A Guideline for Double Skin Facades in an Initial Design Phase: Applying Cross Ranking and Fuzzy Logic Methods for Temperate Climate Region

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ABSTRACT

Climate change and global warming have become a quandary for today and as a result architects faced with unexpected design process issues.

In this context, expected performance requirements of building façades advanced to beyond of being resistant against the environmental effects of such as wind and rain forces and transfer of the loads. Expected requirements also include becoming active to keep constant user comfort under flexible climate conditions also using renewable energy sources for energy conservation and being able to adapt itself when its needed to reach a certain level of economic sustainability. Architects used numerous façade systems in their projects; currently double skin façade systems become the most common façade system in use to meet these expectations.

This thesis aimed to develop a scale that can be utilized during the early design stage to identify potential risks that can be faced after the construction process for a façade system, which can adapt itself according to different requirements of users and dynamic external factors.

Designers may have the possibility to evaluate their designs using the recommended value of risk assessment during the early design stage.

Keywords: Double Skin Façade, Intelligent Envelopes, Design Strategies, Occupant Comfort

ÖZ

Mimarların ufuktaki hedefi yaşam çevresini tekrar düzenlemek ve bunu yaparken yapılaşmaya ve dünya ya tekrar bir bakış açısı kazandırmaya çalışmaktır. Global dünyanın sorunu haline gelen küresel iklim değişiklikleri bugünün tasarımcılarını bilinmeyene yada tahmin edilemeyene karşı bir tasarım süreci ile karşı karşıya bırakmıştır.

Bu bağlamda, bina cephelerinden beklenilen performans gereksinimleri dayanıklı olmaları, yükleri aktarmaları, rüzgara, kara ve yağmura karşı dayanımlı olabilmenin ötesine geçmiş ve kullanıcı konforunu değişken iklim şartları altında sabit tutabilmek ve ekonomik açıdan sürdürülebilirlik sağlayabilmek için enerji korunumu, yenilenebilir enerji kaynaklarında yararlanabilmek ve ihtiyaç doğrultusunda değişkenlik göstermek gibi bazı yeni gereksinimleride karşılamaları beklenmektedir. Bu beklentileri karşılamak adına mimarlar çeşitli cephe sistemlerini yapılarında kullanmışlardır, günümüzde ise en yaygın cephe sistemi olarak çift cidarlı cepheler ön plana çıkmaktadır.

Bu tezde, dış faktörlerin karakterlerine ve faklı kullanıcı gereksinimlerine uyum sağlayabilme özelliği gösterebilen değişken yapı kabuklarını baz alarak mimarlara yapım sürecinden sonra karşılaşılabilecek riskleri belirlemek amacı ile tasarım surecinde faydalanılabilecek bir skala geliştirilmeye çalışılmıştır.

Tasarımcılar, önerilen risk değerlerini kullanarak tasarımını değerlendirme olanağına

sahip olabilirler.

Anahtar Kelimeler: Çift Cidarlı Cepheler, Akıllı Cepheler, Tasarım Stratejileri, Kullanıcı Konforu.

DEDICATION

To My FAMILY

Tarık İlter & A.Kıvanç İlter

Cemaliye E. İlter & Kayla K. İlter

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
AVPV	Average Performance Value
CDD10	Cooling Degree-Day Base 10°C
DSF	Double Skin Façade
DV	Dependent Value
DV_L	Natural Lighting Objective Dependent Value
DV_S	Sun Control Objective Value
DV_{SD}	Sound Control Objective Dependent Value
DV_T	Thermal Comfort Objective Dependent Value
DV_V	Natural Ventilation Objective Dependent Value
EN	European Standards
FG	Functional Grade
FV	Functional Value
FV_L	Natural Lighting Functional Score (min. and max.)
FV_S	Sun Control Functional Score (min. and max.)
FV_{SD}	Sound Control Functional Score (min. and max.)
FV_T	Thermal Comfort Functional Score (min. and max.)
FV_V	Natural Ventilation Functional Score (min. and max.)
HDD18	Heating Degree-Day Base 18°C
LR	Light Reflectance
LT	Light Transmittance

OPV	Overall Performance Value
PMV	Predicted Mean Value
PPD	Predicted Percentage of Dissatisfied
PV_L	Natural Lighting Performance Value
PV_S	Sun Control Performance Value
PV_{SD}	Sound Control Performance Value
PV_T	Thermal Comfort Performance Value
PV_V	Natural Ventilation Performance Value
R-Value	Thermal Resistance
SC	Solar Coefficient
SHGC	Solar Heat Gain Coefficient
TSC	Total Shading Coefficient
U-Value	Thermal Transmittance
VT	Visible Transmittance
ΣFVA	Total Objective Value

Chapter 1

INTRODUCTION

Because of the energy crisis in the 1970s, efficient use of energy is necessitated for the buildings. Rapid developments in technology, which makes life easier for human beings, required more and more energy. Excessive use of fuel consumption and energy resources globally increasingly caused environmental pollution in serious levels that has created serious problems for all countries. For this reason, the efficient use of energy and nature-friendly energy resources have emerged as a popular topic of research.

Among the relevant studies, especially for high-rise building energy control systems for building skins became more important. Hence, the 40% of the entire heat in high-rise buildings is lost by the building envelope. In these buildings, the energy consumption loads can be reduced through energy control systems by controlling heat loss and heat gains in winter and summer periods. Intelligent skins and double skin facades (DSF) derived from these systems.

These developments emerging in the building design assign the task of balancing the climate particularly between outdoor and indoor at the building façade. This task leads to the development of a new system as well as new materials on facades including a large part of the building envelope (Lakot, E., 2007).

The thermal comfort of indoor spaces is instantly influenced by the use of DSF. De Gratia and De Herde searched for obtaining a definite/certain pre-set indoor comfort parameters (Gratia and De Herde, 2004). As an example, for a building, located in Uccle, Belgium, they formed an essential research with considering the cooling or heating loads regarding the seasonal changes, and the thermal behavior by using the external climatic conditions in terms of winter, fall, summer and spring days. Throughout the case used in the research, they discovered using DSF on the distinctive position of the building façade facilitated an increase of the cooling loads throughout summer and decrease of the heating loads throughout winter.

However, the use of DSF might be challenging in temperate climates due to larger sun gain. Hence, warm temperature in temperate climates is permanent throughout the year without demonstrating any differentiation during summer or winter (Guardo et al., 2009). On this basis, double or triple glazing improved mechanical or natural ventilation and/or shading devices are included in the approach of improving the thermal performance of DSF. In the light of these assets DSF systems can be named as one of the intelligent façade systems

In addition to energy control systems DSFs delivers different ventilation opportunities for structures. DSF systems allow occupants to be able to use openings that are located on the internal layer for the top floors of high-rise buildings. The walkways, which are positioned in the air cavity among the internal and external layer of DSF systems, offer a service and maintenance of the structure with ease. Besides moveable louvers placed in the air cavity control the sun radiation of the façade and provide comfortable internal space for the occupants.

1.1 Problem Definition

In the past decades, building design is forced to expand its functionality at a retreating cost. The increasing variety and increasing complicated demands in design regarding energy efficiency, cost efficiency and user comfort as well as; creating a suitable indoor climate at buildings enabled a broad use of mechanical systems.

In the context of architecture, the intelligent building envelope term has been commonly used as a type of built form in the mean of artificial intelligence, which provides a dynamic cooling, ventilation, heating and lighting for indoor space to achieve an optimal balance among the energy efficiency and user comfort.

First, the term “intelligent” is used in the United States in early 1980s, to describe the building design. In fact, the term intelligence is developed in architecture through a corresponding ground with the term “smart”. The main intense of intelligence is to declare the same kind of abilities where “smart” means for buildings, their structures and materials (Schwartz, 2002).

Intelligent Building Institution in Washington describes the term intelligent in the context of architecture as ‘a building which incorporates several systems for managing resources in a corresponding mode to maximize the technical performance and investments as well as operating cost savings (URL 1).

International Council for Research and Innovation in Building and Construction Working Group W98 (1995) on Intelligent and Responsive Buildings describes the intelligent building as a responsive architecture, where each occupant meets the conditions of being cost-effective, productive, environmentally responsive and continuously interactive with *process, place, people,* and *management* (Ghaffarianhoseini et.al, 2016). In the study of Clement place, people, process, and management are defined as the four basic elements of which an intelligent building resides through in (Clements, 1997). Place refers to fabric, structure and facilities. The process refers to automation, control or systems. People are replaced as the user/ occupant. And management is the phase of maintenance, performance, the interrelation among them (Clements, 1997).

European Intelligent Building Group (EIBG) puts the intelligent building into the context and relations of materials, technologies and systems. According to the view of EIBG, there is an integrated relation among them during the process of building design or construction, which allows meeting or exceeding the needs of the stakeholders (URL 2).

There are three characteristics of which an intelligent building ought to possesses as following features (Atkin, 1988):

- An intelligent building should provide an immediate protection about climatical events happening both inside and outside.
- An intelligent building should be competent to decide about the most efficient mode to provide the productive, comfortable, and appropriate environment for the product(s).
- An intelligent building should immensely answer to the needs of occupants/users.

The above building characteristics are all related to the nature of human beings. In addition, they show modest similarities with the autonomic natural intelligence of an existence. In fact, the idea is utilized with the influence of how some systems in nature are responsive and adaptive.

In the literature there are many definitions describing probabilities on how an intelligent building achieves the balance/stability between energy use and occupant comfort. Therefore, one of the problems is that; the variations between definitions drastically pose conflicting understanding of what is an intelligent building.

On the other hand, the field of architecture today should not solely provide a simple task about the occupant comfort and energy efficiencies such as thermal control, natural ventilation, sun control, day lighting, etc. In fact, architecture or architectural design should provide foremost service functions where these parameters are well adapted.

Since architecture does not deeply evolve with the good adaptation of the mentioned issues above; the other problem is that a high-percentage of buildings in planet serves as an energy consumer. Buildings should not serve the consumer in the problem of "reduction of resources of our planet". In fact, buildings should act upon as being an energy efficiency source using current technological and scientific advances (Hawken et al, 1999). In a broader sense, buildings should act as a significant catalyst to the reduction of environmental quality and natural resources of our planet. However, the lack of adaptable intelligent building skin, which could vary, based on dynamic conditions of an environment. Currently, many buildings utilize an extra energy use that drastically affects the reduction of resources of our planet. This is, in fact, because of most of the building skins is constructed as static systems that do indicate any optimal energy performance and optimal indoor comfort and limits the energy efficiency of building. In general, the static performance of building skin mostly poses a high-energy use in many building installations (which are responsive to controlling the building climate) and discomfort for occupants. Nevertheless, a building could dictate its own energy consumption with the potential of its building skin. Building skin is the interface between the outdoor climate and indoor climate. Therefore, it is one of the most significant parts of a building that could accomplish energy efficiency. In fact, the building skin serves as an environmental filter to the building by manipulating the effects of the outdoor climate to the climate of indoor space (Glass, 2002).

The frequent use of traditional building skin is another factor affecting the problem defined above. Yet, the environment of building changes over time based on a climatically variability such as seasonal cycles, short-term weather conditions, etc. Such issues frequently impose a dynamic change in comfort preferences of occupants. However, the traditional building skins are extremely rigid. Moreover, they do not allow a flexible capability to adapt itself to none of the variability of climate by means of thermal features.

Throughout above problems, the study gives a notice on benefits of using an intelligent facade system in the building that could contribute to the energy efficiency as well as occupant comfort. An intelligent facade system demonstrates a wide range of variability that enhances with natural lighting, ventilation, cold or heat assortment, sound and noise insulation, protection from pollution, glare sun and rain, sun gain, and provision of outside and inside view (Rubnicu, 2012). This system could be also seen as climate adaptive systems that have the capability to change their features or functions or performances according to the changes in climatic requirements and comfort conditions. Consequently, an intelligent facade system could be the most adaptive part of the building that could change to minimize the energy, to adapt itself and to respond the dynamic environmental conditions.

Hence, the study indicates following questions in relation to the defined problems above and DSF systems:

- How does a DSF systems manage to adapt itself to the varying changes of the environment by means of least expenditure of energy?
- What type of dynamic possessions may assist building skin with flexible outdoor environment conditions to acquire the desired indoor ambiance?
- What are the main objectives, which have a direct relation to creating a desirable indoor climate for the occupants?
- What sort of components can be used for DSF systems to provide occupant comfort?

1.2 Aims and Objectives

The life period of building's four stages can be identified as (Williamson et.al, 2003):

- *The production process*; that covers design together with the construction of the structure.
- *Using phase;* of the structure that covers the operation and maintenance

process.

- *Renewal, improvement and recovery phase;* that is parallel to the production process of the structure.
- *Demolition phase*; which covers the re-use or disposes of building materials or their components.

In general, life period of a building strongly depend on the production process that covers the design stage, where all fundamental decisions are taken for the building and further processes. The design stage level compromises a significant consign for the following processes. Furthermore, the sustainability is one of the curial aspects leading the architecture and architectural design of today.

In terms of energy, sustainability aims to reduce the consumption of energy sources with a proper technical provision. The building facades can redefine the present-day architectural terminologies, which enhances the architectural value of the structure by exploration of the technical systems and renewable energy sources.

Within this perception, double-skin facades can be accepted as one of the technical systems that offer to use renewable energy sources to heat the building in wintertime through using sun heat recovery. Moreover in the summer season overheating can be avoided by using the air circulation and an effective sun control. Besides, double-skin facades improve the infiltration of daylight in to the internal spaces, which aid to reduce the use of artificial lighting. To attain the reduced energy consumption in the buildings, double-skin facades perform a significant responsibility. Subsequently, sustainability in the buildings can be led by this assistance of the double-skin facades.

On this basis, the general objective of the study is to help the designers in the initial design stage/process of a building through a catalogue, of which shows performance levels of DSF system elements that demonstrate the ability to response the different requirements of the users and environmental factors of a given context/region in a given climate zone.

In fact, there is not a developed standard system which suite or to fulfill the problems of different buildings at different contexts/regions of different climate zones. Therefore, there is a need to implement different, but context-dependent strategies, which are merging with the specific environmental conditions of that very context.

Consequently, the purpose of the study is to fill this gap by signifying the importance of developing an adaptation level/degree for every building responding the variables of occupants' comfort and environmental conditions. Having said that, the study gives a notice on DSF systems and their performances while it also *believes a building could develop an adaptation behavior through its façade design*.

1.3 Methodology and the Case Selection

In order to induce conceptions from the human comfort and double-skin facade system studies, the thesis combines diverse subjects of studies.

Therefore, the appropriate selection of the methodology is vital to prevent generalizations that will reduce the potential and the prosperity of the double-skin façade concepts and its effects on human comfort. Hence, making the assessment depending on one method through only using single case study with a single precise variable of double-skin objectives is not fitting to the idea of adaptability/flexibility as a challenging notion of the investigated system. The deliberation of numerous methods and case studies are determining the sophistication of the methodology.

The methodology is grounded on a single theoretical core, which is established by gathered theories of assessment. Thereafter, distinct cases ranked through complementary statements with interrelated methods.

The core and assessment principles, which is going to be used in this thesis to challenge various subjects about the assessment of DSF components through the main objectives of DSF with regard to occupant comfort, is provided by the theoretical background. The theoretical context explores various issues such as thermal, visual and auditory comfort, the concept of DSF, history, classification of DSF, and technical description of DSF to strengthen the bridge between two different fields of architecture and to build up the requirements for assessment principles for DSF components to achieve occupant comfort. Therefore, two different evaluation methods are combined to get more precise results according evaluation of design and performance of the design elements. Cross ranking method is selected in order to assess the design, which is tested previously in many different design area evaluations. In addition to that, fuzzy set logic has been applied to the results for the purpose of identifying the tentative distinctive comfort standards of occupants.

1.3.1 Case Studies

In terms of establishing a relation among theoretical backgrounds, case studies have been used in this study to understand their conceivable executions in existing situations. The major quantities of the theoretical background are explored by the use of case studies. Accordingly, altered systems and consequences are shaped in individual cases. Because of this frequentative progression, different points of views obtained for the research questions through each case study.

The studied countries are stated with a new coding by ASHRAE Standards 55- 2010. Because of the ASHRAE standards are generated to determine a benchmark for performance criteria to guide the building construction industry and for methods of measurement and testing. The ASHRAE Standards 55-2010 defined the temperate climate region in the following table with the given values and the specified encoding.

Table 1: Climatic region coding in ASHRAE Standards 55 (ASHRAE Standards 55, 2010).

Zone Number	Thermal Criteria
3A-3B	$2500 < \text{CDD } 10\,°\text{C} \leq 3500$
3C	$\text{CDD } 10°\text{C} \leq 2500$, $\text{HDD}18°\text{C} \leq 200$
4A-4B	$\text{CDD } 10°\text{C} \leq 2500$, $2000 < \text{HDD } 18°\text{C} \leq 3000$
4C	$2000 < \text{HDD } 18°\text{C} \leq 3000$
5A-5B-5C	$3000 < \text{HDD } 18°\text{C} \leq 4000$
6A-6B	$4000 < \text{HDD } 18°\text{C} \leq 5000$

Since the study involved with the quantitative research, it requires a quite large number of cases and numerical data, which are obtained from surveys and experiments. Owing to the lack of traveling, the detailed information of the required technical knowledge is obtained from the books, numerous former and recent research papers, and web sources. In addition to this, the technical data of certain components are obtained from the brochures of several companies dealing with the production of DSF components.

1.4 Limitations and Contribution

A wide range of criteria could be defined and settled in double skin façade (DSF) systems. For example, these criteria could be addressing the goals, asserted to be achieved by DSF or the materials and their potentials or the control mechanisms that are applied. In this study, the limitation of the focus is developed on two integrated bases; first is the behaviors and characteristics of DSF systems, and second is the façade systems that perform and adapt themselves according to the changing climatical conditions of the environment.

The design and the process/operation of DSF systems impel variable fields of research in architecture, engineering, computational and material sciences. In this thesis, the data revealed from the above fields reveal a significant approach in DSF systems, which indicate a beneficial outline for the architectural design of an intelligent building skin.

However, the notion of the intelligent building is not the focus area of this thesis. The study is mainly limited with the intelligent building skin, where a special attention is given to the performance of the building skin that acting as an environmental filter. The main aim here is to put a limit to the functionality of the building skin. Moreover, the extra/additional characteristics are only discussed when they bear an enhancement for the building skin performance.

Due to the lack of a standard building system, that suit or fulfill an adaptability to the changing requirements of occupants' comfort and climate by its façade design, the study seeks an answer for such a need by merely focusing on non-domestic buildings such as school buildings, office buildings, or buildings serve as retail or health care facilities. Simply, the study limits its research by only analyzing non-domestic buildings to discover or implement an adaptation degree for a building by focusing its building skin performance through changing environmental conditions. The study brings another limitation to the selection of the cases by means of their location. The study examines different cases in different countries that take place in the temperate climate region.

1.5 Structure of the Thesis

The body of this study is separated into three fundamental sections and six chapters that counterpart to the three general objectives of the study, i.e., theoretical framework, analyzing the selected cases and assessment of DSF component through proposed method.

The theoretical framework, which is the first fundamental section, is deliberated through Chapter 1, Chapter 2 and Chapter 3. The main aim of the first three chapters is to clarify the criteria of evaluation that will be used for ranking the DSF components in accordance with occupant comfort. Three constituents as form this fundamental section.

Chapter 1 define the context of the study, explains the aims and objectives with limitations of the thesis. The intention of this chapter is to generate the research question/s that the thesis laid on.

Chapter 2 states the fundamental principles of human comfort standards. Common ground has been established between different methods of researchers in fundamental principles of human comfort such as thermal comfort, auditory comfort, and visual comfort.

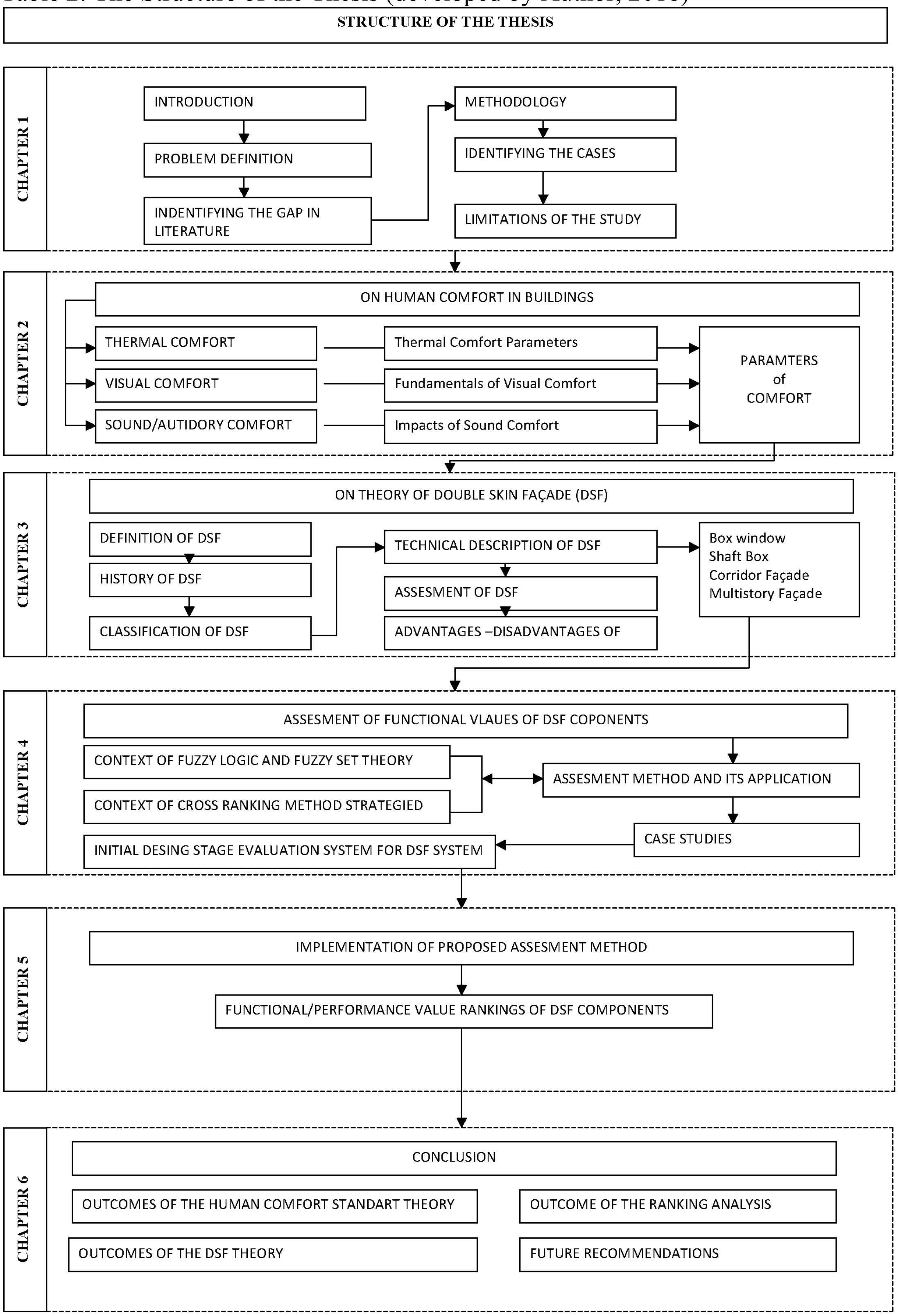
Chapter 3 explores the basic principles of double-skin façade, its development throughout the decades with regards to various trials of the pioneers. It promises a definition of the conventional concept of double-skin façade by referring to the several researchers. The aim of the chapter is to enlighten the concept of double-skin façade, its role to achieve occupant comfort under various external conditions so as to outline the principles for assessment.

Chapter 4 is establishing the second part of the thesis, where the selected cases are analyzed and the assessment method of double-skin components performance values in distinctive objectives for delivering occupant comfort is defined. The chapter explores the distinctive cases and discusses the application of double-skin façade systems through its components and implementation. In addition to this, it also describes the proposed assessment method in individual phases within the light of tangible samples by applying the cross ranking method and fuzzy set logic.

Third and the last general objective of the study take place in Chapter 5. This chapter deals with the application of the proposed assessment method. The main subject of the study finds its body by finding the overall and average performance/functional values of several double-skin components and states under five main objectives of occupant comfort.

Finally, in Chapter 6, each section of the thesis exposed and argued with their findings. To summarize and blend the results/findings of the distinct methods from diverse substances is the main objective of this chapter. It also describes the essential difficulties of the applied method and features the possible improvements of the future studies (Table 2).

Table 2: The Structure of the Thesis (developed by Author, 2018)



Thesis schedule is organized as follows:

- Determination of the problem and explanation of the scope of the thesis and provide the solution for the specific problem accordingly.
- The unveiling of the basic concepts used in the study.
- Revealing the DSF systems and their classifications to explain the concept of adaptability in the building façade.
- Analyzing the selected cases contingent upon given limitations.
- Application of the recommended evaluation method.
- The explanation the results of the applied evaluation method.

Chapter 2

ON HUMAN COMFORT IN BUILDINGS AND TEMPERATE CLIMATE

The term '*comfort*' is fundamentally described as the nonappearance of distress (URL 3). Indeed, the expression '*comfort*' may be utilized to represent a feeling of happiness, a feeling of cosines, or a condition of physical and mental wealth. Here, conditions depending on varied factors are the fundamentals of rationalization of comfort quality in any environment.

Occupant's comfort in a building is significantly dependent on the varied controls on varied conditions that are assembled between them and their indoor environments (Nicol and Humphreys, 2002). The term 'comfort zone*'* is fundamentally described as indicating of the accurate atmosphere in physical, physiological and mental estimations (Houghton and Yaglou, 1923). Upon a more vital definition, the comfort zone of occupants is the physical, physiological or mental capacity to control the varied conditions in a given environment.

In a building; there are several factors that affect the occupant's comfort. In the studies of Frontczak and Wargocki, it is seen that the design characteristics of buildings, the individual characteristics of occupants/users, and external varied climate conditions demonstrate a great effect on comfort quality regarding the fundamental conditions of indoor spaces as thermal, visual, and acoustic, especially in internal environments (Frontczak and Wargocki, 2011).

In general, these factors are classified under three significant areas. According to the reviewed literatures, these factors are; thermal factors, pointing the temperature appeals in physical and personal spheres; visual factors, meaning the light intensity and visual of the room; acoustic/sound factors, consisting of sound waves at the environment around them.

This chapter will provide a review of fundamental theories and international standards related to the human comfort in buildings. Indeed, a theoretical background and remarkable works that gave a way to the studies/researches related to human comfort will be discussed. Therefore, a theoretical literature survey is given through: understanding thermal, visual and acoustic comforts, as well as some important features of them; and understanding the comfort impacts of occupant performances/activities and occupants' comfort perceptions in buildings. In this essence, general overviews for each are addressed.

