated (naturally or mechanically). As Lee et al., (2002) describe, *"as reradiation from absorbed radiation is emitted into the intermediate cavity, a natural stack effect results, which causes the air to rise, taking with it additional heat"*. For proper ventilation of the cavity it is really important to select carefully the combination of the type of the panes and the type of the shading devices so as not to overheat the cavity and thus the interior space. The geometry of the cavity can be really critical since the width and height of the cavity and the size of the openings can be crucial for the intermediate temperatures and for the airflow (if the cavity is naturally ventilated). Another important parameter that should be considered is the positioning of the shading devices. Both Oesterle et al., (2001) and Lee et al., (2002) describe the proper position of the sun shading (as they claim, it should be positioned in the outer half of the intermediate space).

Stec et al, (2000) claim that *"half of the inner façade should be insulated if comfort with natural ventilation is the objective. Otherwise mechanical cooling should be applied"*.

Night time Ventilation: During the hot summer days, when the external temperature is more than 26°C there is a possibility that the interior spaces may be easily overheated. In this case, it may be energy saving to pre-cool the offices during the night using natural ventilation. In this case, the indoor temperatures will be lower during the early morning hours providing thermal comfort and improved air quality for the occupants. In the same time, the use of natural night time ventilation affects the heat storage of the surrounding materials (furnishing, ceilings, walls, etc). If on the other hand windows and doors are closed and if the mechanical ventilation and cooling systems cease to work at night, the heat will be trapped inside causing discomfort the early morning hours. One main advantage of the Double Skin Facades is that they can provide natural night ventilation that is both burglar proof and protected against the weather. According to Lee et al., (2002) *"Double-skin facades have been designed for the purposes of allowing night time ventilation, with the reasons of security and rain protection cited as main advantage"*.

According to Stec et al, (2000) *"night cooling by natural cross ventilation requires large openings in the outer façade (for example open junctions between the panels with an effective opening of 2% of the floor area)"*.

Energy savings and reduced environmental impacts: In principle, Double Skin Façades can save energy when properly designed. Often, when the conventional insulation of the exterior wall is poor, the savings that can be obtained with the additional skin may seem impressive. According to Oesterle et al., (2001) *"Significant energy savings can be achieved only where Double Skin Facades make window ventilation possible or where they considerably extend the period in which natural ventilation can be exploited. By obviating a mechanical air supply, electricity costs for air supply can be reduced. This will greatly exceed the savings mentioned before"*.

According to Arons, (2001), *"energy savings attributed to Double Skin Facades are achieved by minimising solar loading at the perimeter of buildings. Providing low solar factor and low U Value minimises cooling load of adjacent spaces"*. Additionally, as the author describes in his MSc thesis, although no study has been yet published of operational costs versus construction/embodied energy impacts, the Gartnet Company claims that the Double Skin Facades save natural resources by reducing energy consumption during the operational life of the building.

Better protection of the shading or lighting devices: Since the shading or lighting devices are placed inside the intermediate cavity of the Double Skin Facades they are protected both from the wind and the rain.

Reduction of the wind pressure effects: The Double Skin Facades around high rise buildings can serve to reduce the effects of wind pressure. Oesterle et al., (2001) claim that: *"although that it is certainly possible to reduce short-term pressure fluctuations caused for example by gusts of wind, this is facilitated by the buffer effect of the intermediate space. Constant pressure on the façade however can spread unhindered into the intermediate space and if the windows are opened into the rooms".*

Transparency – Architectural design: In almost all the literature sources, is mentioned the desire of the architects to use bigger portions of glazing surfaces. As Lee et al., (2002) claim, *"the double skin façade is a European Union architectural phenomenon driven by the aesthetic desire for an all-glass façade".*

According to Kragh, (2000) "*transparency in architecture has always been desirable and the problem has always been to realise a transparent building envelope without compromising energy performance and indoor climate. For years the development of advanced façade and environmental systems has aimed at creating fully glazed buildings with low energy consumption and high level of occupant comfort. Ventilated double skin facades reducing solar gains in summer and providing thermal insulation in winter is an example of a technology, which is becoming still more common".*

Natural Ventilation: One of the main advantages of the Double Skin Façade systems is that they can allow natural (or fan supported) ventilation. Different types can be applied in different climates, orientations, locations and building types in order to provide fresh air before and during the working hours. The selection of Double Skin Façade type can be crucial for temperatures, the air velocity, and the quality of the introduced air inside the building. If designed well, the natural ventilation can lead to reduction of energy consumption during the occupation stage and improve the comfort of the occupants. Lee et al., (2002) describe that *"Natural ventilation can be introduced in a variety of ways: 1) with operable windows, ventilation can be driven by wind or thermal buoyancy (or stack effect) to ventilate a single side of a building or to cross ventilate the width of a building; 2) stack-induced ventilation uses a variety of exterior openings (windows in addition to ventilation boxes connected to underfloor ducts, structural fins, multi-storey chimneys, roof vents, etc.) to draw in fresh air at a low level and exhaust air at a high level and 3) atria enables one to* *realize a variant of stack ventilation, where the multi-storey volume created for circulation and social interaction can also be used to ventilate adjacent spaces".*

Thermal comfort – temperatures of the internal wall: Since the air inside the Double Skin Façade cavity is warmer (compared to the outdoor air temperature) during the heating period, the interior part of the façade can maintain temperatures that are more close to the thermal comfort levels (compared to the single skin facades). On the other hand, during the summer it is really important that the system is well designed so as the temperatures inside the cavity will not increase dramatically. Proper combination of Double Skin Façade type and geometry, size of openings, type and positioning of shading devices and pane types can assure improved results for every building type and climate.

Fire escape: Claessens and De Hedre mention that the glazed space of a Double Skin Façade may be used as a fire escape. Other authors categorize the different types as described below.

Low U-Value and g-value: Kragh, (2000) claims that the two main advantages of the Double Skin Façades are the low thermal transmission (U-Value) and the low solar heat gain coefficient (g value).

Table 5.1 Advantages mentioned in different literature sources. Some of the statements are mentioned in the text.

Advantages mentioned by author	Oeserle et al., (2001)	Compagno, (2002)	Claessens et al.	Lee et al., (2002)	B.B.R.I., (2002)	Arons, (2000)	Faist, (1998)	Kragh, (2000)	Jager, (2003)
Lower construction cost (comparing to electrochromic, thermochromic photochromic panes)	√								
Acoustic insulation	√			√		√	√	√	√
Thermal insulation during the winter	√	√		√	√		√	√	
Thermal insulation during the summer	√	√		√			√	√	
Night time ventilation	√	√	√	√		√			
Energy savings and reduced environmental impacts						√			
Better protection of the shading or lighting devices	√	√		√					√
Reduction of the wind pressure effects	√	√	√						√
Transparency – Architectural design				√	√	√		√	
Natural ventilation	√	√		√		√	√		√
Thermal comfort – temperatures of the internal wall	√	√		√	√	√	√	√	
Fire escape	√								
Low U-Value and g-value		√				√		√	

5.2 Disadvantages of the Double Skin Façade Concept

The disadvantages mentioned in literature concerning the Double Skin Façade concept are described below:

Higher construction costs compared to a conventional façade. As Oesterle et al., (2001) describe, *"no one would dispute that double skin facades are more expensive than single skin forms: the construction of the outer layer and the space between the two skins makes the former type more elaborate".*

Fire protection: There is not yet very clear whether the Double Skin Facades can be positive or not, concerning the fire protection of a building. Oesterle et al., (2001) claim that: *"Virtually, no information exists on the behaviour of this kind of façade in the case of fire"*. Jager (2003) gives a detailed description of the fire protection of each type of Double Skin Façade for different building types. Some authors mention possible problems cause by the room to room transmission of smoke in case of fire.

Reduction of rentable office space: As mentioned above, the width of the intermediate cavity of a Double Skin Façade can vary from 20 cm to several meters. This, results to the loss of useful space Oesterle et al., (2001) describe it as *"the additional effective room depth caused by the façade projection"*. Often the width of the cavity influences the properties inside it (i.e. the deeper the cavity is, the less heat is transmitted by convection when the cavity is closed) and sometimes the deeper the cavity is, the more improved thermal comfort conditions are next to the external walls. Thus, it is quite important to find the optimum depth of the façade in order to be narrow enough so as not to loose space and deep enough so as to be able to use the space close to the façade.

Additional maintenance and operational costs: Comparing the Double Skin and the Single Skin type of façade, one can easily see that the Double Skin type has higher cost regarding construction, cleaning, operating, inspection, servicing, and maintenance. Oesterle et al., (2001) give an extensive description of the method to estimate the costs. As he claims, still there is not a very efficient way to estimate the costs.

Overheating problems: As described above, if the Double Skin Façade system is not properly designed it is possible that the temperature of the air in the cavity is going to increase overheating the interior space. Jager, (2003) claims that to avoid overheating, the minimum distance between the internal and external pane should not be less than 200 mm. Compagno, (2002) mentions that the key criteria are the width of the cavity and the size of the ventilation openings.

Increased air flow velocity inside the cavity, mostly in multi storey-high types. Possible important pressure differences are mentioned between offices in case of natural ventilation via the cavity.

Increased weight of the structure: As it is expected the additional skin increases the weight of the construction which increases the cost.

Daylight: The daylight properties of Double Skin Facades are similar to other types of glazed facades (i.e. single skin façade). This is the main reason that the provision of daylight and the visual comfort is not extensively described in this chapter of the literature review. However, Oesterle et al., (2001) focus on the main differences specific to Double Skin Facades. As the authors describe, *"these include:*

- *the reduction of the quantity of light entering the rooms as a result of the additional external skin and*
- *the compensatory effect of larger areas of glazing".*

Acoustic insulation: As described above, it is possible that sound transmission problems (room to room or floor to floor) can take place if the façade is not designed properly.

Table 5.2 Disadvantages mentioned in different literature sources. Some of the statements are mentioned in the text.

Disadvantages mentioned by author	Oeserle et al. (2001)	Compagno (2002)	Claessens et al.	Lee et al. (2002)	B.B.R.I. (2002)	Arons (2000)	Faist (1998)	Kragh, (2000)	Jager (2003)
Higher construction costs	√				√	√			√
Fire protection	√				√				√
Reduction of rentable office space	√								√
Additional maintenance and operational costs	√		√		√				√
Overheating problem	√	√			√		√		√
Increased air flow speed					√				
Increased weight of the structure			√						√
Daylight	√								
Acoustic insulation	√				√				√

5.3 Assessment of Double Skin Façade types

In this part, different types of Double Skin Facades are compared as mentioned in several sources of literatue. The comparison is made for:

- Sound insulation
- Fire protection
- Natural ventilation –air quality

Table 5.3

	Box window type	Shaft box façade	Corridor façade	Multi-storey facade
Sound insulation	Used both when there are high external noise levels or when special requirements concerning sound insulation between adjoining rooms exist	The fewer openings (compared with the box window type) provide better insulation against the external noise	Problems with sound transmission from room to room	Suitable when external noise levels are high, but problems of sound transmission within the intermediate space
Fire protection	Low risk factor (not any room is linked to each other)	Low risk factor (the rooms are only connected with the ventilation shaft)	Medium risk factor (the rooms of the same storey are linked)	High risk factor (all the rooms are linked with each other)
Natural ventilation –air quality	Openable windows, proper for natural ventilation	Caution should be paid in the way that the airstreams are grouped together from a number of façade cavities into a single shaft	Caution should be paid so that the exhaust air from one room doesn't enter the room above. The problem can be solved with the diagonal configuration	As a rule, the rooms behind multi-storey facades have to be mechanically ventilated

6 Measurements – Test Rooms and Real Buildings

In this section two types of studies are described. Measurements that took place in test rooms and in real buildings.

Saelens and Hens, (2001) in "Experimental evaluation of Airflow in Naturally Ventilated Active Envelopes" describe the most common measurement techniques for calculating the air flow rates both in naturally and mechanically ventilated active envelopes. The airflow in ducts and cavities can be determined by measuring:

- the pressure difference across an orifice, nozzle or venturi tube
- the air velocity using anemometers
- the air flow directly using tracer gas techniques

In the same paper the airflow through naturally ventilated active envelopes has been experimentally analysed. As the author describes *"a method was proposed to determine the airflow through the cavity by means of the pressure difference over the lower ventilation grid. From the pressure difference over the lower ventilation grid, the airflow rate through the cavity can be determined from the pressure characteristic of the active envelope. The method has been verified by tracer gas measurements and proved to be reliable".*

Saelens, refers to Onur et al., (1996) in his PhD thesis. As he describes, *"for mechanically ventilated cavities, measuring the pressure difference across an orifice placed in the exhaust duct is an excellent way to determine the airflow rate*. However, this method is less suited for naturally ventilated cavities. As Saelens in "Experimental evaluation of Airflow in Naturally Ventilated Active Envelopes", (2001) describes, "*the driving forces are usually small and because of the high flow resistance of the orifice, the flow in the cavity would be too much affected. Furthermore, it would be difficult to find a suitable place for the orifice as no exhaust duct is available".*

Saelens, (2001) after studying reports of Park et al. (1989); Faist, (1998) and Jones, described a second method to estimate the airflow rate measuring the air velocity with anemometers. According to the author "*the determination of the airflow rate from velocity measurements seems evident, but is likely to produce erroneous results. The velocity in a naturally ventilated channel is not uniform across the section and is influenced by lowering or raising the shading device. Furthermore, there is no guarantee that the resulting velocity vector is perpendicular to the reference surface (a typical concern using omnidirectional anemometers). Detailed information about the velocity vectors may be obtained by placing an array of individual velocity measuring points, which however, may affect the development of the airflow in the cavity. Hence, determining the airflow rate in naturally ventilated active envelopes from measured velocities is a less recommendable method.*

A third, less common method, is the use of tracer gas measurements (Ziller (1999); Busselen and Mattelaer (2000)). Tracer gas techniques such as the constant concentration, constant emission and tracer dilution method (Raatschen, 1995 and ASHRAE, 1997) make it possible to determine the airflow rate in both naturally and mechanically ventilated active envelopes without interference with the driving forces. Busselen and Mattelaer (2000), however, point out that it is difficult to perceive the highly fluctuating airflow rate accurately with the constant emission technique".

In "Modeling of air and heat transport in active envelopes", Saelens, Carmeliet and Hens, (2001) compare five models of a mechanically ventilated active envelope with different complexity using measurements. As the authors describe, *"It was shown that radiation and convection in the cavity have to be modelled separately in order to become reliable results".* They also found that *"for an accurate prediction of active envelope performances, the vertical temperature profile has to be implemented properly (e.g. by an exponential expression").* A sensitivity study performed with the numerical model reveals that the air temperature at the inlet of the cavity, the airflow rate, the distribution of the airflow in the cavity and the angle of solar incidence are the governing parameters.

Kragh, (2000) and (2001) describes 10 full-scale rooms made by Permasteelisa. As he describes, the test rooms are being continuously monitored in terms of energy consumption and indoor environment (room temperatures and temperatures across the glazing systems). The building envelope configurations comprise double skin walls (naturally ventilated, mechanically ventilated, indoor-indoor and outdoor-outdoor) demonstrating stand-alone systems as well as integration between façade and environmental system.The measurements are described more in detail below:

Measurements in each room:

- Room ambient temperatures (3 heights, 3 distances from façade)
- Façade surface temperatures (3 heights on the different layers of the façade)
- Façade cavity temperatures, when applicable
- Room ambient humidity
- Transmitted solar radiation through façade
- Outlet/inlet airflow rate and temperature
- Outlet/inlet water flow rate and temperature (hot and cold water)

Outdoor measurements:

- Total solar irradiance (on vertical)
- Long wave irradiance (on vertical)
- Illuminance (on vertical)
- Dry bulb temperature
- Relative humidity
- Wind speed and direction

Mobile measurements:

- Indoor illuminance (3 positions)
- Room ambient temperatures (3 positions)

Saelens, (2002) describes in his thesis measurements carried out at the Vliet test building. According to him, *"two one storey high multiple-skin facades and a traditional envelope were built and tested under real climatic conditions. The aim of the measurements is twofold. Firstly, the measurement set-up is used to extend the knowledge of the thermal behaviour of multiple-skin facades. The set-up allows a more accurate control, measurement and change of the different parameters compared to in situ measurements. Secondly, the data are used to evaluate modelling assumptions and to derive and check relationships for modelling parameters".*

The author compares different models for the convective heat transfer coefficient with the measurements. Additionally, the measurements are used to evaluate the numerical model and to assess the reliability of models with different levels of complexity. Finally, the data are used to assess how the inlet temperature should be determined".

Shiou Li in 2001 wrote a MSc thesis which proposes a protocol for experimentally determining the performance of a south facing double glass envelope system. As he describes: *"As a proof of concept, the protocol was applied to an experimental study of a south-facing, single story double glazed ventilated wall system. Two modular full-scale double glazed window* *models with naturally or mechanically assisted ventilation were constructed and monitored for a range of weather conditions. The goals of this investigation were to develop and apply the test protocol and to monitor and analyze the thermal performance of these two systems and to improve our understanding of the double façade system. Using this test protocol preliminary results show the average cavity heat removal rate is approximately 25% higher for the active system when compared to the naturally ventilated system. Also, the passive system has a higher temperature difference between the indoor glass surface and the indoor air than the active system. This experimental protocol can be further applied to determine other performance issues of the double envelope system".*

7 Costs and Investments

The construction and maintenance cost of a Double Skin Façade system is not very often described in the existing literature. It is impressive how contradictory opinions one can find by reading reports from different authors. In some of the documents, the Double Skin Façade system may be mentioned as "Energy Saving Façade". In others, the energy consumption during the occupation stage and thus the cost, is noted as the main disadvantage.

Without any doubt, the construction and the maintenance cost of a Double Skin Façade is higher than a Single Skin one. However, if the façade is designed properly, it is possible to reduce the energy consumption mainly from heating, cooling and ventilating the building and thus reduce the "operational" cost. At this point it has to be stressed that a careful design has to take into account many different parameters connected both with the use of building (building scheme and type, orientation, occupancy schedule, equipment etc) and its location (climate, daylight availability, temperature, site & obstructions, latitude, atmospheric conditions etc).