2.1 International Standards on Occupant Comfort

The leading global strategies and standards on occupant comfort are:

- International Standard ISO 7730. Standard is grounded on Fanger's Predicted Percentage of people Dissatisfied among the atmosphere (PPD), and the Predicted Mean Vote (PMV) that intends to calculate the mean thermal perception of a set of occupants.
- ASHRAE 55 defines conditions that are being considered satisfactory for a

specific percentage of users, including calculation methodologies for thermal comfort based on PMV/PPD

- CEN 15251: Criteria for the indoor environment including thermal, indoor air quality, light and noise. The CEN standard defines minimum ventilation requirements, minimum and maximum indoor temperatures that can be used for energy calculation, assessment and certification. It is different than prescribed standards because it makes a difference between mechanically ventilated systems and naturally ventilated systems. For buildings without mechanical ventilation /cooling, alternative methods are proposed.

2.2 Thermal Comfort

In varied models, thermal comfort is described in relation to an expected comfort response furnished by either physiological condition of a body or nonphysical factors (Jones, 2002). ANSI/ASHRAE STANDART 55-2010 (American Society of Heating, Refrigerating and Air-Conditioning Engineers) defines the thermal comfort as the condition of mind that utters satisfaction among thermal environment. In more detail, it is the condition of mind that is surveyed with a subjective assessment of satisfied thermal condition, of which inter-relates the occupants' satisfaction with temperature conditions of a given environment (URL 4). In other words, the thermal comfort is the optimization of a broad satisfaction with the thermal environment (Dahlan, 2009).

It could be notified that thermal comfort is one of the significant aspects revealing the human comfort in terms of temperature; and is one of the essential domains to be considered in the design of built environments (URL 4). Frontczak and Wargocki

(2011) showed that the thermal comfort is affirmed as the key fundamental condition influencing as well as contributing improvements to the occupant comfort in internal environments (Frontczak and Wargocki, 2011). Rupp, Vásquez, and Lamberts (2015) discussed thermal comfort alert in built environments by accomplishing a very large literature review out of 466 papers, which is addressing the human thermal comfort in the built environments. With this study, they assess the great impact of thermal comfort and its parameters to improve the comfort quality at indoor environments (Figure 1) (Rupp, et.al, 2015).

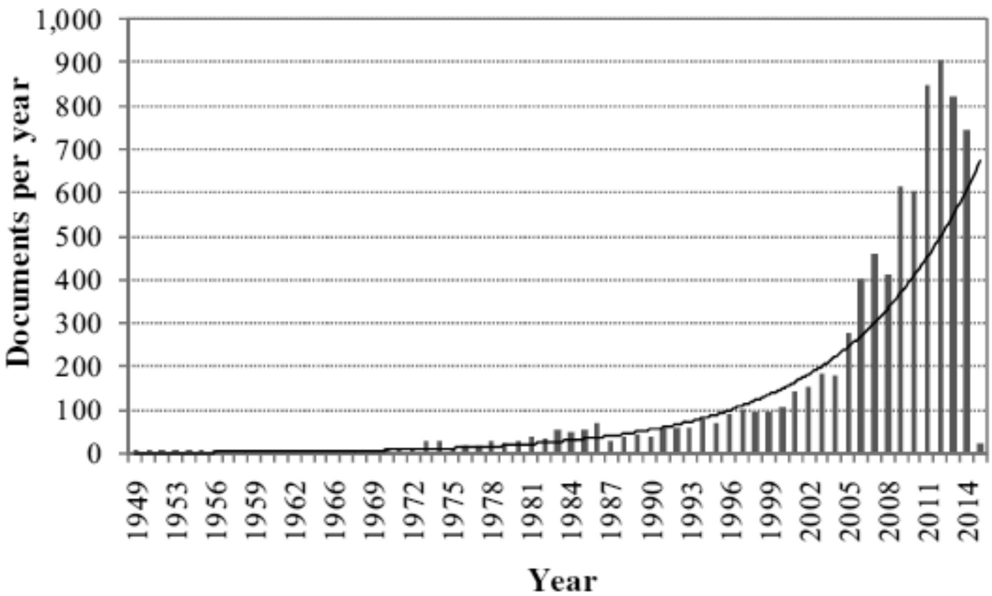


Figure 1: The Range of Articles by Year Published Related to Thermal Comfort in the Built Environment (Adopted after, Rupp, et al. 2015).

In fact, the concepts related with thermal comfort have gained gravity in the 21st century so far, where many researches asserted the possibility of controlling the indoor environment climate (Fabbri, 2015). In this context, many researches primarily influenced from a very early studies of Vernon and Warner (1932), Gagge (1936) and Bedford (1936) (Humphreys, et.al, 2011). Vernon and Warner presented the Corrected Effective Temperature (CET) by replacing the dry bulb temperature with globe temperature (Vernon and Warner, 1932). Gagge accomplished the idea of asserting the interdependent relationship between the human and their surrounded environment on the issue of energy exchanges/interactions (Gagge, 1936). His study intended to correlate the principle of thermodynamics for human body with implementing *"two nodes model- temperature control system, the equation of heat balance of the human body"* (Fabbri, 2015). Following the work of Gagge, Thomas Bedford examined the thermal comfort environments with a field case in United Kingdom, involving 2,500 workers in the light industry. His research focused on measuring air temperature, air speed, mean radiant temperature, and humidity (Bedford, 1936). Winslow et al. developed a series of physiological and physical principles, which convinces to measure the thermal interactions between human body and their surrounded environments (Winslow, et al, 1937). Houhgton and Yaglou proposed the Effective Temperature Index (ET) by established to provide a method for determining the relative effects of air temperature and humidly comfort (Houhgton and Yaglou, 1923). Later on, Yaglou and Minard proposed Wet Bulb Globe Temperature (WBGT) in the context of merging the effects of relative humidity, temperature, and heat exchange to define the degree of experience on warmth temperature conditions (Yaglou and Minard, 1957). Humphrey presented in more detail the significant correlation of thermal comfort upon the indoor and outdoor environments (Humphrey, 1976; 1978; 1992; 1996). Dear and Brager (1997) developed today's most common thermal comfort standards known as ASHRAE. The study is based on re-examining the thermal comfort data verified from all over the world. The comfort temperature in this study is taken into account and attention is given to associate average of monthly temperature at every specified location (Dear and Brager, 1997).

Through the feedback from the reviewed literature on thermal comfort it could be asserted that thermal comfort integrates varied relevant conditions to the indoor temperature. These conditions are comprehensible together to resolve the standards for temperature control through any thermal condition. In reality, revealing an understanding of human thermal comfort drastically entails exposing of all factors and their interactions with their environments. That means, an overall thermal comfort is not merely interdependent to solely one dimension, such as focusing on only physical factors. It should be noticed that there are also psychological and physiological reactions, which integrates along with diverse physical variables as humidity, temperature, noise, light, etc. in a building (Parsons, 2000). In general, thermal comfort is clarified with six parameters; four being physical factors and two as individual factors. The physical factors are;

1. Air temperature,
2. Air speed,
3. Relative humidity
4. Mean radiant temperature,

while, the individual factors can be counted as;

5. *Apparel protection,*
6. *Movement level.*

2.2.1 General Terms of Thermal Comfort

The term *artificial climate* is the modified climate by occupants, regarding developing motorization technology and industrialization of society (URL 5). A significant number of individuals spend a large portion of their lives (frequently over 95%) in a counterfeit atmosphere (Fanger, 1970).

With the enhancement of mechanical technology, a significant interest is increased to indicate artificial comfort atmospheres regarding temperature control of indoor spaces (URL 6). American Meteorological Society characterizes artificial climate as the ambiance that is created or altered by the occupants; it is not related to the external conditions of the close surrounding and refers to the enclosed space conditions. The fundamental aim here is to achieve the essential comfort degree for the occupants through varying temperature conditions, where they would define themselves as comfortable.

Nonetheless, it is noted that 'no heated temperature condition can fulfill everyone'. A gathering of individuals is liable to a similar room atmosphere; it will not be conceivable, because of natural differences, to fulfill everybody in the meantime (Fanger, 1970). Along with such an impact, Fanger suggests that to reach an ideal occupants comfort in the case of a gathering for instance; the most reliable condition for indoor resides through the thermal comfort (Fanger, 1970).

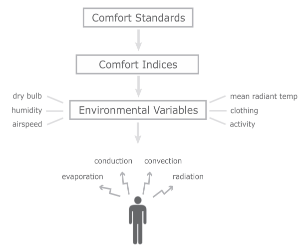
The *thermal neutrality* is one of the aspects of thermal comfort that elucidates singular comfort (URL 6). The thermal neutrality of bias for the human is characterized as the condition of which might not support for hotter or colder environments (Fanger, 1970). The main aim is to provide a harmony between the warmth created by digestion and the warmth lost from the body. Thus, human body drastically utilizes physiological procedures. Keeping up this warmth adjustment is the key condition/situation to accomplish a neutral thermal feeling (Charles, 2003). It is important to note that the body temperature of human is not constant. It varies based on the part of the body as well as the temperature of the air. Yet, the +35 C° is the absolute minimum and +40 C° is the maximum value for the human body (Butera, 1998). Thus, in the framework of thermal neutralizing, the human body is affirmed as a ‘thermodynamic’ structure that could designate a mechanical occupation, of which a low temperature utilizes the oxygen as source of warmth/ heat. Such a framework requires conditions that could preserve a balanced indoor temperature approximately +37.5C°. In order to keep the indoor temperature at a consistent thermal neutrality; the warmth of the body must be equivalent to the rate of warming. In fact, the thermo-regulatory system of the human body provokes preserving the heat balance since the heat balance is essential for comfort and survival of people (URL 6).

In addition to thermal neutrality, the *thermal indoor climate* is one of the key attributes of a building. It is the atmosphere of which is ought to ideally encourage the physical performances of the most of the occupants in a room (Van Der Linden, et al. 2006). Hence, the thermal indoor climate is the total physical features in a room that affects a person’s breath and warmth change, as well as other non-thermal factors (Fanger, 1970). Van Der Linden et al. demonstrates the importance of thermal comfort at a building with claiming that, the happiness of the clients in an indoor space of a building is essentially dictated by the nature of the thermal indoor atmosphere (Van Der Linden, et al. 2006). Such an explanation of Van Der Linden et al., in fact, clearly emphasize the individual comfort desires about an indoor atmosphere quality relies to the thermal climate of that indoors.

2.2.2 Thermal Comfort Parameters

It is fundamentally hard to define a single substantial variable for assessing the human comfort. As mentioned earlier, the thermal comfort could be revealed through six parameters, which are characterized by individual factors and environmental factors as shown in below table (Table 3).

Table 3: Parameters of Thermal Comfort (Adopted after, Laurel 2012).



Individual Factors	Environmental Factors
Activity Level	Air Temperature
	Mean Radiant Temperature
Clothing Insulation	Relative Humidity
	Air Speed

Since, the study is configuring an understanding on the thermal comfort, one of the significant essences must be considered in a building design; the necessity of better understanding the environmental factors is crucial for this study. The study does not have any means to evaluate individual factors. Therefore, a detailed explanation is solely given to the air temperature, mean radiant temperature, relative humanity and lastly air speed.

Air Temperature

Air temperature is the standard temperature of the air around an occupant. The mean of standard regards to a particular space and time (ASHRAE Standard 55-2004). Since, the determination of air temperature is best done by feeling it, it could be notified as the feeling based on comfort estimation of how cold or hot a thing/object/space etc. is. However, there are numerous variables that are influencing the quality of the air temperature or asserting an entire accumulation. These variables are defined by BBC (2009) as air moistness, density, and the speed of the wind.

Mean Radiant Temperature

Mean radiant temperature is simply the surface temperature of entire objects adjacent to a body. According to the definition of ASHRAE, a mean radiant temperature is the consistent surface temperature of an enclosed space, of which similar amount of radiant heat would be exchanged by an occupant (ASHRAE, 2004), as the radiant resides in electromagnetic waves of the objects that are occurred by their temperature. In the case of when a person’s body is significantly hotter than its surrounding environment, the body releases more radiation than it absorbs. In such a condition the body impels an intensity to cool. Through a converse condition, the body intends to heat. Apparently, the emission and absorption reach a level of balance. Therefore, it could be noted that the body is in thermal equilibrium as a result of this process (Halliday, et al. 2003). However, such a process is strongly dependent on the shape of a person’s body. Hence, to make an accurate measurement of mean radiant temperature is particularly difficult.

Relative Humidity

Relative humidity could be defined as the ratio of the partial pressure of water vapor in the air to the saturation pressure of water vapor at the same temperature and total pressure (URL 6). The vapor pressure is equally distributed over the space. Therefore, it is sufficient to measure the humidity at only one location of the space. As, the human body cools itself by regulating its temperature with evaporation; it demonstrates a significant sensitivity to humid air. In the condition of humid air, the human body estimates a lower evaporation than an arid/dry air condition. Throughout the rate of heat transfer, the human perceives the level of temperature. For instance, in the conditions of when the humidity level is high, a human feels warmer. Conversely, human feels colder when the humidity level is low. For a better explanation, if we assume that the relative humidity is 0% and the air temperature is 24 C^0, the human feels the air temperature as 21C^0. On the other hand; if the humidity is 100% and the 24 C^0 is saturated with water vapor; the felt temperature increases to 27C^0 and the condition of air is very dry.

Air speed

Air speed is mainly the rate of air movement in a space. However, there is not a noticeable or recognizable connection between the enhanced thermal comfort and increased air speed. Nevertheless, ASHRAE suggests that when the air speed can be controlled by the occupants, the increased air speed could be utilized for maximizing the temperature towards the thermal comfort level (ASHRAE, 2003). In this regard, the integrated air speed to the given temperature might pose a kind of similar heat loss from the body. Nonetheless, the preferred air speed varies according to each individual person. The thermal comfort is one of the most significant factors convincing the human health and comfort. However, the relationship between the human health and comfort is not constructively assigned yet. On this basis, for decades, various studies have been provoked to define the requirements of the thermal comfort for achieving comfortable environments for occupants, their performances and their health. In this sense, the fundamental intent is primarily amalgamated on determining the most efficient fundamentals in thermal comfort, as well as factors affecting it.

2.2.3 Models on Thermal Comfort

Until today all of the studies about to thermal comfort either used analytical or adaptive approaches (Almeida, 2010). The analytical approach mainly correlates the indices of climate charters (the environmental air speed, temperature, humidity etc. variables) and thermal sensation experiences of people towards the combined conditions of the given environmental comfort variables/factors (*See. Houghten and Yaglou, 1923; Yaglou and Miller, 1925; Vernon and Warner, 1932; Fanger, 1970; ASHRAE 55-2004*). On the other hand, the adaptive approach reveals the determination of comfort standards or conditions of the given field studies. In the context of adaptive approach, the analysis employs a pragmatic resultant recording the occupants' thermal experiences, of which variables affecting the thermal comfort are warranted with regards to occupants' performances and their interactions with their surrounding environments in a building (*See. Humphreys, 1975, 1979; Auliciems, 1981; De Dear, 1998*). In the context of these two approaches varied studies are impelled with different degrees of complexities both in analytical and adaptive approaches. Yet, each study in either of these approaches has the intense of obtaining or exposing varied impacts of thermal comfort on occupants and its built environment. This section conveys a review of merely two key methods in terms of informative details since they comprise experimental-empirical exploration and lead a grounded basis for the further phase of the study.

- PMV/PPD Method of Fanger, 1970
- Adaptive Comfort Method

2.2.3.1 PMV/PPD Method of Fanger, 1970

It could be claimed that Fanger is one of the most prominent contributors to his well-known studies in the field of thermal comfort studies. Throughout various studies, Fanger revealed rational approaches reclaiming a deep survey on thermal comfort and its relationship with occupant performances and health (Fanger, 1970). Therefore, the study discovers various considerable correspondences between Fanger's thermal comfort approaches and thermal comfort theory.

Fanger developed a general comfort equation to determine an optimal thermal comfort level satisfying the occupant desires (Fanger, 1970). To accomplish an optimal thermal comfort, a significant importance is given to the conditions, which analyze the requirements and quantify the variables. In such a framework, we see that Fanger studied a varied amount of field experiments that measure the surrounding variables with captivating analytical feedbacks from a thermal sensation data collection among people on a suitable psychophysical scale. In 1967, Fanger with his article, titled 'Calculation of Thermal Comfort: Introduction of a basic comfort equation' presented a basic rating scale inducing the occupants' perception on comfort (Fanger, 1967). After a short time, Fanger published his fundamental book; Thermal Comfort. The book has been a pioneer for such a new discipline of comfort, of which elucidate the varied conditions of comfort in buildings. While, he utilized a practical measuring conditions (Fanger, 1970). In more detail, Fanger made several trials on research to define the substituting energy between the human and surrounding environment. The successive trials asserting a *'heat balance equation'* that determines a degree of wellbeing regarding varied conditions of heat. In this way the heat balance equation is accounted in a sequence of comfort diagrams residing through in six variables, namely, air temperature, air speed, relative humidity, mean radiant temperature, metabolic rate, and clothing (Figure 2) (Fabbri, 2015).

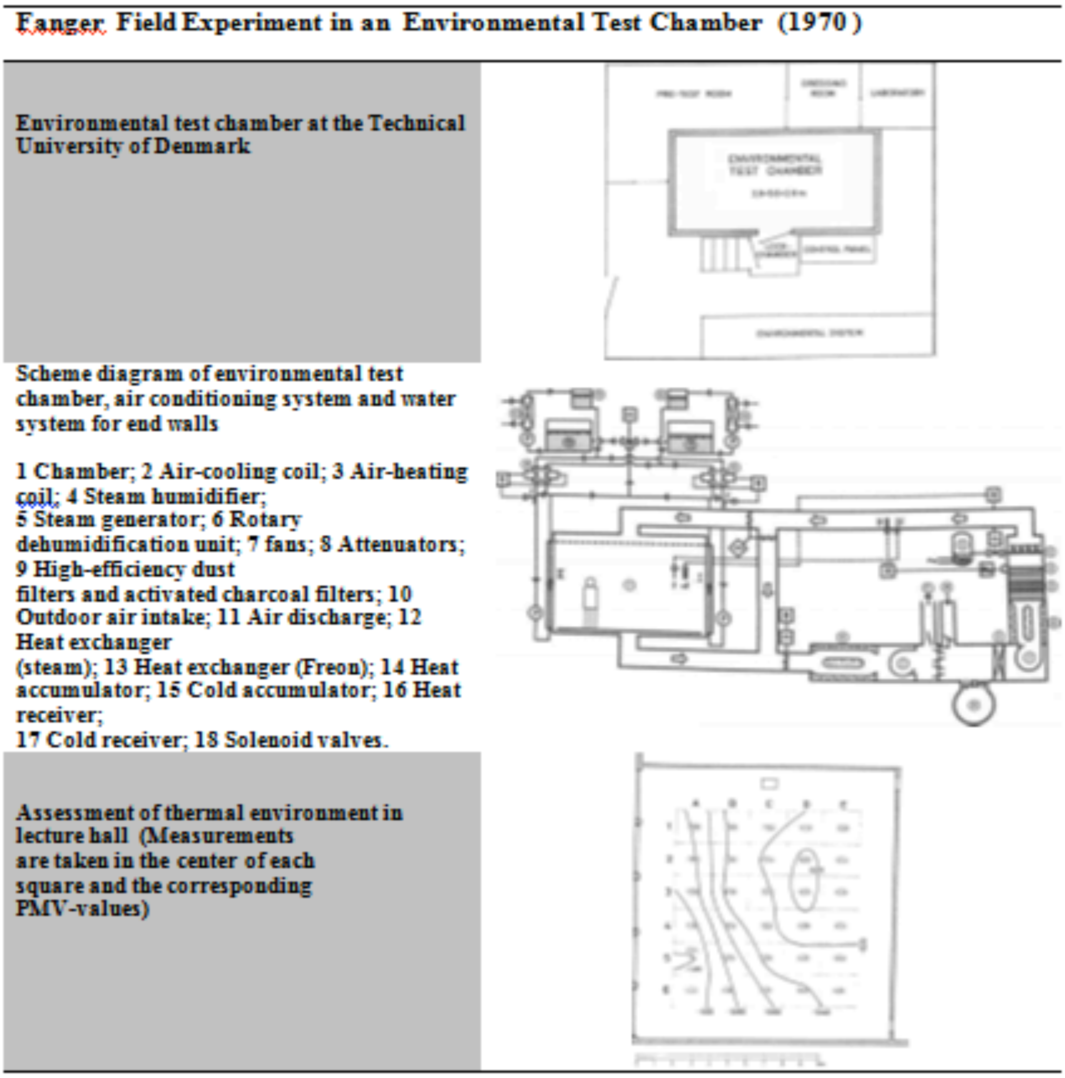


Figure 2: A Field Study in Environmental Test Chamber, Fanger, 1970 (Adopted after Fabbri, 2015).

The developed equation facilitated on a digital ground provided relative and an absolute influence of the diverse variables. The obtained data is shaped among various numerical diagrams to be used in Engineering Science. In general, Fanger's equation is frequently utilized in data calculation of the industrial and engineering studies, as well as in practice (practical applications). In practice, reliable methods are essential for quantifying the given comfort conditions in a rational calculation. The result of the rational calculations is appropriate to assign reliable quantitative comfort conditions for operating both existing forms and newly developing systems of thermal comfort installations. In fact, Fanger's equation has a fundamental importance in engineering calculations for operating installations of thermal comfort and also developing of new systems.

Fanger suggests revealing a thermal perception index of an environment, is essential. This index is drastically diverged from the optimum comfort and it grounds the basis of asserting a rational method for rating the thermal comfort value/quality of a given environment. Since, the index includes the same six variables, i.e., relative humidity air speed, mean radiant temperature, air temperature, clothing, and movement level of thermal comfort in the equation. The integration of index in equation enables quantitatively evaluating the influences of varied thermal environments on occupants' thermal perception in a particular space (Charles, 2003).

It should be declared that the comfort equation impels solely to understand the essential combination of variables accomplishing optimum thermal comfort. In essence, he combined his heat balance equation/comfort equation with an experimental data within a climate chamber by recording occupants' vote on regularly changed six comfort variables, of which the PMV index was calculated. Therefore, a thermal comfort perception index model, namely 'Predicted Mean Vote' (PMV) on the scale of psychophysical (Fanger, 1970) is proposed. The model endorses the capability to forecast thermal perception of a large group of occupants on a seven-task thermal perception scale (Table 4).

Table 4: Predicted Mean Vote Thermal Perception Scale (Adopted after, Fanger, 1970)

+	3	Hot
+	2	Warm
+	1	Slightly Warm
	0	Neutral
-	1	Slightly Cool
-	2	Cool
-	3	Cold

The consequence of accomplished diagram from the experimental analyses facilitated to identify the percentage of displeased occupants, of who are disturbed during the practice from the given thermal environment (URL 6). Fanger declares the magnitude of displeased occupants' percentage in the model as 'Predicted Percentage of Dissatisfied (PPD)'. By use of the above rating scale, the percentage of dissatisfied occupants is aimed to be defined in a more heterogeneous thermal quality in a given indoor. Apparently, with assigning an indoor having more heterogeneous thermal quality in the experimental analysis, a large number of dissatisfied occupants are expected. This approach led to obtaining data representing how many expected dissatisfied occupants might appear under the given thermal condition. Of course, this reveals moderately prediction. Moreover, it partially estimation of the percentage of dissatisfied occupants with the utilization of actual heating on air conditioning (Fanger, 1970). PPD is dependent on the Predicted Mean Vote. Therefore, the occupants voted +2, +3, –2, or –3 on thermal perception scale, in PMV, are assumed as the dissatisfied occupants (ASHRAE Standard 55-2010).

Copious field analysis implied that alterations in predicted temperature because of PMV is not equivalent with the occupant sensitivity, which is in accordance with the dissimilarities among the predicted and tangible neutral temperatures. Dear et al. (1993) uncover those predictions done by PMV is mostly coherent with perceived neutral temperatures, however in non-neutral circumstances diversities are noticed between tangible and predicted temperatures. Consequently, in front of these outcomes in accordance with temperature vicissitudes occupants are more delicate than the predictions of PMV model. Conferring to these, specifically in field analysis PMV model cannot be accepted always as a decent conjecture for estimating the tangible thermal perception. In many applied sceneries, the accuracy of PMV method can be reduced through deprived assessments of two major variables with difficulties in acquiring precise measures that are listed as (Charles, 2003):

- Clothing insulation,
- Activity level.

2.2.3.2 Adaptive Comfort Method

The adaptive method is developed in response to the approach that people demonstrate natural ability to adapt themselves to the changing temperature conditions of the environment. Therefore, the adaptive thermal method intended to incline thermal comfort within the principle of adaptability. As Auliciems expresses occupants demonstrates the ability to restore the thermal comfort when an appealed change poses thermal discomfort (Auliciems, 1983). Parallel to the Auliciems definition, Nicol et.al also note that in a condition of any discomfort, people assign response of adaptability to reinstate the comfort (Nicol, et. al, 2002). In addition, Nicol and Roaf also signify that occupants always constrain an individual control, as opening/closing the windows, changing the clothing, turning the fans/air-conditions on, etc., on dynamic and varied environmental conditions to adapt themselves in means of comfort, since there is a consequent interaction drawn by occupants with their environments (Nicol and Roaf, 2005).

The same approach is involved in the adaptive thermal theory as people could adapt to different temperatures in the conditions where external climate affects the indoor climate in terms of comfort (Dear and Brager, 1998). Overall, the approach considers the dynamic and varied conditions of individuals as well as the external or internal environment to affirm a comfortable situation in the framework of adaptation. Consequently, the adaptive thermal method in fact, is resided on controlling the dynamic environmental climate conditions that are weighting the thermal preferences and expectations of occupants at indoor environments. Since the characteristics of the buildings forces diverse possibilities for the comfort adaptation of occupants, they also might allow a control for occupants by means of changing the conditions according to their expectations and preferences. In such a context, variable field studies revealing their specific adaptive methods (*See.* Auliciems, 1983.; Auliciems and De Dear, 1986; de Dear and Brager, 1998; Nicol, 2004; Nicol and Humphreys, 1998; Humphreys, 2007; de Dear de, 2007) are intended to be surveyed for determining the occupants' thermal comfort adaptation through random environmental competences (Figure 3). The general outcome of the studies revealed from field surveys imposed a novel model shift from the work of Fanger's theory. The studies figured that internal active temperatures are showing linear deteriorations relatively comparing to the existing external temperatures. The adaptive comfort is verified relatively in three core of human comfort sensation- as physiological, psychological and behavioral (Dear and Brager, 1998). Several studies put their focus on signifying the relationship between the neutral precinct, the adaptive probabilities and environmental motivation by addressing both individual adjustments (performance, intake, changing clothing, position etc.) and building/environmental adjustments (controlling fans, doors, windows, air-conditions etc.) (Baker and Standeven, 1996; Olesen, 2000; Cena and De Dear, 2001; Mui and Chan, 2003; Liu, et.al., 2013).

Adaptive comfort equations.

Climatic zone	Location/source	Equation	Remarks
Meta studies	Humphreys [1]	$T_n = 11.9 + 0.534T_o$	FR buildings
	Humphreys [1]	$T_n = 23.9 + 0.295(T_o - 22)\exp(-[(T_o - 22)/(24\sqrt{2})]^2)$	MC buildings
	Humphreys [1]	$T_n = 24.2 + 0.430(T_o - 22)\exp(-[(T_o - 22)/(20\sqrt{2})]^2)$	MC and FR
	Auliciems [1]	$T_n = 9.22 + 0.48T_a + 0.14T_o$	MC and FR
	ASHRAE Standard 55-2004 [98]	$T_n = 17.8 + 0.31T_o$	FR buildings
	EN15251 [103]	$T_n = 19.39 + 0.302T_{RMT}$; $T_{RMT} > 10\ ^\circ C$	FR buildings
		$T_n = 22.88\ ^\circ C$; $T_{RMT} \leq\ ^\circ C$	
Type B	Pakistan [52]	$T_c = 18.5 + 0.36T_{oh}$	FR buildings, historic outdoor mean temperature
	Tunisia [51]	$T_n = 11.56 + 0.532T_{RMT}$	FR buildings
Type C	Shanghai [11]	$T_n = 15.12 + 0.42T_o$	FR buildings
	Hong Kong [62]	$T_n = 18.303 + 0.158T_o$	MC buildings
	Bari, Italy [80]	$T_n = 17.80 + 0.315T_{RMT}$	MC and FR
Type D	Harbin [9]	$T_n = 11.802 + 0.486T_o$	FR buildings, in summer

Here, T_o is outdoor monthly mean temperature; T_{oh} is the historical outdoor monthly mean temperature (averaged over 30 years in the given case); T_a is the indoor air temperature; T_n is the neutral or comfort temperature; T_{RMT} is the running mean temperature. Both the local ACEs given here that use T_{RMT} as an index of outdoor temperature, use similar formulations for T_{RMT} as EN15251. All temperature units are in degrees Celsius.

Figure 3: Showing Adaptive Methods and their Equations Developed in the Field (Mishra and Ramgopal, 2013).

2.2.4 ASHRAE Standard 55 – 2010

ASHRAE 55-2010 is one of the fundamental international standards utilized in the field of thermal comfort evaluation studies. In 1984, ASHRAE is established as an international society with the aim of providing technical thermal comfort standards or HVAC (heating, ventilation and air-conditioning) principles, revealing an indoor thermal-control approach (ASHRAE Standard 55, 2010).

Several studies of Dear and Brager conducted in more than a decade correspond to development of a very significant method which is frequently used in the field of thermal comfort measurements/assessments (De Dear et.al., 1988; De Dear and Leow, 1990; De Dear et.al. 1991; De Dear and Fountai, 1994; De Dear and Brager, 1998; De Dear and Schiller, 2001; De Dear and Brager, 2002). Significantly, with the field study carried in 1998 by examining 160 office buildings from 9 countries of 4 continents, they established a database from a series of raw data. The results showed that; the preferred temperature of occupants depend on the outdoor temperature since the acceptance and preference of the occupants of naturally ventilated buildings represented a broader range of temperature than the ones who are in mechanically cooled in other words air-conditioned, buildings. In cooperation with Dear and Brager study (1998), ASHRAE derived ASHRAE RP-884 database (as an optional method) to set an adaptive comfort standard model relative to thermal, visual/lighting and acoustics/sound for evaluating naturally ventilated buildings through varied environmental zones. In addition to this, the ASHRAE configured their first adaptive comfort model as ASHRAE 55- 2004 standard, relating the internal comfort temperature to existing external temperature with an 80-90% satisfaction (ANSI/ASHRAE Standard 55-2013).

The ASHRAE Standard 55- 2010 is obligated to the realm of changeability in occupant thermal responses in relation with diversity in current thermal experiences considering the availability of control opportunities, changes in clothing, and changes in occupant preferences and expectation (ANSI/ASHRAE Standard 55-2013). Therefore, ASHRAE 2010 indicates the standards of thermal comfort opportunities in response to a mathematical modeling referring to the Fanger's studies. Recently, many practitioners utilize the ASHRAE 55- 2010 standards to define the optimal thermal conditions. Hence, it demonstrates a range of thermal environmental conditions including the combinations of indoor environmental quality with personal factors; that are essential for the human-body (ASHRAE Standard 55- 2010). At this point, ASHRAE 55-2010 signifies the importance of retaining a well-qualified or well-optimized thermal comfort for occupants in an indoor environment, where HVAC design engineers must be compelled with this purpose. Therefore, a heat balance model considering the factors forming thermal sensation (humidity, temperature, air speed, mean radiant temperature- performance, clothing) is configured by ASHRAE 55-2010 standard. In this context, varied requirements for varied types of buildings as, commercial buildings, hospitals, hotels, dormitories, schools, houses are defined and estimated. In Table 5, the recommended/-required parameters for indoor environment thermal comfort that are defined by ASHRAE 55-2010 Standard are given.

Table 5: ASHRAE 55-2010 Recommended- Required Indoor Design Parameters (ASHRAE 55-2010).

Indoor Spaces	Winter Conditions		Summer Conditions	
	Temperature C°	% RH	Temperature C°	% RH
Rooms	23 C° - 24 C°	%30 - %35	23 C° - 26 C°	%50 - %60
Lobbies	20 C° - 23 C°	%30 - %35	23 C° - 26 C°	%40 - %60
Meeting Halls	20 C° - 23 C°	%30 - %35	23 C° - 26 C°	%40 - %60

ASHRAE 55-2010 declared the psychometric diagram conferring to PPD/PMV method in Figure 4, which signifies the adequate amalgamation of humidity values and air temperature. The adequate comfort zone (90% of it) exposed with the purple color.

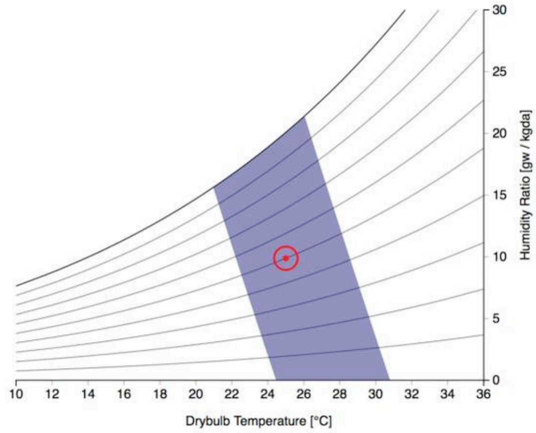


Figure 4: Psychometric Chart (URL7)

Figure 5 signifies the temperature relative humidity instead of regular psychometric diagram. It displays the adequate combination of relative humidity values and air temperature in accordance with PPD/PMV method that take place in the ASHRAE

55-2010.

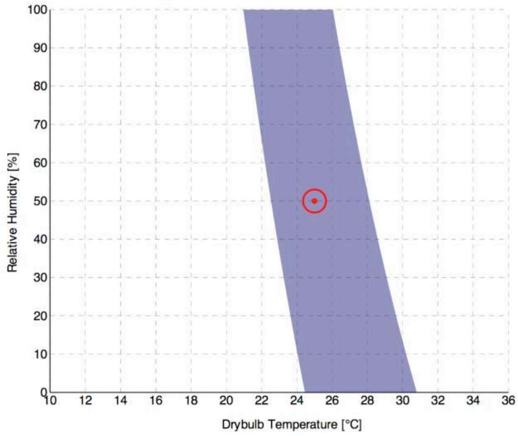


Figure 5: Temperature-Relative Humidity Chart- PMV Method (URL7).

2.3 Visual Comfort

There is not only one extensively accepted definition of visual comfort. There are different definitions developed based on the factors/metrics/parameters they are focused on. In general, visual comfort is mainly aimed to be defined as a condition, which is revealed based on many factors such as the amount, uniformity, direction and degree of the light as well as the balance of contrasts, the absence/existence of glare and the temperature of color in a room (URL 8). Since the visual comfort is the consequence of varied complex but integrated factors that work together in many ways, different environmental contexts involve with different factors (Lemon, 2015). In other words, these factors are not steady. They all acquire distinctive forms or role according to the distinctive characteristics of environments.

2.3.1 Fundamental Metrics Characterizing the Visual Comfort

2.3.1.1 Uniformity of Light

The uniformity of light is the consistency on the spread of light along a given environment. The uniformity of light functions reduces the visual discomfort.

Indeed, continuous adaptation of eye supplied by the uniformity of light positively affects the avoidance of visual stress. The uniformity of light depends on the consistency of adequate illuminance, light per unit area on a given surface. The uniformity of light is significantly utilized to resolve and clarify the light encountering visual comfort or discomfort in a particular environment, which might drive the same attribute for varied conditions.

2.3.1.2 Glare

In some conditions, the high degree of natural or artificial lighting impels a very shining/bright/luminous environment. Since the eye endorses a coherent visual comfort with the adequate degree of light, a luminous environment poses difficulty in seeing of occupants. In fact, glare is the condition of the disrupted feeling in visual perception of the eye such as visibility, discomfort and performance etc. due to luminance (IESNA, 2000).

Further, the glare is the appealed condition of which a source of uncontrolled light is excessively brighter than the standard visual luminance. Carlucci end their colleagues describe the glare as the condition of when the occupants perceive an excessive amount of light or when occupants experience a broad range of illuminance, and these drives to disability glare (Carlucci et. al., 2015). According to the Illuminating Engineering Society (IES) (IESNA, 2000), glare occurs because of the given conditions when:

- a very high degree of light in terms of the amount or
- a great contrast, a very excessive range of luminance exists.

To decrease or reduce the disrupted feeling in visual perception occurred by glare, a very luminous part of the environment could be darkening. The darkened part mainly contributes to lowering the degree of luminance. However, this progression excessively contrasting the darken parts and highly luminance parts. Such a condition creates discomfort glare, where occupant visual performance is faced with an increasing worsening. Comparing to the discomfort glare, the disability glare is demarcated easier to be determined in a given space as the discomfort glare is very subjective (Osterhaus, 2005). The study of Kleindienst and Andersen presents that a vital evaluation of glare in a building or establishing a certain guide to the building design is not possible, due to glare is very much dependent on the occupant location and, position, individual tolerance in adaption ability of eye to a luminance environment and a wide range of variability in luminance (Kleindienst and Andersen, 2009). Nonetheless, there are significant methods developed to control the glare in buildings. For instance, the glare posed due to natural lighting could be manageable with the implementation of architectural solutions in design (Andersen, 2008). Especially shading is seen one of the key architectural solutions to control the glare in buildings, where surfaces are shaded with use of shading elements or roof extensions, etc.

2.3.1.3 Quality of light in rendering colors

The quality of light is relatively integrated with the natural lighting of an environment. In other words, the natural lighting is the core domain for rendering colors in the mean of adequate quality, where the eye corresponds with uniformity in visual comfort. In many of the studies, the quality of light is aimed to be captured in the natural light impact by researching indoors as working spaces, living rooms, schools, libraries, hospitals etc. Detailed information is molded on representing the positive effects/benefits on quality of natural lighting in which it is superior to physical, psychological and physiological well being and comfort of occupants. The quality of light involved through natural lighting could be endorsed for improving productivity and performances of occupants by revealing an adequate rendering of colors in the environment. The quality of natural light shows differences than the artificial light like the frequent change of the concentration on the diffusion of light into space and the color uniformity affecting the eye. Nevertheless, a high degree of natural light diffusion into an environment such as working space can pose non-uniform lighting that is destructing to the rendering of colors, where the eye reacts in way of visual discomfort (Carlucci et.al, 2015).

2.3.1.4 Amount of Light

The visual perception range of an eye is incredible: the eye see where the amount of light is less than 0.1 lux or even more than 100,000 lux (URL 9).

The accurate amount of the light rationalizes the optimal visibility for the occupants. In relation to the amount of light, occupants accomplish their discomfort or comfort condition. Very often the condition of discomfort might occur when the amount of light is very low or very high (Carlucci et.al, 2015). The amount of the light is dependent on the amount of light seen by a specified surface, which is the resultant of reflected light from all sources around it. Luminous flux is the amount of light that is totally perceived given by a light source. In other words, the luminous flux is the light coming from a surface accomplishing the perceived light totally. The brightness of a light source is fundamentally measured in terms of lumens. This measure indicates the brightness of the light source (URL 4).

On the other hand, illuminance is the amount of the light that attains to a specified point of a specified surface in terms of physical quantity and it is measured in terms of lux. In other words, luminance is the light that is falling on a particular surface. Lux is utilized to optimize the visual comfort in an environment, as the luminance is also utilized through building standards for determining the minimum degree of light (URL 4). Regarding this, illuminance is not dependent on the material of a specified surface, but the color and reflection degree from all other surfaces around. In buildings, the most important impact related to light is to having an adequate amount of light mainly supplied by natural lighting for the activities of the occupants. The measurements are usually conducted through a particular working surface in a given building. Related to this, different indoor environments demonstrate different identical specifications on brightening conditions (Table 6) (Boduch and Fincher, 2009).

Table 6: Recommended Illuminance quantities for various indoor spaces (Adopted after Boduch and Fincher, 2009).

Lux Requires For Appropriate Illuminance									
50	100	150	200	300	500	750	1000	1500	2000
Rarely used interiors for movement and little detail	Occasional interiors for movement and casual seating	Occasional interiors with detail but some risk to others	Occupied interiors for visual tasks with some detail	Visual tasks moderately easy with high contrast or large size	Visual tasks moderately difficult or color judgement required	Visual tasks difficult (small, low contrast)	Visual tsks very difficult (small, low contrast)	Visual tasks extremely difficult, optical aids and local lighting may help	Visual tasks exceptionally difficult, optical aids and local lighting will help
Tunnels, walkways	Corridors, changing rooms, auditoria	Loading bays, medical stores, plant rooms	Foyers and entrances, turbine halls, dining rooms	Libraries, sport and assembly halls, teaching spaces	General offices, engine assembly, kitchens, labs	Drawing offices, ceramic decoration, chain stores	General inspection, electronic assembly, gauge and tool rooms, supermarkets	Fine work and inspection, hand tailoring, precision assembly	Assembly of minute, mechanisms, finished fabric inspections

2.3.2 Daylight and Occupant Performance in Buildings

Recently, most of the studies are conducted to determine the visual comfort relevant to occupant requirements and the lighting of environment. Our perception depend on the existence of light, hence, its effect on us is quite natural (Boubekri, M, 2008). The light is one of the most crucial factors in human life running the conditions for physical and psychological well being such as health, safety, and happiness (URL 8). Having said that, the visual comfort is commonly a subjective perception and shows differences on many ways. In other words, different occupants in an environment impose different reflections to the factors of visual comfort. For instance, an occupant reflection to the natural lighting, accesses to the views or direct sunlight in to a building could be different than others (URL 10). Therefore, a significant impact is attained to understand how the quantities/qualities of light and access to view affect the occupant comfort (Carlucci et. al., 2015). Hawthorne lighting experiments examines how irrelatively increasing or decreasing the lighting levels in a workspace affect the occupants work performances. The study is fundamentally developed with a focus of human perspective. Throughout the study, it has been obtained that, increasing or decreasing the light levels increased the work performances of occupants. Indeed, the physical environment is modestly declared irrelevant, when the productivity improvements of the occupants are considered (Roethlisberger and Dickson, 1939). In converse to Hawthorne lighting experiments, Newsham et al. proclaims evaluating the lighting by means of economy, where human perspective is distinguished inconsequential (Newsham et. al., 2005). Therefore, in their study, the significant role of natural lighting on occupant comfort at a given indoor space is drastically defined. According to this study, occupants that have a direct interaction with a window in a workplace presented more satisfied comfort level, rather than the ones who do not have any interaction with a window. Simply, they distinguish the need of individual control on lighting. They believe that controlling the individual lighting could operate different preferences of individuals. Hence, impelling an individual control on lighting adjusted the potential to assemble self-selected or preferred lighting conditions in a space (Newsham et. al., 2005). Another direction is taken by Boyce et.al (2003) where, they deter the lighting quality by investigation of a field simulation research. The study involves field simulations developed within the framework of comparing *best practice* (which is representing the office lighting conditions) and *base case* (which is representing lighting condition of modern office practice) lighting conditions in offices. In such an approach, work performances of occupants are measured over a complete working time of a day. Consequently, a wide range of differences is obtained regarding individual's lighting preferences. In other words, the result clearly signifies that a stabilized lighting level is not sufficiently responding to each occupant's lighting preferences (Boyce et. al., 2003).

Retaining visual comfort drives revealing a proper embodiment with obstacles (*quality, quantity, and balance vise*) of light and view. The International Commission on Illumination (CIE) developed a set of parameters influencing the visual comfort at an indoor lighting and its correlation with a building's spatial design characteristics (Table 7) (Iacomussi, et.al, 2015).

Table 7: Set of parameters influencing visual comfort developed by CIE (Adopted after Iacomussi et. al, 2015).

Lighting	Glare (from luminaries, daylight, bright surfaces like windows, …)	**visual comfort appraisal in relation with the spatial design characterizations**	Space and room appearance
	Veiling reflections		Surfaces brightness and color
	Illuminance levels (work plane, surrounding, ...);		Light distribution
	Luminance ratios and uniformities		Appearance of light and luminaries
	Color rendering index – CRI		
	Correlated Colour Temperature – CCT		
	Flicker		

Yet, the design of buildings plays an important role in estimating the essentials for occupant's visual comfort, since the buildings are serving people (UrL 4). The lighting issue in buildings drives a significant correlation with the energy use. The use of electrical (artificial) lighting in buildings poses a large amount of energy consumption. The light source, room, and luminary (leading light) of a lighting system are drastically the primary aspects affecting the energy consumption (Pohl and Werner, 2010). Leadership in Energy and Environmental Design (LEED) notifies the lighting as a key catalyst for impelling environmentally responsive high performance buildings. To lower a lighting impact on energy efficiency can be achieved in many ways in technological or traditional innovations such as utilizing natural lighting, the energy efficient lighting installation, high incidence diffusion controls, automatic or manual lighting operators in the design of building (Carlucci et.al, 2015).

On the other hand, the contribution of using artificial lighting to occupant comfort and their productivity is also debated. However, the daylight is determined as a factor differing in many ways from the artificial lighting (Anter, 2013). As De Carlie and their friends state, “artificial light is static, while natural one changes all over the day and year, providing many different scenarios which can enhance productivity and attention” (De Carli et. al., 2008). The use of natural lighting is advocated more imported in buildings and more efficient than the artificial lighting to lower the energy efficiency, increase the visual and psychological comfort, and performances of occupants (Heschong et. al, 2002; Boyce et. al, 2003). Therefore, the use of daylight in buildings gained an ultimate importance to improve the visual comfort and well being (De Carli, et.al, 2008). Several studies generally illustrate that, most of the occupants in an indoor space prefer natural lighting as a factor improving comfort and performance instead of electric lighting (URL 4). Galasiu and Veitch also notify that daylight usage during working ensures less discomfort and stress comparing to the electric lighting (Galasiu and Veitch, 2006). Boyce claims “daylight is clearly preferred over electric lighting as a source of illumination and states”. How daylight influences visual performance depends on how it is delivered. Either good task of performance or bad task of performance can be expected depending on the amount of daylight delivered.” (Boyce, 2003). This positive contribution of daylight could be accomplished with spatial quality specified by a window and it could also be related to the quality of daylight (Veitch, 1998; Boyce, 2003). However, the daylight cannot be the sole source in a building, since it is demonstrating variability in its continuity depending on the time, season, place, etc. As a result, the adequate amalgamation of natural light and artificial light is crucial to estimate optimal visual comfort in terms of light during the day and night time.

2.4 Sound/Auditory Comfort

The sound could be defined as the form of vibrated particles in waves that can be spread towards entire directions in environment by revealing a pattern of density and refraction. In other words, the sound could be illuminated as the energy that is accomplished by pressure waves and diffuses in-to space with the aid of pressure of the air in the environment. Hence, the sound is one of the significant factors endorsing the comfort quality for the occupants. It intimates an integrated relationship with the other comfort factors (thermal and visual conditions) for improving the comfort quality of indoor spaces as well (GSA, 2012).

Significantly, the occupants could indicate a discomfort in terms of sound based on the amount of noise at outdoor or adjacent spaces, or the quality of sound control at indoor space etc. (URL 11). In such a context, the effect of sound on occupants' comfort experience is indented to be understood. Several studies are conducted with sound through examining its movement and its speed across spaces, -*from outdoor to indoor, or from adjacent space to specified indoor space, etc*., while a significant attainment is given to the connection of sound speed and movement with the degree air density (URL 12). Appropriate prevention systems are justified crucial to control the essential sound quality at indoors for occupant comfort (Bitencourt, undated). Under such a focus, varied studies compelled sound comfort adjustments at different types and parts of buildings. Cotana and Gorettti inspect the acoustic performances of buildings regarding the facades, walls and floors, different noise sources, and occupant expectations to assess acoustic performance index, which is enabling comfort for the occupants in buildings (Cotana and Goretti, 2010). Huckemann et al.

evaluate the sound comfort properties of doubles skin façades (DSF) by measuring the insulation performance from external noise based on standard EN ISO 140-5 for varied conditions (Huckemann, et al., 2009). Norma Técnica Brasileira – NBR (2003) demarcates their study on understanding the concept of sound and its relation with occupant comfort and their well-beings through determining the interfering sound sources in health care service buildings (Bitencourt, undated). Italian standard project UNI U20001500 introduces the acoustic classification of buildings where each classification signifies the varied levels of sound comfort (Italian National Decree DPCM, 1997).

2.4.1 Impacts of Sound Comfort

2.4.1.1 Noise

Noise is generally defined within the framework of 'undesirable/unpleasant sound' that is negatively affecting the human comfort at an environment or an indoor (Souza, et. al. 2003; Bitencourt, 2011). Noise is mainly the formation of a vibration. The noise demarcates variation in its types depending on the location of the source; *as indoor noise and outdoor noise.* The indoor noise is mainly occurring from the sources as footsteps on a floor, air-condition, a machinery vibration etc. While the outdoor noise is more relevant to the sources such as traffic noise, construction activities, people, etc. In this regard, two different types of sound are valid in terms of their transmission path, noticed as either *airborne sound* or *impact sound* (URL 13). Airborne sound is the sound where air serves to transmit the sound waves from the sources such as radios, television, speakers or etc. Impact sound is the sound where continuous vibrations are endangered at a surface from a source as footsteps, mobile phone vibrations etc. rather than traveling in the air. A source might appeal both of the types, although each of the types represents variations in the mean of transmitting sound. Therefore, they assign different prevention and insulation installation in buildings such as considering absorption degrees and qualities of the materials, distances among the surfaces etc. Noise attributes a wide range of comfort impacts in buildings (URL 14). Understanding the sound comfort embody the impact of noise, since the quality of buildings represents the overall occupants comfort. Therefore, the effects of noise through space are dependent on the design of that space. In other words, the transmission of noise changes according to the design opportunities of buildings.

Parameter of Human Hearing

The integrated limits of the degree and frequency define sound perception or experience. Hearing performance of a human being ranges from 20Hz to 20000Hz. The human being can hear sounds that measured in decibels from 0dB (quiet) till 130dB, which is a stance for initiation level of discomfort. Through this range phenomenological experience of loudness can be obtained (Grondzik et. al, 2010).

2.4.1.2 Loudness

The level of sound pressure is not affecting the volume precisely. The sound pressures, which appear instinctively, can be perceived in higher levels as louder tones in every specified ground or sound frequency. Nevertheless, the experienced sound in Phons increases and decreases in non-linear volume, if the frequency of the sound changes and sound pressure remains perpetual (Grondzik et. al, 2010) (see Figure 6). Conspicuously, the range of the human voice frequency is mostly perceptive by the human ear.

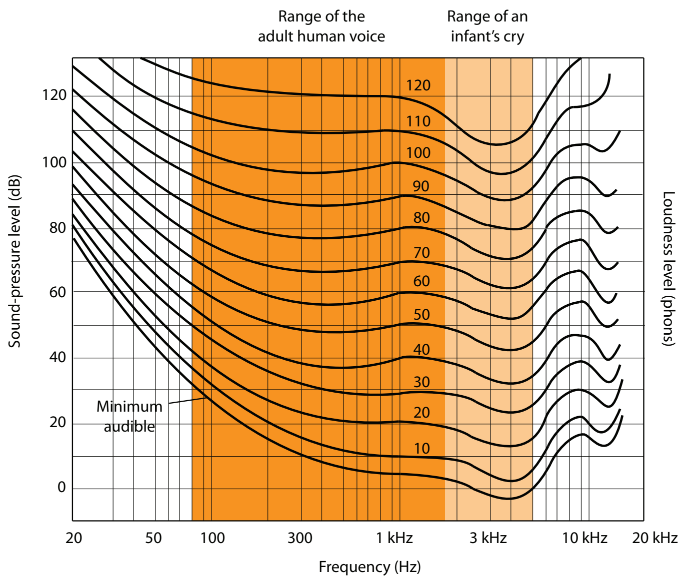


Figure 6: Phons and the Effect on the Human Ear (Boduch, and Fincher, 2009).

2.5 Köppen Climate Classification and Temperate Climate Definition

One of the most extensively used climate classification system is the Köppen climate classification, which is first published by Wladimir Köppen in 1884 (Rubel, F.; Kottek, M., 2011). Beside of this, in between 1918 and 1936 Köppen made several modifications on the classification system. Lately, another climatologist Rudolf Geiger has done some alterations in 1961 (Geiger, R., 1961). Climate zones divided into five main groups by the Köppen climate classification and each group specified according to their seasonal precipitation and temperature patterns.

Köppen climate classification defines these five groups of climate zones as:

- Tropical (A)
- Dry (B)
- Temperate (C)

- Continental (D) and,
- Polar (E)

The following illustration in figure 7, demonstrates the distribution of five major groups of climatic zones on the World map.