Straube, (2001) in "The technical Merit of Double Skin Facades for Office Buildings in Cool Humid Climates" claims that *"Double facades are merely one approach to overcoming the large energy consumption and comfort problems that are created by the use of excessive glazing areas of interior performance. The most environmentally sound and least expensive construction and operating cost) solution avoids the problems that Double Facades are intended to solve by reducing glazing area and increasing the quality of the glazing product".*

Jager, (2003) presented constructional and maintenance costs for Standard and Double Skin Facades. According to him:

"Investments (in Central Europe)

- *Standard façade 300 to 500 Euro/ m²*
- *Double Skin Standard 600 to 800 Euro/ m²*
- *Double Skin with adjustable air in and outlet 700 to 1000 Euro/ m²*
- *Double Skin with openable exterior sashes 800 to 1300 Euro/ m²*

Running Costs (in Central Europe)

- *Standard façade 2.5 to 3.5 Euro/ m² and cleaning operation*
- *Double Skin façade 4 to 7.5 Euro/ m² and cleaning operation".*

Oesterle et al., (2001) mention that, *"as yet, neither comprehensive, conclusive cost calculations, nor generally applicable methods of assessing cost effectiveness exist".* The authors analyze the eight step method for planning of buildings proposed by Drees and Höh. These are the eight steps:

1. Determining the purpose of the study
2. Listing the alternatives
3. Determining the investment costs
4. Determining the follow-up costs
5. Determining the effective costs for the use of the building
6. Determining and analyzing differential costs
7. Establishing a ranking and making recommendations
8. Supplementary cost-benefit analysis

The three different methods of calculating the costs for the use of a building:

- Simplified calculating method
- Calculation on the basis of annuity
- Dynamization of costs for the use of the buildings

Oesterle et al., (2001) Drees and Höh agree that it is usually immaterial which method is used for comparing alternatives. Therefore, a cost-efficiency ranking will be independent of the method of calculation.

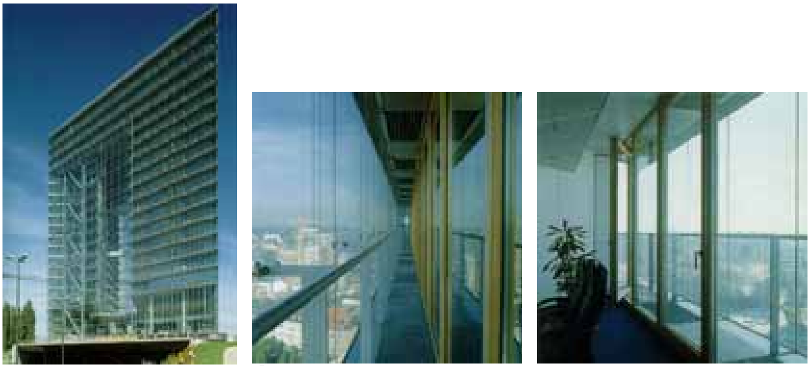
The authors affirm that, in general, economic analyses of façade alternatives should take account of both the investment and operating and maintenance costs.

8 Examples of Office Buildings with Double Skin Façade

The main purpose of this section is mostly to provide references for building examples which are described briefly. In the following pages the building examples are categorized by country in order to make clear how the type of construction is influenced by the climatic conditions. However, not necessarily all the constructions are adapted to the climate.

8.1 Germany

8.1.1 Düsseldorf city gate (Düsseldorfer Stadttor)

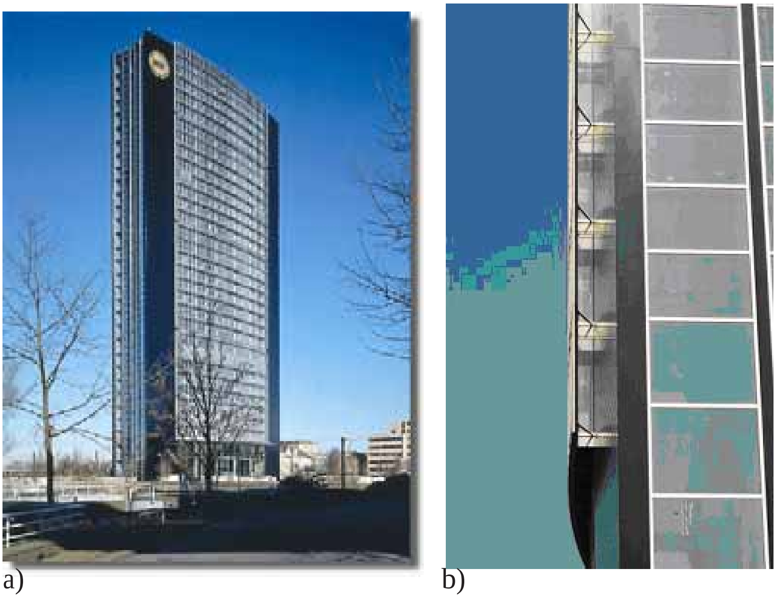

a) b) c)

a) South face of “City Gate” (LBNL – http://gaia.lbl.gov/hpbf/picture/casestudy/dusseldorf/building.jpg).
b) View of the D.S.F. cavity (LBNL – http://gaia.lbl.gov/hpbf/picture/casestudy/dusseldorf/window3.jpg).
c) View of the interior glazing (LBNL – http://gaia.lbl.gov/hpbf/picture/casestudy/dusseldorf/window1.jpg).

Table 8.1 Düsseldorf city gate (Düsseldorfer Stadttor)

Authors – Web sites	BBRI, (2002), Oesterle et al., (2001), Lee et al., (2002), Univ. of Waterloo, Compagno, (2002)
Architect	Petzinka
Location of the building	Düsseldorf
Façade Type	The façade is a corridor type. The intermediate space between the two skins is closed at the level of each floor.
Ventilation of the cavity	The air supply and exhaust openings in the external façade layer are situated near the floor and the ceiling. They are laid out in staggered form from bay to bay to prevent vitiated air extracted on one floor entering the space on the floor immediately above.
Façade construction – Pane type	The entire building is enclosed in a glass skin so that a 56-meter-high atrium space is created at the centre. The outer layer consists of a 12 mm safety glass and the inner is a low –E glazing with a wooden frame. Two corridor widths are encountered in the building (90 cm and 140 cm).
Shading device type	The solar blinds are situated near the outer glazing layer.
HVAC	The natural ventilation in the intermediate space allows to naturally ventilate the rooms with outside air during long periods of the year. The first years of operation show that the building can be naturally ventilated for roughly 70-75% of the year. No complete climatisation of the office room was installed. The office rooms are equipped with chilled ceiling.

8.1.2 ARAG 2000 Tower



a) b)

c)

a) View of ARAG 2000 Tower (http://www.josef-gartner.de/referenzen/arag.htm)
b) View of the cavity (http://gaia.lbl.gov/hpbf/casest_a.htm)
c) View of the façade (Compagno, 2002, p. 157)

Table 8.2 ARAG 2000 Tower

Authors – Web sites	Oesterle et al., (2001), Compagno, (2002)
Architect	RKW, Düsseldorf, in collaboration with Norman Foster, London.
Location of the building	Düsseldorf

Façade Type	The façade is designed as a shaft-box system.
Ventilation of the cavity	Each of the box windows has its own 15 cm high air-intake opening in the form of a closable flap. Vitiated air is extracted into the exhaust-air shaft via a bypass opening. The shaft, in turn, is ventilated via louvers in front of the services story. In order to exploit the collector effect of the façade intermediate space more efficiently in winter, the air-extract shaft is also designed to be closed if required.
Façade construction – Pane type	The inner façade layer was constructed with conventional vertically pivoting aluminium casements with low-E glazing.
Shading device type	Louvered blinds were installed in the outer third of the roughly 70 cm deep intermediate space between the façade layers.
HVAC	The free window ventilation is possible for 50-60 percent of the year. During periods of extreme weather conditions, a high level of thermal comfort can be attained with mechanical ventilation.

8.1.3 Headquarters of Commerzbank


a)


b)

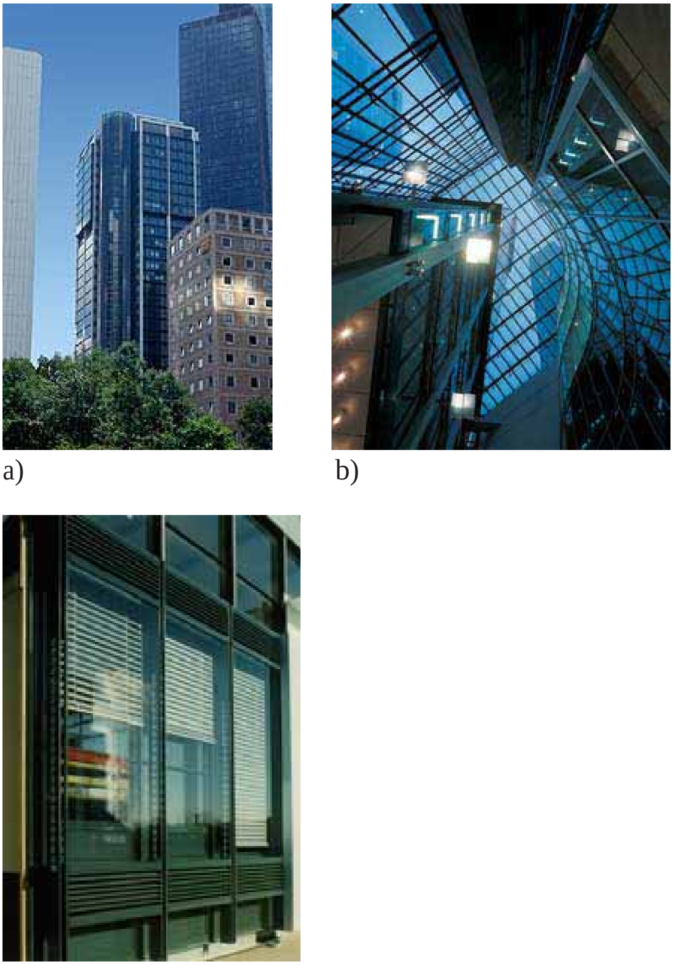

c)

a) Commerzbank (http://csw.art.pl/new/2001/arch.html)
b) Interior of Commerzbank (http://www.archleague.org/tenshadesofgreen/commerz.html
c) Entrance of Commerzbank (http://www.archleague.org/tenshadesofgreen/commerz.html

Table 8.3 Headquarters of Commerzbank

Authors – Web sites	Compagno, (2002)
Architect	Foster and Partners
Location of the building	Frankfurt
Façade Type	It consists of a three storey sealed outer skin, a continuous cavity and an inner façade with operable windows.
Ventilation of the cavity	Two variations on the principle of the “buffer zone” for natural ventilation of the offices were used: as a double skin façade and as a winter garden.
Façade construction – Pane type	The outer skin consists of 1.4 × 2.25 m sheets of 8 mm toughned glass. The 12 cm high air inlets and outlets are located above and below the grey fritted glass cladding on the parapets; these vents are not closable.
Shading device type	Air louvers were provided at the lower and upper ends of the cavity.
HVAC	No information given.

8.1.4 Eurotheum



a)

b)

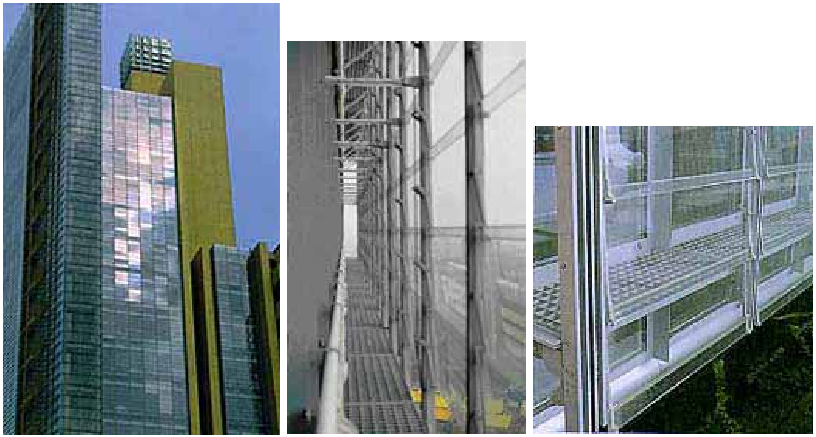
c)

a) View of Eurotheum (Wolfgang Leonard – http://home.t-online.de/home/wleonhard/wlhdahch.htm).
b) Interior of Eurotheum (http://www.nma.de/euroth-4.htm).
c) Shading devices (http://gaia.lbl.gov/hpbf/picture/casestudy/euro/window.jpg).

Table 8.4 Eurotheum

Authors – Web sites	Lee et al., (2002)
Architect	Novotny Mähner and Associates
Location of the building	Frankfurt
Façade Type	The façade grid is 1350 mm wide and 3350 mm tall. Each unit, which is pre-fabricated off-site, consists of a 6-grid span, one-storey tall.
Ventilation of the cavity	Fresh air is supplied through 75-mm diameter holes in the vertical metal fins on each side of the glazing unit. Warm air is extracted through an exterior opening at the ceiling level. This opening is equipped with louvers to prevent the penetration of rain and is covered with anti-bird mesh.
Façade construction – Pane type	The internal skin consists of thermally-broken aluminium frames and double-pane, manually-operated, tilt-and-turn windows. The external skin consists of single-pane, fixed glazing.
Shading device type	Power-operated blinds are located in the 34-cm-wide air cavity corridor.
HVAC	No information given.
Comments	Residential and office mixed-use building is 100-m high and has a square 28 by 28 m plan. Only part of the building is designed with a double-skin façade, which provides natural ventilation for most of the year. Office space occupies the lower part of the Eurotheum Tower while the top seven floors are used for residential purposes.

8.1.5 Debis headquarters



a) b) c)

a) South façade Debis headquarters (Space modulator – http://www.nsg.co.jp/spm/sm81~90/sm87_contents/sm87_e_debis.html).
b) Cavity of Debis headquarters (Compagno, 2002, p. 145).
c) Openable exerior skin (Space modulator – http://www.nsg.co.jp/spm/sm81~90/sm87_contents/sm87_e_debis.html

Table 8.5 Debis headquarters

Authors – Web sites	Lee et al., (2002), Crespo, Oesterle et al. (2001)
Architect	Renzo Piano Building workshop, Paris, in collaboration with Christoph Kohlbecker, Gaggenau.
Location of the building	Berlin
Façade Type	Corridor façade.
Ventilation of the cavity	In a closed position, there is a 1 cm peripheral gap around the louvers (with an overlap of 5 cm). Opening the louvers to a greater angle results in only a small increase in the air-exchange rate. On the other hand, opening the external skin to a greater degree has a positive influence on the ventilation, since it helps to remove the heat in the intermediate space. During the summer, the exterior glass louvers are tilted to allow for outside air exchange. The users can open the interior windows for natu-

	ral ventilation. Night-time cooling of the building’s thermal mass is automated. During the winter, the exterior louvers are closed. The user can open the internal windows to admit to the warm air on sufficiently sunny days.
Façade construction – Pane type	The inner skin consists of a strip-window façade with double low-E insulating glazing in aluminium frames. In every façade bay, there is a side and bottom-hung casement, supplemented by a motor-operated, bottom-hung top light. The solid up-stand walls on the room face are lined with insulated panels with a covering of toughened safety glass. On the west side of the building, the upstand walls are clad with terracotta elements fixed to an aluminium supporting structure, which forms the internal section of the three-bay outer façade elements. The floors to the façade corridors consist of sheets of toughened safety glass laid on metal gratings. This construction provides a smoke-proof division between the stories. Walkway grills occur at every floor within the 70-cm wide interstitial space and are covered with glass to prevent vertical smoke spread between floors.
Shading device type	Sliding louver blinds were installed in front of the inner façade. This allowed the sunshading to be located close to the inner skin, while at the same time still complying with airflow requirements into the rooms. In a closed position, there is a 1 cm peripheral gap around the louvers (with an overlap of 5 cm). The exterior skin consists of automated, pivoting, 12-mm thick laminated glass louvers. Minimal air exchange occurs through these louvers when closed.
HVAC	The possibility of providing window ventilation for the rooms was also investigated. The scope for natural window ventilation is approximately 50 percent of the operating time in the upper part of the building and 60 per-

	cent in the lower part. A mechanical ventilation plan was installed to provide partial air-conditioning for those periods in winter and summer when extreme weather conditions prevail. The building is mechanically ventilated during peak winter and summer periods (To< -5°C, To>20°C).The conditioned air is either cooled or heated and is injected continuously into the rooms, ensuring a threefold air change every hour (3 ach).
Comments	The main objective of the clients and the planner was to create an environmentally sustainable and user-friendly building. Various measures were implemented with this in mind: the offices were provided with a natural system of ventilation (air-intake and extract); the air-conditioning plant was reduced to sensible proportions; the thermal insulation was optimized and concepts were introduced for the improvement of the micro-climate (extensive roof planting, the recycling of rainwater, the creation of areas of water, etc.). To achieve these goals, large scale investigations and research work were undertaken.

8.1.6 (GSW) Headquarters

a) b) c)

a) Exterior view of GSW Headquaters(LBNL - http://gaia.lbl.gov/hpbf/picture/casestudy/gsw/gswm.jpg)
b) Interior view of the east triple façade system (LBNL - http://gaia.lbl.gov/hpbf/picture/casestudy/gsw/gswd.jpg)
c) Interior view of the east triple façade system (LBNL - http://gaia.lbl.gov/hpbf/picture/casestudy/gsw/gswf.jpg)

Table 8.6 (GSW) Headquarters

Authors – Web sites	Lee et al., (2002)
Architect	Sauerbruch Hutton
Location of the building	Berlin
Façade Type	22-storey, 11-m wide office building with cross ventilation and a double-skin thermal flue on the west-facing façade.
Ventilation of the cavity	This 11-m wide office building allows for cross ventilation. Outside air admitted from the east façade provides cross ventilation to the opposing west façade. The prevailing window direction is from the east. The west façade acts as a 20-storey high shaft inducing vertical airflow through stack effect and thermal buoyancy. Where partitioned offices occur, sound-baffled vents permit airflow across the building.

Façade construction – Pane type	The east façade consists of automatically and manually-operated triple-glazed windows with between-pane blinds. The west façade consists of a double-skin façade with interior double pane windows that are operated both manually and automatically and a sealed 10-mm exterior glazing layer. The interstitial space is 0.9 m wide.
Shading device type	Exterior louvered metal panels also occur on the east façade to admit fresh air independently from the windows. On the west façade wide, vertical, perforated aluminium louvers located in this interstitial space are also automatically deployed and manually adjustable. The louvers can be fully extended to shade the entire west façade.
HVAC	During the heating season, the air cavity between multi-layer façade acts as a thermal buffer when all operable windows are closed. Warm air is returned to the central plant via risers for heat recovery. Fresh air is supplied from the raised floor system. Radiant heating and cooling are provided. Thermal storage in the ceiling and floor was created using exposed concrete soffits and a cementitious voided screed system. Various building systems such as lighting and diffusers are either integrated into the soffit or into the voided screed.

8.1.7 Halenseestraße

a) b) c)

a) Exterior view of Halenseestraße (LBNL - http://gaia.lbl.gov/hpbf/picture/casestudy/halensee/building3.jpg)
b) Cavity (LBNL - http://gaia.lbl.gov/hpbf/picture/casestudy/halensee/window.jpg)
c) Shading devices (LBNL - http://gaia.lbl.gov/hpbf/picture/casestudy/halensee/window2.jpg)

Table 8.7 Halenseestraße

Authors – Web sites	Lee et al., (2002)
Architect	Hilde Léon, Konrad Wohlhage
Location of the building	Berlin
Façade Type	The top west-facing seven stories of this ten-storey building are designed with a double-skin façade. Façades on other orientations are conventional single-layer windows.
Ventilation of the cavity	Fresh air is mechanically drawn from the roof, then passed down to the intermediate space of the double-skin façade through vertical channels at both ends of the corridor. Air is extracted through the horizontal ducts leading to vertical channels situated in the centre of the façade.