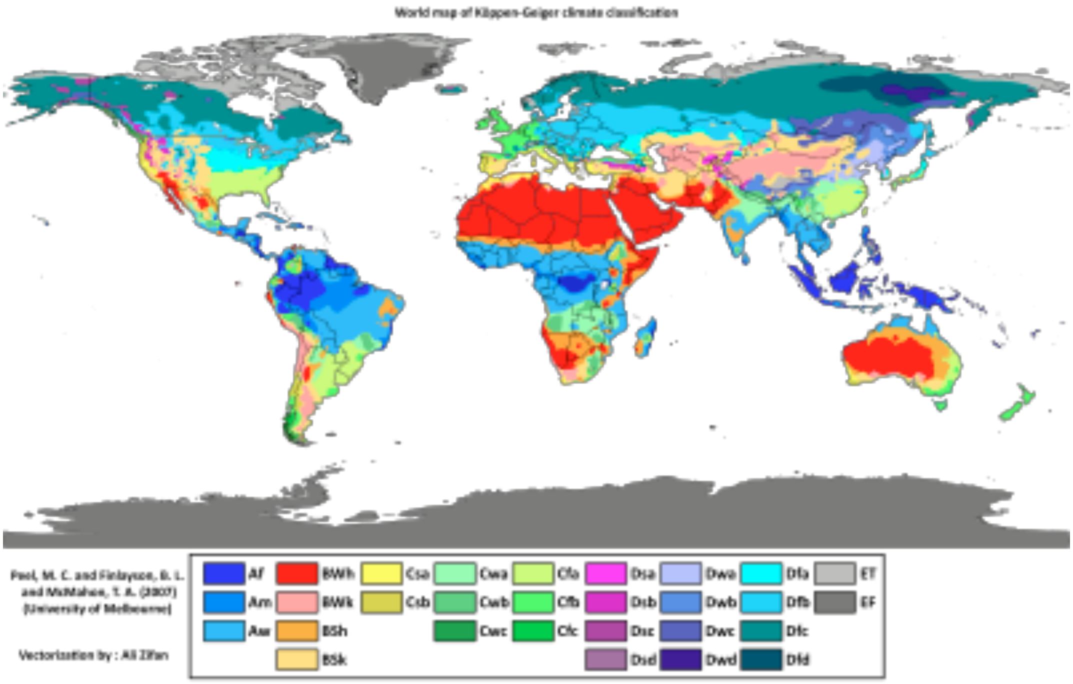


Figure 7: World Map of Köppen-Geiger Climate Classification System (Adopted from Peel et al., 2007).

2.5.1 Temperate/ Mesothermal Climates

The climatic zone that does not bring extremes of precipitation in both rain and snow and temperature can be named as temperate climate. Concerning winter and summer period's climatical changes are not exasperatingly tremendous and can be seen commonly as invigorating. The average temperature of temperate climate zone is stated as above 0 °C coldest and the warmest month is above 22 °C by the Köppen climate system.

According to the Köppen climate classification, temperate climate is divided into four sub-groups. These sub-groups are defined as;

- Mediterranean climates,
- Humid subtropical climates,
- Oceanic climate and,
- Highland climates.

2.5.2 Design Parameters for Temperate Climate Zones

Depending on those sub-groups conflicting needs of warm-humid and hot-dry climates must be satisfied by the structure. Also, for the highland climatic conditions principles of solar heat gain and heat conservation need to be considered.

By using abstemiously sized openings together with adequate thermal insulation materials and a sufficient volume of thermal mass could stipulate conventional conditions for most of the time.

The following table demonstrates the design parameters in temperate climate zones for three main occupant comfort objectives as thermal, visual and acoustic comfort.

Table 8: Design Parameters for Temperate Climate Zones.

Design Parameters for Temperate Climate Zones		
Thermal Comfort	**Visual Comfort**	**Acoustic / Sound Comfort**
Orientation and room placement should be south facing.	The depth of the interior should not be excessive.	Windows should be of medium size to provide adequate sound pressure.
Compact Structures with minimal but proper sun-oriented exterior surfaces are desirable.	Windows should be of medium size, the total window area should not exceed 25% of the floor area.	Space ratio as depth and height should be proportional to avoid echo.
A too excessive thermal mass should be avoided.	Windows should be equipped with tightly closing glazed panels.	The use of additional sound absorber or reflector materials.
The outer surfaces should posses absorption capacity but low emissivity.	Shade in summer and heat gain in winter is necessary.	Cross-ventilation may bring negative effect on acoustic comfort.
Using a thermal buffer zone towards the north.	In warmer regions a bright surface with higher reflectivity is appropriate	
Ventilation must be controllable.	Absorptive, dark surfaces are possible in recessed areas, where the summer sun does not reach.	
Courtyard buildings with proper wind protection	The use of insulated internal shutters	
Arrangements for a proper cross-ventilation are necessary	Shading devices should be movable to provide desired solar heat gain.	

Chapter 3

ON THEORY OF DOUBLE SKIN FACADES

Verifiably, to compromise better internal conditions, the building façade can be designed and adjusted. Building envelope can become a segment that the sun-based radiations are constricted by the building in different advances as preserving, transmitting and reflecting the sunlight by use of diverse tools and types in facades. Thermal diversities and sun radiations presented to be more consistent with opaque envelopes, which enables certain warmth to stream indoor for the structure against to the coated or glazed parts of the envelope. For this reason, an envelope also decides the thermal mass of the structure that straightforwardly influences its thermal reaction.

In the mid-1980s, Davies declared the building envelope as an intuitive section of the structure that needs to react according to the climatical circumstances as a polyvalent wall where the envelope must be a dynamic component reacting to the specialized, ecological, and stylish prerequisites of the current structures (Davies, 1981). The advancement of Double Skin Façade (DSF) was coordinated into the assembled conditions with contentions, for example, energy efficiency, sustainability, and environmentalism. Thus, nowadays, architects are more enthusiastic about DSF systems. These façade systems are the building configuration decided for the most part via:

- The visual ambition for a completely glazed façade that indicates to increase transparency,
- The valuable requirement aimed at the better quality internal condition,
- The requirement in the best interests of enhancing the audibility,
- The reduction of energy use.

The indication of DSF systems is not rare. According to the increment necessity of comprehensive design approach, DSF systems have been prevalent for the architects in practice because of their multidimensional characteristics plus versatility to adjusted climatical circumstances.

The design of the DSF framework is definitive for the execution of the building. On the off chance that the strategy is thorough and the targets to be accomplished are all around characterized, at that point the DSF systems are sufficiently adaptable to encounter with climatic vicissitudes for most of the structures.

3.1 Definition of Double Skin Façade (DSF) Systems

In 2002, Belgian Building Research Institute (BBRI) designated that, a dynamic façade is a façade, which covers one or more stories established with several layers (BBRI, 2002). The air cavity between the layers of the façade can be ventilated naturally or mechanically. The ventilation procedure within the cavity might change through demand/s and occasion/s. Meanwhile, gadgets and frameworks are the most synchronized part to enhance the indoor atmosphere with dynamic or inactive systems.

Boake et al. depicted the DSF systems mainly as a pair of glass skins, which are isolated through an air channel (Boake et al., 2003). The primary layer of the system is generally for protecting. The air channel in between the layer of the system is assigned against extreme temperatures, sound and wind protection. Within the air channel between these layers, frequently, sun control devices also appear. Entire components may be planned diversely hooked on quantities of stages and mixes together strong and translucent layers.

Arons, characterizes the DSF systems as a façade that enables inside and/or outside air to circulate across the system of binary individual planar components (Arons, 2000). The system occasionally mentioned as the dual skin.

Uuttu, depicts the DSF as a set of glazed skins isolated with a transitional space with the range of 0.2 m up to few meter width range (Uuttu, 2001). This transition space also named as air cavity or air corridor. The transitional space in between the glazed layers is mainly preferred as a protection against acoustic and thermal discomfort. The primary layer of the skin fills in as a feature of regular auxiliary or a drape divider, whereas the second layer is generally a single pane. Glazed skin can cover only a segment of the structure or it may extend completely over it.

Double skin façade defined by Saelens, is development of an envelope that comprises of glare surfaces isolated through a space, which is utilized as an air passage (Saelens, 2002). This explanation incorporates three fundamental components:

- The envelope formation,
- The transparency of the bounding surfaces,
- The cavity airflow.

As indicated by Claessens and De Herde (undated), DSF systems are like an extra building skin that is attached to the current façade of the structure (Claessens and De Herde, undated). The second skin of the façade system fundamentally is transparent. Two layers of the system create a cushion zone in-between, which is predominantly serves to protect the structure. The buffer zone between the skin layers might be warmed by sun-oriented heat, contingent upon the introduction of the façade. In wintertime, south oriented frameworks can help the building for heating purposes by utilizing the sun oriented heated air within the buffer zone. In all circumstances, this buffer zone must be ventilated to avoid overheating.

Compagno pronounces the DSF as an additional glazed façade layer brought to the front of the definite façade of the building (Compagno, 2002). These types of facades can be appropriate because of the protection served by sun control units, which are located in the air cavity between the layers of the frameworks, where the structure is facing with influences of punitive weather conditions and air contamination or the buildings that require sensitive sound control due to vicinity of busy streets.

3.2 Retrospective Chronicle of the Double Skin Façade

Enhancing the indoor conditions for occupants of the building by the exploitation of physical marvels are not a novel notion. For instance, wind catchers, called badgir in Persian or maqlaf in Arabic, have utilized by the Middle Eastern societies. (Jaworska-Michałowska, 2007).

Early references of DSF are dated in the 19th century as design proposals. Jean-Baptise Jobard depicted a multi-layered façade organization that is made of two glazed screens and mechanically ventilated air space in-between to provide warm and cool atmosphere when it is required, in 1849 (Heim and Janicki, 2010).

As a part of Steiff toy factory in Giengen, Germany accurate double skin façade is constructed for the first time in 1903 (Figure 8, 9) (Fissabre and Niethammer, 2009).

Figure 8: The Original Factory Building as it is Today (URL 15).

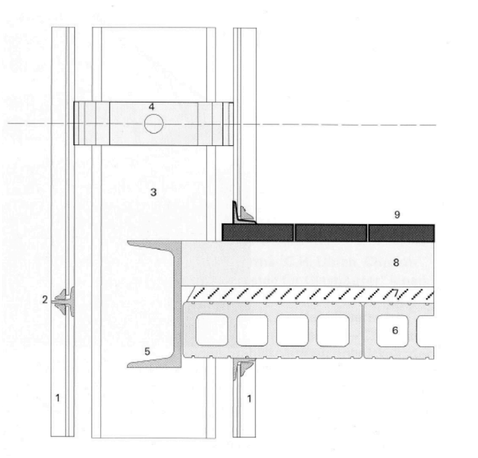


Figure 9: Vertical Section of the Double Skin Facade (Fissabre and Niethammer, 2009).

The progressive outline arrangements utilized as a part of the development of this building including twin layers of glass were effective to the point that they were imitated in 1904 and 1908. The external curtain wall divider built by Richard Steiff in Giengen is found to be completely decent with the advanced definition that was made in 1961 by Rolf Schaal (Schall et al., 1961).

The new idea has applied by Le Courbusier, which is called "*mur neutralisant*" that addresses a system to improve the internal climate by using natural physical phenomena. Le Courbusier first presented this idea, for Villa Schwob in Switzerland in 1916, and then, for La Cité de Refuge project in Paris in 1929 (Le Corbusier, 2001).

Le Corbusier initiated an improvement for "*mur neutralisant*" idea with novel technological system, named "*la respiration exacte*". The concept of this system comes from the necessity of a structure that could belong to all nations and climates. Which means, one single structure can adapt itself to any site and its climatic conditions with the *respiration exacte*. Le Corbusier aimed to create 18 °C room temperature and humidity related to the context by the help of fans, which are blowing this air via carefully distributed air channels and diffusers (Banham, 1984).

The fixed envelope as a noteworthiness of the "*respiration exacte*", the south-west introduction of the original façade, the transparent glass layer that, citing Le Corbusier, allowed the "indescribable delight of full daylight", and summer period joined together, made of the Cité de Refuge the primary reported instance of over-heating with genuine wellbeing outcomes for the inhabitants.

The urgent necessity to lessen the overdose of *indescribable bliss* drove Le Corbusier to the advancement of an excellent development: the *brise-soleil*, an extremely astounding auxiliary development, considering an outside egg-case of vertical and horizontal blinds, was initially connected as retrofit on the south façade of the Cité de Refuge (Figure 10).

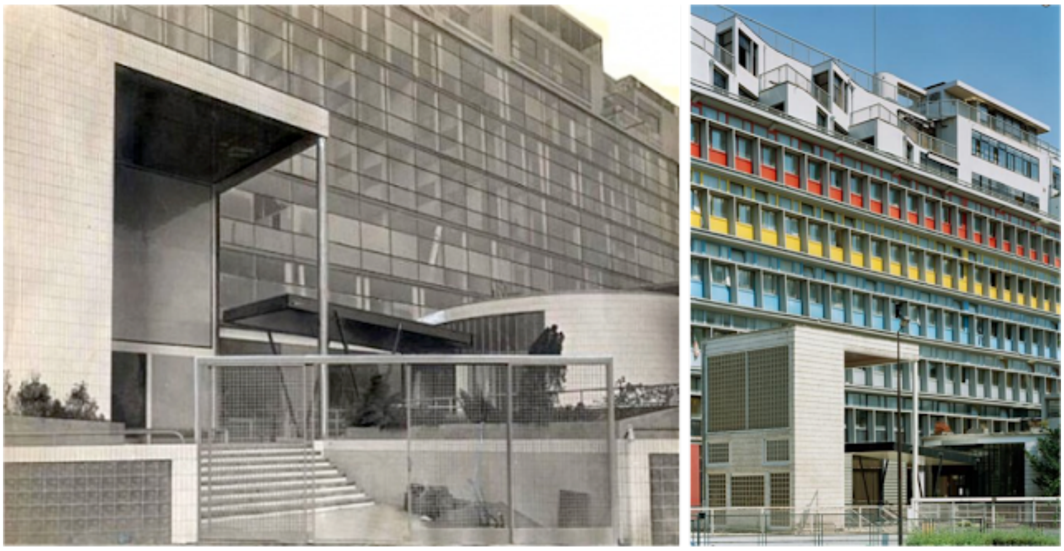


Figure 10: Facade of the Cité de Refuge After Completion and Nowadays (URL 16).

The creative vision of Le Corbusier was based on bringing a comfort zone for inhabitants' while pushing the utilization of completely transparent facades and decreasing their negative consequences. According to "*mur neutralisant*", which also known as neutralizing wall Le Corbusier conceived in glass stone or unified structures with a belt of couple centimeters in-between. In cold regions warmed air, in hot regions cooled is blustered through this tight belt in between the layers. Because of this application Le Corbusier planned to hold inside surface of the layer at 18°C.

In Scandinavia, an arrangement of two glazed layers that contains the stream of air in between them was patented in 1957. Following to this incident, in 1967 for the main office building of the EKONO Company in Finland the arrangement of the ventilated layer was utilized.

During the years between 1973-1979, amid the mounting vitality emergency, a strengthening of research into energy legitimization and a reduction in general energy consumption in the development of structures happened. In the 1980's of the twentieth century, an ever-increasing number of structures were worked in with mechanically ventilated DSFs, particularly in Europe. A novel comprehension of the vitality utilize and the as of late figured ideas in the field of ecology and inhabitant comfort prompt ascent in the utilization of DSFs started from the 1980 onwards.

In 1980, the Occidental Chemical Center in the U.S.A has been constructed. It was the first building in North America (Boake et al., 2003) (Figure 11).

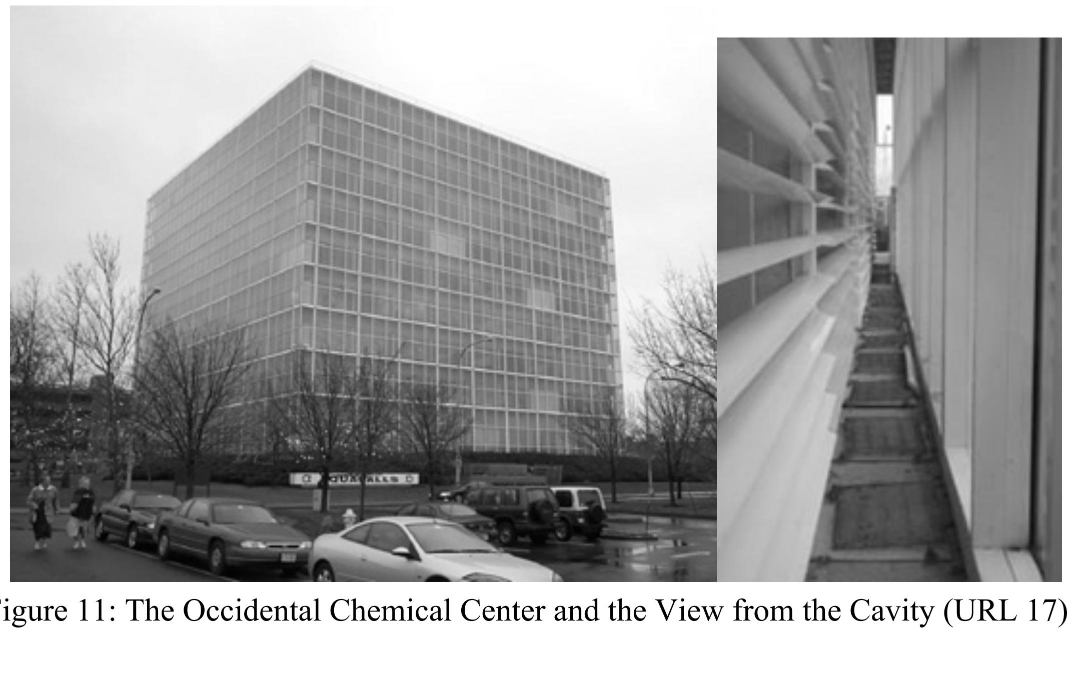


Figure 11: The Occidental Chemical Center and the View from the Cavity (URL 17).

Besides, in 1978 Lloyd's Building in London begins outlining by the Richard Rogers and Partners and accomplished in 1986. Mechanically ventilation was done by fan formed terminals located, in the ground level. These terminals authorize the air at the base of the DSF to gain successfully enclosed framework operating the air it possess. The majority of these facades are planned to utilize ecological worries as a contention, like the approach Arup Associates outlined in 1984 for the Briarcliff House in Farnborough, England. In 1993, Herzog and De Meuron modified an existing building (the SUVA building) in Basel with a new glazed layer and glass louvers within a rational unity. Such cases indicate that visual impact of transparency of glass layers are taken into foremost consideration among the ecological worries. In the 1990's, two factors firmly influence the multiplication of double skin facades.

- The rapid development of equipment and software design enables complex computations to form the organization of facades.

- The expanding natural anxieties begin affecting compositional plan both from a specialized point of view, yet additionally, as a radical impact that makes "green structures" a great appearance for commercial design.

The two important variables, which are underlined on above make double skin façades in a perfect world suited for elevated structures.

In 1997, Ingenhoven, Overdiek Kahlen und Partner's RWE AG Headquarters and Commerzbank HQ by Foster and Partners, brought a response to an altered argument for DSF about windows to be able to open in spite of tough wind situations in tall buildings with the expanding inclination to attempt to oblige particular adaptability.

Debis Tower as a less extraordinary case of the same tendency, crafted by Renzo Piano was constructed in 1998. However, the company did a broad ecological investigation concerning the facades of the building. The adaptability of the diverse layers of the facades permitted additionally by this confinement in tallness, which enables the facade to unreservedly work to adjust effortlessly according to individual concerns (Russell, 1998).

At the end of the 1990's, another tendency recognized that drive the ecological contentions into the second stage. The Museum of Modern Art, New York in 1995 arranged a presentation named "Light Construction", which brought the transparency as a fundamental issue on compositional task for the façade design of the buildings (Terence, 1995).

Towards the end of the era, an interest with the layering and transparency appeared in several activities with geometric reflections, rashly titled as "minimalist architecture". This alternative trend of transparency quickly exploited in numerous nations with tasteful impacts. As a result, the terminology of double skin finds a new body to itself as utilization of double glazed layer, and investigating through various materials and quantities of opacity and ending up with a reinterpretation of the cavity wall.

3.3 Classifications of the Double Skin Façades

Double skin facade systems are cited in the literature with diverse approaches of numerous researchers. The category of construction, the goal, basis, and airflow type in the cavity, etc. can help to classify these systems.

In the 2000, the double skin facades categorized according to the ventilation type of the air cavity by Kragh, in three types *;* (1) naturally ventilated wall, (2) active wall and (3) interactive wall (Kragh, 2000).

Naturally Ventilated Wall

An extra layer is introduced to the exterior of the building structure. The additional layer provides an extra thermal protection for structure in periods without sun-based radiation. In addition to this, façade is naturally ventilated from or to outside when heated air by the sun radiation rises in the cavity (sun control units in the cavity must consume the sun radiation), which can be described as stack effect. When the heated air is exiled to, the outward this may cause lessened sun heat gain. The distinction between external temperature and the heated air within the air cavity between the layers is obligatory for the systems to operate. Therefore, this kind of systems cannot be suggested for hot regions.

Active Wall

A supplementary layer is connected to the building envelope; ventilation system of the building uses the returned air from the internal space through the cavity of the façade layers. During the times with sun-grounded heat energy that recovered by the sun control units (blinds), it is evacuated via ventilation outlets. Solar energy discharged by heat exchangers during the days of warming difficulties. The external temperature of the internal layer is preserved immediately to room temperature to prompt expanded inhabitant comfort on the vital limits both in cold and, with no or minimal sunlight intervals. In light of the foregoing, such kind of façade systems are suggested for cold expanses, according to enrich expanded comfort levels and conceivable recuperation of sun energy.

Interactive Wall

The origin of the interactive wall is quite like the naturally ventilated wall with the critical contrast that the ventilation is constrained. Conferring to that feature, such kind of systems is not contingent on stack effect only, the system can operate with excessive ambient temperature conditions as well. Through cold intervals, without sun heat such as nighttime, amplified thermal protection can be obtained with reduced ventilation. Such kind of façade systems is ideal for regions with hot climatical conditions where the cooling loads are excessive. Besides those sun and thermal performance advantages the system also provides natural ventilation even in high-rise structures using operable windows.

Arons, explains two forms of façades:

A continuous façade (minimum one story) out of two layers with an air inlet, which is sited at the lower level of the story and air outlets on the above level as “airflow facade” (Arons, 2000).

The second form of explained facades by Arons is “airflow window”, which is described as a double sheet façade with a bay and vent spread out less than the spacing between ceiling and floor.

Magali, (2001) allocates the DSF in two main groupings (Magali, 2001):

1. Double skin façade on several stories.
2. Double skin façade apiece of one story.

The parallel segregating into the air cavity is the main difference in grouping the facades according to Magali. Besides, each of these groups is separated into the subgroups. The core objective of this separation is “tightness” of the façade related with the opportunity of having operable windows on different layers of the façade system. The grouping has been proposed by Magali can be found in Table 9.

Table 9: Double-skin facade grouping by Magali (Adopted after Magali, 2001).

Group 1: Double Skin Façade on Several Stories	1A: the two layers are airtight.	**Group 2: Double Skin Façade Per Floor**	1B: internal and external layers are airtight.
	2A: non-airtight internal layer airtight external layer.		2B: non-airtight internal layer -airtight external layer.
	3A: non-airtight external layer -airtight internal layer.		3B: non-airtight external layer- airtight internal layer.
	4A: non-airtight internal and external layers.		4B: non-airtight internal and external layers.

Uuttu, (2001) classifies seven types as- *building-high double skin facades, story-high double skin façades, shaft façades, box window type, shaft box type, corridor façade, and multi-story double skin façade* of the Double Skin Façade systems in a parallel approach to Oesterle et al., (2001) explained below (Uuttu, 2001).

Building-High Double Skin Facades

For such kind of façade systems, the air cavity is not isolated at every story, rather air cavity stretches out the entire tallness of the building.

The fundamental thought of incessant air cavity through the entire height of the structure is that the accompanying: openings in the external layer of the skin located on the rooftop edge guide the warmed air out, which is raised and collected in the air cavity during the sunny days. While for the fresher substitution, the inlets sited close to the base of the structure draw air.

Story-High Double Skin Façades

In this system of double skin facades, air channels separate each intermediate floor level horizontally.

Box Double-Skin Façades

Simultaneously vertical segments for every window on each floor cooperate with inlet and outlet vents that make box double-skin facades as sensitive ventilated façade. Consequently, the least level of air heating along these lines the best level of natural ventilation is not out of ordinary. Because of the segmentation, the system additionally provides fire safety for the building.

Shaft Façades

An air cavity with entire building height and a double skin façade with story high are the constituent parts of the shaft facades. The exhaust air is transferred from the story high double skin façade cavities located on both sides to a full height cavity, which forms the vertical channel for debilitating air. Here it ascends, because of the stack effect and outflows towards the opening at the upper part.

Through the corresponding attitudes of E.Lee et al. (2009) and Saelens (2002), double skin facades are characterized according to their cavity typologies/geometries by Oesterle et al., (Oesterle et al., 2001) that are depicted in the following terms.

Box Window Type

The façade system in this paradigm is divided into independent frames with smaller portions by vertical and horizontal partitioning.

Shaft Box Type

Series of independent frames as box windows are accompanying through vertical channels positioned on the building. Indicated shafts enhance stack effect in this model.

Corridor Façade

For fire security, acoustical and ventilation reasons, floor-to-floor (horizontal) partitioning is comprehended for this archetype.

Multi-Story Double Skin Façade

There is neither vertical nor horizontal partitioning exists in between the layers of double skin façade system. The ventilation of the cavity achieved by significant vents located close to the ground level and the rooftop of the building.

Another typology as "Louvers Façade" is introduced by BBRI (BBRI, 2002). The external layer of this sort of façade is comprised of mechanically rotating transparent louvers. These louvers can create a comparatively airtight façade when they are in the closed state. Opposite to that position, increased ventilation for air cavity can be attained when the louvers are in an open state.

According to Safer et al. (2005), double skin facade is sort of an exceptional cover, which comprise of a constant building façade with frequently transparent secondary skin layer positioned in front of it (Safer et al., 2005). The air cavity between the layers is relatively significant in terms of ventilation. The ventilation strategy can be activated in three modes as mechanically, natural and hybrid, system/mix-mode, to contribute to energy saving in cold periods and reduce overheating complications in hot periods (Safer et al., 2005).

Ding et al. and friends expressed that; DSF systems contain three main sections, which are internal façade, external façade and the intermediate buffer zone as air space in between (Ding et al., 2005). Increased acoustic and climatic protections against to the external conditions are provided by external façade. The intermediate buffer zone is there to supply a protection for internal façade/spaces from cooling loads by positioning the customizable and flexible sunshade appliances into it (Wenting et al., 2005).