Façade construction – Pane type	The 12-mm single-pane external skin of this double-skin façade is completely sealed while the internal skin consists of sliding double-pane glass doors.
Shading device type	A blind was installed within the 85-cm wide, 1-storey high interstitial space.
HVAC	During the summer, the blinds can be used to block solar radiation while the interstitial space is mechanically ventilated. At night, internal heat gains are removed with mechanical ventilation. During the winter, solar gains pre-warm the air in the interstitial space.
Comments	The double-skin façade reduces noise from the adjacent highway towards the west.

8.1.8 Galleries Lafayette


a)


b)

a) View of the Galleries Lafayette (Permasteelisa - http://www.permasteelisa.com.sg/images/galeries/01b.jpeg)

b) View of the Galleries Lafayette (Permasteelisa - http://www.permasteelisa.com.sg/images/galeries/06b.jpeg)

Table 8.8 Galleries Lafayette

Authors – Web sites	Compagno, (2002)
Architect	Jean Nouvel
Location of the building	Berlin
Façade Type	Storey high type (horizontally divided cavity)
Ventilation of the cavity	The inlet and outlet vents are placed at each floor, the lowest degree of air heating and therefore the most effective level of natural ventila-

	tion is to be expected. The openings remain permanently open and are fitted with wires to keep birds out.
Façade construction – Pane type	The 29 mm thick insulating glass unit with an 8 mm glass on the outside and a 6 mm low –E coated glass on the inside, has a cavity filled with argon.
Shading device type	Perforated louvre blinds of stainless steel are fitted as solar control in the 200 mm wide cavity.
HVAC	The façade enables natural ventilation of the offices for most of the year. If the outside temperature is too low or too high, a mechanical ventilation system is switched on.
Comments	The unusually designed Double Skin Façade is intended to serve as an information carrier and act as an optical attraction. It also serves protection against the external noise.

8.1.9 Potsdamer Platz 1


a)


b)

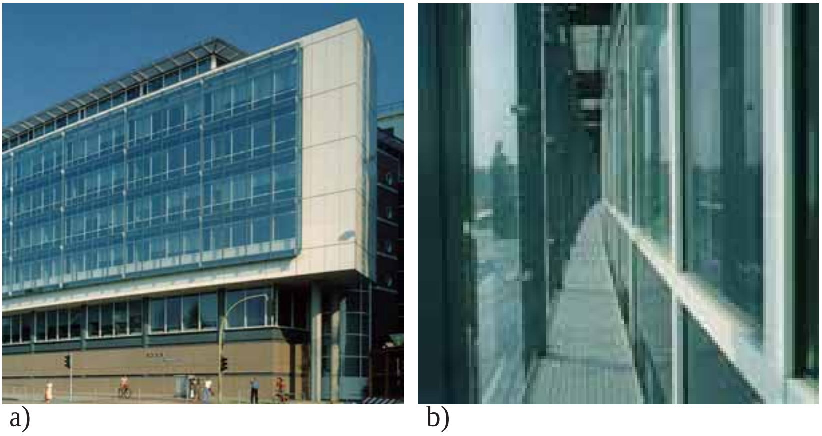
a) View of the Potsdamer Platz 1 (http://berlin1.btm.de/infopool/jsp/e_sw_potsdamer-platz.jsp)

b) View of the Potsdamer Platz 1 (http://berlin1.btm.de/infopool/jsp/e_sw_potsdamer-platz.jsp)

Table 8.9 Potsdamer Platz 1

Authors – Web sites	Oesterle et al., (2001)
Architect	Hans Kollhoff
Location of the building	Berlin
Façade Type	Traditional engineering-brick façade with rectangular window openings (box window construction).
Ventilation of the cavity	The outer pane of glass sits in a side-hung casement. The ventilation of the intermediate space and the internal rooms is effected via a gap 6 cm high beneath the outer pivoting casement.
Façade construction – Pane type	The internal window is designed as a side- and bottom-hung casement with low-E glazing in an oak frame and with aluminium cover strips externally. The intermediate space between the façade layers is roughly 22 cm deep.
Shading device type	A louvered blind is installed, the location of which was optimized in respect of its rear ventilation by designing the upper louvers to be fixed at a flatter angle, so that they remain permanently open, even when the blind is lowered.
HVAC	The combination of window ventilation with additional mechanical support under extreme weather conditions allows a very high degree of thermal comfort to be achieved.

8.1.10 Deutscher Ring Verwaltungsgebäude


a) b)

a) View of the Deutscher Ring Verwaltungsgebäude (LBNL - http://gaia.lbl.gov/hpbf/casest_c.htm)
b) View of the Deutscher Ring Verwaltungsgebäude cavity (LBNL - http://gaia.lbl.gov/hpbf/casest_c.htm)

Table 8.10 Deutscher Ring Verwaltungsgebäude

Authors – Web sites	Lee et al., (2002)
Architect	Dipl.-Ing., von Bassewitz, Patschan, Hupertz and Limbrock
Location of the building	Hamburg
Façade Type	Storey high Double façade.
Ventilation of the cavity	The top of the four-storey façade has a rain-proof opening with overlapping glass panes that allow air exchange. For cooling, solar radiation absorbed by the exterior glazing layer is vented or extracted by natural convection through the top opening at the fourth floor.
Façade construction – Pane type	The exterior skin is point-fixed, toughened, solar control, single-pane glazing. The interior skin consists of low-E coated, double-glazed, punched windows and spandrels. There are staggered exterior openings at the base of the curtainwall (not clear whether at each floor or simply at the base of the four-storey façade).

	Some of the interior windows are operable to allow for cleaning within the interstitial space. Walkway grills occur at every floor within this interstitial space.
Shading device type	Blinds are positioned interior to the internal glass windows
HVAC	No information given.

8.1.11 Valentinskamp/Caffamacherreihe

a) b)

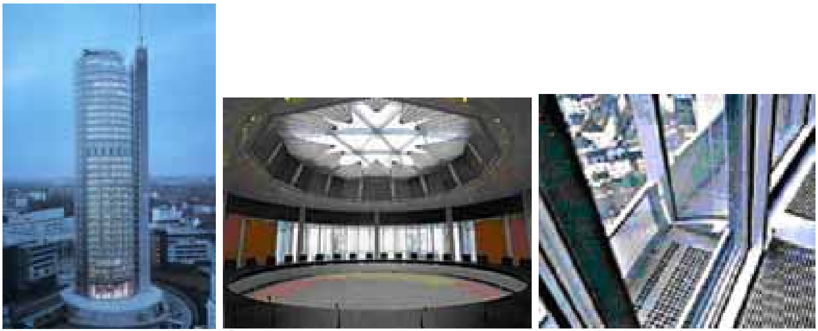
a) View of the Valentinskamp (http://gwm50.gad.de/rz/gwm/webdbs/xfdifa.nsf/0/09f5ef4c16169b2d41256ba000256478?OpenDocument)
b) View of the façade (Oesterle et al., (2001), p. 122)

Table 8.11 Valentinskamp/Caffamacherreihe

Authors – Web sites	Oesterle et al., (2001)
Architect	Reimer and Partner, Elmshorn
Location of the building	Hamburg
Façade Type	Double-skin façade in conventional form of construction with permanently ventilated intermediate space.
Ventilation of the cavity	No information given.

Façade construction – Pane type	Inner façade: aluminium prefabricated post-and-rail construction, with side- and bottom-hung casements in alternate façade bays. Outer façade: steel supporting sections with point-fixed toughened safety glass.
Shading device type	Aluminium louver blinds (louver width: 80 mm).
HVAC	No information given.

8.1.12 RWE AG Headquarters



a) b) c)

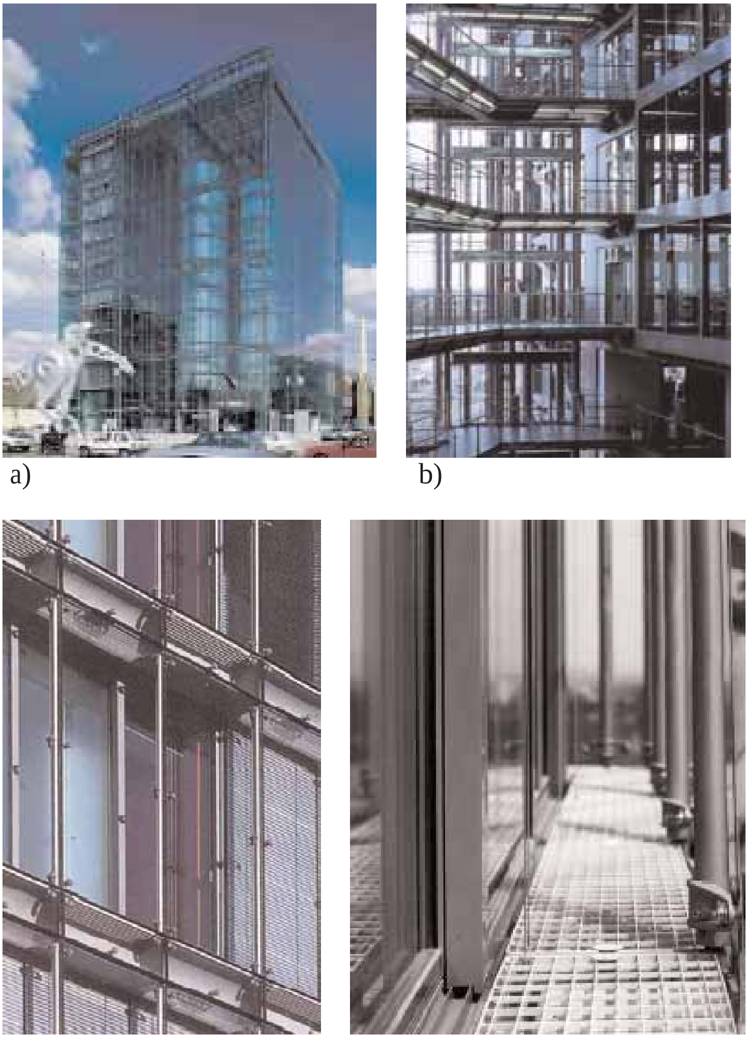
a) View of the RWE AG Headquarters (LBNL - http://gaia.lbl.gov/hpbf/casest_j.htm)
b) The boardroom on the upper most floor (Space Modulator - http://www.fes.uwaterloo.ca/architecture/faculty_projects/terri/Gruchala.pdf)
c) View of the cavity (LBNL - http://gaia.lbl.gov/hpbf/casest_j.htm)

Table 8.12   RWE AG Headquarters

Authors – Web sites	Lee et al., (2002), Kragh, (2000), Collins, (2000), Space modulator, Arons, (2000)
Architect	Ingenhoven Overdiek and Partners
Location of the building	Essen
Façade Type	A transparent interactive façade system which encompasses the entire building.

Ventilation of the cavity	Outside air admitted through the 15 cm high ventilation slit at the base of one module is then ventilated to the exterior out the top of the adjacent module. The type of ventilation is diagonal.
Façade construction – Pane type	The exterior layer of the double-skin façade is 10-mm extra-white glass. The interior layer consists of full-height, double-pane glass doors that can be opened 13.5 cm wide by the occupants (and wider for maintenance). The 50-cm wide interstitial space is one-storey (3.59 m) high and one module (1.97 m) wide. An anti-glare screen is positioned on the interior.
Shading device type	Retractable venetian blinds are positioned just outside the face of the sliding glass doors (contributes to interior heat gains?) within the interstitial space. Daylight, direct solar and glare can be controlled with blinds and an interior anti-glare screen.
HVAC	The extra air cavity acts as a thermal buffer, decreasing the rate of heat loss between outside and inside. Fresh air is supplied through the opening at the bottom and warm air is exhausted through the opening at the top of the façade. During extreme cold conditions, the windows are closed. Warm air is returned to the central plant via risers for heat recovery in the winter. The façade provides good insulation in the winter and with the combination of slatted blinds, effective solar protection in the summer.
Comments	The design of the RWE façade system was influenced by the clients' desire for optimum use of daylight, natural ventilation, and solar protection.

8.1.13 Print Media Academy



a) b) c) d)

a) View of Print Media Academy (http://www.fes.uwaterloo.ca/architecture/faculty_projects/terri/ds/PMA.pdf)
b) Interior atrium (http://www.fes.uwaterloo.ca/architecture/faculty_projects/terri/ds/PMA.pdf)
c) View of the façade (http://www.fes.uwaterloo.ca/architecture/faculty_projects/terri/ds/PMA.pdf)
d) View of the cavity (http://www.fes.uwaterloo.ca/architecture/faculty_projects/terri/ds/PMA.pdf)

Table 8.13 Print Media Academy

Authors – Web sites	Bohren and Boake, (2001)
Architect	Schroder Architeckten and Studio Architekten Bechtloff
Location of the building	Heidelburg
Façade Type	Box window type
Ventilation of the cavity	Cross ventilation. A cross ventilation control system exists that moderates the buffer space between the outer and inner glazing. This is done by opening sets of upswing glass louvers to allow outside air flow to pass through and push the heated air in the cavity out, thus cooling the building envelope.
Façade construction – Pane type	The box unit comprised of a single glass pane at the exterior side and a sealed double glass pane on the inner side. Between the two panes is a 46 cm air space.
Shading device type	The shading system is a mechanical aluminium blind system that controls solar heat gain. These blinds roll down on the inside of the cavity and angle according to the suns angle. The aluminium reflects the solar heat into the box unit heating the buffer space. The louver venting system then manages the cavity to minimize building heat loss and gain.
HVAC	Fresh air can be gained by operating the inner window slider. The slider allows air from the office and cavity to exchange. The buildings central system then controls the rate of air flow into the cavity space; this is done by adjusting the exterior glass louver to harmonize building pressure and temperature. It also prevents destabilization of the building environment from several weather conditions.

8.1.14 Victoria Life Insurance Buildings


a)


b)


c)

a) View of Victoria Life Insurance Buildings (LBNL - http://gaia.lbl.gov/hpbf/picture/casestudy/ensemble/window3.jpg)
b) View of the cavity (LBNL - http://gaia.lbl.gov/hpbf/picture/casestudy/ensemble/windowa.jpg)
c) View of the façade (LBNL - http://gaia.lbl.gov/hpbf/picture/casestudy/ensemble/windowc.jpg)

Table 8.14 Victoria Life Insurance Buildings

Authors – Web sites	Lee et al., (2002), Compagno, (2002)
Architect	Valentyn & Tillmann, Köln
Location of the building	Sachsenring, Cologne
Façade Type	Multi storey facade
Ventilation of the cavity	Fresh air is supplied at the bottom level and is extracted at 21 m height through power-operated vents. Both layers of this buffer double façade are completely sealed.
Façade construction – Pane type	The external skin consists of 15 mm laminated solar control glazing; the internal skin consists of solar control fixed glazing.
Shading device type	Aluminum 50-mm-wide louvers are integrated into the 80 cm-wide corridors, which are equipped with walkway grilles for access.

HVAC	The building is conditioned with a conventional HVAC system. Adjacent twin towers do not utilize the double-skin façade system.
Comments	The main advantage of the double-skin façade system is the improvement in thermal comfort. In winter, the air vents in the corridor can be closed, letting the air warm up, which reduces the difference between inside and outside temperatures and consequently reduces heat loss. Warm air increases the surface temperature of the glass, which makes the area near the windows more thermally comfortable. For this building, the large glass area provides daylight access, which enhances motivation, performance and productivity at work.

8.1.15 Victoria Ensemble


a)


b)


c)

a) View of the Victoria Ensemble (van den Valentyn Architecture - http://www.vandenvalentyn.de/98vv/ve/ve-15.htm)
b) Atrium (van den Valentyn Architecture - http://www.vandenvalentyn.de/98vv/ve/ve-18.htm)
c) Entrance of the building (van den Valentyn Architecture - http://www.vandenvalentyn.de/98vv/ve/ve-08.htm)

Table 8.15 Victoria Ensemble

Authors – Web sites	Oesterle et al., (2001)
Architect	Thomas van den Valentyn.
Location of the building	Cologne
Façade Type	Double-skin façade splayed outward from bottom to top at an angle of 2,6°.

Ventilation of the cavity	The façade is used exclusively as a means of regulating thermal insulation for different weather conditions. The intake of air is via a trench at the foot of the building, while vitiated air is extracted at roof level.
Façade construction – Pane type	No information given.
Shading device type	Continuous strips of flaps were installed around the entire building at the foot and the top of the façade to control temperatures. The flaps can be opened or closed according to needs.
HVAC	A central control system keeps the flaps closed when external temperatures are low, so that the layer of air trapped between the two skins of the façade ensures maximum thermal insulation. When external temperatures rise, the flaps are opened to allow the ventilation of the intermediate space and to prevent it overheating. The façade thus provides the building with variable thermal protection that can be a dapted, as required, to ambient conditions.

8.1.16 DB Cargo Building

a) b)

a) View of the DB Cargo Building (Oesterle et al., 2001, p. 129)
b) View of the façade (Oesterle et al., 2001, p. 129)

Table 8.16 DB Cargo Building

Authors – Web sites	Oesterle et al., (2001)
Architect	INFRA in collaboration with Rhode, Kellemann, Wawrowsky + Partner.
Location of the building	Mainz
Façade Type	Double-skin strip-window façade. The construction is a combination of box-window and corridor-façade types: there are no vertical divisions on the structural axes, yet the shallow depth of the cavity between the façade layers means that this space is not a corridor in the true sense.
Ventilation of the cavity	Natural ventilation
Façade construction – Pane type	Inner façade: aluminium window construction with side/bottom-hung casements. Outer façade: aluminium load-bearing sections; point-fixed toughened safety glass. The aim of reducing the sound-level by at least 5 dB, while at the same time ensuring natural ventilation of the offices for as much of the year as possible, was achieved by designing continuous air-intake and extract slits with the appropriate dimensions. These are laid out horizontally on every floor. Vertical dividing elements were not inserted in the intermediate space in view of the use of the building. The shallow depth of the cavity and the high level of traffic noise externally made a division of this kind unnecessary. The intermediate space’s depth is approximately 23 cm.
Shading device type	Aluminium louvered blind (louvered width: 80 cm).
HVAC	The construction of a double-skin façade made window ventilation possible, thereby overcoming the problem of a non-openable façade with inevitable air-conditioning of the adjoining rooms. A partial air-conditioning system was installed, providing a 2.2 fold hourly air change (ach).

Comments	Taking into account the savings made in the air-conditioning, the simple form of construction and the high degree of prefabrication of the façade resulted in an economical solution.

8.1.17 Gladbacher Bank

a) b)

a) Gladbacher Bank before the refurbishment (Oesterle et al., 2001, p. 174)
b) Gladbacher Bank after the refurbishment (Oesterle et al., 2001, p. 174)

Table 8.17 Gladbacher Bank

Authors – Web sites	Oesterle et al., (2001)
Architect	Schrammen und Partner.
Location of the building	Mönchengladbach
Façade Type	The Double Skin Façade was a part of a refurbishment project. The outer layer is designed as a virtually frameless glass construction, articulated into a series of horizontal stepped-back planes. The concept is based on the shaft-box façade principle.
Ventilation of the cavity	No information given.
Façade construction – Pane type	A single layer of reflecting, sun-screen glazing was inserted in the outer skin.
Shading device type	Adjustable sunshading in the intermediate space.

HVAC	The thermal uplift over the three upper stories and the appropriate dimensioning of the air-intake and extract openings ensure a satisfactory supply of external air for the rooms when the inner façade is open.
Comments	Takinginto account the savings made in the air-conditioning, the simple form of construction and the high degree of prefabrication of the façade resulted in an economical solution.

8.1.18 Energie/Versorgung Schwaben (ENBW)

a) b) c)

a) View of the entrance (baggeridge - http://www.baggeridge.co.uk/baggeridge/Exports/German_apps/app_image1/germany1_zoom.htm)
b) Extension for ENBW (Oesterle et al., 2001, p. 126)
c) Detail of box window construction (Oesterle et al., 2001, p. 126)

Table 8.18 Energie/Versorgung Schwaben (ENBW)

Authors – Web sites	Oesterle et al., (2001)
Architect	Lederer, Ragnarsdottir, Oei.
Location of the building	Stuttgart.
Façade Type	Box-window construction.
Ventilation of the cavity	No information given.

Façade construction – Pane type	Inner façade: Wood casements in laminated construction board with bottom- and side-hung opening lights in aluminium. Outer façade: slide-down/push-out casement construction, operated by electric motors.
Shading device type	Aluminium louver blinds (louver width: 80mm).
HVAC	No information given.

8.1.19 BML Headquarters Building


a) b)

a) Photo of model of the building (Oesterle et al., 2001, p. 127)
b) Photo of model of refurbished façade (Oesterle et al., 2001, p. 127)

Table 8.19 BML Headquarters Building

Authors – Web sites	Oesterle et al., (2001)
Architect	Ingenhoven Overdiek Kahlen
Location of the building	Stuttgart
Façade Type	Box-window construction.
Ventilation of the cavity	No information given.
Façade construction – Pane type	Inner façade: Wood casement construction with side- and bottom-hung opening lights. Outer façade: all-glass pivoting lights, operated by electric motors.
Shading device type	Aluminium louver blinds (louver width: 100 mm).
HVAC	No information given.

8.1.20 Post Office Tower

a) b) c)

a) Photo of model of Post Office Tower (Oesterle et al., 2001, p. 160)
b) View of Post Office Tower (http://www.qscaudio.com/images/press/2003/06_03/bonn_tower_hi.jpg)
c) View of the cavity (http://www.office-work.com/officework/Space/228143.html)

Table 8.20 Post Office Tower

Authors – Web sites	Oesterle et al., (2001)
Architect	Murphy/Jahn, Chicago
Location of the building	Bonn
Façade Type	Slenderly dimensioned, filigree double-skin facades with automatic controls. The façade construction is suspended in nine-story-high sections.
Ventilation of the cavity	No information given.
Façade construction – Pane type	Flint glass is foreseen for the inner and outer skins.
Shading device type	The north side of the tower has a smooth planar external façade with integrated flaps. All opening lights in the external skin are operated by electric motors controlled from a central monitoring system.

HVAC	The structural concept provides for a transmission of horizontal (wind) loads via a series of so-called ‘wind needles’ situated on every floor and every façade axis. The south face of the tower has a scale-like construction, with horizontally pivoting lights that allow an intermittent air-intake and extract and thus natural ventilation of the offices. The inner façade skins contain narrow side-hung casements in alternate façade bays. These are also operated by electric motors and serve to ventilate the offices by natural means.

8.1.21 Tower block at Olympic Park

a)

a) Photo of model of Tower at the Olympic Park (Oesterle et al., 2001, p 131).

Table 8.21 Tower block at Olympic Park

Authors – Web sites	Oesterle et al., (2001)
Architect	Ingenhoven, Overdiek and Partner.
Location of the building	Munich

Façade Type	Double-skin curtain-wall façade in prefabricated unit-construction system.
Ventilation of the cavity	No information given.
Façade construction – Pane type	Inner façade: aluminium window construction with side- and bottom-hung casement doors. Outer façade: aluminium supporting sections; linear bedding of glass.
Shading device type	Aluminium louver blinds (louver width: 80 mm).
HVAC	No information given.

8.1.22 Business Tower

a)

b)

c)

a) View of model of Bussiness Tower (Oesterle et al., 2001, p. 120)
b) Entrance of Business Tower (http://www.josef-gartner.de/referenzen/referenzen2e.htm)
c) Façade of Business Tower (Oesterle et al., 2001, p. 121)

Table 8.22 Business Tower

Authors – Web sites	Oesterle et al., (2001)
Architect	Architects Working Group, Dürschinger+ Biefang/Jörg Spengler. Façade planning: DS-Plan GmbH, Stuttgart.
Location of the building	Nuremberg
Façade Type	Double-skin façade with permanently ventilated cavity. Unit construction system with extremely high level of prefabrication.
Ventilation of the cavity	No information given.
Façade construction – Pane type	Inner façade: prefabricated aluminium special frame construction with side- and bottom-hung casements, and opening flaps, each in every second bay. Outer façade: prefabricated aluminium special frame construction with screen-printed glass panes over edges of floor slabs.
Shading device type	Aluminium louver blinds (louver width: 100 mm).
HVAC	No information given.

8.1.23 Business Promotion Centre and the Technology Centre

a) b)

a) View of Business Promotion Centre (Compagno, 2002, p. 120)
b) View of the façade (Compagno, 2002, p. 120)

Table 8.23 Business Promotion Centre and the Technology Centre

Authors – Web sites	Compagno, (2002)
Architect	Foster and Partners in cooperation with Kaiser Bautechnik
Location of the building	Duisburg
Façade Type	Curved double-skin façade.
Ventilation of the cavity	Air is injected at slightly higher than ambient pressure into the lower part of the cavity and the warming effect results a natural stack effect. This air rises and removes heat from the louver blinds and continues upwards to be expelled into the open air through small openings by the roof edge.
Façade construction – Pane type	Clear single glazing. The façade consists of 1.50 × 3.30 m toughened, 12 mm thick panes suspended in vertical aluminium mullions. The inner façade skin consists of storey high

	side-hung windows with thermally broken aluminium profiles and insulating glass units; outside is a 6 mm float glass, inside is an 8 mm laminated glass with low-E and the cavity between is filled with argon gas.
Shading device type	Perforated, computer-controlled aluminium louvers are incorporated into the cavity between the two skins.
HVAC	As the building is situated next to a very busy road the option of full air conditioning was preferred to other solutions with natural air ventilation. A displacement ventilation system is used. The fresh air flows in through narrow slits along the window front and spreads out along the floor forming a ‘fresh air pool’.
Comments	Since the building went into operation, overheating problems have been reported in the top floors.

8.2 Finland

8.2.1 Sanomatalo


a)


b)

a) View of Sanomatalo (Uuttu, 2001, appendix A)
b) View of the vavity (Uuttu, 200, appendix A1)

Table 8.24 Sanomatalo

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehtitoimisto Jan Söderlund & Co. Oy
Location of the building	Helsinki
Façade Type	The building's east-, south- and west façades are double-skin façades. Double-skin façade 5 000 m². The façade type is box window
Ventilation of the cavity	The cavity is closed and can be vented by motor-operated vents at the top and bottom, which are controlled by thermostats.
Façade construction – Pane type	The inner envelope consists of three glass layers: - inner glass: toughened and laminated 6+4 mm, in between a 0.76 mm PVB - middle glass: toughened 4 mm - outer glass: toughened and coated selective sun protection glass 6 mm - the space: argon and krypton gas The outer envelop: - toughened and laminated 6+6 mm glass panes The width of the intermediate space is 700 mm.
Shading device type	Blinds exist inside the inner envelope.
HVAC	No information given.
Comments	A maintenance gondola fixed onto the girders of the roof enables outside maintenance. The gondola has a rack for a glass pane. Inside maintenance is handled from the intermediate space with a security cable wire.

8.2.2 SysOpen Tower

a) b)

a) View of SysOpen Tower (Uuttu, 2001, appendix C)
b) View of the façade (Uuttu, 2001, appendix C)

Table 8.25 SysOpen Tower

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehdit Tommila Oy
Location of the building	Helsinki, Pitäjänmäki
Façade Type	Double-skin façade 5 800 m². The façade type is box window.
Ventilation of the cavity	No information given.
Façade construction – Pane type	The inner envelope consists of 2k=2k4-18, 26 mm thick glass and the outer envelope consists of 1k=1k8 tempered, 8 mm thick glass. The width of the cavity is 550 mm.
Shading device type	Automatic solar blinds are placed inside the cavity.
HVAC	No information given

8.2.3 Martela


a)


b)

a) View of Martela (Uuttu, 2001, appendix D)
b) View of the façade (Uuttu, 2001, appendix D)

Table 8.26 Martela

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehdit Tommila Oy
Location of the building	Helsinki, Pitäjänmäki
Façade Type	The double-skin façade is totally separated from the main frame of the office building. The inner envelope is connected to a vertical I-profile column going along the outer edges of the intermediate floors from the foundation to the top. Double-skin façade 1800 m^2. The façade type is box window
Ventilation of the cavity	Each floor has two service doors to the cavity. Ventilators are installed at the corners of the cavity area. Their purpose is to move warm air through the corners.
Façade construction – Pane type	Inner envelope: (850 mm high and 2700 mm wide) - heat insulating glass, 4 mm + 4 mm laminated due to the rail requirements Outer envelope: (one story high and 1350 mm wide) - 12 mm tempered glass

	The thickness of the outer envelope's glass pane would have been 15 to16 mm without a vertical aluminium rod support. The width of the cavity is 700 mm.
Shading device type	A set of solar blinds is installed in the cavity.
HVAC	No information given.

8.2.4 Itämerentori


a) b)

a) View of Itämerentori (Uuttu, 2001, appendix E)
b) View of the cavity (Uuttu, 2001, appendix E)

Table 8.27 Itämerentori

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehtitoimisto Helin & Co.
Location of the building	Helsinki
Façade Type	Double-skin façade 4 000 m². The façade type is box window.
Ventilation of the cavity	The windows of the inner envelope are fixed. However ventilation doors open to the intermediate space. The intermediate space has gravitational ventilation.
Façade construction – Pane type	The outer glazed skin consists of 6-8 mm toughened glass. The circular part of the building has laminated glass. The glass panes were Heat-Soak tested. The average size of one glass pane is 2692 mm wide, 855 mm high and the

	weight is 30 kg. The horizontal joints of the pane have weathering steel glazing bars and the vertical joints are sealed with silicon sealant. The width of the cavity is 925 mm.
Shading device type	Motorized solar shading blinds are placed outside the inner envelope's windows.
HVAC	No information given
Comments	The cavity has no service platform. Maintenance within the intermediate space is carried out with a gondola fixed onto the girders of the roof. The gondola can move freely within the cavity because no service platform exists. Outside maintenance is performed in a similar way.

8.2.5 Nokia Ruoholahti

a) b)

a) View of Nokia Ruoholahti (Uuttu, 2001, appendix F)
b) View of the cavity (Uuttu, 2001, appendix F)

Table 8.28 Nokia Ruoholahti

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehtitoimisto Helin & Siitonen Oy
Location of the building	Helsinki
Façade Type	Double-skin façade 8 000 m². The façade type is box window.

Ventilation of the cavity	The windows of the inner envelope are fixed. However ventilation doors open to the intermediate space. The intermediate space has gravitational ventilation.
Façade construction – Pane type	Inner envelope: - double insulating glass Outer envelope: - 6 mm thick, tempered glass with a silk pattern, which was baked onto it with a ceramic paint in connection with the annealing process.
Shading device type	The top of the intermediate space is provided with an adjustable louvre, while the bottom is open. A gondola fixed onto the cantilever girders of the roof provides access into the intermediate space for maintenance purposes. There is no service platform in the cavity.
HVAC	No information given.
Comments	The glass cladding delimits a favourable microclimate inside the building and helps to restrict the excessive amount of solar heat and traffic noise.

8.2.6 Sonera

a) b)

a) View of Sonera (Uuttu, 2001, appendix L)
b) Interior of Sonera (Uuttu, 2001, appendix L)

Table 8.29 Sonera

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehtitoimisto SARC
Location of the building	Helsinki
Façade Type	The starting point was to create an office block into the industrial environment. The street--side façades are partly covered with almost black, screen-printed and laminated glass panes. Double-skin façade 1060 m². The façade type is box window.
Ventilation of the cavity	The cavity formed is open at bottom and top.
Façade construction – Pane type	Inner envelope: - green 6 mm glass (outer) - argon gas 15 mm (middle) - selective 4 mm Ekoplus- glass (inner) Outer envelope: - 4+4 mm laminated glass (in between 0,76 mm opal sheet) elements. Both of the glasses are tempered and Heat Soak tested. One of the glasses is clear and the other one is grey with a silk screen-printed pattern.
Shading device type	No information given.
HVAC	No information given.

8.2.7 High Tech Centre

a) b)

a) View of High Tech Centre (Uuttu, 2001, appendix K)
b) View of the cavity (Uuttu, 2001, appendix K)

Table 8.30 Hi Tech Centre

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehtitoimisto Helin & Siitonen Oy
Location of the building	Helsinki
Façade Type	Double-skin façade 12 000 m². The façade type is storey high. The cavity is separated at each intermediate floor.
Ventilation of the cavity	No information given
Façade construction – Pane type	The inner envelope consists of two different kinds of windows. The lower windows consist of: - float glass 6 mm - argon gas 18 mm - clear selective float glass 6 mm and the upper windows consist of: - tenpered float glass 6 mm - argon gas 18 mm and tubes monitoring light - clear selective float glass 4 mm

	The outer glass skin consists of 10 mm tempered glass. The horizontal joint has an aluminium glazing bar and the vertical joints are left open with a 10 mm gap. The cavity is only 342 mm deep and not accessible.
Shading device type	No information given
HVAC	No information given
Comments	The inner envelope's windows can be opened to perform cleaning inside the cavity. Outside cleaning is performed from a hoist.

8.2.8 Radiolinja

a) b)

a) View of Radiolinja (Uuttu, 2001, appendix B)
b) View of the cavity (Uuttu, 2001, appendix B)

Table 8.31 Radiolinja

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehdit Tommila Oy
Location of the building	Espoo, Keilalahti
Façade Type	Double-skin façade 10 000 m². The façade type is box window.
Ventilation of the cavity	The air in the cavity can be used for heating and cooling purposes.

Façade construction – Pane type	Inner envelope windows: (aluminium frame) - 6 mm selective glass (inner), - 4 mm float glass (middle) and - 6 mm tempered glass (outer) The outer envelope: (1.3 m wide and 3.6 m high) - 12 mm thick tempered glass The intermediate space is about 650 mm deep.
Shading device type	Motorized solar shading blinds are placed in the cavity.
HVAC	No information given.

8.2.9 Nokia K2

a) b)

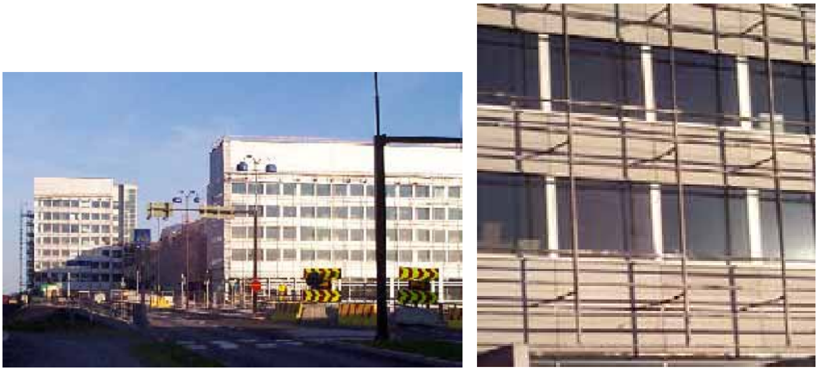
a) View of Nokia K2 (Uuttu, 2001, appendix G)
b) View of the cavity (Uuttu, 2001, appendix G)

Table 8.32 Nokia K2

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehtitoimisto Helin & Co
Location of the building	Espoo, Keilalahti
Façade Type	Double-skin façade 1900 m². The façade type is box window.
Ventilation of the cavity	No information given.

Façade construction – Pane type	Inner envelope: - double insulating glass Outer envelope: (900 mm high and 1500 mm wide) - 6 mm thick tempered glass The width of the cavity is 600 mm.
Shading device type	Solar blinds are installed in the cavity.
HVAC	No information given
Comments	A maintenance rail exists only in the roof areas were it is difficult to reach with a hoist. The cleaning within the intermediate space is done from the service platform. A water post is installed in the cavity.

8.2.10 Iso Omena mall


a) b)

a) View of Iso Omena mall (Uuttu, 2001, appendix H)
b) View of the façade (Uuttu, 2001, appendix H)

Table 8.33 Iso Omena mall

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehdit Tommila Oy
Location of the building	Espoo, Matinkylä

Façade Type	Two of the façades include a double-skin façade. One of them is situated towards the highway Länsiväylä and its purpose is to damp the traffic noise. Double-skin façade 1000 m^2. The façade type is box window.
Ventilation of the cavity	The cavity is not open at the top. The cavity is closed at its sides. The bottom of the cavity is closed with a laminated glass for sound insulation purposes.
Façade construction – Pane type	The inner envelope’s glass panes are float glass. The outer envelope has 8 mm thick tempered glass. The glass panes are 2600 mm wide and 2000 mm high. The width of the cavity is 1000 mm.
Shading device type	No information given.
HVAC	The roof will have a felt covering and a rain moulding where a drain for rainwater starts and goes to the HVAC-room through the inner wall element.
Comments	A gondola fixed onto the girders of the roof enables inside maintenance. Outside maintenance is done from a hydraulic hoist.