Roth et al. and Baldinelli stated that double skin facades differentiated from a single skin façade with its outer glazed layer that is separated from an inner glazed layer with an air cavity coordinated into a curtain wall. Frequently air cavity contains adjustable sun control systems (Roth et al., 2007; Baldinelli, 2009). Ordinarily, inner layer consist of double or single pane glazing with openable or fix windows. Heat-strengthened safety or laminated safety glass usually used on outer glazed layer.

Kim and Song, and Wang contended by having a construction of buffer space between two transparent layers, as external and internal skin brands, thus, double skin facade is a compound of layer skins. Single or double pane glass of safety or float glass can be appropriate for both skins (Kim and Song, 2007; Wang, 2008). To achieve thermal protection, modifiable shading gadgets ordinarily mounted at the buffer space. Multi-story, corridor, box and shaft-box facades are the typical typologies of double skin facade systems.

Chan et al. argued that, “a building facade covered with multiple glazed layers on one or more stories can be referred as double skin facade” (Chan et al., 2009). The external layer can be entirely glazed, frequently this layer made of a hardened single glazed unit. Interestingly internal layer in most of the applications are not fully glazed and generally insulating double-glazing is used to establish that layer. Both layers can be ventilated mechanically/naturally or airtight. The air cavity width between glazed layers can be up to 20 cm to 200 cm.

During the winter periods, reduced heat loss can be obtained through seal double - skin façade, which promises an improved thermal insulation. Although ventilated double skin facade systems can help the building for cooling desires through absorbing the heat energy from overheated glazing by air circulation in the cavity (Shameri et al., 2011).

Components that establish the double skin facades, which is expressed variously by several researchers. Based on these studies, double skin facades are commonly comprised of the following layers.

External Glazing

Essentially laminated safety glass or heat-strengthened safety glass is used to establish the external layer/glazing of the DSF. Either automated or manually operating vents can ventilate externally located glazing layer. This layer also provides a protection that can be designed as the rain screen.

Internal Glazing

In order to diminish the sun heat gains of the interior spaces, sun diffusion glazing or low-E coating can be used for internal glazing layer. However, frequently operable or fixed thermal insulating (triple or double pane) glazed unit is preferable. In comparison with the external layer/glazing, internal layer can be less transparent depending on the ventilation scheme of the building. Moreover, this layer might contain operable or non-operable panes.

Intermediate Cavity

The intermediate air cavity can be ventilated naturally, mechanically or with a hybrid system that (combined natural and mechanical ventilation). Its depth can define substantial assets of the cavity. The depth/width of the cavity may show variations according to the concept of the system, the common range for the width is in between 20 cm to 200 cm.

The intermediate cavity can be used as a shield for the indoor spaces from the disproportionate effects of outdoor components by fixing the adjustable shading advancement gadgets within the cavity. This procedure is more affordable than utilization of remotely mounted systems.

3.4 Technical Description of DSF

3.4.1 Types of Façade Construction

In relation to their purpose it relies upon cavity configuration, airflow function and cavity geometry. There are numerous attitudes to the categorization of double skin facades.

As indicated by Eberhard Oesterle, the categorization depends on the cavity geometry respecting the usefulness of the ventilation (Oesterle, 2001). In this regard four construction typologies of double-skin facades are:

- Box Window
- Corridor Façade
- Shaft Box
- Multi Story Façade

3.4.1.1 Box Window

A façade with a single glazing or a ventilated double window equips a second window. A ventilated double window mostly is the window doubled inside or outside. Hence, openings run as a substantial component on the surface of the wall regarding the assessment of apportioning. In the literature notions of double windows that are naturally ventilated entitled as Box window (Bestfaçade, 2005).

Box units are separated through auxiliary inlet belts and horizontal split between floors based on room-by-room divisions. In light of this information, box-window facades can be portrayed as individual single story double skin facade units.

The air inlets and outlets are positioned on the external single glazed layer to permit the access of fresh air and exhale the stale air in the cavity. An operation of air exchange through external layer may provide the naturally ventilated intermediate space and indoor spaces.

Box-window type formation is the most usually utilized circumstance here because of excessive outdoor noise intensities or when the sound transmittance is the unique necessity between contiguous rooms (Figure 12).

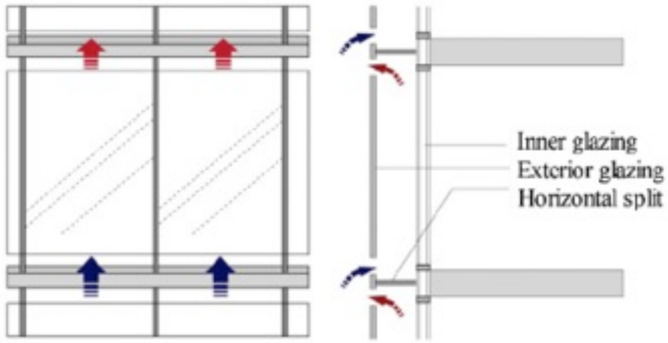


Figure 12: Distinctive Box-window Prototype (Osterle et al., 2001).

Both vertical and horizontal divisions in the cavity space bring certain crucial advantages such as:

- Improved acoustic protection,
- Individually controlled natural ventilation in accordance with diverse occupant requirements,
- Fire protection.

3.4.1.2 Corridor Façade

Those facades are described by a cavity that covers a large part of the facade, which is common across the entire floor. The cavity boundaries are restricted to the level of every floor, which means cavity of each floor operated individually. Generally, a cavity mostly conceivable to walk between layers and creates an access to the internal spaces (Bestfaçade, 2005).

A corridor façade is divided horizontally at every floor level. There are no vertical partitions in the system except the corners of the building, which is needed for acoustical, operational, fire protection and ventilation purposes. This prototype physically considered as a single story facade.

External skin contains air inlets and outlets are located close to the ceiling (outlet) and floor (inlet) levels respectively (Figure 13). For a high-rise building's façade configuration, corridor facade is completely applicable.

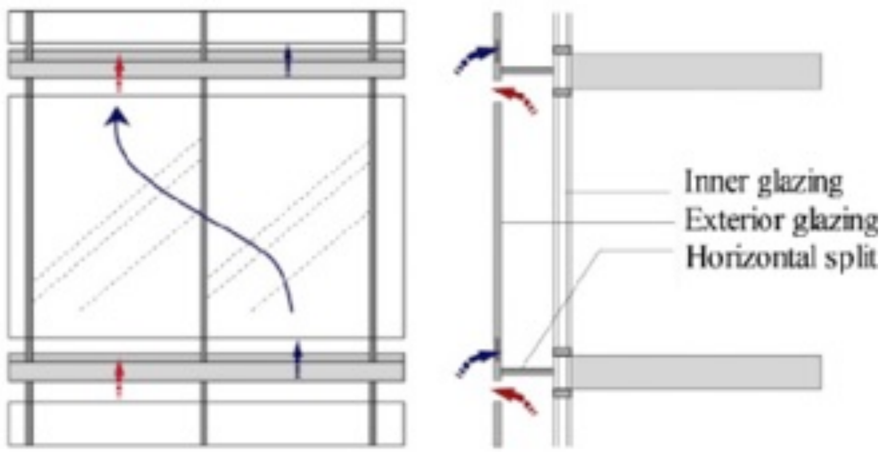


Figure 13: Distinctive Corridor Double-Skin Prototype (Osterle et al., 2001).

3.4.1.3 Shaft Box

The main goal of adjusting the apportioning the façade to make an expanded stack effect is to empower natural ventilation. Along these lines, it is logical that this kind of façade and apportioning is connected just in naturally ventilated DSFs.

It is a facade type that covers more than one story, which is established with repetitive units that are separated with floor levels and vertically positioned air channels. Vertical channels are associating each façade units while providing fresh air for empowering the stack effect. Naturally drawn air deported by outlets that are positioned above levels of the air channel (Figure 14) (Bestfaçade, 2005).

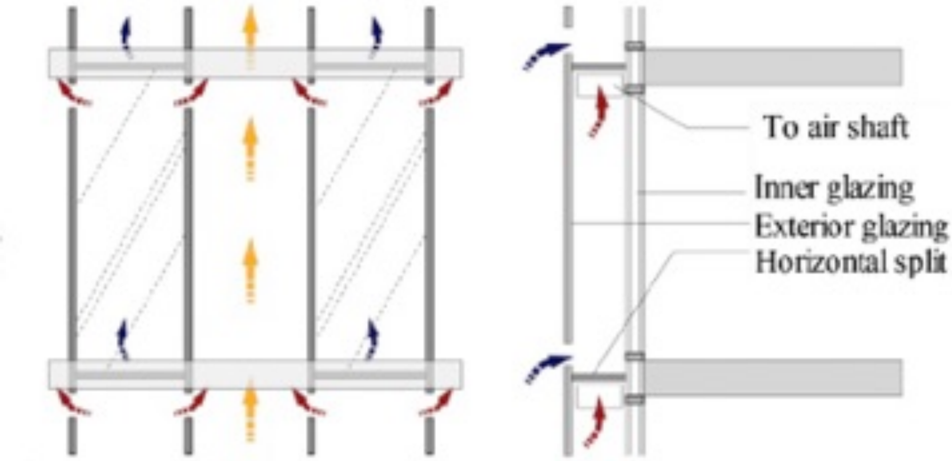


Figure 14: Distinctive Shaft Box Prototype (Osterle et al., 2001).

This model can be described as an exclusive adaptation of the mixture between multi-story façade and box window type together with single story cavity. Shaft box facade consists of the following features:

- Box window units and vertical channel components with the alternative arrangement.
- At every story, the vertical channels are connected with contiguous box windows through an airflow opening.
- Outstanding stack effect magnets the warmed air from the individual box units into the vertical air canal and to the highest point of the channel where it is depleted.

In the circumstances where thermal uplift needs supplementary provision, airflow might be mechanically separated out through (hybrid ventilation) vertical channels.

3.4.1.4 Multi-Story Double Skin Facade

Multi-story DSF are decoded with an expansive volume of air space between glazed layers without any partitions neither vertical nor horizontal direction, which prevents the airflow through the cavity. Mainly to support cleaning and maintenance reasons, the introduced cavity between glazed layers are sufficiently wide-ranging to allow approach for the occupants from each floor level, which can be also promenaded.

The cavity can be perceived as continuously all over the structure without any apportioning in numerous cases. Usually, the systems with described typology natural ventilation are utilized dominantly. Notwithstanding, few examples also reported with the same typology, with the mechanical ventilation.

The main commitment of employing this specific typology predominantly is, having outstanding sound control implementations with respect to external commotion (Figure 15) (Bestfaçade, 2005).

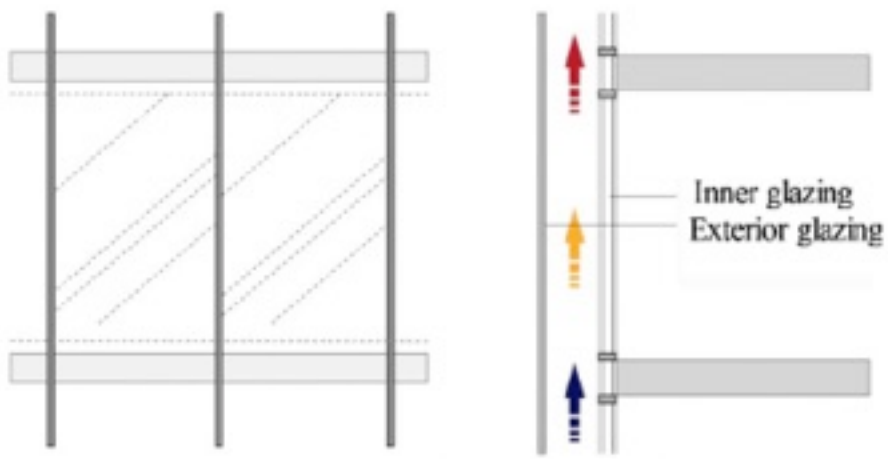


Figure 15: Distinctive Multi-Story Archetype (Osterle et. al., 2001).

The main advantages of the use of multi-story facade formation are as follows:

- Horizontal and vertical throughout the air cavity placed between glazed layers provide enhancement of sound protection.
- Natural ventilation can be accomplished by occupant control.
- Solar control gadgets positioned within the cavity operating like a protection filter against climatic fundamentals rather than remotely mounted systems.

3.4.2 Integration of Double Skin Façade Systems to the Building

Supporting buildings in terms of heating ventilation and air conditioning (HVAC) systems is defined by some authors as the main concern of integration of double skin facade systems to the building. According to the different seasonal requirements double skin façade can operate in many variations like pre-heat air during winter, recover heat during winter and mid-season, and extract hot air in summer season conditions.

As indicated by Osterle et al., it is communicated however generally not affirmed that the number of HVAC devices is lessened owing to DSF system construction (Osterle et al., 1999). A few situations exist, where the absence of HVAC (mechanical ventilation) systems integrated with the façade, which can prompt inconvenience for indoor and such performance evaluation by the occupants demonstrate significant varieties.

"The integration of the double skin facade to the buildings is reasonable if they satisfy to enable natural ventilation for an extended interval of the year, notwithstanding confrontational states like strong winds and excessive sound levels", is stated by some authors. Authors determined that when the implemented DSF systems deprived of the support of mechanical ventilation systems, following conditions must be gathered.

- Must deliver adequate insulation.
- Encountered constitutional parameters of opening areas and impediments of profundity as indicated by the requirements of natural ventilation of workspaces.
- DSF construction ought to provide a perceptible communication with the external atmosphere.
- When required, façade system must allow nighttime cooling.
- Deprived of mechanical ventilation such as air conditioning or lower thermal comfort can be accepted.

In contrast to these authors, some others are relating the optimum energy and thermal performance of double skin facade straightforwardly associated by the combination with the mechanical ventilation systems (HVAC). Methods for a recreation model and validated with test facilities, the integration of DSF within buildings are assessed by Stec and van Paassen (Stec, and van Paassen, undated). According to this assessment, to attain a sufficient application for double skin facades, Stec and Van Paassen state that “strong necessity of integration of the mechanical ventilation for indoor climate and detailed design of the façade is essential” (Stec, and van Paassen, undated). Following tasks are suggested by authors to be applied during the design procedure in case of integrating a double skin facade to the building.

- According to the requirements of thermal performance, ventilation, sound control, etc. functions of the double skin facade must be stated.
- According to mentioned necessities/requirement selection of the facade type, dimensions, materials and components should be selected perceptively.
- HVAC system essentially adjusted to be combined with the DSF system.
- Control systems, which supervise the entire system, need to be selected.

The significance of the cavity size, which is a critical dynamic to regulate the temperature within the cavity, is highlighted by Di Maio and van Paassen (Di Maio and van Paassen, 2000). Conferring to them, the limited airflow within the slender cavities leads to high temperatures, opposing to that the prompt stack effect by the wide-ranging cavities allow further heat transfer through the inside of the façade. The selection of a DSF system is determined by the architectural, functional, and economic factors.

An economical, architectural, and functional factor plays an important role in the selection of the double skin facade system. However, climatical conditions and the expected behavior of the system under critical circumstances are the significant priority for a conclusive decision.

3.5 Assessment of DSF Systems According to the Occupant Comfort Objectives

3.5.1 Thermal Performance in DSF Systems

As well as the capability of the air cavity itself, the absorption of the sun radiation is attained by the sun control units/ shading devices that are mostly in horizontal forms and positioned within the air cavity. Shading devices comprehended in various configurations in the cavity such as fixed, manually controlled operable units or full-automotive operable systems that are controlled by the sensors.

Shading devices can be located in front of the building facade by not considering the double skin facade systems as well. However, this is not preferable for multistory structures because of safety concerns and expensive installation costs. The unprotected shading devices mostly used as non-operable/fixed way. This kind of installation deteriorates them according to adaptation to different sun angle conditions. Especially in the morning and late afternoon time because of low sun angles, usually they are not efficient. The importance of DSF systems for shading devices is the protection, which is offered from the environmental fundamentals.

For the aim of keeping the room temperature in expected comfort level for the occupants, the effective way is to prevent incoming sun radiation even before entering the space. External shading devices are the most efficient means of reducing sun heat gain in a highly glazed building. The horizontal blind allows continued use of daylighting and maintains some of the views to the exterior. Sun control units/shading devices are supported with the air cavity under such circumstances as mentioned before. Air cavity itself can discharge a portion of the received sun radiation. Warmed air carried upwards by convection currents and is extracted from the top of the cavity through venting units.

The rate of the heat transfer on the surface of the glass is lowered among the reduced speed of the airflow and the increased temperature of the air in the buffer zone. This may cause the reduction of heat losses with the application of double skin facades to the building. Throughout this method, a higher surface temperature on the internal glass surface is achieved. This means delivering a better utilization of indoor space that are close to the glazed surfaces for the enhanced thermal comfort conditions of occupants (URL 18).

Increased usage area of the indoor space that usually necessitates extra treatment with heating and cooling systems against exposed glazing allowed by this aspect of the buffer zone. In addition, minimized sun heat gain can be manipulated with heat reflection and absorption by the expenditure of enhanced sun heat transmission values for glazing. The use of ‘spectrally selective glazing’ may assist to attain this (URL 17).

The capacity of a glazing material acting inversely against diverse wavelengths of sun energy, or permitting visible light while undesirable invisible infrared heat is rejected, is the definition for ‘Spectral Selectivity’. Associating with the previously available sun control glazing, latest products that allow much clearer glass on the market have reached this distinctive specialty. Glazing with a low sun heat coefficient and high visible transmittance can be considered as selective glass.

Special coatings or absorbing tints generally neutral in color or blue and green or only blue appearance frequently applied on a spectrally selective glazing. Only the sun radiations those are convenient for natural lighting are permitted by an ultimate spectrally selective glass (O'Connor et al, 1997).

3.5.2 Natural Ventilation in DSF Systems

The air cavity of the DSF can be ventilated naturally or mechanically. Figure 16 demonstrates mechanically ventilated façade, which is generally co-operated with the building's HVAC system. The ventilated cavity manages challenges like heat loss, undesired heat gain, and thermal embarrassment by functioning as a thermal cushion. Both wind load/pressure or thermal resilience can be acceptable as the driving force for natural ventilation.

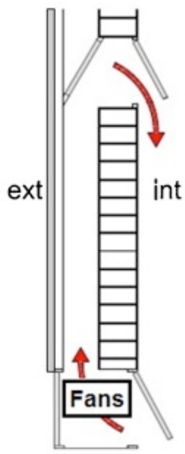


Figure 16: Mechanically ventilated DSF Section (http://www.ars.els-cdn.com).

The natural airflow is not continuous within the cavity and varies according to the climatical conditions, yet it is not an easy task to control airflow in the cavity and for the upper floor levels in high-rise buildings as wind pressure on the façade. Figure 17 represent the naturally ventilated façade, which can be utilized as an air insulation space for acclimatized inner spaces and provides openings for bringing fresh air for indoors.

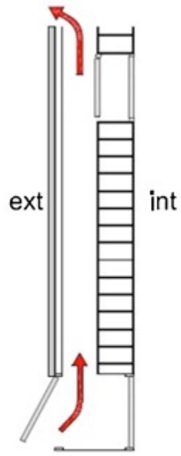


Figure 17: Naturally Ventilated DSF Section (http://www. ars.els-cdn.com).

Occupant access to the airflow, which can be utilized, to ventilate and cool the indoor is permitted by natural ventilation. In the operation phase of the building, utilizing the passive ventilation more than mechanical ventilation systems can reduce CO_2 production of the structure. The accessible buffer zone is the key component of the double skin facade in terms of natural ventilation for occupants. Operable windows on the external glazed layer of the façade system also assist natural ventilation in some cases. Such openings need to be resistant to dominant wind load at the higher levels of high-rise buildings.

In the higher altitudes of high-rise buildings, putting these openings for natural ventilation can be attained through introducing an extra pane of glass to reduce the dominant wind load (Compagno, 1995).

The impact of smoke, sound, heat and noise transfer from one section to another can be eliminated by compartmentalizing the air cavity into individual segments through grilles or vents at every floor level similar to Stadttor building in Dusseldorf. The use of vents or grilles allows the control of the incoming air by reducing air velocity, protecting from rain, and reducing noise transmission from exterior. The functional advantages of the grilles and vent titled as (URL 18).

Utilization of less dependent mechanical systems and exploited natural means is the most effective technique to reduce energy consumption on building services (Farmer, G. and Guy, undated).

3.5.3 Natural Lightning in DSF Systems

Daylighting is essential in two dimensions. To start with, it diminishes the amount of required artificial lighting and secondly, in comparison with artificial lighting, the attribute of light obtained from the sunlight is more preferential. The expanded glazed surface of double-skin facades enhances the admittance of natural lighting to the indoor. Another essential part of natural lighting for indoors is the ratio between floor height and floor area (URL 18).

Health and productivity level of the occupants is directly related to the good lighting of the spaces. Additionally, natural light plays an important role for the mental health and well-being with its spectral composition and variations (URL 19).

Complete glazing treatment that is a component of an expanded daylighting may cause unwarranted heat and glare at specific circumstances during the day. Their undesirable effects can be controlled with additional measures in configuration. The amount of undesirable glare triggered by the expanded penetration of the sunlight can be controlled and lessen through sun control units/gadgets which are positioned between glazed layers into the air cavity.

3.5.4 Sun Control in DSF Systems

Frequently, choosing the accurate method for calculations may resolve the difficulties related to sun and optical properties on double skin facades. Spectral dependence/wave lengths, polarization, the angle of incidence have a direct effect on optical properties of materials resembling as absorbance, transmission and reflectance of incident sun radiation.

The compulsory calculations of material properties can be easily done with obtainable information about them. Conversely, the calculation is a time-consuming process, especially the accumulation of venetian blinds into the cavity may extend this process further (URL 20).

Van Dijk and Oversloot, stated that,

> An exact description of the way sun radiation travels through the system would require a full three-dimensional calculation using the full matrix of transmission, absorption and forward and backward reflection for each angle of incidence at each component. For venetian blinds this would include the curvature of the slats and taking into account possible specularity of sun reflection at its surface. (Van Dijk and Oversloot, 2003; cited in Poirazis, H., 2006)

The frame also provides a shield for incoming unusual sun radiations to the façade, but this may cause shading on all layers with a reflection or absorption of the radiation partially. Absorbed sun energy with unbalanced distribution may be a consequence for such circumstances (Manz, 2004). Temperature assumption in the cavity can be affected by asymmetrical allocation. In this way, it is fundamental to have the capacity to make the optical assets explicit as an element of the point of frequency and to have the capacity to represent shading (Poirazis, 2006).

According to the absorbent structure of specifically Venetian blinds and further shading devices some complications may occur during the modeling. In accordance with Van Dijk and Oversloot, venetian blinds are (Van Dijk and Oversloot, 2003):

- Relatively transparent to sun radiation.
- Moderately transparent to thermal radiation.
- Have an effect of scattering when transmitting the sun radiation.
- Exposed design against to air movements within the cavity.

3.5.5 Sound Control in DSF Systems

Even in the environments of excessive external noise level, double skin facades proposed a condition to constraint indoor noise level for occupant comfort. In buildings, natural ventilation plays an important role in maintaining the indoor sound pressure in rational levels affected by external noise (Sakamoto and Aoki, 2015).

Various researchers studied the impacts of introducing an additional transparent layer on facades while few others studied the effects of an extra absorptive material hooked on the buffer zone to improve sound insulation concerning the acoustic assets of naturally ventilated double-skin facades (Osterle et.al, 1999).

Among the others, Blasco aimed to improve supplement for double skin facade by applying the standards EN 12354-1 and 3. Grounded on a double wall sound transmission model Blasco (2004) proposed, three methods to assess the sound insulation for double skin facade explained as deflection due to vents that located on the external layer of the façade and limited elements of structural components in general (Blasco, 2004). In low-frequency range exactness of the sound pressure (dB) can be reduced owing to the deflection effects on the external part of the structure (Hopkins and Lam, 2009). In respect to the directivity of the sound that is emitted through the cavity, deflection performs a significant duty (Gompeters, 1964; Wilson and Soraka, 1964; Gibbs and Balilah, 1989; Oldham D.J and Zhao, 1993). Barclay and colleagues underlined the significance of ventilation performance and sound revelation incorporations in buildings (Barkley et. al, 2012). Furthermore, Bibby and Murray investigated the applications of ventilation grill acoustic silencers (Bibby and Murray, 2015). Bajraktari appraised the outcomes of air cavity with sound insulation materials and vents spacing on sound control performance (Bajraktari et al., 2014; 2015).

Acoustic performances need to be carefully evaluated since if it is indubitable that the second layer is a good sound screen for the noise coming from outside. It is also evident that during the periods in which natural ventilation is used and the openings of the inner layer are open, room-to-room or floor-to-floor sound transmission will take place enhanced by the cavity (IEA, 2000).

3.6 Advantages and Disadvantages of DSF Systems

In the following section different opinions in the literature explaining the double skin facade construction with their necessities and subtle facts are presented (URL 21).

3.6.1 Advantages of DSF Concepts

Lower Construction Cost

Compared to the systems utilizing the photochromic and thermochromic and electrochromic panes, double skin facade systems have lower costs due to unstable material properties of others (environmental and climatic states affect their properties). With the corresponding arrangement of system components, the double skin facade also attains the excellence of adaptability. Instead, the panes are promising although being extremely high-priced.

Acoustic Insulation

Sound insulation appears as one of the major motivations to operate a double skin facade according to various authors. Diminishing the sound transmission from space-to-space or from the external environment can reduce the internal noise level to establish a more comfortable zone for inhabitants. Concerning the internal and external noise contamination, the quantity of the openings and the configuration of the double-skin façade performs a critical responsibility for accomplishing the sound insulation. Jager claimed that at least 100mm need to be recommended to accomplish sound insulation (Jager, 2003). In 1998, a report titled "Calculating Acoustic Aspects of Double Skin Facades", presenting actual measurements and calculations published by Faist. Conclusively, Oesterle and friends proclaimed a general explanation of acoustic performance (Oesterle et al., 2001).

Thermal Insulation

Due to their external façade layer, double skin facade systems can specify enhancing thermal insulation in extreme conditions of climatical states asserted by various researchers.

Cumulative external heat transmission resistance caused by extra skin layer attains enhanced thermal insulation during the winter period. In comparison with a single skin façade, the equivalent thermal transmission coefficient Ueq value of a constant ventilated façade will be lesser in quantity. Moderately or totally closed air cavity in the heating period can improve the consequences. Diminution of heat losses indicated by an expanded temperature of the air and reduced speed of the airflow within the cavity instigate lower heat transfer rate on the glass surface. This situation may conclude with the preservation of expanded temperatures on the internal part of the inner pane.