8.2.11 Kone Building

a) b)

a) View of Kone Building (Uuttu, 2001, appendix I)
b) View of the cavity (Uuttu, 2001, appendix I)

Table 8.34 Kone Building

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehtitoimisto SARC Oy
Location of the building	Espoo, Keilalahti
Façade Type	The inner layer consists of one storey high units suspended from the intermediate floors. Double-skin façade 5000 m^2. The façade type is box window.
Ventilation of the cavity	The cavity is open from the bottom and each floor has vents, which can be opened.
Façade construction – Pane type	Inner envelope: - insulating glass Outer envelope: (1350 mm wide and 3900 mm high) - 8 mm tempered clear glass panes with a silk screen pattern. The outer surface has varying glasses depending on the orientation. Beside the lift shaft there is a fire resistant glass. The deflection of the outer glass pane is not sig-

	nificant because the glass pane is supported on each four sides. The width of the cavity is 580 mm.
Shading device type	No information given.
HVAC	No information given.
Comments	Inside maintenance is handled from the service platform in the cavity, which is equipped with a security wire rope. A gondola fixed onto the girders of the roof enables outside maintenance and cleaning.

8.2.12 Nokia Keilalahti

a) b)

a) View of Nokia Keilalahti (Uuttu, 2001, appendix J)
b) View of the façade (Uuttu, 2001, appendix J)

Table 8.35 Nokia Keilalahti

Authors – Web sites	Uuttu, (2001)
Architect	Arkkitehtitoimisto Helin & Siitonen Oy
Location of the building	Espoo, Keilalahti
Façade Type	Double-skin façade 8600 m². The façade type is box window.

Ventilation of the cavity	In summertime the louvres are mainly open to let warm air go out and fresh air flow in at the bottom of the cavity. In winter-time they are closed to form a heat-insulating buffer.
Façade construction – Pane type	The outer envelope: (width 1350 mm and height 3600 mm) - 6 mm tempered clear glass The inner envelope: - 2k6-12 selective glass, argon gas in between The outer glass pane is placed between a flat bar and an acid resistant tube. It is sealed with elastic butyl. The width of the cavity is 690 mm.
Shading device type	Solar blinds are placed outside the inner envelope to restrict the excessive amount of solar heat. At the upper end of the intermediate space motorized louvers are plced.
HVAC	No information given
Comments	The cleaning of the outer glasses is done from a hoist. A maintenance rail only exists in the roof areas where it is difficult to reach with a hoist. Inside maintenance and cleaning of the outer glass panes is done from the service platform.

8.2.13 Korona

a) b)

a) View of the Korona building (Uuttu, 2001, appendix M)
b) View of the façade (Uuttu, 2001, appendix M)

Table 8.36 Korona

Authors – Web sites	Uuttu, (2001)
Architect	ARK-house arkkitehdit Oy
Location of the building	Viikki
Façade Type	The cylindrical form of the building has an energy saving effect; the area of the envelope is small compared to the volume of the building. The double-skin façade covers 3/4 of the building's outer shell. Double-skin façade 2500 m². The façade type is box window.
Ventilation of the cavity	In winter fresh air is taken from the southern side of the building and used in the HVAC-system. In summer the fresh air is taken from the northern side. The exhaust air is conducted to the cavity when the cavity's enthalpy is smaller than the enthalpy of outside air.
Façade construction – Pane type	The windows in the inner envelope have a selective 2k insulating glass where the outer glass is K Glass and the inner glass is clear 4-6 mm laminated glass. The outer envelope consists of clear, 6 mm thick float glass and partly also selective glass. Partly the cavity is about 2 meters wide and partly more to form winter gardens.
Shading device type	No information given.
HVAC	Results have shown that up to 75% have been saved energy costs for heating.
Comments	The cleaning of the glass skins can be difficult because no service platforms exist in the 13 meters high cavity area.

8.2.14 JOT Automation Group

a)

a) View of JOT Automation Group Building (Uuttu, 2001, appendix N)

Table 8.37 JOT Automation Group

Authors – Web sites	Uuttu, (2001)
Architect	ARK-house arkkitehdit Oy
Location of the building	Viikki
Façade Type	Double-skin façade 1000 m^2. The façade type is box window.
Ventilation of the cavity	No information given.
Façade construction – Pane type	Inner envelope: (triple) - 6 mm antisun, green glass (outer) - 4 mm clear glass (middle) - 4 mm clear glass (inner) Outer envelope: (3600 mm high and 1500 mm wide) - 10 mm tempered, Heat Soak-tested, green sun protective glass panes. The cavity formed is one meter deep.
Shading device type	No information given.
HVAC	No information given.

Comments	A service platform exists for maintenance. On the southern and western side of the building a double-skin façade is suspended from a steel truss to reduce traffic noise and solar radiation.

8.3 Sweden

8.3.1 Kista Science Tower, Kista

a) b) c)

a) View of Kista Science Tower
b) View of the cavity
c) Shading devices

Table 8.38 Kista Science Tower

Year of construction:	2002 – 2003
Size:	32 storeys, 6000 m^2 double skin façade, floor area 700 m^2/storey i.e. appr. 22000 m^2
Use:	Office, cell-type or open-plan office
Architect:	White arkitekter (participated during the entire building process)
Contractor:	NCC
Facade contractor	FFT – Feldhaus, Flexfasader, Trosa Glas
Motive:	Image, commercial property development project, fully glazed façade to give a feeling of volume

Principle of façade construction:	Two of the three facades (triangular floor plan)are double skin facades, the third (to the north) is a single skin facade. The double skin facades are of the type corridor façade with diagonal ventilation. The cavity with gangways on each floor and automatically controlled (2.7 m sections) perforated Venetian blind. Internal Venetian blinds will be installed on the north side. Non-openable windows. Scücho building system.
Construction, material:	Prefabricate one-storey high aluminium construction Outer skin: 8/10 mm H, non-coloured Inner skin: double-pane sealed glazing units with LE glass, non-coloured, 1.35 m on centre
Climate system in rooms:	Balanced ventilation with heat recovery, indoor design temperature in winter 22 ±1,5°C, in summer 24°C at design outdoor temperature +26°C. Active cooling beams 2.7 m on centre
Daylight:	-
Energy:	IDA ICE simulations by Theorells and NCC Teknik.
Sound:	Thanks to the double skin façade the requirements on the inner skin has been lowered.
Fire:	Every fourth storey is fire sectioned. The office areas are equipped with a sprinkler system.

8.3.2 NOKIA House, Kista

a) b)

a) View of the façade
b) View of the façade

Table 8.39 Nokia house

Year of construction:	1999-08 – 2001-03
Size:	Floor area 42 350 m², 23 400 m² premises. Appr. 3150 m² double skin façade.
Use:	Office and research centre
Architect:	White arkitekter
Façade Contractor:	Skanska Glasbyggarna
Motive:	Image, reduced cooling demand, protection for Venetian blinds, possibility to do without radiators, aesthetics and futurist facade, sound reduction from the highway E 4.
Principle of façade construction:	One-storey high cavity divided into five slits with openable glazed gables. 700 mm cavity with gangways on each floor. Motorized Venetian blinds, controlled by a pyranometer. Perforated 5%.
Construction, material:	Outer skin: 10 mm

	Inner skin: Double pane sealed glazing unit with outer pane of soft coated LE glas, 12 mm argon gas och inner pane of 300/30 clear glass for the wall below the window.
Climate system in rooms:	Winter +21°C ±2°C. Operative 20°C. Summer +23°C +2–3°C.
Daylight:	Daylight redirection with split Venetian blinds.
Energy:	Radiators and active cooling beams. District heating.
Sound:	Good. Calculated values fulfil the requirements.
Fire:	The building is equipped with a sprinkle system. No sprinkler system in the double skin facade.

8.3.3 Arlanda, Pir F, Sigtuna

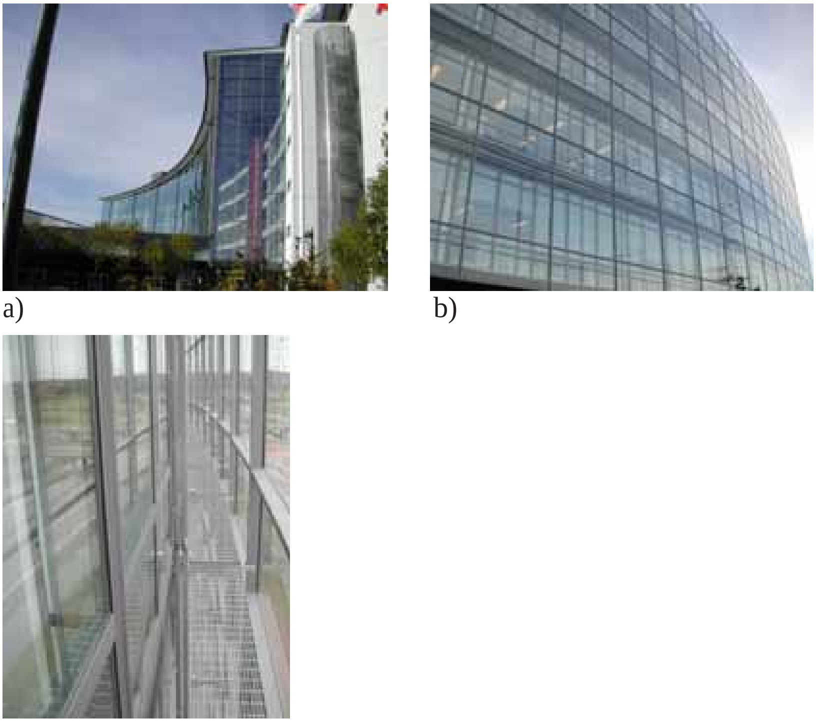
a) b)

a) View of the Arlanda
b) View of the façade

Table 8.40 Arlanda pir F

Year of construction:	2001
Size:	Floor area 67500 m², appr. 13000 m² double skin façade
Use:	Terminal building for the Star Alliance Group
Architect:	KHR AS
Façade contractor:	Flex facades
Motive:	Image, reduced cooling demand. The Architect wanted a fully glazed facade. The HVAC engineers allowed a solar factor of 0,15. With a traditional façade solution this meant either 50% covered façade area or permanent exterior solar shading. With a double skin façade intermediate solar protection in the form of Venetian blinds could fulfil the wishes of the architect.
Principle of façade construction:	800 mm (600 mm free/open) cavity the height of the building, with vertical sections of glass 60 m on centre. Motorized exhaust opening at roof level. 9.5 m long (!!) Venetian blinds. Non-openable windows. Cleaning with cleaning basket.
Construction, material:	Outer skin: 6 mm float glass. Lower big panes: 12 mm H Diamant Securit (iron free). Inner skin: 6 mm Planitherm Futur, 20 mm argon, 6 mm clear float. Lower big panes: 8 mm Planitherm Futur,16 mm argon, 8,76 mm Contrasplit.
Climate system in rooms:	In the VIP-lounges the requirement is max. operative temperature 26° and the remaining lounges max. operative temperature 27°. No deviation upwards is tolerated.
Daylight:	No daylight redirection.
Energy:	Convectors and cooling beams. District heating from the Brista plant in Märsta. District cooling from own cooling plant – free cooling from Halmsjön.
Sound:	Design sound reduction through the facades is Rw= 40 dBA.
Fire:	A sprinkler system is installed.

8.3.4 ABB Business Center, Sollentuna



a)

b)

c)

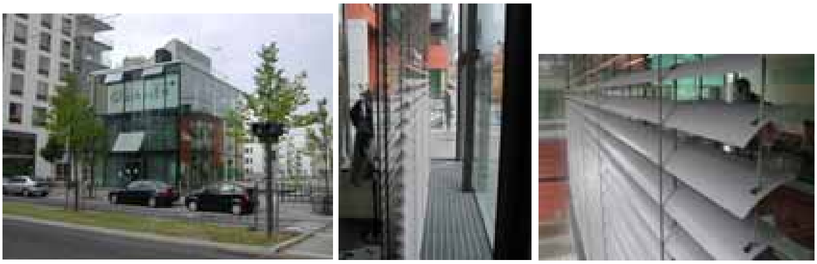
a) View of ABB
b) View of the façade
c) View of the cavity

Table 8.41 ABB Business Center

Year of construction:	2002
Size:	Floor area 18 000 m², ca 3200 m² double skin facade.
Use:	Office, cell-type or open-plan office
Architect:	BSK after ideas from Archus-Arosia
Façade contractor:	Trosa Glas
Motive:	Image. Calculations with double skin façade resulted in lower cooling demand than single skin facade. Sound proofing against the motorway E4.

Principle of façade construction:	3000 m^2 curved double skin façade facing west and north divided into four vertical shafts. 800 mm cavity the height of the building with automatically controlled non-perforated Venetian blinds and with grating gangway on each floor. Air enters at the bottom through the grating and leaves at the top through motorized controlled dampers. Non-openable windows. Inner curtains have been added for daylight control.
Construction, material:	Aluminium frame construction with 8 mm H single panes in the outer skin and LE glass in the inner skin (double pane sealed glazing unit) with Argon filling.
Climate system in rooms:	Balanced ventilation with heat recovery, active cooling beams. Convectors to prevent draught every second compartment. Winter to 21°C , summer 25°C.
Daylight:	No redirection of daylight
Energy:	District heating. Energy balance calculated with BVF^2 and IDA ICE simulations by Energo.
Sound:	
Fire:	A sprinkler system is installed

8.3.5 GlashusEtt



a) b) c)

a) View of GlashusEtt
b) View of the cavity
c) Shading devices

Table 8.42 GlashusEtt

Location:	Stockholm
Year of construction:	2001 – 2002
Size:	3 floors above and 2 floors below ground. Each plan approximate 100 m². 125 m² is double skin façade. Also one stairwell is built as a 1.5 m large double skin façade at the two upper floors.
Use:	Exhibition, office, and conference. In ground floors is a pump station and an electrical switchgear for the district located. The upper part is used as a technical information centre, showing HVAC, use of solar energy, fuel cell, biogas and municipal systems.
Architect:	Stellan Fryksell, Tengbom Arkitekter AB.
Contractor:	Grus och Betong AB
Facade contractor	Skandinaviska Glassystem AB
Motive:	Image, fully glazed façade to give a feeling of volume and show the possibility of using double skin façade for reducing energy consumption for cooling and heating.
Principle of façade construction:	The facades towards SSE, including parts of the adjacent façades, are double skin façades. The facades towards ESE are mostly made of single skin façade. The facade towards WSW contains an elevator, stairwell and shaft. Those are made of concrete. The facade towards NNE are made as single skin façade at the ground floor and contains one stair-well, which is build as a 1.5 m large double skin façade at the two upper floors. The double skin facades are of the type corridor façade with vertical ventilation over the whole height of the façade. The cavity with gangways on each floor and automatically controlled perforated Venetian blind.

	At the top and at the bottom there are automatically controlled dampers for controlling the airflow in the cavity. Non-openable windows.
Construction, material:	On-site erected steel construction. Outer skin: 2×8 mm Planibel Top N. Sealed glazing units with argon. Same parts are laminated and hardened. U-value=1,1, and for the façade < 1,3. Inner skin: 8 mm single-pane hardened glass.
Climate system in rooms:	Balanced ventilation with heat recovery. Active cooling beams. Indoor temperature is depending on the outdoor temperature, and varies between 22-26°C. With a dead zone of 1°C in comfort mode and 6°C in economy mode. Design outdoor conditions in summer is +27 °C 50% RH.
Daylight:	Daylight redirection with the automatically controlled Venetian blinds, which also can be manually controlled for each façade and floor.
Energy:	SolarCAD simulations by Omedia AB and IDA ICE simulations by WSP VVS-teknik.
Sound:	Noise reduction in the outer skin is 36 dB.
Fire:	The 3 floors over ground is one fire protection zone. This is possible because these storeys are equipped with a sprinkler system.

8.4 United Kingdom (UK)

8.4.1 Helicon Finsbury Pavement

a) b) c)

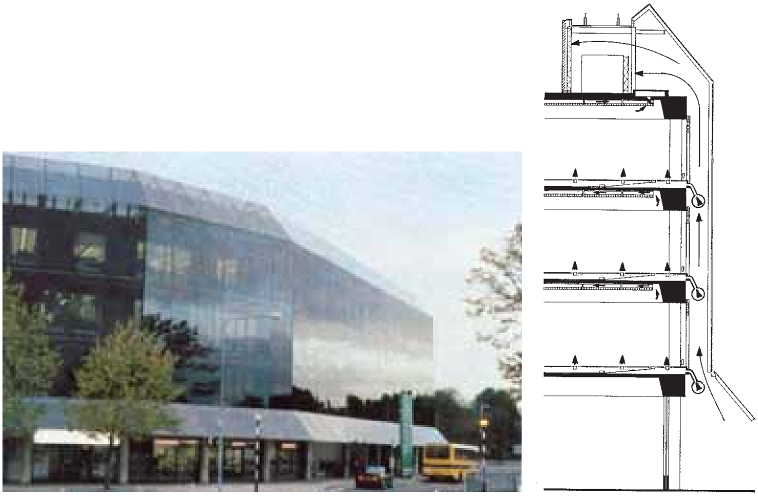
a) View of Helicon Finsbury Pavement (http://www.permasteelisa.com.sg/images/theelicon/01b.jpeg)
b) Shading devices (http://www.permasteelisa.com.sg/images/theelicon/03b.jpeg)
c) View of the cavity(http://www.permasteelisa.com.sg/images/theelicon/05b.jpeg)

Table 8.43 Helicon Finsbury Pavement

Authors – Web sites	Lee et al., (2002), Kragh, (2000)
Architect	Sheppard Robson
Location of the building	Finsbury Pavement, London
Façade Type	Extensive, clear full height inner and outer glazing due to the relatively deep floor plan.
Ventilation of the cavity	Both the origin and destination of the air in the cavity are external. In periods with no solar radiation, the extra skin provides additional thermal insulation. In periods with solar irradiation, the skin is naturally ventilated from/to the outside by buoyancy (stack) effects - i.e. the air in the cavity rises when heated by the sun (the solar radiation is absorbed by blinds in the cavity). Solar heat gains are reduced as the warm air is expelled to the outside.

Façade construction – Pane type	Mirror or solar tinted glass.
Shading device type	Intermediate louvre blades (14% perforation and 70% solar reflectance).
HVAC	Building Boasts chilled ceilings and floor based air supply as a lower energy, more comfortable alternative to high capacity VAV and fan coil systems.

8.4.2 Briarcliff House



a) b)

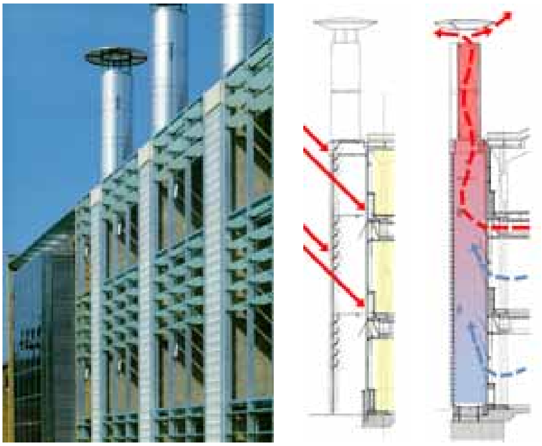
a) View of Briarcliff House (Compagno, 2002, p. 119)
b) Air flow inside the cavity (Compagno, 2002, p. 119)

Table 8.44 Briarcliff House

Authors – Web sites	Compagno, (2002)
Architect	Leslie and Godwin
Location of the building	Farnborough
Façade Type	Predominantly an Active Wall (or Climate Wall)

Ventilation of the cavity	Mechanically ventilated cavity. The air flow rate is 75 m^3/h per linear meter of façade. An extra skin is applied to the inside of the building envelope; inside return air is passing through the cavity of the façade and returning to the ventilation system. In periods with solar radiation the energy, which is absorbed by the blinds, is removed by ventilation. In periods with heating loads, solar energy can be recovered by means of heat exchangers.
Façade construction – Pane type	External Double glazing unit – 150 mm depth of the cavity – single pane internal glazing.
Shading device type	Automatically controlled venetian blinds are placed inside the cavity.
HVAC	The active wall is combined with an air-handling unit to provide thermal comfort, while the ventilation air is used to control humidity and indoor air quality.

8.4.3 Building Research Establishment

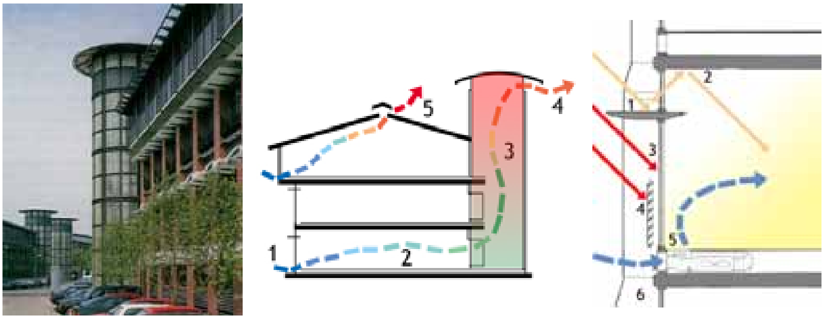

a) b) c)

a) View of the façade (LBNL - http://gaia.lbl.gov/hpbf/casest_a.htm)
b) Cross section of the façade (LBNL - http://gaia.lbl.gov/hpbf/casest_a .htm)
c) Cross section thourgh the ventilation stack (LBNL - http://gaia.lbl.gov/ hpbf/casest_a.htm)

Table 8.45 Building Research Establishment

Authors – Web sites	Lee et al., (2002)
Architect	Fielden Clegg
Location of the building	Garston
Façade Type	Low-rise, low-energy office building. A shallow open-office plan is coupled to a highly glazed façade.
Ventilation of the cavity	A passive stack ventilation system was designed as an alternative ventilation strategy for the open plan offices during extreme cooling conditions. Vertical chimneys draw hot air through the duct in the wave-form structure as well as through bottom-hung, hopper, etched windows. Low-resistance propeller fans are mounted at the top-floor level, to provide minimum ventilation and to flush internal heat gains during the night.
Façade construction – Pane type	No information given.
Shading device type	Translucent motorized external glass louvers, controlled by the building management system. They can be overridden by the occupants. The glass louvers can be rotated to diffuse direct solar or to a horizontal position for view.
HVAC	The floor plan is divided into open-plan and cellular offices allowing cross ventilation in the open plan arrangement while the 4.5-meter-deep cellular offices are located on the north side with single-sided natural ventilation.
Comments	A key feature of this building is the integration between natural ventilation and daylighting strategies.

8.4.4 Inland Revenue Centre



a) b) c)

a) View of Inland Revenue Centre (LBNL - http://gaia.lbl.gov/hpbf/casest_h.htm)
b) Cross section diagram for the ventilation strategy (LBNL - http://gaia.lbl.gov/hpbf/casest_h.htm)
c) Section diagram for the façade strategy (LBNL - http://gaia.lbl.gov/hpbf/casest_h.htm)

Table 8.46 Inland Revenue Centre

Authors – Web sites	Lee et al., (2002)
Architect	Michael Hopkins & Partners
Location of the building	Nottingham
Façade Type	Low-rise L-shape buildings with corner staircase towers.
Ventilation of the cavity	Fresh air is drawn through underfloor duct and grill which can be mechanically-induced. Warm air exhaust through the door, connected to the stair tower. Solar gain in the tower increases thermal buoyancy, warm air is drawn up through the tower by stack effect. Operable tower roof moves up and down to control the rate of air flow and the warm air is exhausted at the roof ridge on the top floor.
Façade construction – Pane type	Triple glazing with between-pane adjustable blinds.

Shading device type	Integrated lightshelf shades are installed. External brick piers provide lateral solar shading.
HVAC	Cross ventilation in office area by open windows.
Comments	The main strategies of the building are the maximization of daylight and engineered natural ventilation.

8.5 The Netherlands

8.5.1 Technical University of Delft Library


a) b) c)

a) View of the Library (Compagno, 2002, p. 116)
b) View of the façade (Compagno, 2002, p. 117)
c) Interior view (http://www.smartarch.nl/smartgrid/items/014_library.htm)

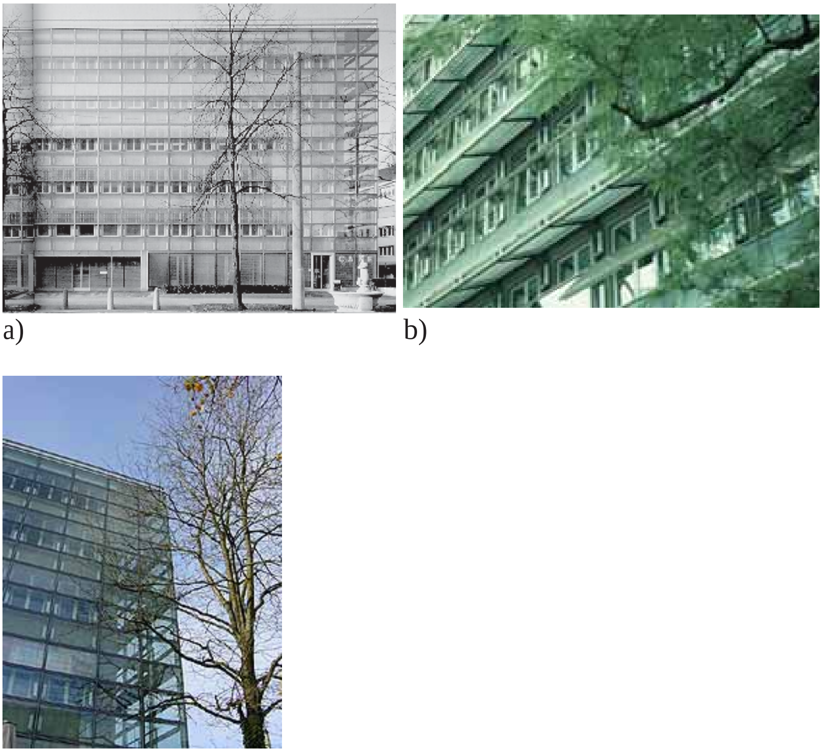
Table 8.47 Technical University of Delft Library

Authors – Web sites	Kragh, (2000), Compagno, (2002)
Architect	Mecanoo Architekten
Location of the building	Delft
Façade Type	Predominantly an Active Wall (or Climate Wall).
Ventilation of the cavity	Mechanically ventilated cavity. The air flow rate is 75 m^3/h per linear meter of façade. An extra skin is applied to the inside of the build-

	ing envelope; inside return air is passing through the cavity of the façade and returning to the ventilation system. In periods with solar radiation the energy, which is absorbed by the blinds, is removed by ventilation. In periods with heating loads, solar energy can be recovered by means of heat exchangers.
Façade construction – Pane type	External Double glazing unit with U-value of 1.5 W/m^{2}K made up of an 8 mm outer sheet and a 6 mm inner sheet with low-E coating – 150 mm depth of the cavity – single pane internal glazing 8 mm thick. It is a tougned glass designed as a sliding door thet gives acces to the cavity for cleaning.
Shading device type	Automatically controlled aluminium venetian blinds are placed inside the cavity.
HVAC	The active wall is combined with an air-handling unit to provide thermal comfort, while the ventilation air is used to control humidity and indoor air quality.

8.6 Switzerland

8.6.1 CAN-SUVA Building


a) b)

c)

a) View of the SUVA Building (http://people.deas.harvard.edu/~jones/lab_arch/H_and_dM/translations/hdm_4/hdm_4.html)
b) View of the façade (http://www.dcue.dk/Default.asp?ID=286)
c) View of the façade (http://www.arcspace.com/kk_ann/Basel/)

Table 8.48 CAN-SUVA Building

Authors – Web sites	Lee et al., (2002)
Architect	Herzog and De Meuron
Location of the building	Basel
Façade Type	Prismatic panel in double envelope system.
Ventilation of the cavity	No information given.

Façade construction – Pane type	The double-skin façade is divided into three sections. The upper section is made of insulating glass with integrated prismatic panels which automatically adjust itself as a function of the altitude of the sun. The vision window is made of clear insulating glass and is manually operated by the occupant during the daytime. The lower level window is automatically controlled to stay closed when solar and thermal insulation is required.
Shading device type	No information given.
HVAC	No information given.

8.7 Belgium

8.7.1 UCB Centre

a) b)

a) View of the UCB Centre (http://www.rics.org/about_us/awards/ucb_centre.html)
b) View of the façade (BBRI -_http://www.bbri.be/activefacades/images/ucb_01_siteweb_assar.jpg)

Table 8.49 UCB Centre

Authors – Web sites	Kragh, (2000), BBRI, (2002)
Architect	E. Bureau Verhaegen
Location of the building	Brussels

Façade Type	Predominantly an Active Wall (or Climate Wall)
Ventilation of the cavity	Mechanical ventilation is required in order to extract the solar heat from the façade cavity. The air flow rate is $40m^3/h$ per module (width 1.5 m), corresponding to 27 m^3/hm. The air velocities are: Inlet: 0.5 m/s Cavity: 0.05 m/s Outlet: 0.4 m/s
Façade construction – Pane type	External Double glazing unit with U-Value of $1.3W/m^2K$ – 143mm depth of the cavity – clear single internal glazing.
Shading device type	Motorized blinds are positioned in the ventilated cavity.
HVAC	Heating: The heating is provided by the supply air, which results in lower installation costs, and means that the glazing can be continued down to the floor level. The ventilation air is re-circulated when the building is not occupied. Cooling: The cooling is provided by mean of chilled ceilings operating with water at temperatures between 15°C and 17°C.

8.7.2 Aula Magna

a) b)

a) View of Aula Magna (http://www.infosteel.com/nl/R%C3%A9sultats%20Concours%202002%20cat%20A.htm)
b) View of the façade (BBRI - http://www.bbri.be/activefacades/images/AulaMagna/AulaMagna.jpg)

Table 8.50 Aula Magna

Authors – Web sites	BBRI, (2002)
Architect	Samyn & Partners
Location of the building	Luvain (situated in a calm environment)
Façade Type	There is no horizontal partitioning inside the façade.
Ventilation of the cavity	There is no interaction between the air used to ventilate the building and the ventilation of the façade. The ventilation pattern of the façade is natural and is based on the stack effect. No fan assists the ventilation. When the temperature in the cavity exceeds a given value, motorised windows at the bottom and the top of the façade are opened.
Pane type – Façade construction	Double glazing was placed in both sides of the cavity – 70mm depth of the cavity. Solar controls are installed in the cavity.
Shading device type	Venetian blinds. In principle the blinds are in all circumstances lowered. They are placed near the interior glazing layer.

HVAC	The whole building is equipped with a mechanical ventilation system. The heating and eventually the cooling of the building are realised via the ventilation system. No heat exchanger is installed in the building.

8.7.3 DVV Building


a) b)

a) View of DVV Building (http://www.civil.uwaterloo.ca/beg/ArchTech/Brussels%20Case%20Study.pdf)
b) View of the windows (http://www.civil.uwaterloo.ca/beg/ArchTech/Brussels%20Case%20Study.pdf)

Table 8.51 DVV Building

Authors – Web sites	BBRI, (2002), Saelens, (2002)
Architect	No information given
Location of the building	Brussels (centre)
Façade Type	Climate façade (double window system).
Ventilation of the cavity	In the offices, the heat produced can be removed with the exhaust air. The exhausted air is then brought to the climate façade. Ducts are therefore placed into the false ceiling. The air direction of the façade is from the top to the bottom of the façade.

Façade construction – Pane type	It consists of a double window and a single window separated approximately 15 cm from each other. The double window is double glazed at the exterior (U Value ~ 1.8 W/m^2K) and single glazed at the interior. The single window is a single pane safety glass.
Shading device type	The solar control is situated in the air cavity near the inside glazing layer. It is centrally controlled according to the orientation and the storey of the façade. No user control is available.
HVAC	The whole building is equipped with a central mechanical ventilation system. The air is centrally conditioned. The air is distributed in the different offices and is centrally exhausted. No heat exchanger on the exhaust air is installed. During the summer, a free cooling strategy can be applied if significant temperature difference between the inside and the outside is registered.
Comments	Measurements and extensive description of the building are given in "Low-energy design and airflow windows, some considerations illustrated with a case study" of Saelens and Hens.

8.8 Czech Republic

8.8.1 Moravian Library


a)


b)


c)

a) View of Moravian Library
b) View of the openable façade
c) View of the cavity - shading devices

Table 8.52 Moravian Librrary

Authors – Web sites	Pavel Charvat, Brno University of Technology
Date of completition	Spring 2001
Location of the building	Brno
Façade Type	The facades are eight stories high and nearly 50 m long.
Ventilation of the cavity	The building has openable double facades, which are used for natural ventilation of the building during warm seasons. One of the façades is used for solar preheating of ventilation air in cold seasons.

Façade construction – Pane type	The air cavity between the glass facade and the building facade has a width of 550 mm.
Shading device type	Two types of sunshades are used with the facades; fixed horizontal load bearing sunshades, which can also be used for cleaning and maintenance and motorized vertical sunshades on the building facade (windows).
HVAC	In air preheating mode the facade is closed and outdoor air enters the facade at the bottom and is drawn to the ventilation system through the openings at the top. In natural ventilation mode the facade is opened and the building is cross ventilated by means of opened windows.

8.9 United States of America

8.9.1 Seattle Justice Centre

a) b)

a) View of Seattle Justice Center Building (http://www.greenroofs.com/Seattle%20Justice%20Center%20Model%20by%20NBBJ.jpg)
b) View of Seattle Justice Center Building (http://gaia.lbl.gov/hpbf/picture/seattle.jpg)

Table 8.53 Seattle Justice Centre

Authors – Web sites	Lee et al., (2002)
Architect	Hegedus
Location of the building	Seattle
Façade Type	A nine-storey high heat extraction double-skin facade.
Ventilation of the cavity	No information given.
Façade construction – Pane type	Monolithic glazing on the outside and insulated glass on the inside of the thermal buffer.
Shading device type	Cat walks at the floor levels and light shelves at 8 feet above finish floor.
HVAC	No information given.

8.9.2 Occidental Chemical Center


a) b) c)

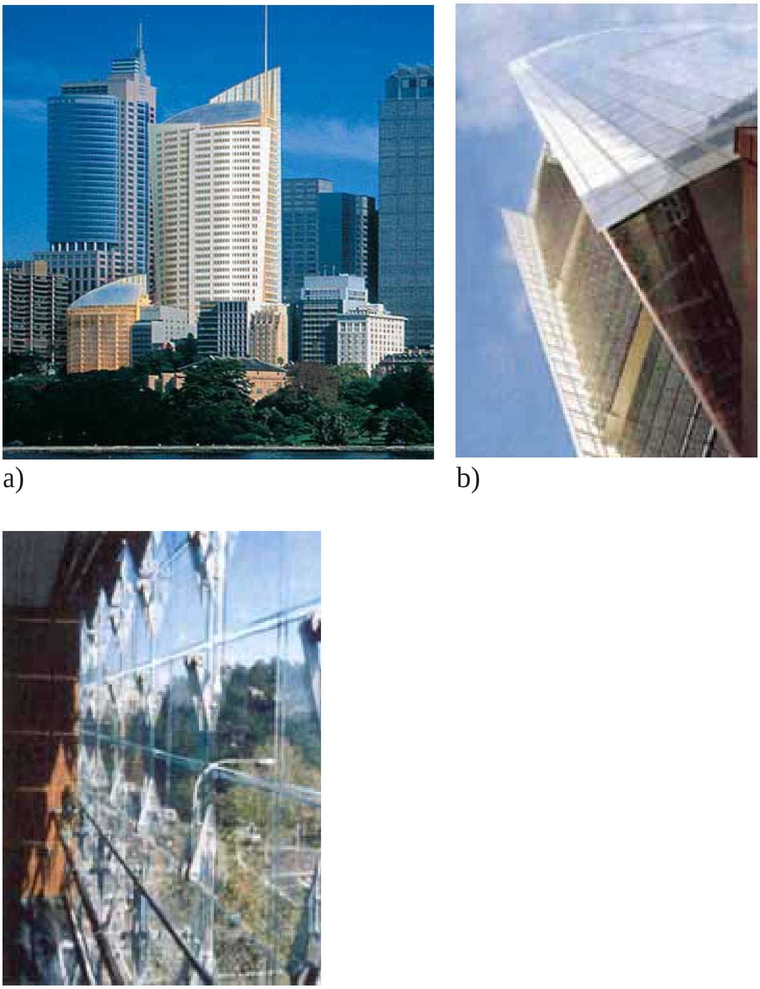
a) View of the building (http://www.fes.uwaterloo.ca/architecture/faculty_projects/terri/ds/hooker.pdf)
b) View of the cavity (http://www.fes.uwaterloo.ca/architecture/faculty_projects/terri/ds/hooker.pdf)
c) Air flow inside the DSF cavity (http://www.fes.uwaterloo.ca/architecture/faculty_projects/terri/ds/hooker.pdf)

Table 8.54 Occidental Chemical Center

Authors – Web sites	Harrison
Architect	Cannon Design Inc., Principal, Mark R. Mendell
Location of the building	New York
Façade Type	Buffer Facade with undivided, full height air space. Facade divided into four zones, one for each orientation. They are independent of each other as they respond to time of day and sun angle. Steel Frame, metal decking.
Ventilation of the cavity	Two systems: one for the extraction of air from within the wall cavity the second for conditioning of the interior spaces.
Façade construction – Pane type	The depth of the cavity is 1200 mm.
Shading device type	Operable louvers in air space with photocell control and manual override.
HVAC	Cooling - Electrically driven centrifugal chillers (for year-round heat recovery). Heating - gas-fired boilers. Ventilation - low pressure variable air volume distribution. All building systems (louvers, HVAC, fire alarm, security) are controlled by a centralized automated mainframe computer.
Comments	Cost: US$12,500,000 (Bid January 1980) Approximately US$62 per square foot. Design Energy Budget: 114,000 BTU per square foot per year.