Oesterle and colleagues mentioned that to enhance the thermal insulation in double skin facade systems, the proportion of the opening areas should be taken into consideration (Oesterle et al., 2001). Furthermore, results from the researches about the measurements of the intermediate cavity width changes and its effects on the thermal quantity of existing buildings have been provided by other studies.

Stec and van Paassen claim that "*thinner cavity widths provides the uppermost values for heat recovery efficiency*", in their paper "Controlled Double Facades and HVAC", which deals with aspects of preheating on double skin facades (Stec and van Paassen, 2000). Slender cavities have expanded heat transfer coefficients because of having higher air rate. Consequently, having the highest efficiency for preheating, the ventilated air and, thinner cavities with the certain desired airflow are more convenient in winter periods.

When air cavity is mechanically or naturally ventilated the heated air obtained by the sun radiation can be extracted during the summer season. Lee and friends described that the extra heat produced by re-radiation from the captivated sun radiation in the cavity also taken out with the rising air due to stack effect (Lee et. al., 2009). The typology of sun control devices and the arrangement of pane selection are also critical for restraining the overheating both in indoors and air cavity to achieve accurate ventilation of the cavity space. If the air cavity is naturally ventilated, the width and height of the cavity and surface area ratio of the openings are quite important for the airflow and temperature control in the cavity. In addition to these the setting of the sun control gadgets is also a significant constraint.

Stec and van Paassen claimed that, if providing comfort is the main objective through natural ventilation, the inner façade should be insulated until half way (Stec and van Paassen, 2000). Otherwise, the cooling should be applied by mechanical systems. Following that, both Oesterle et al. and Lee et al. explained the appropriate placing of the sun control devices is outer half of the air cavity (Oesterle et. al, 2001; Lee et al., 2009).

Nighttime Ventilation

The external air temperature can reach over 26°C in hot summer days and this may cause overheated indoor spaces. In such circumstances, especially for non-residential buildings, using the natural ventilation at nighttime provides an energy saving through pre-cooled spaces. This method delivers enriched air quality and thermal satisfaction for the inhabitants by lowered indoor temperatures for early morning periods. Instead, if every opening preserved closed besides mechanical cooling systems stop operating at nighttime, this might instigate uncomfortable spaces for morning epochs because of the imprisoned heated air. Delivering natural ventilation at nighttime with supplying protection-in contrast with the weather condition requirements and against incidents like burglary etc. is one of the important advantages of double skin facades.

Lee et al. pronounce the double skin facade as a distinctive design with the main advantage of having intentions for rain protection and security while enabling nighttime natural ventilation (Lee et al., 2009).

As Stec and van Paassen suggests that for proper night cooling operation through natural cross ventilation the necessary opening percentage for efficient utilization is approximately 2% of the floor area on the external layer (Stec and van Paassen, 2000).

Energy Savings and Reduced Environmental Impacts

If it is appropriately designed in certain standards, double skin facades can also be named as one of the energy-saving systems. Double skin facade can reach impressive energy-saving values criterias with the benefit of an extra layer positioned in front of the conventional façade of the building even if the insulation of the conventional façade is not decent.

According to Oesterle et al. when double skin facade enables ventilation through openings or when the significant extension of the natural ventilation occurs then the building can reach to significant energy saving levels (Oesterle et al, 2001). Electricity cost can be reduced for air supply by preventing the mechanical air source.

According to Arons, minimized sun load at the boundary of buildings bring out the energy-saving attributes for double skin facades (Arons, 2000). Reduction of cooling load can be achieved by providing low thermal transmission and low sun factor.

Better Protection of the Shading or Lighting Devices

Shading units and lighting equipment that are positioned inside the air space are fully sheltered from the external weather conditions such as rain and wind by the cavity of the double skin facades.

Reduction of the Wind Pressure Effects

The double skin facade covering the facades of high-rise buildings can reduce the consequences of wind pressure. Oesterle et al. claim that intermediate space with buffer effect enables to reduce instabilities caused by short-term wind pressures like those that wind blasts (Oesterle et al, 2001). Constant wind pressure can be transported into the cavity and then to the indoor if the openings located on the internal layer are opened.

Transparency in Architectural Design

In almost all the literature sources, the desire of the architects to use bigger portions of glazing surfaces is mentioned. In todays' architecture, architects mostly exhibiting the intention of using a bigger portion of glazed surface on their projects and this intention supported with most of the literature sources. As Lee et al. states, in European Union countries aesthetic desire of architects for constructing buildings with completely glass façade is a new architectural phenomenon, which is delivered by using double skin facade systems.

According to Kragh, transparency has continuously been looked for in architectural designs and it conveys the difficulty with itself as an envelope deprived of conceding internal temperature and energy performance (Kragh, 2000). Generating excessive level of occupancy comfort and completely glazed buildings with low energy consumption has been aimed at the improvement of environmental and advanced façade systems for ages.

Natural Ventilation

Double skin facade systems permit natural or sometimes fan supported natural ventilation, this can be accepted as one of the main advantages of the system. They can be applied to provide fresh air for the occupants in usage hours in various environments, situations, building types and orientations. If the system is well designed in terms of ventilation, it may contribute to the reduction of energy consumption and enhance the occupancy comfort standards. Natural ventilation can be sustained in altered procedures. Lee et al. describe these procedures in the following (Lee et. al, 2009).

- Ventilation of the building can be motivated by thermal buoyancy or wind with the assistance of operable windows.
- Various external openings such as windows, under-floor ducts, ventilation boxes or structural fins, roof vents, etc. can be used to support stack effect in the cavity to appeal fresh air in from the inferior levels and deplete air from the high levels of the structure.
- Variant stack-induced ventilation fulfilled with atriums as well, where the social interactions and circulation spaces appear in multi-story structures. They also assist to ventilate nearby spaces.

Thermal comfort – temperatures of the internal wall

Subsequently, compared to the single skin facades, double skin facade's internal layer can preserve temperatures, which are intimate to the thermal comfort level for the occupants, because of having warmer air in the cavity between glazed layers.

Opposing to that, the system must be well designed to regulate the temperature in the cavity during summer periods. For all building and climate type, with the proper combination of the geometry of the cavity, location of sun control units and size and type of the openings can guarantee better outcomes in thermal comfort.

Fire escape

The glazed cavity space can operate as the fire escape in emergencies on double skin facade (Claessens and De Hedre, undated).

Low U-value and g-value

Kragh, claims that the low sun heat gain coefficient/g-value and low thermal transmission/ U-value are the two core advantages of the double skin facades (Kragh, 2000). In Table 10, the main advantages of DSF concepts determined by prominent authors in the field are included.

Table 10: Main Advantages of DSF Concepts

Advantages Stated by Authors	Oesterle et. al.,	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	■								
Acoustic Insulation	■			■		■	■	■	■
Thermal Insulation / Winter	■	■		■	■		■	■	
Thermal Insulation / Summer	■	■		■			■	■	
Nighttime 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	■	■		■	■	■	■	■	
Fire Escape	■								
Low U-Value and g-Value		■				■		■	

3.6.2 Disadvantages of DSF Concepts

Higher Construction Costs

Compared to a conventional facade, double skin facades consume higher construction cost. As Oesterle and colleagues pointed out former type become more elaborate with the construction of external layer of the skin and the established air cavity between two layers of the system and according to that even no one can argue that the cost of single skin systems are more inexpensive than the double skin facades (Oesterle et al.,2001).

Fire Protection

Concerning the fire protection of a building, it is not well defined yet whether the double-skin facades can be unconstructive or not. Nevertheless, even in this situation, stack effect of the air cavity should be kept under control in case of emergencies not to transport the smoke to other floors.

Oesterle et al. claim that in the case of fire, almost no information exists on the behavior of double skin facade (Oesterle et al., 2001). Jager (2003) gives a detailed description about double skin facade types and their domains on fire protection (Jager, 2003).

Reduction of Floor Area

The intermediate cavity in double skin facade systems has a width ranged between 0.2 m to over 2 m as mentioned previously. Because of this area, the loss of beneficial space from the construction area occurs. Oesterle et al. describes it, as due to the facade projection, the operational extra room depth has been absent (Oesterle et al., 2001). On the other hand, deeper cavity provides auxiliary enriched thermal comfort conditions by having less heat transmission through convection achieved with the closed situation of the cavity. The organization of air cavity width becomes relatively critical in design considerations of double skin facade. It needs to be designed with efficient width proportions to allow the use of the closer spaces with certain thermal comfort conditions and not to lose too much space from the floor area.

Additional Maintenance and Operational Costs

Double skin facade systems have higher costs for maintenance, servicing, inspection and for the operation in comparison with single skin façade systems. The method of valuates for the costs for double skin facade systems are specified with a general explanation (Oesterle et al., 2001).

Overheating Problems

As it is stated before, if double skin facade is not designed properly with an optimum cavity size, this may cause overheated indoors by increased air cavity temperature. Jager claims that the minimal expanse of air cavity should not be less than 20 cm to prevent overheating (Jager, 2003). Compagno also mentions that the size of the ventilation openings such as vents and windows and the width of the cavity are the crucial norms for double skin façade design in terms of overheating (Compagno, 2002).

Increased Weight of the Structure

The weight of the construction is more than facade systems with single skin because of an extra skin layer of double skin systems.

Daylight

Daylight properties do not show excessive delineations than the other glazed façade types. Nevertheless, Oesterle et al. describe the main daylighting differences of double skin facades as (Oesterle et al., 2001):

- Additional skin causes decreased amount of light penetrating to the indoor.
- The larger surface area of glazing has a compensatory effect.

Acoustic Insulation

As described above, if the system is not designed appropriately, possibly sound transmission problems are possible to be concluded with.

In Table 11, the disadvantages of DSF Concepts, which are determined by significant authors in the field, are included.

Table 11: Disadvantages of DSF Concepts

Disadvantages Mentioned by Authors	Oesterle et. al.,	Compagno,	Claessens et. al.,	Lee et. al.,	B.B.R.I., (2002)	Arons, (2000)	Faist, (1998)	Kragh, (2000)	Jager, (2003)
Higher Construction Cost									
Fire Protection									
Reduction of the Floor Area									
Additional Maintenance and Operational Cost									
Overheating Problem									
Increased Air Flow Speed									
Increased Weight of the									
Daylight									
Acoustic Insulation									

Chapter 4

ON ASSESSMENT OF FUNCTIONAL VALUES OF DSF COMPONENTS THROUGH THE COMBINED EMPLOYMENT OF FUZZY LOGIC AND CROSS RANKING METHOD

4.1 Methods of the Assessment and Their Applications to the Research

4.1.1 Context of Fuzzy Logic and Fuzzy Set Theory

In literature, the methodology of FAHP is developed in relation to the theory of fuzzy set (Büyüközkan, Kahraman and Ruan, 2004). The fuzzy set concept is first introduced by the Zaddeh, later Buckley developed a set of hierarchical structures for analytically assessing the notion of fuzzy setting (Zaddeh, 1965; Buckley, 1985). Buckley (1985) intended to exploit fuzzy ratios by analyzing the expressions of decision makers through addressing on pair wise comparisons; rather than focusing on crisp values. In addition to the Buckley's approach, Laarhoven and Pedrycz; Boender, de Grann, and Lootsma; Chang, also significantly contributed to develop different alternative solutions in the concept of fuzzy logic by indicating a FAHP-based structured model, which is regarding the significance of compound principle in decision-making problems (Laarhoven and Pedrycz, 1983; Boender, de Grann, and Lootsma,1989; Chang, 1996). However, the fuzzy theory has varied interpretations and diverse alternative solutions developed till today; such an issue poses drastic vagueness on how to analytically adjust the alternatives in a FAHP-based structured model. Subsequent to such confusion; in more recent studies; Chang (1992, 1996) introduces the Chang's extent analysis, which endorses a more uncomplicated/simple FAHP analysis framework comparing to the others. The methodological approach of Chang (1992; 1996; 1999) in the assessment of Chang's extent analysis could be described through the following systematization (Chang, 1992; 1996; Chang, Zhu, Jing, and Chang, 1999).

- First, he dignified the main philosophy that gives a theoretical ground to the fuzzy concept;
- Secondly, he framed the theoretical basis into an analytical assessment where, real case applications are used to support his FAHP analysis approach;
- Finally, he settled the input or core identities of his extent analysis through ensuring the use of triangular fuzzy number on FAHP applications.

Then again, he defines the use of his extent analysis method through the following steps below;

1st step: is the use of triangular numbers to make pair wise comparison in the scale of FAHP.

2nd step: is to import the extent analysis method into the use of synthetic extent values to discover priority weights.

While doing this, he suggests two sets that can be defined at the initial stage of the analysis:

- $X = \{x1,x2,x3,...,xn\}$, *is the object set.*
- $G = \{u1,u2,u3,...,um\}$, *is the goal set.*

The Chang's extent analysis principles affirm every object is regarded as in a same way, and extent analysis for every goal, where *gi* is accomplished. This provides possibility to define/discover/obtain the m values in the form of;

$$M1gi; M2\ gi;.....; Mmgi,\ i=1;2;...;n$$

where triangular fuzzy numbers are;

$$Mj\ gi\ (j=1, 2,...,m)$$

4.1.2 Context of Cross's Design Methods Strategies

According to Nigel Cross, the design process should follow some specific processes and stages that follow each other to reduce the unexpected complications during or at the end of the design process (Cross, 2011). Those stages are elucidated as in the following part.

Clarifying Objectives

The intention is to define the objective and sub-objectives of the design, and to define their associations among each other.

The process is as following;

- Preparation of design objectives list,
- Organizing the list into groups by means of lower degree/level objectives or higher degree/level objectives,
- Representation of the hierarchical relationships and interconnections.

Functional Analysis

This part evolves with the aim of building up the expected purposes of a novel design.

The process is as following;

- Expression of the overall functions for design amongst the exchange of inputs into outputs
- Defining of interactions between functions and sub-functions to ensure their interrelations and interconnections.
- Stating the functional limits/borders of a product that will be designed.
- Seeking for proper/suitable components to perform the functions and their interconnections/interactions. The performing phase of the identified functions could be achieved through various alternative components.

Performance Specification

This is the assembling of the correct specification for the performance that is essential in the task of the design solution.

The procedure is as following;

- Considering the diverse but applicable degrees/levels of generalization in solution. The types, alternatives or features of the product are both reliable within making a choice,
- Determination of the degree/level generalization at which point to be driven,
- Identifying the essential attributes of the performance. It is important to utter the attributes in expressions, if any, which are independent of any solution.

Quality Function Deployment

This is the setting of the targets to be accomplished for the product characteristics that are liable to convince the requirements of users.

The procedure is as following;

- Identifying the requirements of users by means of attributes of products,
- Determining the comparative significances of attributes by using rank ordering or point allocation with comparative weights,
- Evaluating attributes of competing products.

Generating Alternatives

This is for generating an entire range of alternative design solutions that are needed for a design. The procedure is as following;

- Listing the functions or features, which are required for the product,
- Listing the achievable means for every function or feature.

Evaluating Alternatives

This is the comparing of utility values among alternative design proposals by weighted objectives method, of which weighted objectives adjacent to performance. The procedure is as following.

- Listing objectives of the design,
- Rank-ordering the list of objectives,
- Assigning comparative weightings as dependent values to the objectives,
- Establishing the utility score or parameters of performance for every objective.

4.1.3 Application of Fuzzy Logic Theory and Cross Ranking Method in Research Design

First of all, a DSF system should be dynamic and responsive. The following functionality is needed to be provided in terms of qualities of *dynamism* and *responsiveness* (Hayes-Roth, 1995; Selkowitz, 2001);

1. Enduring a control through enhanced sun protection and enhanced cooling load during the process of providing required light by the help of day lighting and asserting thermal comfort.
2. Reducing the operation cost with the help of minimized energy use at cooling, heating, and lighting through optimized thermal tradeoffs and day lighting.
3. Providing affirmative contributions to balance the energy of the building.
4. Reducing cooling load and enduring an enhanced air quality by using natural ventilation systems that have the ability to utilize the building skin as an active air control element.
5. Improving enhanced indoor environment regarding the comfort, performance, and health of the occupants.

According to this functional providing, the main objectives of the DSF system that have the adaptability feature in the face of diverse circumstances of the environmental influences and user requirements are:

- Energy conservation
- Natural ventilation
- Thermal comfort
- Natural lighting

- Sound control

According to the main objective, each DSF element has its own level of significance. A systematic comparison between the pairs of objectives could support the rank-ordering process (Table 12). Herein, a very simple chart could be accomplished to document comparisons of one objective against to another. This comparison provides the weight-value for each objective.

Table 12: Ranking order method, systematic comparing pairs of objectives (Cross, 2000).

Objectives	A	B	C	D	E	TOTAL
A		0	0	0	1	**1**
B	1		1	1	1	**4**
C	1	0		1	1	**3**
D	1	0	0		1	**2**
E	0	0	0	0		**0**

Each objective to be considered sequentially adjacent to each other revealed in the systematic comparing pairs of objectives in rank order method. In other words, every objective is accumulated in the order of alongside the others.

In the chart, the numeric **1** or **0** is entered in the relevant matrix cell depending on consideration degree (according to the degree of being more or less important) of the first objective than the second one, and than the others. To simplify the logic of comparison, one objective against the other objectives, the method suggests asking the question to each as in the following order; '*Is the objective A more important than the objective B? Is the objective A more important than C? Is the objective A more important than the objective D?, etc*.

Since two answers can be relied on as 'more important' or 'less important'. For the case 'more important', the numeric 1 is marked/entered in to the ranking matrix. For the case 'less important', the numeric 0 is marked/entered. However, there always might be the condition of having an equal importance in the comparison of pairs. In such cases, 1/2 could be marked/entered into the relevant cells of pairs (Banham, 1984).

At the same time, the completed form of the matrix cells disposes of ranking relations between row and column for each objective. For instance, if we consider the rank-order in Table 12, the row A recites '0001' and column A recites '1110'.

At the end of the process of comparisons; it is possible to identify the row totals, and so rank orders of each objective. There is such consequential; the highest row total gives the highest priority objective; the lowest has the lowest priority against others.

The following step after completing the comparisons is to allocate a numerical value in the range of 1-10 or 1-100 for every objective by considering the comparative importance positions of each objective at rank-order matrix.

The last step includes calculating a performance rate on ascertained factors/parameters in terms of regarding every objective. In calculation, it is expected to multiply the range of weight value with functional/utility value of every objective and alternative.

The general configuration of the ranking method is described above by means of comparisons of objectives and their weight-values, and next how to find the utility/functional value for each alternative is also given. Cross is announced while scoring 5 or 11 point scale of charge. Table 13 displays ranging system that can be used for ranking of the DSF component in variable statements.

Table 13: 11 and 5-point scale and scoring system (Adopted after Cross, 2000).

11 POINT SCALE	CONNOTATION	5 POINT SCALE	CONNOTATION	
0	Completely Useless Solution	**0**	Inadequate	Far Below Average Comfort
1	Useless Solution			
2	Very Weak Solution	**1**	Weak	Below Average Comfort
3	Weak Solution			
4	Acceptable Solution	**2**	Satisfactory	Average Comfort
5	Adequate Solution			
6	Satisfactory Solution			
7	Good Solution	**3**	Good	Above Average Comfort
8	Very Good Solution			
9	Excellent Solution	**4**	Excellent	Far Above Average Comfort
10	Ideal Solution			

The utility/functional values given above are utilizing the ground for the comparison of alternative designs. Yet, the utility/functional value ranges can be added to comparisons for every alternative. This in fact gives the total range for every alternative. The found total ranges impose an organizational overall performance ranking for every alternative (Cross, 2000). Thus, the thesis uses the Cross's five-point evaluation range/scale as shown in Table 14.

Table 14: Five-point scale evaluation (Cross, 2000).

FIVE- POINT SCALE	MEANING
0	Inadequate / far below average comfort
1	Weak / below average comfort
2	Satisfactory / average comfort
3	Good / above average comfort
4	Excellent / far above average comfort

In relation with the given information above, there are three stages configured in the structure of initial design phase evaluation method for adjustable DSF systems, which is proposed in the study. This stages the primary stage, the second stage, and the third stage, are elaborated below.

The primary stage is the stage, where it is obligatory to record and range the adjustable alternatives, elucidation for objectives or functions in isolated tables. The alternatives or solution areas of the DSF systems that have the capability of adjustment are (URL 3);

- Energy conservation

- Sun control
- Natural lighting
- Natural ventilation
- Sound control

The 5-point range (0-4) is utilized to assign a range for the alternatives/ elucidation of objectives and functions. The scores may mean comfort level identified with assessed alternative or elucidation for objectives of the DSF systems and every one of them have to be recorded and ranged. In Table 15, assessment table for evaluation of the DSF systems based on certain criteria are given.

Table 15: Table of assessment for the evaluation of the variable alternatives based on relevant objectives (Author, 2018).

DSF Component Type	Adjustment of DSF Component		Functional Evaluation of the DSF Component					Functional Value
	Code No.	Explanation of the statement	0	1	2	3	4	
1	1A							T.F.V.1.A
	1B							T.F.V.1.B

In general, the priority of each objective differs. Therefore, it is essential to weight and assign comparative weighting ranges. Thus, the second stage is the comparison of every objective alongside each other according to the assigned weighting ranges. The weights of the objectives are independent of the fundamental goal and conditions. According to the external requirements, aspects, and the direction of DSF system, each objective for the DSF system components could get diverse weightings. On this basis, to assign an appropriate weight for each objective for DSF system, all aspects should be evaluated.

After assigning a weighting for each objective for DSF system components regarding evaluation of all factors, the last stage is to multiply the ranges of alternatives for objectives with the comparative weighting ranges of the objectives. Through this stage, the total and sub values of the alternatives could be accomplished. However, the entire data, which is gained through the previous stage, is immensely in need of being listed in a table. Table 16 conceptually represents the essentials to attain sub and total values in relation to the utility/function grades and dependent values.

Table 16: The sub and total values related to the function grades and dependent values (Author, 2018).

DSF Component Code No.	Objective1		Functional Value of DSF Component for Objective1	Objective2		Functional Value of DSF Component for Objective1
	Function Grade	Dependent Value		Function Grade	Dependent Value	
A	FG 1A	DV 1	FV 1A	FG 2A	DV 2	FV 2A
B	FG 1B	DV1	FV 1B	FG 2B	DV 2	FV 2B

FV1A= FG1A × DV1. ………………………………………………………… *(Eq.1)*

ΣFVA $_{(1.n)}$ = FV1A + FV2A +………..+FVnA. ……………………………… *(Eq.2)*

In the Eq. *(1)*, FV1A is the functional value of DSF component for objective1 and FG1A is the functional grade of DSF component fitting to objective1 (minimum and maximum). Moreover, A1 is the dependent value/objective weight. Functional grade must be multiplied by the dependent value/objective weight to accomplish functional value of DSF component for objective1. The same process is needed to repeat itself for other objectives in the first DSF component. For the other DSF components, the process must be repeated as well.

The total objective value of the first DSF component (ΣFVA) that has been achieved with the addition of all functional value of DSF components with "n" number is signified in the Eq. *(2)*. For other DSF components, the operation must be repeated.

4.2 Distinctive Cases

The main objective of the case studies is to expose frequently used DSF components. In the framework of the study, a limited number, but the most appropriate cases have been selected. In a broader sense, the most important aspect is the selection of suitable cases, where cases provide an informative enhancement in relation to the proposed ranking method for the DSF system component evaluation. Consequently, the selection of the cases in the study is done through considering following aspects:

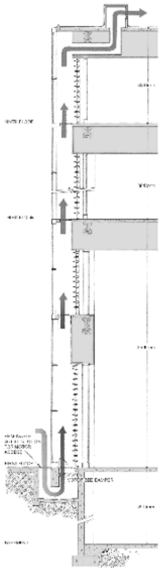
- Being a non-domestic building,
- Incorporating with the main characteristics of DSF systems,
- Being located on a temperate climatic region that is also stated with new coding in ASHRAE Standards 55- 2010 (3A-3B/ 3C/ 4A-4B/ 4C/ 5A-5B-5C/ 6A-6B) (Table 17)

Table 17:ASHRAE 55-2010 Coding for Temperate Climate zones with selected countries (Author, 2018)

Coding	Selected Case Countries
3A-3B	China
3C	Australia
4A-4B	United States of America
4C	Ireland
5A-5B-5C	U.K, Germany, France, Czech Republic, Netherlands, Belgium, Japan
6A-6B	Sweden

4.2.1 Occidental Chemical Center

Table 18: Fundamental investigation of DSF system on Occidental Chemical Center (Author, 2018).

<table>
<tr><th>CASE STUDY - 1</th><th colspan="2">OCCIDENTAL CHEMICAL CENTER</th></tr>
<tr><td>LOCATION</td><td>NEW YORK / U.S.A</td><td rowspan="7"></td></tr>
<tr><td>DSF TYPE</td><td>MULTI STOREY FAÇADE</td></tr>
<tr><td>DSF ORIENTATION</td><td>N-S-E-W</td></tr>
<tr><td>ARCHITECT</td><td>CANNON DESIGN INC., MARK R. MENDELL</td></tr>
<tr><td>COMPLETION</td><td>1980</td></tr>
<tr><td>PROJECT DESCRIPTION</td><td>OFFICE BUILDING</td></tr>
<tr><td colspan="2" rowspan="2"></td></tr>
<tr><td>DOUBLE SKIN COMPONENTS

Frame and Glazing:
1. Exterior Glazing - Blue-Green Tinted Insulating Glass
2. Interior Glazing - Clear Single Glazing

Shading Elements:
1. Sun Shade - Metal Louvers

Ventilation Elements:
1. Lower Operable Ventilation
2. Ventilation Service Grills
3. Upper Operable Ventilation</td></tr>
</table>

The design of the Occidental Chemical Center resides trough promoting maximum transparency to maximize internal day-lighting and to accomplish maximum visual connection with outdoor/ external space. Reflection of the daylight efficiently into the internal spaces is achieved using of white airfoil louvers in the double skin facade cavity. On the other hand, the white louver surfaces refract the sufficient light when the louvers are in the position of being fully shaded. By this way, 50% of the usable floor areas of the building gets benefit from day lighting (URL 3; URL 22).

The outer skin of the building is composed of an aluminum curtain wall. The curtain wall system includes a blue-green tinted insulating glass. The most significant characteristics of such a system is transmitting up to 80% visible light. On one hand, a lucid single glazing is used in the inner skin. On the other hand, 'off-the-shelf' type is used for louvers in the cavity void. The 'off-the-shelf' is generally used as HVAC dampers in application to obtain high velocity.

Significantly, the use of double skin façade in the building skin provides the decrease of assorted external temperature. The DSF indicates such a control to the building by limiting the penetration/diffusion/infiltration effects on the accustomed indoor/interior to an irrelevant level.