8.10 Australia

8.10.1 Aurora Place office tower and residences



a)

b)

c)

a) View of Aurora Place (http://www.dupont.com/safetyglass/lgn/stories/15064.html)
b) View of Aurora Place (Compagno, 2002, p. 148)
c) Outer glazing (Compagno, 2002, p. 149)

Table 8.55 Aurora Place office tower and residences

Authors – Web sites	Compagno, (2002)
Architect	Renzo Piano Building Workshop
Location of the building	Sydney
Façade Type	Double-skin façade with glass louvers. The curved north – south facades of the 44-storey high-rise are of storey-high structural glazing units. The offices are placed in the west – east façade and service places are in between.
Ventilation of the cavity	No information given.
Façade construction – Pane type	The glass in the view-out area of the building is of 1.35 × 2.4 m insulating extra-white glass with an edge frit. The outer skin is laminated glass consisting of a 6 mm thick sheet with a continuous white-fritted dot pattern on the edge and a sheet of 6 mm low-E coated float-glass. Inside is a 6 mm sheet of low-E coated float-glass. The outer glazing consists of laminated 12 mm toughened extra-white glass.
Shading device type	Interior, textile blinds are provided for solar control and glare protection. The opaque areas in front of the parapet and the columns are clad with 2 × 6 mm laminated extra-white glass fritted with a white dot pattern giving 60% cover; there are white powder-coated metal sheets behind this glass. On the north façade which is exposed to the sun, there are horizontal metal sunscreens in addition to exterior textile blinds.
HVAC	In accordance with floor plan requirements, the inner façade is fitted with doors, fixed glazing units and bottom-hung windows for ventilation.

9 Important Information Sources

9.1 Literature

9.1.1 Double Skin Facades, Integrated Planning

This book, written in 2001 by Oesterle, Lieb, Lutz and Heusler is one of the most important ones that one can find, if interested in Double Skin Façades. It covers a wide range of aspects that influence the function and the efficiency of this system. The most important tasks that the book refers to are:

a) Types of construction. Classification of Double Skin Facades and case studies.
b) Detailed description of acoustics and sound transmission. The internal (room to room) and external sound insulation are examined. Case studies are provided.
c) Thermal insulation. Both the thermal insulation during the winter and the summer are examined.
d) Daylight. The daylight properties are not examined in detail, however this is not so important since these are related to glazed buildings and not necessarily double skin facades.
e) Fire protection. The description of the measures is quite detailed. There is also an interesting comparison of how safe the different types of Double Skin Facades are.
f) Aerophysics. The authors start from basic principles of Aerophysics in order to describe the airstreams and the thermal uplifts in Double Skin Facades. There is also a helpful description of the air flows in cavities.
g) High rise buildings.
h) Special characteristics of façade constructions – case studies.
i) Special constructional details (i.e. types of panes, fixings, etc).
j) Air conditioning – case studies.

k) Economic viability. The authors suggest in a quite detailed way methods to estimate the cost during the construction and maintenance stage.

The main advantage of this book is that it describes in an overall way the Double Skin Façade system allowing the reader to understand its main function. On the other hand it is often detailed providing useful information for further research and detailed case studies. Thus, this book can be used by readers with different background and interests.

9.1.2 Intelligent Glass Façades

This book, written by Compagno, (2002) refers not only to Double Skin, but also to all types of glazed facades. The main advantage of the book is that it starts with basic optical, thermal and technical properties of the pane providing a satisfactory background. A detailed description of different types of panes follows informing the reader about every individual pane type and coating. The book focuses on:

- The Glass Pane
    - Base Glass (Clear-White Glass, Body Tinted Glass, Photosensitive Glass, Photochromic Glass)
    - Surface Coatings (Reflective and selective coatings, Manufacturing process, Cold Mirror Coatings, Anti Reflection Coatings, Dichroic Coatings, Ceramic-Enamel Coatings, Angular Selective Coatings)
- Laminated Glass
    - Functional layers (Angle-Selective Films, Holographic Diffractive Films, Layers with Photovoltaic Modules)
    - Temperature Depended Layers (Thermotropic Layers, Thermochromic Layers)
    - Electro-Optic Layers (Liquid Crystal Layers, Electrochromic Layers)
    - Gasochromic Systems
- Insulating Glass
    - Gas Fillings
    - Fillings with Insulating Properties
    - Fillings with Solar Shading Properties
    - Fillings with Light Redirecting Properties

Concerning the Building Façades, there is a satisfactory classification and description of both single and double types. The case studies described, help the reader to better understand the constructions and how these technologies are applied in real buildings.

Although that the book does not focus only on Double Skin Façade systems, it can be really useful to a reader who is interested to gain more detailed knowledge in the main element of fully or highly glazed office buildings.

9.1.3 Energy Performance Assessment of Single Storey Multiple-Skin Façades

The PhD thesis of Saelens written in the Catholique University of Leuven in 2002 is one of the most advanced document in the energy performance assessment of single storey multiple-skin facades. Both experiments and numerical simulations have been made. As the author describes, *"Experimental work was done on naturally and mechanically ventilated single storey multiple-skin facades. Field experiments showed that good design and excellent workmanship are of crucial importance to obtain the desired performances"*.

A numerical model was developed and validated using experimental data provided from a controlled experimental set-up. In order to evaluate the energy performance of multiple-skin facades, the numerical model was implemented in an energy simulation tool. As Saelens describes, *"The results for a traditional facade solution with exterior shading device, a naturally ventilated double-skin facade and two mechanically ventilated multiple-skin facades are compared. The results are particularly sensitive to the modeling of the inlet temperature and the multiple-skin facade model complexity. By using multiple-skin facades it is possible to improve some components of the overall building's energy use. Unfortunately, most typologies are incapable of lowering the heating and cooling demand simultaneously. Only by combining typologies or changing the system settings according to the particular situation, a substantial overall improvement over the traditional insulated glazing unit with exterior shading can be obtained. The results further indicate that evaluating the energy efficiency of multiple-skin facades can not be performed by analyzing the transmission losses and gains solely. It is imperative to take into account the enthalpy change of the cavity air and to perform a whole building energy analysis. As a consequence of the diversity of the results, designers should be aware that multiple-skin facades do not necessarily improve the energy efficiency of their designs"*.

9.1.4 Properties and Applications of Double Skin Façades

The MSc thesis of Arons was written in 2000 in Massachusetts Institute of Technology (MIT). In the beginning of the thesis the author defines the Double Skin Façade system and classifies them mentioning the primary and secondary identifiers. The author does not present many case studies, but gives a very detailed description providing the reader all the necessary information he may need.

In the main part of the project, the author describes the existing calculation methods. After this description, a simplified numerical model of a typical Double Skin Façade is developed. This model is made for energy performance evaluation of multiple types. As the author describes *"the basic configuration for the window under study has a layer of insulating glass on the exterior, an air cavity and a single interior layer of glass. An inlet is assumed at the bottom and an outlet at the top.*

Two Dimensional heat transfer, neglecting edge effects are considered. The system is considered in the steady state condition, with constant temperatures throughout. Conduction and radiation are considered in the horizontal plane (one dimensional) and convection is considered in the vertical direction (also one dimensional)".

9.1.5 Study of Current Structures in Double Skin Façades

A Msc thesis was written in Helsinki University of Technology in 2001 by Uuttu. The main purpose of this thesis was to investigate the current structures in Double Skin Façades.

A short historical description and classification of double skin façades is included in the thesis. The thesis focuses mostly on the structural systems in double-skin façades. Uuttu divides the systems into three main types:

- cantilever bracket structure
- suspended structure and
- frame structure.

As the author describes, *"Cantilever bracket structures and suspended structures are most commonly used in Finland. Further double-skin façades constructed in Finland differ greatly from the ones constructed in Germany. In Finland, the cavities in double-skin façades are building-high, while in Germany they are partitioned horizontally at each intermediate floor and verti-*

cally on each window. This difference, results in the fact that the double-skin façades in Germany enable natural window ventilation, while in Finland their main purpose is to act as a raincoat for the inner façade".

In the last chapters of the thesis, interviews with different parties involved in double skin façade projects are included. Opinions concerning their past experience are given from architects, structural designers, contractors, manufacturers and HVAC – designers. Fourteen double-skin façades in Finland and five double-skin façades in Germany are given in the Appendix of the mentioned MSc thesis.

Finally, one additional reason that makes this thesis even more important as a backround source, for this literature review study is that it is one of the few documents written in English referring to Double Skin Façade Systems located in Nordic Climate.

9.1.6 Source Book for Active Façades by the BBRI

The document named "Source Book for Active Façades" has been written in the scope of a 2-year project from Belgian Building Research Institute (BBRI) in 2002. The document is subdivided in three main parts:

- In the first part definitions and examples of "active façades" are given in order to clarify the different existing concepts of these façade types. Each façade concept is described, explained and illustrated by pictures or figures.
- The aim of the second part of the source book is to identify the different considerations that are important in the decision making process for choosing an active façade.
- The third part of the document develops a classification system with three different levels of the active façades:
    - ¤ General and technical information about the façades and the building
    - ¤ Invariable characteristics of the façade and the building
    - ¤ Variable characteristics of the façade and the building

As the authors describe, *"The Invariable characteristics are descriptive elements that stay invariable whatever the season or the buildings use. These concepts can be deduced from the plans of the façade i.e. no knowledge of the use of the building is necessary to classify the façade. Each façade gets only one classification for each concept.*

The Variable characteristics make a distinction depending on the external/internal environmental conditions and the use of the building during different periods of time. Also knowledge of the systems scheme and performance is here necessary to classify the façade. A façade can have a time dependent classification system".

This document provides basic information for better understanding of the Double Skin Façade System. Although that it is not going very deep in the aspects of this façade system, it fulfils its main goal, i.e. to provide a satisfactory background for the reader.

9.1.7 High Performance Commercial Building Façades

This study, written in Lawrence Berkley National Laboratory (LBNL) in 2002 by Lee, Selkowitz, Vladimir Bazjanac, Vorapat Inkarojrit and Christian Kohler is organized around five major topics:

- Technological solutions used to create high-performance building facades.
- Design process (involves the conceptualization, analysis, procurement and implementation of a façade).
- Design tools.
- Performance assessments of existing or proposed "high-performance" façade systems.
- Building case studies.

This document is one of the most important ones when it comes to building facades. Apart from the well described case studies, it provides interviews which help the reader understand how each system applies to every building type. Additionally, it is a very satisfactory source for references, if one is interested to find related literature or web sites.

9.2 Web Sites

Some of the most important Web – Sites that were used for the report are mentioned bellow:

Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Berkeley, California. http://eetd.lbl.gov.

Harvard University and M.I.T. Research on Advanced Building Envelopes. http://www.buildingenvelopes.org

International Energy Agency (IEA), Solar Heating and Cooling Program (SHC). http://www.iea-shc.org/.

Helsinki University of Technology (HUT) electronic academic dissertations. http://lib.hut.fi/Diss/.

Helsinki University of Technology (HUT), Laboratory of Steel Structures. http://www.hut.fi/Units/Civil/Steel/index.html.

Katholieke Universiteit Leuven, Laboratorium Boufysica.
http://www.bwk.kuleuven.ac.be/bwf/index.htm.

Belgian Building Research Institute (BBRI).
http://www.bbri.be/activefacades/

University of Waterloo, School of Architecture.
http://www.fes.uwaterloo.ca/architecture/.

ESRU Publications.
http://www.esru.strath.ac.uk/publications.htm#books.

Energy Research Group, University College Dublin, School of Architecture. Mid-Career Education, Solar Energy in European Office Buildings. http://erg.ucd.ie/mid_career/mid_career.html.

Energy Comfort 2000 project.
http://erg.ucd.ie/EC2000/download_main.html.

Battle McCarthy's. Consulting Engineers & Landscape Architects.
http://www.battlemccarthy.com/.

10 Discussion and Conclusions

10.1 Introduction

Double Skin Façades were developed mostly in Europe in order to arrive at increased transparency combining acceptable indoor environment with reduced energy use. Different literature sources prioritise in a different way the main goals that can be achieved when choosing this façade type. Thus, it is important to briefly describe the methodology which should be followed when designing a façade, in order to optimize the function, performance and use of the Double Skin Façade System.

First of all, the clients and users have to ask for quality by specifying performance requirements for the building to be built or refurbished. Then, the engineer/architect responsible for the façade design should prioritise the main goals that need to be achieved during the design, construction, and occupation stage of the building. This should be done in close co-operation with all the other engineers or designers of the building. The design constrains and parameters can be complicated and often interact with each other. These parameters and constrains are:

- Design constrains are the ones that the designer should take into account in the early stage of the decision making process, in order to achieve a more overall approach and to be more accurate in his predictions avoiding unpleasant surprises that will increase the constructional or operating costs. These are:
  - ¤ Climate (solar radiation, outdoor temperature, etc)
  - ¤ Site and obstructions of the building (latitude, local daylight availability, atmospheric conditions, exterior obstructions, ground reflectance, etc)
  - ¤ Use of the building (operating hours, occupant’s tasks, etc)
  - ¤ Building and Design regulations

- Design parameters are the ones that the designer can influence during the decision making process. When designing a Double Skin Façade System, these parameters concern (not given in order of importance) the:

  - Design and type of the façade
  - Structural design of the façade
  - Geometry of the cavity
  - Use of the air inside the cavity – type of cavity ventilation – HVAC strategy of the entire building
  - Opening principles of the cavity, the interior and the exterior façade
  - Type of glazing, shading and lighting devices
  - Material choice for the panes and the shading devices
  - Positioning of shading devices

The interaction between these parameters is obvious. The more detailed the prediction of the interaction of the design parameters is, the more precise the estimation of the desired performance of the system can be, leading to better understanding of the system.

In order to ensure that the engineer responsible for the façade design can achieve desired results, the process should be gradual, iterative and the approach overall. Thus, after defining the design constructions and parameters, the main goals that need to be fulfilled should be analyzed. These concern:

- Energy use
  - During the construction stage (usually 10 to 20% of the total energy use)
  - During the occupation stage (usually 80 to 90% of the total energy use)

- Indoor climate
  - Thermal comfort
  - Visual comfort
  - Acoustics
  - Air quality

- Environmental profile of the façade – building
  - Environmental impacts during the construction and demolition stage
  - Environmental impacts during the occupation stage

- Architectural design
  - Aesthetics

  - Ergonomic design

- Cost
  - Investment cost
  - Maintenance cost
  - Operation cost (see energy use)

After defining the importance of the individual mentioned goals, all the involved participants (architects, HVAC designers, users, etc) in the project must together prioritize them.

The main objective of the engineer responsible for the façade design is to study the design parameters and suggest solutions that respond to the prioritized expectations, in order to optimize the efficiency of the system.

10.2 Classification of Double Skin Façades

The classification of Double Skin Façades can be crucial for the approach of the concept of the system. In the existing literature different ways of classification are mentioned. However, the most common one is to categorize the façade according to its geometry. The four types mentioned are:

- Multi Storey Façade
- Shaft Box Façade
- Corridor Façade
- Box Window Façade

The opinion of the author is that since the geometry and type of Double Skin Façades are crucial for the properties of the air inside the cavity, such a classification can be a good starting point. The function of the façade and thus the HVAC strategy is closely depending on the temperature and air flow of the air between the glass layers. The main characteristics that influence the properties of the air in the cavity are the:

- cavity depth
- pane type
- type and position of shading devices
- size and position of the inlet and outlet openings of the cavity
- ventilation strategy

Repeated simulations when changing these characteristics can provide useful information for the way that the temperature of the air at different heights of the cavity changes for different configurations. These simulations, when different design constrains are considered, can provide a better understanding of the performance of the system.

As described above, if the designer of the façade is able to understand the function and the flexibility of the system, considering the prioritised needs for the building, he can optimize the function of the façade (e.g. provision of natural ventilation by preheating the air inside the cavity before it enters into the building, better control of the heat losses of the façade by changing the size of the cavity openings, etc) and determine technical details with respect to the mentioned design parameters in order to fulfil the mentioned goals.

It is clear that different classifications can lead to different system solutions. It is very important to be focused on the main goals that have to be achieved and on the main design constrains that can influence the sensitivity of the desired performance, in order to make more secure predictions.

10.3 Design Parameters

In the existing literature, one can find basic information concerning the structural design of Double Skin Facades. Reports written in Helsinki Institute of Technology (Laboratory of Steel Structures) provide information for construction technologies more oriented to Nordic countries.

The choice of proper pane type and shading devices can be 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. A choice of panes which leads to preheating of the air inside the cavity during winter providing natural ventilation with lower energy use, can lead to overheating problems during the summer. The properties of the blinds (absorbance, reflection and transmission) and geometry may also affect the type of air flow in the cavity. As mentioned in the literature, in large scale projects, it is useful to find proper combinations of the glazing types and (often) the solar shading devices placed inside 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:

- The type of exterior openings influence the type of air flow and the air velocity in the cavity (more important in high-rise buildings). The design of the interior openings is crucial for the air velocity and the flow indoors and thus the ventilation rate and the thermal comfort of the occupants.
- The size of the openings is crucial for the air flow and the air velocity and thus for the temperatures in the cavity. Openings that can be controlled are more expensive but they are very important for the façade design.
- The positioning of the openings influences the type of air flow and defines the origin and destination of the air inside the cavity. The design of the façade is directly depended on this aspect since the use of the air inside the cavity is a part of the decision making process.

The selection of pane types depends on the Double Skin Façade type (depth and height of the cavity), the climatic conditions (location of the building) and the HVAC strategy (natural, fan supported or mechanical ventilation of the cavity). As described in the literature it is possible to use Low-E coated, Solar Control, or other types of glazing units instead of clear glass. Apart from the physical properties of the panes, their positioning has a fairly high impact on the cavity properties. For example, the Low-E coatings as external layers increase the temperature inside the cavity since they decrease the heat loses to the outside. Although that during the summer it may be possible to overheat the cavity, during the winter it is easier to preheat the air supplied into the building. If the mentioned coating is applied as an interior layer then the heat losses from the interior of the building to the cavity are decreased and the cavity can maintain better temperatures during the summer but during the winter the cavity is cooler. Similar interesting results can be concluded if the double glazed unit is placed as an interior or exterior layer.

The material choice, the geometry and the positioning of the shading devices are important for the type of air flow, the thermal properties of the cavity and for the visual comfort of the occupants. As mentioned, it is very often that the venetian blinds (probably the most popular shading device used for this façade type) are placed inside the cavity for better protection. The material properties of the blinds (absorbance, transmittance and reflectance) should be considered in the design stage since they influence the type of air flow and the thermal properties of the cavity. Additionally, the exact position of the blinds inside the cavity should be calculated since the closer the blinds are to the interior pane, the warmer the inner layer gets, often overheating the part of the cavity between the blinds and the inner layer during the cooling periods. It is the opinion of the author that it could be worth investigating the possibility of setting two positions (or more if found necessary) inside the cavity that the blinds could be placed (moved) during different periods of the year for improved temperatures on the interior surface.

10.4 Building Physics – Properties of the Cavity

If the air flow and thus the temperatures at different heights of the Double Skin Façade Cavity are calculated, then the mentioned design parameters of the Double Skin Façade can be optimized for efficient performance. The level of detail in air flow calculations can often be crucial for the design of Double Skin Facades. On the other hand, the more detailed the approach is, the more time and effort are needed.

Different approaches are mentioned in the existing literature. Clearly, the CFD (Computational Fluid Dynamics) simulations are being used more and more, since they can provide details of the temperature fields and airflow patterns. This level of detail is important when designing the cavity. The type of interior and exterior openings, the size and the geometry of intermediate placed shading devices, and the type of ventilation strategy can influence the type of air flow. Thus, CFD simulations can provide useful details, decreasing the possibilities of unpredicted mistakes during the design stage. However, the airflow simulations are still difficult. As Jaroš et al. describe, *"the applicability of the CFD simulation is still restricted to the relatively simple cases"*. The authors conclude that *"the capabilities of CFD simulation will grow with the increasing capabilities of hardware and software"*.

Currently, computing programs and numerical models are developed in order to calculate the air flow in natural ventilated cavities. The detailed level is not high, but if the approximations are correct, useful results can be concluded. Poirazis et al., (2003) used partly the WIS software in order to calculatethe air flow and the temperatures of multi storey Double Skin Facades when different panes are applied. The results are interesting since the calculations took place for different hours and temperatures, both with and without blinds and for different cavity inlets and outlets. These calculations can be very useful in understanding how the system reacts in different conditions and how the individual façade characteristics can interact with each other, influencing the system performance. Probably when designing the façade, additional and more detailed information e.g. provided by CFD will be needed, but certainly more simple approaches can help the designer to understand the system performance.

In different studies, results from measurements (both from real buildings and test rooms) are also presented. Measurements in real buildings can be very useful. On the other hand, test rooms can provide flexibility in the design of the façade since different cases can be examined and compared. Additionally, the measurements in test rooms are also easier to control and analyze. Both simulations and measurements of Double Skin Façades are important for a better understanding of the concept. Thus, a combination of measurements and simulations could definitely lead to a more overall approach.

10.5 Advantages – Disadvantages

In the studied literature different advantages and disadvantages of the Double Skin Façade system are given, very much depending on location and type of building. As described above, the mentioned system is complicated. By prioritizing the main goals in a different way, different types of façades could be suggested. Below, some examples are given, in order to explain how each construction type influences the performance of the mentioned system.

Acoustic Insulation

If the building is located in a heavily polluted area with high external noise levels, then a multi storey double skin façade type is often suggested. The outer layer does not have any openings, in order to avoid noise transmission (from outdoors to indoors). On the other hand, exactly for the same reason, the room to room noise transmission makes this type inappropriate when the internal noise levels are high for certain types of occupation.

The multi storey façade can be appropriate since the quality of the outdoor air is poor and natural ventilation is avoided. Thus, no preheated air is inserted in the offices during the heating period. The inlet and outlet openings can be closed in order to provide additional thermal insulation. However, the ventilation of the cavity is poorer during the summer months often causing overheating problems.

Thermal Insulation

As already described, during the winter the external additional skin provides improved insulation. The reduced ait velocity and the increased temperature of the air inside the cavity lower the heat transfer rate on the surface of the glass which leads to reduction of heat losses. This concept highly depends on the location of the building, on climatic parameters and on daylight availability. When the energy demand for heating is high, the box window type can be suggested since the preheated air inside the cavity can be introduced in the offices and still provide thermal comfort and low energy use. During the summer, the warm air inside the cavity can be extracted by mechanical, fan supported or natural ventilation.

Certain façade types may cause overheating problems. In central Europe the temperatures inside the cavity of a multi storey façade with natural ventilation will increase dramatically leading to thermal discomfort of the occupants. In this case fan supported or mechanical ventilation could be suggested although the energy use would increase. A completely openable outer layer can solve the overheating problem during the summer months, but will certainly increase the construction cost.

Natural Ventilation

One of the main advantages of the Double Skin Façade systems is that they can allow natural (or fan supported) ventilation when possible. As already mentioned, the selection of Double Skin Façade type can be crucial for temperatures, air velocity, and the quality of the introduced air inside the building. If designed well, the natural ventilation can lead to reduction of energy consumption during the occupation stage and improve the comfort of the occupants. It is obvious that each façade type will preheat the supplied air more or less efficiently. Attention should be paid in order to avoid systems mixing used and fresh air and thus decreasing the quality of the supplied air.

Others

Double Skin Facades can also:

- Provide natural night ventilation that is both burglary proof and protected against the weather
- Save energy if designed properly for heating, cooling and lighting the building
- Provide better protection of the shading or lighting devices
- Reduce the wind pressure effects

It is clear that the design of the system is crucial for the performance of the building. It is a personal opinion and hypothesis of the author that the Double Skin Facades can provide improved indoor climate compared to a single skin façade with respect to the energy use if designed properly. If the approach is overall and the goals are clear, then the mentioned system is flexible enough to meet outdoor climatic changes for every type of building use. Finally, it is necessary to clarify that optimum façade design demands individual approach in order to determine the interactions between the design parameters for every building case and understanding the sensitivity of each system.

11 Summary

This report describes the Double Skin Façade concept, the design parameters, the building physics and finally the optimization of the system when integrating into office buildings. Examples of buildings are also described.

11.1 Definition – Concept

The Double Skin Façade is a system consisting of two glass skins placed in such a way that air flows in the intermediate cavity. The ventilation of the cavity can be natural, fan supported or mechanical. Apart from the type of the ventilation inside the cavity, the origin and destination of the air can differ depending mostly on climatic conditions, the use, the location, the occupational hours of the building and the HVAC strategy. The glass skins can be single or double glazing units with a distance from 20 cm up to 2 meters. Often, for protection and heat extraction reasons during the cooling period, solar shading devices are placed inside the cavity.

The solar properties of the Double Skin Façade do not differ from the Single Skin Façade. However, due to the additional skin, a thermal buffer zone is formed which reduces the heat losses and enables passive solar gains. During the heating period, the preheated air can be introduced inside the building providing natural ventilation with retained good indoor climate. On the other hand, during the summer overheating problems were mentioned when the façade was poorly ventilated. Different configurations can result in different ways of using the façade, proving the flexibility of the system and its adaptability to different climates and locations.

11.2 Classification

The classification of Double Skin Facades differs in the existing literature.

- The most common way of categorization is according to the type (geometry) of the cavity:
    - ¤ Multi storey Double Skin Façade: In this case no horizontal or vertical partitioning exists between the two skins. The air cavity ventilation is attained via openings near the floor and the roof of the building.
    - ¤ Corridor façade: Horizontal partitioning is created for acoustical, fire security or ventilation reasons.
    - ¤ Box window type: In this case horizontal and vertical partitioning divide the façade in smaller and independent boxes.
    - ¤ Shaft box type: In this case a set of box window elements are placed in the façade. These elements are connected via vertical shafts situated in the façade. These shafts ensure an increased stack effect.

The classification of the Double Skin Facades can also be made according to the:

- Type of ventilation
    - ¤ Natural
    - ¤ Fan supported
    - ¤ Mechanical

- Origin of the airflow
    - ¤ From inside
    - ¤ From outside

- Destination of the airflow
    - ¤ Towards inside
    - ¤ Towards outside

- Airflow direction
    - ¤ To the top
    - ¤ To the bottom (only in case of mechanical ventilation)

- Width of the air cavity
    - ¤ Narrow (10 - 20 cm)
    - ¤ Wide (0.5 – 1m)

- Partitioning
  - Horizontal (at the level of each storey)
  - No horizontal partitioning
  - Vertical

11.3 Design Parameters

Apart from structural characteristics, the report focuses on the principles of interior and exterior façade openings and types of panes and solar shading devices. These two parameters and the geometry of the façade define the function of the façade.

The most common pane types used for Double Skin Facades are:

- The internal skin is often a thermal insulating double pane. The panes are usually toughened or unhardened float glass. The gaps between the panes are filled with air, argon or krypton.

- The external skin is often a toughened (tempered) single pane. Sometimes it can be a laminated glass instead.

Cases with different panes are also mentioned. Lee et al., (2002) claim that the most common exterior layer is a heat-strengthened safety glass or laminated safety glass. The interior façade layer consists of fixed or operable, double or single-pane, casement or hopper windows. Low-emittance coatings on the interior glass façade reduce radiative heat exchange between indoors and outdoors (depends on winter/summer case).

Oesterle et al., (2001) suggest that for higher degree of transparency, flint glass can be used as the exterior layer. Since the number of the layers and the thickness of the panes are greater than in a single skin construction, it is really important to maintain a "clear" façade. The main disadvantage in this case is the higher construction costs since the flint glass is more expensive than the normal one.

If specific safety reasons occur (i.e. bending of the glass or regulations requiring protection against falling glass), then the toughened, partially toughened or laminated safety glass can be used.

The shading devices used, are usually horizontal louvres placed inside the cavity for protection. In the existing literature, there is no extended description concerning the material and the geometry of the shading devices. However, it is mentioned that in large scale projects, it is useful to investigate the material and position inside the cavity of panes and shading devices. It is also worth considering proper combination of these two elements in order to reach the desired temperatures.

11.4 Building Physics

The calculation of the air flow in a naturally ventilated cavity is necessary in order to predict the temperatures at different heights. Since natural ventilation is one of the main goals of this system, it is really important to ensure an acceptable indoor climate, when introducing the air of the cavity inside the offices. In the existing literature, results for air velocities and temperatures inside the cavity are given as a result of:

- Simulating the Double Skin Façade system using existing software
- Developing numerical models
    - ¤ Building energy balance models
    - ¤ Zonal airflow network models
    - ¤ Computational Fluid Dynamics (CFD) models
- Measurements in real buildings
- Measurements in test rooms

There are different ways to calculate the air flow inside the cavity. Some of the most important works are briefly mentioned below:

- Arons, (2000) has developed a (two dimensional) simplified numerical model of a typical Double Skin Façade. The purpose of the model is to predict the energy performance of multiple types of Double Skin Facades.
- Gan, (2001) presented in an article a numerical method that he developed for the prediction of thermal transmittance of multiple glazing based on Computational Fluid Dynamics.
- A two-dimensional numerical model for single storey multiple-skin facades with mechanical as well as natural ventilation was developed by Saelens, (2002) in his PhD thesis.
- Hensen, et al. (2002) give an overview of the methodology of a design study in order to calculate the properties inside the Double Skin Façade Cavity (temperatures, airflow, etc), using a network approach fully integrated in a building thermal energy model.
- Manz presented in 2003 an article concerning the development of a numerical simulation model of heat transfer by natural convection in cavities of façade elements.
- Manz and Simmler, (2003) presented an experimental and numerical study of a mechanically ventilated double glass façade with an integrated shading device. Optical properties were calculated and a transient 2D computational fluid dynamic model was developed. The computing program FLOVENT was used for the CFD simulations.

- Poirazis et al., (2003) studied 4 different types (panes) of Double Skin Facades and calculated the temperatures at different heights of the cavity and for each layer. The calculations were made partly using two computer programs (WIS and MathCAD) and partly implementing their own numerical model.
- Grabe, (2002) presented a paper which deals with the development and validation of a simulation algorithm for the temperature behaviour and the flow characteristics of double facades.
- Todorovic and Maric (1998) developed a model for estimating the inter-space air temperature and the associated cooling/heating load per hour. Calculations are made for specific double-façade constructions designed for the climatic conditions of mid-latitude Europe (45° N).
- Saelens and Hens, (2001) presented a numerical model that evaluates the thermal behaviour of active envelopes showed and comparisons with in situ measurements. The numerical model was implemented in an energy simulation program, and an annual energy simulation was carried out for a selected number of active envelope typologies.
- Shiou Li, (2001) presented a protocol for experimentally determining the performance of a south facing double glass envelope system. Two modular full-scale double glazed window models with naturally or mechanically assisted ventilation were constructed and monitored for a range of weather conditions. The goals of this investigation were to develop and apply the test protocol and to monitor and analyze the thermal performance of these two systems and to improve the understanding of the double façade system.

11.5 Advantages – Disadvantages

The advantages and disadvantages of the Double Skin Façade system for different locations and buildings mentioned in the existing literature are described briefly below:

11.5.1 Advantages

Lower construction cost compared to solutions that can be provided by the use of electrochromic, thermochromic or photochromic panes (their properties change according to climatic or environmental conditions).

Acoustic insulation: In view of some authors the sound insulation can be one of the most important reasons to use a Double Skin Façade. Reduced internal noise levels inside an office building can be achieved by reducing both the transmission from room to room (internal noise pollution) and the transmission from outdoor sources i.e. heavy traffic (external noise pollution). The type of the Double Skin Façade and the number of openings can be really critical for the sound insulation concerning the internal and the external noise pollution.

Thermal insulation: During the winter the external additional skin provides improved insulation. The reduced speed of the air flow and the increased temperature of the air inside the cavity lower the heat transfer rate on the surface of the glass which leads to reduction of heat losses.

During the summer the warm air inside the cavity can be extracted by mechanical, fan supported or natural ventilation. Certain façade types can cause overheating problems. However, a completely openable outer layer can solve the overheating problem during the summer months, but will certainly increase the construction cost.

Night time ventilation: During the hot summer days, the interior spaces can easily be overheated. In this case, it may be energy saving to pre-cool the offices during the night using natural ventilation. The indoor temperatures will then be lower during the early morning hours providing thermal comfort and improved air quality for the occupants.

Energy savings and reduced environmental impacts: In principle, Double Skin Façades can save energy when properly designed. Often, when the conventional insulation of the exterior wall is poor, the savings that can be obtained with the additional skin can be important.

Better protection of the shading or lighting devices: Since the shading or lighting devices are placed inside the intermediate cavity of the Double Skin Facades they are protected both from wind and rain.

Reduction of the wind pressure effects: The Double Skin Facades around high rise buildings can serve to reduce the effects of wind pressure.

Transparency – architectural design: In almost all the literature, the desire of the architects to use larger glazed facades is mentioned.

Natural ventilation: One of the main advantages of the Double Skin Façade systems is that they can allow natural (or fan supported) ventilation. Different types can be applied in different climates, orientations, locations and building types in order to provide fresh air before and during the working hours. The selection of Double Skin Façade type can be crucial for temperatures, the air velocity, and the quality of the introduced air inside the building. If designed well, the natural ventilation can lead to reduction of energy consumption during the occupation stage and improved comfort.

Thermal comfort – temperatures of the internal wall: Since the air inside the Double Skin Façade cavity is warmer (compared to the outdoor air temperature), the interior part of the façade can maintain temperatures that are more close to the thermal comfort levels during the heating period (compared to the single skin facades). On the other hand, during the summer it is really important that the system is well designed so as the temperatures inside the cavity will not increase dramatically.

Fire escape: The glazed space of a Double Skin Façade may be used as a fire escape.

Low U-Value and g-value: Two advantages of the Double Skin Façades are the low thermal transmission (U-value) and the low solar heat gain coefficient (g-value).

11.5.2 Disadvantages

Higher construction costs compared to a conventional façade.

Fire protection: There is not yet very clear whether the Double Skin Facades can be positive or not, concerning the fire protection of a building. However, some authors mention possible problems caused by the room to room transmission of smoke in case of fire.

Reduction of rentable office space: The width of the intermediate cavity of a Double Skin Façade can vary from 20 cm to two meters. This results in the loss of useful space. Often the width of the cavity influences the properties inside it (i.e. the deeper the cavity is, the less heat is transmitted by convection when the cavity is closed) and sometimes the deeper the cavity is, the more improved thermal comfort conditions are next to the external walls. Thus, it is quite important to find the optimum depth of the façade in order to be narrow enough so as not to loose space and deep enough so as to be able to use the space close to the façade.

Additional maintenance and operational costs: Comparing the Double Skin and the Single Skin type of façade, one can realize that the Double Skin type can have higher costs regarding construction, cleaning, operation, inspection, servicing, and maintenance.

Overheating problems: If the Double Skin Façade system is not properly designed it is possible that the temperature of the air in the cavity may increase the overheating of the interior space.

Increased air flow velocity inside the cavity, mostly in multi storey-high types. Considerable pressure differences are mentioned between offices in case of natural ventilation via the cavity.

Increased construction weight: As it is expected the additional skin increases the weight of the construction which increases the cost.

Daylight: The Double Skin Facades are similar to other types of glazed facades (i.e. single skin façade). However, Oesterle et al., (2001) describe, that Double facades cause the reduction of the quantity of light entering the rooms as a result of the additional external skin.

Acoustic insulation: It is possible that sound transmission problems (room to room or floor to floor) can take place if the façade is not designed properly.

11.6 Conclusions

Double Skin Façades for office buildings were developed mostly in Europe in order to arrive at increased transparency combining acceptable indoor environment with reduced energy use. However, some of the literature sources claim that the main disadvantage of this system is that in countries with high solar gains the air temperatures inside the cavity are increased during periods with warm weather, leading to overheating problems. The thermal discomfort leads to higher energy consumption for cooling. Thus, according to the opinion of some authors the Double Skin Facades are not energy efficient.

The truth is that the Double Skin Facades are systems that highly depend on the outdoor conditions (solar radiation, outdoor temperature, etc) since they allow the outside conditions to influence the indoor climate. Thus, it is obvious that each Double Skin Façade has to be designed for a certain building location and façade orientation otherwise the performance of the system will not be satisfactory. The constraining parameters that have to be taken into account in the early design stage are:

- Climate (solar radiation, outdoor temperature, etc)
- Site and obstructions of the building (latitude, local daylight availability, atmospheric conditions, exterior obstructions, ground reflectance, etc)
- Use of the building (operating hours, occupant's tasks, etc)
- Building and design regulations

The design parameters that have to be studied in order to improve the façade performance and ensure reduced energy use and good indoor environment are:

- Design and type of the façade
- Structural design of the façade

- Geometry of the cavity
- Use of the air inside the cavity – type of cavity ventilation – HVAC strategy
- Opening principles of the cavity, the interior and the exterior façade
- Type of glazing, shading and lighting devices
- Material choice for the panes and the shading devices
- Positioning of shading devices

It is really important to understand the performance of the Double Skin Façade by studying the physics inside the cavity. The geometry of the façade influences the air flow and thus the temperatures at different heights of the cavity. Different panes and shading devices result in different physical properties. The interior and exterior openings can influence the type of flow and the air temperatures of the cavity. All together these parameters 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 individuality of the façade design is the key to a high performance. It is necessary for the design approach to be overall considering the façade as an integrated part of the building and detailed enough in order to determine all the parameters that will lead to a better performance.

Futher research and development are needed within the following fields:

- Development of CFD techniques and simple approaches for predicting the physical properties of the cavity
- Feedback from real buildings
- Comparison with a partially glazed façade single skin façade
- Prediction of energy use for the entire building
- Study application in Sweden.

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