In winter periods, a degree of sun collection acts as a thermal buffer to accumulate an appropriate internal accustomed environment against subfreezing external conditions. Significantly, the flow of warm air from the sunnier sides to cooler sides (shaded exposure) imposes some heat convection around the building. While the temperature in buffer space is checked in the extreme environmental conditions, it has been signified that the temperature differs 5.5°C from bottom to top. This is because of the convection current creates 8.3 °C temperature difference among north to south. While the building is unpopulated at nighttime, the conditioned air from daytime process aimed to be saved by keeping the cavity louvers entirely closed. In reality, apart from weekends, the louvers are mainly open, especially when the weather is very cold and when the computers are all shut down.

In summer periods, the cavity is being vented at top and bottom. This is for decreasing sun build-up and increasing the airflow. A 10-15% heat recovery is achieved by a heat wheel on the exhaust air extract. The heat recovery around 10-15% is accumulated to precondition the air ventilation.

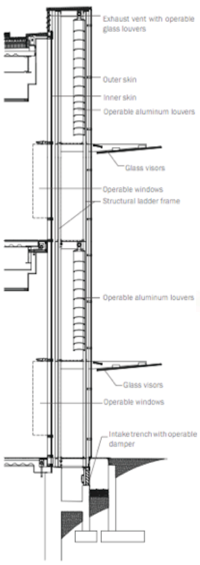
Through these circumstances, the aspects of air conditioning, heating and the ventilating requirements are convinced through two low-pressure variable air volume (VAV) air-handling units. By draining air with an air-to-air heat exchanger at WC, a pre-heated or pre-cooled minimum ventilation air is obtained. A fan assisted VAV together with heating coils is found in the outer zone, whereas having only VAV is seen adequate for the inner zone. In the glazed cavity, the use of operable horizontal louvers is providing adaptable sun control and preventing direct sun radiation during summer and winter periods. The building has 12 aluminum louvers on every floor. The louvers expanses vertically 20 cm along the 450 cm distance between columns. In the arrangement of responding ambient sunlight conditions, motorized screw shaft roads are used to provide power drive for every segment. The louvers on each floor follow the sun to control and reduce the sun heat gain in the occupied area during the daytime period. However, louvers do not impose any limitation for the penetration of diffuse daylight while they serve to control heat gain for the occupied area. In order to stop the movement of the louvers, two photocell sensors are located at each facade of the building. When the mode of photocell is on a shade, the louvers are in the adequate mode of shading the interior space of the building. Since the louvers are positioned for full shade in 45°, louvers are entirely closed during nighttime and other occupied hours to keep the conditioned air from the daytime process (Table 19) (URL 21).

Table 19: Overall assessment of Occidental Chemical Center (Author, 2018).

Façade System	▪ Ventilation cavity ▪ Full height air space
Energy	▪ Buffer space gap ▪ Operable double façade, independent of each other as they respond to the sun angle
Natural Ventilation	▪ Natural ventilation with movable louvers ▪ Air cavity between building façade and the glass façade that circulates the fresh air
Operation Mode	• Operable horizontal louvers in air space with a photocell control

4.2.2 Cambridge Public Library

Table 20: Fundamental investigation of DSF system on Cambridge Public Library (Author, 2018).

<table>
<tr><th>CASE STUDY - 2</th><th colspan="2">CAMBRIDGE PUBLIC LIBRARY</th></tr>
<tr><td>LOCATION</td><td>MASSACHUSETTS</td><td rowspan="7"></td></tr>
<tr><td>DSF TYPE</td><td>MULTI-STOREY</td></tr>
<tr><td>DSF ORIENTATION</td><td>S-W</td></tr>
<tr><td>ARCHITECT</td><td>WILLIAM RAWN ASSOCIATES, ARCHITECT</td></tr>
<tr><td>COMPLETION</td><td>2009</td></tr>
<tr><td>PROJECT DESCRIPTION</td><td>LIBRARY BUILDING</td></tr>
<tr><td colspan="2" rowspan="2">
</td></tr>
<tr><td>DOUBLE SKIN COMPONENTS

Frame and Glazing:
1. Exterior Glazing - Insulating Glass
2. Interior Glazing - Double Glazing
3. Structural Frame -Vertically Orient Vierendeel Trusses
4. Maintenance Catwalk - Aluminum Grills

Shading Elements:
1. Operable Sun Shade - Aluminum Louvers
2. Sun Shade Canopy - Glass Visors

Ventilation Elements:
1. Lower Operable Ventilation - Operable Damper
2. Upper Operable Ventilation - Glass Louvers</td></tr>
</table>

In Cambridge Public Library, the double skin facade is a multi-story facade with a full depth of 90 cm thermal flue (Hoseggen et al, 2008). A complete transparency and protection from an unwarranted heat loss, gain and glare is achieved for the building using of DSF (URL 23).

In reality, the multi-story facade serves to save energy, primarily comparing to a curtain wall it increases 50% of the energy efficiency. On the other hand, it maximizes the user comfort especially at reading spaces of the library. The façade includes 75cm airspace. This space is capable to be opened in summer periods to protect the extreme heat flow from external environment to indoor, while serving as a thermal blanket during the winter period by being closed.

The facade demonstrates the advance of indicating a diffusion of an adequate natural sunlight into space significantly with the contribution of fixed and movable shading devices. Besides of the sunlight, the façade also authorizes a frequent flow of fresh air through operable windows. The heat from the cavity can be transmitted into the building during spring, fall and winter times (Figure 18; a, b, c).

a) Double skin cavity b) Aluminum louvers c) Louvers adjust to the low sun

Figure 18: Air Cavity with Movable Shading Units; a) Double Skin Cavity, b) Aluminium Louvers, c) Louvers adjust to the Low Sun (Cambridge Public Library Case Study: A Double Skin Glass Wall (Brochure), Boston, MA).

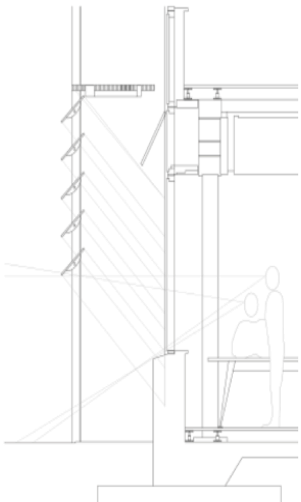
Table 21: Overall assessment of Cambridge Public Library (Author, 2018).

Façade System	▪ Ventilation cavity ▪ Full height air space
Energy	• Air space, effectively creating a thermal barrier between internal and external environments • Upper and lower vents are modulating the temperature of the cavity
Natural Ventilation	▪ Natural ventilation with movable louvers ▪ Air cavity between the building façade and glass façade which circulates the fresh air ▪ Operable windows allow fresh air
Operation Mode	• Operable louvers in air space

4.2.3 Building Research Establishment

Table 22: Fundamental investigation of DSF system on Building Research Establishment (Author, 2018).

CASE STUDY - 3	BUILDING RESEARCH ESTABLISHMENT
LOCATION	WATFORD / UK
DSF TYPE	SHAFT BOX FAÇADE
DSF ORIENTATION	S
ARCHITECT	FIELDEN CLEGG
COMPLETION	1997
PROJECT DESCRIPTION	OFFICE BUILDING



DOUBLE SKIN COMPONENTS

Frame and Glazing:

1. Interior Glazing - Double Glazing

Shading Elements:

1. Sun Shade -Translucent Motorized External Glass Louvers

Ventilation Elements:

1. Vertical Chimneys
2. Low-Resistance Propeller Fans Located On Top

The building integrates the day lighting and natural ventilation strategies with the use of DSF. Although the building demonstrates an open plan typology together with cellular offices; the challenge of day lighting and natural ventilation is revealed into a highly glazed façade. Besides to a highly glazed facade, cellular offices, in 4.5 meters deep, are located on the north side with single-sided natural ventilation. These cellular offices, in fact, serve to indicate a cross ventilation in the open plan arrangement of the building. To shade the glazed façade, translucent motorized external glass louvers are used which can be prevailed by the occupants. The louvers are controlled by an enhanced bailing management system (URL 24). The glass louvers have the potential of revolving to diffuse the direct sun entering the internal spaces. Moreover, they provide maximum view while they are positioned horizontally. However, there is also a stack ventilation system, which is included as an alternative ventilation strategy for the open-plan offices in the case of excessive cooling conditions.

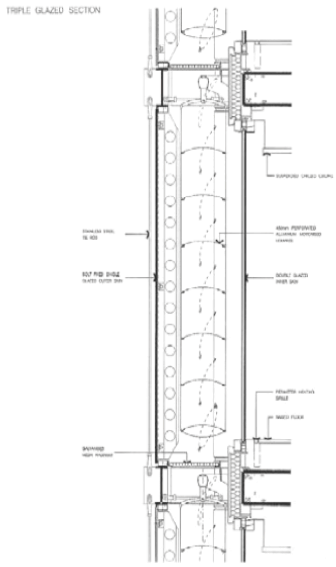
On the other hand, to draw hot air through the tube/pipe in the structure, bottom-hung, hopper, or fixed windows; we see that vertical chimneys are used in the design (URL 24). To allow daylight to enter the indoor areas, fixed glass blocks are used to glaze the exterior of the stacks. Minimum ventilation is provided by the use of low-resistance propeller fans located at the top-floor level. These fans also contribute to swilling out the internal heat gain during the nighttime (Table 23) (Edwards, 1998).

Table 23: Overall assessment of Building Research Establishment (Author, 2018).

Façade system	▪ Motorized external glass louvers ▪ Glazed façade
Energy	▪ Low resistance propeller fans ▪ Vertical chimneys draw hot air ▪ Thermal barrier with movable ventilation channels
Natural Ventilation	▪ Duct providing space conditioning and ventilation ▪ Waveform roof structure allows natural ventilation
Operation Mode	▪ Motorized external glass louvers

4.2.4 Helicon Finsbury Pavement

Table 24: Fundamental investigation of DSF system on Helicon Finsbury Pavement (Author, 2018)

CASE STUDY - 4	HELICON FINSBURY PAVEMENT	
LOCATION	LONDON	
DSF TYPE	MULTI-STOREY	
DSF ORIENTATION	E-W	
ARCHITECT	SHEPPARD ROBSON	
COMPLETION	1996	
PROJECT DESCRIPTION	RETAIL AND OFFICE	
		**DOUBLE SKIN COMPONENTS** **Frame and Glazing:** 1. Exterior Glazing - Toughened Single Glazing 2. Interior Glazing - Triple Glazed Cladding **Shading Elements:** 1. Automated Sun Shade - Perforated Metal Louvers **Ventilation Elements:** 1. Lower Operable Vents 2. Upper Operable Vents

The Helicon Finsbury Pavement building is designed with triple glazed facades, which is creating 88.5 cm cavity the on east, and west side. This cavity has sun control blinds and it entrains a support to the structure of the façade. The façade is dressed with opaque elements with a silver grey covered aluminum panel system (URL 22). During the winter period, heating of the building is partly provided by use of a perimeter heating system and a tempered air supply. The perimeter heating system consists finned tubes laid in channels. Moreover, there are standard non-condensing boilers located at the basement plant room of the building. These types of boilers provide hot water to air ventilation managing units, domestic hot water, and perimeter heating.

The DSF is formed by 12 mm frameless single glazing outer pane and triple glazed panels for inner. Such a façade acts as a thermal chimney throughout its leaning blinds for sun control and mechanical vents. The DSF on east and west can be closed to act as a thermal buffer during cold winter weather by reducing heat loss. However, the DSF on east and west can also be automatically opened either with high or low-level openings. This process drastically endorses a stack effect for removing the undesired sun built up in the cavity earlier than it penetrates the building.

Multi-serviceable aluminum blinds are used in the cavity of the building façade. These blinds are capable to be lowered or raised or even tilted according to the external lightning level, sun gain and temperature.

Nevertheless, the daylighting, especially for the profound floor plates of the retail areas of the building is provided using a full- height glazing. On one hand, the daylight level of the atrium is increased by staring back the office floor plates. On the other hand, the staring back of the office floor plates contributed to maximizing the daylight into office areas.

Interestingly different than many other buildings, the double skin void hosts maintenance walkways. These maintenance walkways serve to provide a level of sun shield/protection at every floor level. The facade system is also designed with automatically working aluminum louvers that provide active sun control. The horizontal louvers are in the form of the curved aluminum sheet, which is 450 mm wide, 3 meters long, and 425 mm vertical spacing. Each unit of the louvers has 14% perforations. Throughout this 14% perforation of each unit, the façade absorbs 3% sun radiation as the maximum and also reflects 7% of sun radiation as minimum. Significantly, the louvers, which are located between floors 2-6, are designed with the ability to skew up to an angle 70°. These louvers skew up based on the sun conditions.

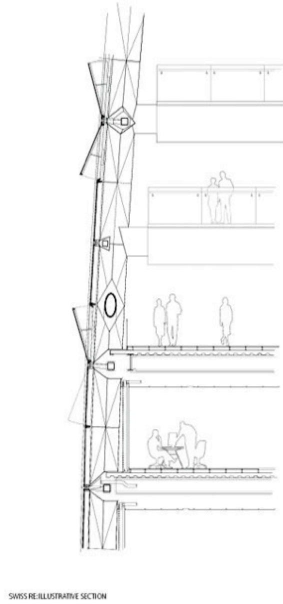
While louvers provide sun protection, the double skin serves for thermal control. During winter periods, the cavity is closed and it acts as a thermal barrier to reduce the heat loss, especially from the offices. Nevertheless, in summer periods the cavity is open to establish a stack effect by removing the unwanted sun gain from heated louvers and the cavity before it enters the building (Table 25).

Table 25: Overall assessment of Helicon Finsbury Pavement (Author, 2018).

Façade system	▪ Full height double skin façade elements for natural ventilation
Energy	▪ Naturally ventilated buffer space gap ▪ Solar tinted glass ▪ Thermal barrier with movable ventilation channels
Natural Ventilation	▪ Natural ventilation with movable ventilation channels ▪ Climatic buffer corridor circulates fresh air
Operation Mode	▪ Electrical venetian blinds for sun control

4.2.5 Swiss Re Building / St. Mary Axe

Table 26: Fundamental investigation of DSF system on Swiss Re Building/St. Mary Axe (Author, 2018).

CASE STUDY - 5	SWISS RE BUILDING / ST. MARY AXE	
LOCATION	LONDON	
DSF TYPE	SHAFT BOX	
DSF ORIENTATION	N-S-E-W	
ARCHITECT	FOSTER AND PARTNERS	
COMPLETION	2003	
PROJECT DESCRIPTION	OFFICE BUILDING	
		**DOUBLE SKIN COMPONENTS** **Frame and Glazing:** 1. Interior Glazing - Operable Laminated Glass 2. Exterior Glazing - Tinted Double Glazed Glass **Shading Elements:** 1. Sun Shade - Computer Controlled Perforated Aluminum Louvers **Ventilation Elements:** 1. Openable Glass Screen 2. Ventilation Chimneys 3. Venting Flaps

Swiss Re Building is designed to maximize daylight and natural ventilation. A DSF system is giving a significant energy efficiency characterization to the building. The outer layer of the double skin is formed by a double-glazed glass. The glazed in fact is formed by mullions and triangular windows. These windows consist venting flaps that permit captured heat to be cultivated or discarded according to the heating or cooling requirements of the building (URL 25). The inner layer is made of operable laminated glass that allows accessibility only by maintenance. Air cavity between two layers contains a row of horizontal computer controlled perforated aluminum louvers. Cavities in every floor generate six shafts. These shafts assist the whole building as a natural ventilation system (URL 3). In addition, the shafts serve as light wells, where infiltration of the daylight into the building is allowed.

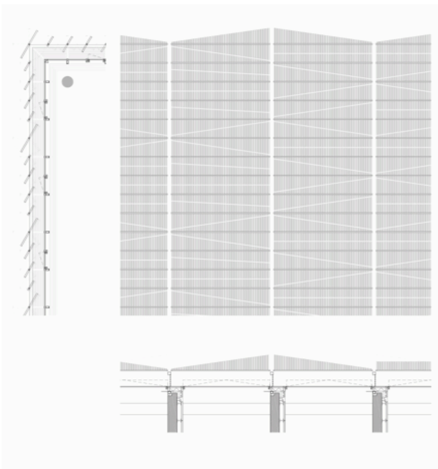
The building demonstrates a very specific energy efficiency comparing to traditional contemporary designs. The building uses 50% less energy than a traditional contemporary building. The aerodynamic curved shape of the building and its integrated DSF system plays a very significant role on such result. The curve form impels an enormous potential to maximize the natural ventilation and minimize the wind loads, even though, offices on the sides ventilate the exhaust air at the double wall cavity. The spiral atrium of the building also contributes to the ventilation for each floor, which is rotated from the plane. At every six floors, there are air-purifying gardens, which also serve as fire-safety hubs (Table 27).

Table 27: Overall assessment of Swiss Re Building / St. Mary Axe (Author, 2018)

Façade system	▪ Full height double skin façade for natural ventilation
Energy	▪ Naturally ventilated buffer space gap ▪ Tinted double glazed glass ▪ Thermal barrier with ventilation shafts
Natural Ventilation	▪ Natural ventilation with ventilation shafts ▪ Climatic buffer corridor circulates fresh air
Operation Mode	▪ Computer controlled venting flaps and sun blinds

4.2.6 The Thyssen Krupp Headquarter- Q1

Table 28: Fundamental investigation of DSF system on The Thyssen Krupp Headquarter- Q1 (Author, 2018).

<table>
<tr><th>CASE STUDY - 6</th><th colspan="2">THE THYSSEN KRUPP HEADQUARTER (Q1)</th></tr>
<tr><td>LOCATION</td><td>ESSEN</td><td rowspan="6"></td></tr>
<tr><td>DSF TYPE</td><td>MULTI-STOREY</td></tr>
<tr><td>DSF ORIENTATION</td><td>N-S-E-W</td></tr>
<tr><td>ARCHITECT</td><td>JSWD ARCHITEKTEN</td></tr>
<tr><td>COMPLETION</td><td>2010</td></tr>
<tr><td>PROJECT DESCRIPTION</td><td>OFFICE BUILDING</td></tr>
<tr><td colspan="2"></td><td>DOUBLE SKIN COMPONENTS
Frame and Glazing:
1. Interior Glazing - Double Glazed Heat Insulated Glass
2. Exterior Layer - Operable Stainless Steel Lamellas
Shading Elements:
1. Sun Shade - Stainless Steel Sun Shades
Ventilation Elements:
1. Operable Openings
2. Floor To Ceiling Captious Openings</td></tr>
</table>

The building looks as if it is made of two large "L" shapes hugging a large central atrium between them. It is 700 sq-m glass façade on the north and south, creating a floating space between inside and outside.

The glass façades have 96 windows each, held in a place by fine steel cable structures. On the other hand, operable vertical lamellas and thin steel profiles are comprised at the front façades of the offices. The building accumulates 30% less energy use than a standard building by its geo-thermally heated structure.

The facade is designed through three layers; the first layer is a glass spatial and thermal enclosure; the second layer is the inner layer, which provides glare protection with a fabric; and the third layer is the outer layer that has sunscreens (Figure 19).

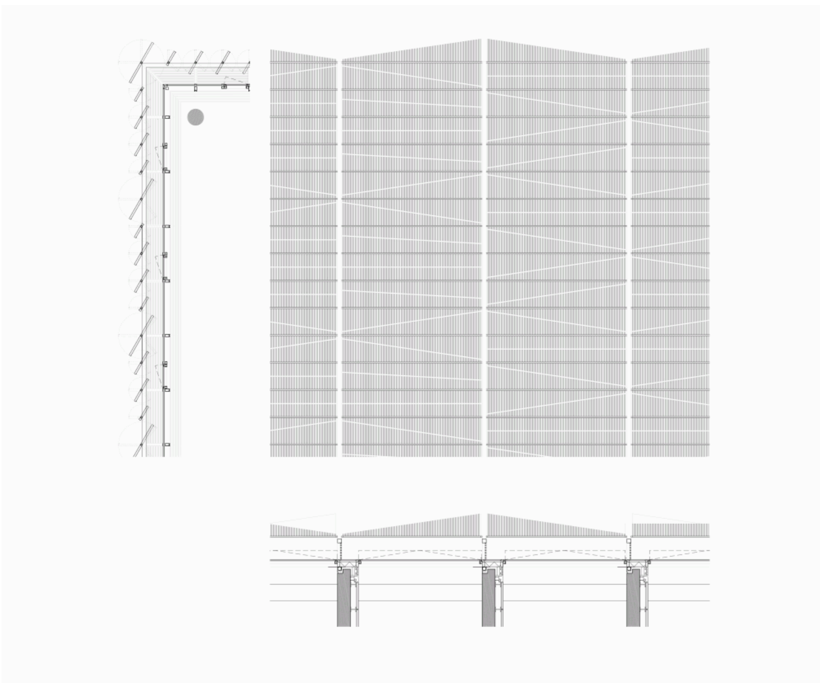


Figure 19: System Detail of Thyssen Krup Headquarter in Essen (UrL 26).

The exterior façade of the building is formed by very high (3.6 meters) sunshades that cover approximately 8000 m^2 of the façade. The shading elements are stainless steel and they are fixed on a vertical steel frame. Although they are fixed huge structures, they have the ability to be opened and closed based on the behaviors of sun rays by control of electric motors. At the same time, they allow diffusing of the daylight into the inner space (offices). Significantly, the shading elements demonstrate the following characteristics (Figure 20):

1. When they are closed, they are in a position of being parallel to the glass façade.
2. When they are moving with the sun, their position is in variable and perpendicular to the sun.
3. When they are open, the horizontal lamellas move parallel to the glass façade.

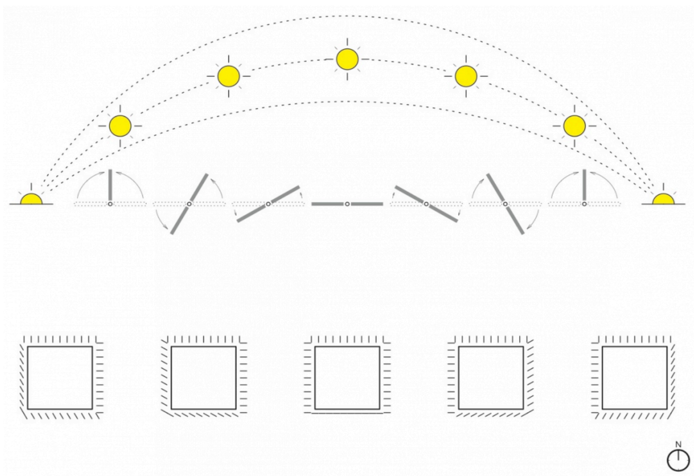


Figure 20: Sunshade Diagram of Thyssen Krupp Headquarter (UrL 26).

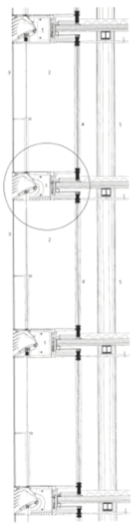
The variation in the triangular, rectangular and trapezoid elements to the facade impels following the sun. It protects the building from overheating and allows the reflection of daylights into the interiors. The façade elements can be moved even in wind speed of 70 km/h (Table 29).

Table 29: Overall assessment of ThyssenKrupp Head Quarter (Author, 2018)

Façade system	▪ Glass surface with full floor height ▪ Floor to ceiling double skin façade elements for natural ventilation
Energy	▪ Buffer space gap ▪ Double glazed heat insulated glass units
Natural Ventilation	▪ Aluminum ventilation elements with diagonal form ▪ Sliding windows at inner façade ▪ Floor to ceiling captious openings for ventilation
Operation Mode	▪ Moveable stainless-steel sunblind ▪ Textile sunscreens ▪ Sliding windows towards buffer space for natural ventilation

4.2.7 Stadttor / City Gate (Germany)

Table 30: Fundamental investigation of DSF system on Stadttor/City Gate (Author, 2018).

<table>
<tr><th>CASE STUDY - 7</th><th colspan="2">STADTTOR (CITY GATE)</th></tr>
<tr><td>LOCATION</td><td>DUSSELDORF</td><td rowspan="7"></td></tr>
<tr><td>DSF TYPE</td><td>CORRIDOR FAÇADE</td></tr>
<tr><td>DSF ORIENTATION</td><td>N-S-E-W</td></tr>
<tr><td>ARCHITECT</td><td>PETZINKA PINK UND PARTNER ARCHITECT</td></tr>
<tr><td>COMPLETION</td><td>1997</td></tr>
<tr><td>PROJECT DESCRIPTION</td><td>OFFICE BUILDING</td></tr>
<tr><td colspan="2" rowspan="2"></td></tr>
<tr><td>DOUBLE SKIN COMPONENTS

Frame and Glazing:
1. Exterior Glazing - Toughened Planar Glazing
2. Interior Glazing - Low-e Double Glazing

Shading Elements:
1. Operable Sun Shade - Aluminum Venetian Blinds

Ventilation Elements:
1. Ventilation Boxes - Automatically controlled damper. Alternate boxes act as inlet and outlet vents, with grilles into the cavity from the top and bottom of the box respectively</td></tr>
</table>

The building structure is formed by steel columns. However, the inside of the columns is filled by a reinforced concrete material. Apart from the steel structure system, the external façade is dressed with full-height planar glazing panels. This imposes to get maximum benefit from the daylight and view. The glazing panels are located between horizontal bands of aluminum ventilation boxes. The use of single glazed planar glass constitutes the walls of a vertical atrium. On the other hand, the office floors of the building are surrounded/ enveloped by use of a double skin facade, where its cavity serves to make a ventilated perimeter zone, in a range of 1.4-0.9 m depth. A cynical planar glazing forms the 15 mm outer face of the DSF. Since, the glass façade is low iron optic-white, it provides maximum transparency for the inner spaces. In such an approach, revolved high-performance timber windows are used vertically for the inner skin part. Such a façade system performs a low-E coating. The building demonstrates 50% overall energy transmissions without blinds, and with blinds this amount can be 10% lowered. Furthermore, a 68% light transmission is achieved by the envelope.

In general, the building uses operational mechanical ventilation, where a heater battery in the air-handling units pre-heats the provided air together with a district heating system. Even so, the building consists of automatic blinds in the cavity of double skin to operate the building temperature and humidity. In addition, the building facilitates cooling ability at night times whenever it is required. In terms of ventilation, the outer façade has automatically controlled ventilation flaps that push up the air into the cavity. The natural ventilation is achieved by manually opening the inner windows. In other words, it is achieved by when they are opened by the users/occupants. If the ventilation flaps of the building are automatically opened and the inner windows are opened by the users, the building achieves approximately 70% natural ventilation throughout a year. The building achieves this 70% value while 25% of the year is below 5 °C and only 5% of the year temperature be above 22°C.

In the case of below 5 °C temperature, the building uses pre-heated mechanical ventilation, where the radiant heating panels are charged between 6-9 am. The flaps are all closed while the mode of mechanical ventilation is on. In order to discard the reduction activated by humidity and to discard cold downdraught, atrium is occasionally being opened and solely the vents at the top are open. During nighttime, the ventilation flaps are being closed. The cavity can be lowered to ascertain an additional insulation to the building. During daytime, the flaps are generally closed and mechanical ventilation starts to function if the pressure disparity exceeds the 50Pa.

In the case of above 22 °C temperature, the building uses pre-cooled mechanical ventilation, the supplied air by heated/cooled mechanical ventilation distributed to the building by ceiling diffuser slots (URL 22). In the system developed for ventilation, each floor level consists of ventilation boxes that are integrated into the façade depth. In fact, the building has 3.3 linear kilometers of ventilation boxes in the façade. These ventilation boxes are automatically controlled with a damper. While, the grilles place in the cavity impels the alternate boxes to act as outlet and inlet vents for the bottom and top of the box correspondingly. Given that, the flaps have ability to be entirely opened or closed. However, above 22°C, the flaps are kept open to prevent the blinds from overheating and to cool building structure.

During the rainy days or heavy windy days, the flaps are opened solely 10%. After a full closure, the flaps are opened first 10%, then 100%. Significantly, the building achieves ventilation throughout two settings; the double skin cavity ventilates the outer offices at the surface and inner offices are ventilated from the atrium, of which atrium is ventilated naturally.

The building in the identity of a glass cube is surrounded by glass louvers to bring sun and wind control to the building. The louvers that are positioned at the bottom and top of the glazed wall implement varied control strategies for the opening such as 25%, 75% or 100%. The louvers are also controlled by the wind speed and direction. For instance, during harsh windy whether based on the direction of the wind comes, the relevant façade louvers could be closed to discard the wind movement through the building.

In addition to the glass louvers, 20 cm behind of the external face of the building is involved by venetian blinds. The blinds have the characteristics of three orienting positions that are controlled by the light switch, such as 45° tilt, completely closed, or horizontal steadiness.

The blinds automatically lowered themselves in relation with the photocell detectors situated on every façade. In other words, to reduce the glare the blinds lower themselves 45°, as still allow daylight diffusion in if a particular facade of the building is getting negatively affected from the sunshine. They stay in raised position while the sunshine does not affect any face.

The sun protection is achieved by indicating 1,4 m depth cavity. The cavity prevents the most direct sunlight to enter the building. In fact, the ventilation flaps are attuned based on the diverse pressure measures of every side of the building (Table 31).

Table 31: Overall assessment of Dusseldorf City Gate (Author, 2018)

Facade system	▪ Movable ventilation channels ▪ Floor to ceiling, double skin façade elements for natural ventilation
Energy	▪ Buffer space gap ▪ Low-E glazed heat insulated doors ▪ Thermal barrier with movable ventilation channels
Natural Ventilation	▪ Natural ventilation with movable ventilation channels ▪ Climatic buffer corridor circulates fresh air
Operation Mode	▪ Moveable ventilation channels on facades for natural ventilation ▪ Electrical venetian blinds for sun control

4.2.8 Deutsche Post

Table 32: Fundamental investigation of DSF system on Deutsche Post (Author, 2018).

CASE STUDY - 8	DEUTSCHE POST	
LOCATION	BONN	
DSF TYPE	CORRIDOR FAÇADE	
DSF ORIENTATION	NW - SE	
ARCHITECT	HELMUT JAHN	
COMPLETION	2003	
PROJECT DESCRIPTION	OFFICE BUILDING	
		**DOUBLE SKIN COMPONENTS** **Frame and Glazing:** 1. Exterior Glazing - Uncoated Clear Glass 2. Interior Glazing - Thermally Insulated Glass **Shading Elements:** 1. Operable Sun Shade - Aluminum Venetian Blinds **Ventilation Elements:** 1. Control Flaps

The Deutsche Post building is one of the successful representations of the environmental technology and the construction technology in terms of ventilation and temperature control. The most significant characteristics of the building are (1) its glass DSF and (2) exhaustive use of groundwater.

The structure of the DSF is designed through a very light-supporting framework that is large high-strength special steel (URL 27). The structure has characteristic of being flexible withstand against the wind forces by use of significant steel compression members and has ability to be moved by its link joints. In addition to the lightweight structural façade systems, the facade is formed by thermally insulated-gas filled-glass walls, which are extending from floor up to the ceiling. Glass walls allow daylight to enter in. On one hand, the DSF provides fresh air for the high-rise tower without requiring any ducting. In general, the ventilation ducts in high-rise buildings covers a large amount of space inside the building. On the other hand, the tower does not appeal a need for air conditioning system. As acknowledged, the air condition system negatively affects the top floors of the high-rise buildings.

The cavity of the double skin is signified through 1.70 meters on south and 1.20 meters on north. In this cavity, sunblinds are placed to control sun gain and wind. In order to control the temperature, the cavity serves during winter period as an insulator reducing the heat loss. Especially, 20% less heating is expected to be used by building (URL 28). At summer period, the temperature is controlled with the fresh air that is gained during the cooler nighttime hours. Especially, this fresh air is mainly obtained through the windows, which are inserted into the primary facade. These windows have the ability to be opened and closed with aim of naturally managing/operating the internal temperature. An uncoated large clear glass is used on the outer face/external skin. The uncoated large glass has control flaps that naturally ventilate the internal spaces throughout all seasons. On the other hand, the external skin acts as a protection shield for the inner part from wind, noise and rain. The facade also demonstrates the ability to balance the temperature by means of preventing the glass from the risk of being broken. At each floor division, a narrow aluminum panel is positioned to contain ventilation equipment in the service areas (Table 33).

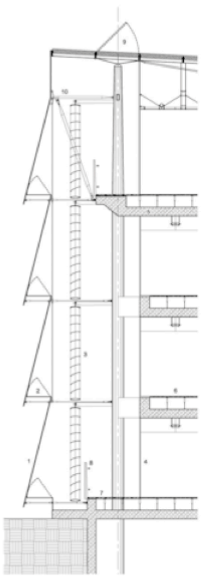
Table 33: Overall assessment of Deutsche Post (Author, 2018).

Facade system	▪ Gas-filled, thermally insulated glass walls ▪ Glazed inner facade
Energy	▪ Double skin works like an insulating air cushion, reducing the heat lost to the outside ▪ Double glazed heat insulated glass units
Natural Ventilation	▪ Outer skin largely consists of uncoated clear glass which has control flaps allowing natural ventilation ▪ Sliding windows at inner facade
Operation Modes	▪ Moveable aluminum sunblind ▪ Sliding windows towards buffer space for natural ventilation

4.2.9 Bayer Headquarters

Table 34: Fundamental investigation of DSF system on Bayer Headquarters (Author, 2018).

CASE STUDY - 9	BAYER HEADQUARTERS
LOCATION	LEVERKUSEN / GERMANY
DSF TYPE	MULTI STOREY FAÇADE
DSF ORIENTATION	SE
ARCHITECT	HELMUT JAHN
COMPLETION	2003
PROJECT DESCRIPTION	OFFICE BUILDING



DOUBLE SKIN COMPONENTS

Frame and Glazing:

1. Exterior Glazing - Single Toughened Glass
2. Interior Glazing - Double glazed heat insulated glass units

Shading Elements:

1. Sun Shade - Perforated Aluminum Louvers

Ventilation Elements:

1. Opening Fins
2. Inner Walls Contains Operable Windows
3. Exhaust Air Window on Top

Bayer Headquarters is designed as totally glass twin-shell facade. The glass twin-shell facade provides significant natural ventilation and lighting to the building. The natural ventilation is maximized in spring and fall comparing to the winter and summer periods. The outer shell/skin has characteristic of inserting sun-shading devices/elements to the facade. In addition, the outer shell also acts as a protection shield towards the wind, noise, and rain.

Punctured aluminum louvers (30 cm wide), which are placed into the cavity of glass shell walls, control the sun gain. In order to retain the visual connection with the outdoor and to minimize the sun gain, insulation and glare, a special attention is given to the design of the puncturing pattern of aluminum louvers (URL 29). In addition to the louvers, an exterior metal mesh only affords to shade the tops of the building (Figure 21).

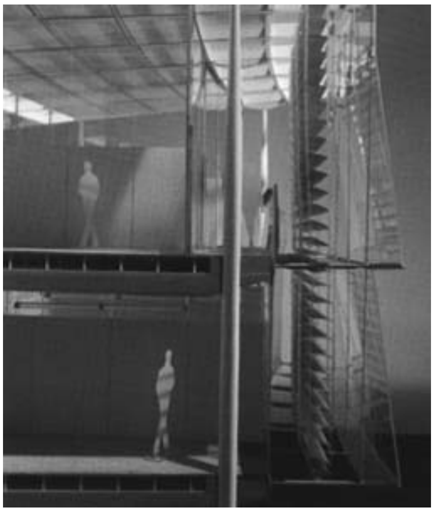


Figure 21: Section Model (UrL 30).

Apart from the sun control, the two glass walls indicate laminar airflow to control the heat transmission. Since two layers of air are separated, the outer layer is being heated by the interaction of sunlight to exterior glazing skin and blinds. Nonetheless, heated air leaves the skin surface through openings/channels at the roof, while moving up with a natural chimney effect. Ground ducts through interior side of the blinds indicate a cooler air at the inner layer. During the process of diffusing air into the occupied space, tempered fin-tube convectors estimate satisfying natural ventilation with a satisfying temperature. In fact, the fundamental source of the temperature control is the radiant coils reeled in the exposed concrete ceiling. These radiant coils decrease the temperature-exchange task of air. To distinguish heated air for removing the grills, a natural stratification is achieved through required lower air velocity. The ventilation air is significantly drawn from the fan boxes or under-pressure air system to every module through fin tubes. On the other hand, the essential clean ventilation air is conveyed by a low-volume distribution system. While doing this, occupants individually could control the tempered exterior air consistent with their air volume and temperature choices. The occupant also could control the operable windows that are placed to the inner wall. The operable windows provide large amounts of fresh airflow into the building, while the exterior environment conditions are appropriate. By this way, naturally ventilating the building through year could be modulated depending on the suitability of exterior conditions (URL 29). There is a displacement system to provide the essential comfort temperature level in the building when in summer or winter period the satisfying temperature cannot be achieved. The displacement system is being fed by a convector. The convector serves for cooling or heating the gained air from the façade system for mechanically generating the comfortable indoor environment. Along with, a computerized building management system is asserted to determine the most efficient operational mode for balancing the indoor and outdoor conditions. According to the records, the endorsement of the twin-shell façade and climate concept in building reduce the service costs by 60%.

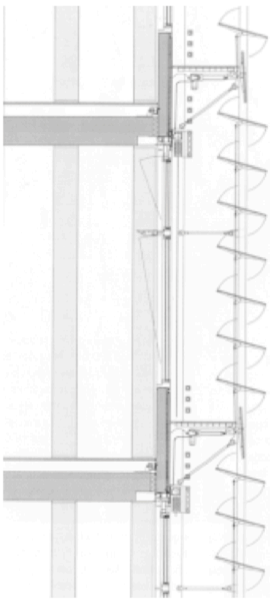
The concrete structure has an integral heating and cooling pipe system, which takes the advantage of the low energy characteristics of water and the thermal storage capacity of concrete (Table 35).

Table 35: Overall assessment of Bayer Headquarter (Author, 2018).

Facade system	▪ Glass surface with full floor height ▪ Full story height double skin façade elements for natural ventilation
Energy	▪ Buffer space gap ▪ Double glazed heat insulated glass units
Natural Ventilation	▪ Aluminum ventilation elements with diagonal form ▪ Sliding windows at inner façade ▪ Floor to ceiling captious openings for ventilation
Operation Mode	▪ Moveable aluminum sunblind ▪ Textile sunscreens ▪ Sliding windows towards buffer space for natural ventilation

4.2.10 Lyon’s Cite International

Table 36: Fundamental investigation of DSF system on Lyon's Cite International (Author, 2018).

CASE STUDY - 10	LYON’S CITÉ INTERNATIONAL	
LOCATION	LYON / FRANCE	
DSF TYPE	MULTI STOREY FAÇADE	
DSF ORIENTATION	N	
ARCHITECT	RENZO PIANO	
COMPLETION	2004	
PROJECT DESCRIPTION	MIX-USE	
		**DOUBLE SKIN COMPONENTS** **Frame and Glazing:** 1. Exterior Glazing - 8mm Low-e Coating 2. Interior Glazing - 6mm Low-e Coating **Shading Elements:** 1. Sun Shade - Automatically Controlled Aluminum Venetian Blinds **Ventilation Elements:** 1. Mechanically Ventilated Cavity.

Lyon's Cité International building has a glass membrane DSF. The membrane can be fully closed during the winter period to heat the indoor. In addition to heat control, the glass membrane ascertains a better output as a sound control as well.

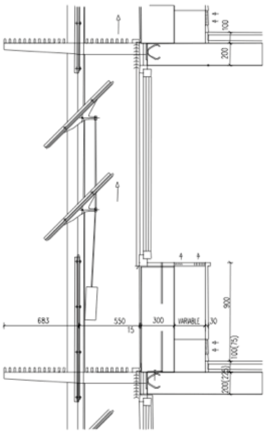
The glass membrane façade has revolving shutters. These shutters are placed 70 cm ahead of the facade skin. At the same time the façade includes electrically operable louvers. For instance, the louvers could be fully opened during summer time to provide a natural cooling. Moreover, the louvers can accomplish removing the hot air from the building (URL 31). The external blinds prevent the glare from being operable from indoor. The maintenance walkways topped with laminated safety glass inserted between the glass layers indicates a sun-shading device effect to the buildings. On the other hand, they provide a barrier to prevent the spread of the fire and smoke (Table 37).

Table 37: Overall assessment of Lyon's Cite International (Author, 2018).

Facade system	▪ Glass surface with full floor height ▪ Full story height double skin façade elements for natural ventilation
Energy	▪ Buffer space gap ▪ Low-E coating glass units ▪ Laminated safety glass indicates a sun-shading device effect
Natural Ventilation	▪ Aluminium ventilation elements ▪ Operable windows at inner, and outer facade
Operation Mode	▪ Electrically operated louvers ▪ Operable windows towards buffer space for natural ventilation ▪ Operable external glass panels

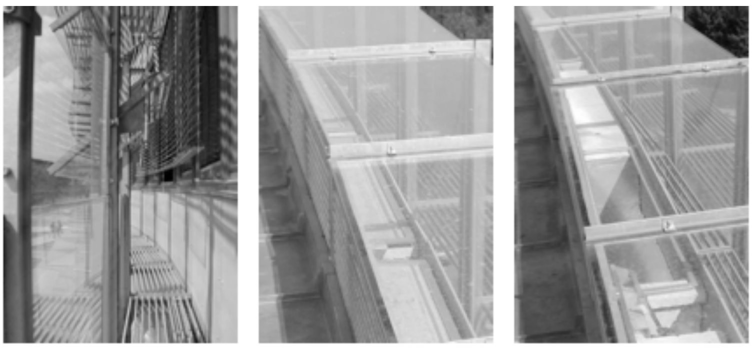
4.2.11 Moravian Library

Table 38: Fundamental investigation of DSF system on Moravian Library (Author, 2018).

CASE STUDY - 11	MORAVIAN LIBRARY	
LOCATION	BRNO / CZECH REPUBLIC	
DSF TYPE	MULTI STOREY FAÇADE	
DSF ORIENTATION	S	
ARCHITECT	TOMAS ADAMEK & PETR BENEDIKT	
COMPLETION	2001	
PROJECT DESCRIPTION	LIBRARY BUILDING	
		**DOUBLE SKIN COMPONENTS** **Frame and Glazing:** 1. Exterior Glazing - 10mm Single Toughened Glass 2. Interior Glazing - Double Glazing **Shading Elements:** 1. Sun Shade - Adjustable Glass Louvers **Ventilation Elements:** 1. Lower Operable Ventilation 2. Ventilation Service Grills 3. Upper Operable Ventilation

The Moravian Regional Library in Brno has eight stories high and 50 meters long facades, including two DSFs. The double skin sun façades are placed on south sides of both wings of the building. The building indicates natural ventilation during warm weathers/seasons with the contributions of its DSFs. One of these DSFs is designed to indicate a sun preheating for the ventilation air during cold weathers/seasons. As Figure 19 shows double skin sun facade on the southern wing of the library building used for the monitoring and numerical investigation. While Figure 23 a, b, c shows the construction and functional principles of the double facade with the total area 1135 m2.

Figure 22: Solar Double Ventilated Facade on the Southern Wing of Brno Moravian Library (Jaros et al., 2002).



a) b) c)

Figure 23: Details of the Structure Inside the Channel of Double Glass Facade; a) Performance of Outlets Over the Roof on the Topp of the Facade, b)Outlets are Closed, c) Outlets are Open (Jaros et al., 2002).

A load bearing cantilevered structure of the double glazed façade attached to the wall of the building is from the zinc galvanized steel elements. The external skin is created from the 10 mm single toughened glass. Since the DSFs have the concept of low energy design along with arranging a passive sun heating and natural ventilation, the external single glass facade employs a naturally cross ventilation with the adjustable louvers during summer (URL 32). In a broader sense, the outer single glazing skin applied on the double facade of the building provides protection from wind and rain, acts as a buffer zone for reducing heat losses and noise, and offers possibilities for natural cross ventilation in the southern wing of the library Sedlák, J., & Mráček, P.,2005). Even so, a cross ventilation is operated by the open windows. The façade is mainly closed when the building is on air pre-heating (UrL 21). During this condition, the air from outdoor penetrates at the bottom/ground level of the façade, where the air inlets are placed (Sedlák and Mráček, 2005). Then from there, the air is taken to the ventilation system among the openings created at the top. In a broader sense, the upper part of the DSFs is closed by a glass sheet. However, ventilation gaps are located on the backside of the double skin façade that can be remotely opened for flow of the air through the façade to outside. When closed, the air from the facade can be sucked into the central ventilation and space heating system.

In response to the DSF essences, a 55 cm width air cavity is created between the building and the glass façade. This cavity also has metal grid of maintenance walkways at each floor. At the same time, these walkways purposes as shading devices against direct sun radiation in summer (Sedlák and Mráček, 2005). In reality, to shade the occupied zone, the façade consists of two types of shading elements apart from the maintenance walkways, (1) fixed sunshades and (2) horizontal load bearing sunshades (Table 39).

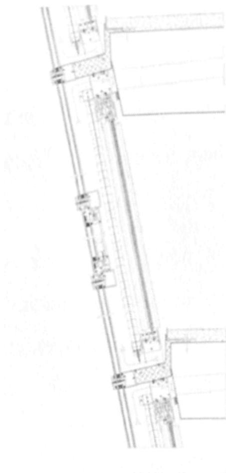
Table 39: Overall assessment of Moravian Library (Author, 2018).

Facade system	▪ Ventilation cavity ▪ Floor to ceiling, double skin façade elements
Energy	▪ Buffer space gap ▪ Operable double facade
Natural Ventilation	▪ Natural ventilation with the movable outer layer ▪ Air cavity between building facade and the glass facade, which circulates the fresh air
Operation Mode	▪ Automatically controlled outer layer for natural ventilation

4.2.12 Technical University of Delft Library

Table 40: Fundamental investigation of DSF system on Technical University of Delft Library (Author, 2018).

CASE STUDY - 12	TECHNICAL UNIVERSITY OF DELFT LIBRARY
LOCATION	DELFT / NETHERLANDS
DSF TYPE	MULTI STOREY FAÇADE
DSF ORIENTATION	NW-NE-SE
ARCHITECT	MECANOO ARCHITECTS
COMPLETION	1998
PROJECT DESCRIPTION	LIBRARY BUILDING



DOUBLE SKIN COMPONENTS

Frame and Glazing:

1. Exterior Glazing - 8/6 mm Low-e Double Glazing
2. Interior Glazing - Single Pane 8 mm Toughed Glass

Shading Elements:

1. Sun Shade - Automatically Controlled Aluminium Venetian Blinds

Ventilation Elements:

1. Mechanically Ventilated Cavity

The Technical University of Delft Library is one of the significant examples of endorsing a "climate wall configuration" at its façade design approach. The building includes at its three facades the idea of CW (climate wall). The wall is revealed with an air-handling unit to achieve thermal comfort while significant ventilation system is combined to control the internal air quality and humidity.

The outer glass of the skin is constructed with the use of low-E double glass units. Each unit is 8-15-6 mm. They are applied to the façade by setting back 8 mm from the inner skin by leaving a 14 cm gap (URL 21).

To indicate a consisting system for the operation between the returned inner air (which is flowing through the cavity of the facade) and ventilation system (which uses the inner returned air), another skin is pertained to the façade of the building. The heat is removed mechanically by passing the indoor airflow from the cavity to the ventilation system (URL 21).

The facade indicates much-enhanced ventilation throughout each season. On one hand, ventilation process removes the obtained energy, which is captivated by the blinds, during the sun radiation periods. On the other hand, the heat exchangers can recover the sun energy during the heating loads periods (URL 33). Besides the ventilation, operable aluminum venetian blinds that are inserted into the cavity provide significant shading to the occupied zone (Table 41).

Table 41: Overall assessment of Technical University of Delft Library (Author, 2018).

Facade system	▪ Ventilation cavity ▪ Floor to ceiling, double skin facade elements for natural ventilation
Energy	▪ Buffer space gap ▪ Low-E glazed heat insulated sliding windows
Natural Ventilation	▪ Natural ventilation with movable ventilation channels ▪ Climatic buffer corridor circulates fresh air
Operation Mode	▪ Moveable ventilation channels on facades for natural ventilation ▪ Automatically controlled aluminum venetian blinds for sun control

4.2.13 UCB Center

Table 42: Fundamental investigation of DSF system on UCB Center (Author, 2018).

<table>
<tr><th>CASE STUDY - 13</th><th colspan="2">UCB CENTER</th></tr>
<tr><td>LOCATION</td><td>BRUSSELS / BELGIUM</td><td rowspan="7"></td></tr>
<tr><td>DSF TYPE</td><td>MULTI- STOREY</td></tr>
<tr><td>DSF ORIENTATION</td><td>NE-SW</td></tr>
<tr><td>ARCHITECT</td><td>E. BUREAU VERHAEGEN</td></tr>
<tr><td>COMPLETION</td><td>2002</td></tr>
<tr><td>PROJECT DESCRIPTION</td><td>OFFICE BUILDING</td></tr>
<tr><td colspan="2" rowspan="2"></td></tr>
<tr><td>DOUBLE SKIN COMPONENTS

Frame and Glazing:
1. Exterior Glazing - Double Glazing
2. Interior Glazing - Clear Single Glazing

Shading Elements:
1. Sun Shade - Automatically Controlled Aluminium Blinds

Ventilation Elements:
1. Mechanically Ventilated Cavity</td></tr>
</table>

The design of UCB Center has an external double glazed (143 mm deep, a 1.3W/m2K-U-value) façade. The façade is involved with a mechanically ventilated cavity and a clear single glazing layer. The mechanical operation of the cavity for ventilation is accomplished with the use of motorized blinds located in the cavity. The motorized blinds are controlled amongst the sun irradiance. The blinds establish airflow with the speed of $40m^3/h$ per unit (URL 34). Since the heating of the indoor is achieved through the supplied air by installations, the double-glazing could be extended till the bottom parts of each floor level without requiring to insert fan coil units. In general, many buildings using dynamic fan coil units indicate acoustic performance. Since fan coil units are avoided in design, the acoustic insulation is achieved with the contribution of extra glazing on façade. In addition, the nonexistence of the fan coil units apparently provides an additional area for each floor.

Overall, installations (re) flow the ventilation air at indoors, apart from the occupied hours of the building. However, the sun radiance is considered on regulating the inlets' air temperature. The upper slabs of each floor level are installed with chilled ceilings-tube type in polypropylene. These ceilings are in integration with the thermal insulation and are operable by the water. They mainly cool the inner spaces by use of water tempered between 15 and 17°C. And it avoids the heat loss with dehumidification of ventilation air. In general, the chilled ceiling support to occupant comfort by decreasing the air movement within the space. Consequently, the building indicates a significant amount of energy saving by using chilled ceiling technology. The detailed data is given in below Table 43 (Caudron, 2000).

Table 43: Showing the energy saving on gas and electricity by the chilled ceiling technology (Adopted after Caudron, 2000).

	%	Per-year	Normal level for an air-conditioned office
Gas	30	BEF 88/m^2	BEF 100 and BEF 126/ m^2
Electricity	44	BEF 357/ m^2	BEF 580 and BEF 641/ m^2

It is imperative to note that, the successful amalgamation of chilled ceiling technology together with a ventilated façade verify valid returns to energy savings due to efficient sun and thermal performances (Kragh, 2001) (Table 44).

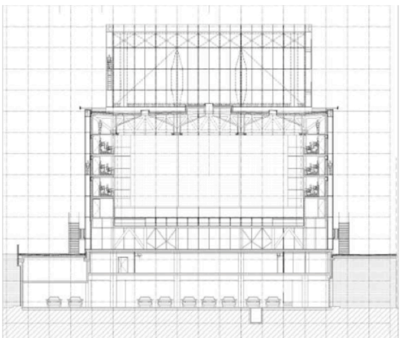
Table 44: Overall assessment of UCB Center (Author, 2018).

Façade system	▪ Ventilation cavity ▪ Floor to ceiling, double skin façade elements for natural ventilation
Energy	▪ Buffer space gap ▪ Low-E glazed heat insulated sliding windows
Natural Ventilation	▪ Natural ventilation with movable ventilation channels ▪ Climatic buffer corridor circulates fresh air
Operation Mode	▪ Moveable ventilation channels on facades for natural ventilation ▪ Automatically controlled aluminum venetian blinds for sun control

4.2.14 Aula Magna

Table 45: Fundamental investigation of DSF system on Aula Magna (Author, 2018).

CASE STUDY - 14	**AULA MAGNA**
LOCATION	LUVAIN / BELGIUM
DSF TYPE	MULTI STOREY FAÇADE
DSF ORIENTATION	N-S-E-W
ARCHITECT	SAMYN & PARTNERS
COMPLETION	1997
PROJECT DESCRIPTION	PERFORMING ART CENTER



DOUBLE SKIN COMPONENTS

Frame and Glazing:

1. Exterior Glazing - Double Glazing
2. Interior Glazing - Double Glazing

Shading Elements:

1. Sun Shade - Moveable Transparent Shading

Ventilation Elements:

- Lower Operable Ventilation Inlets
- Upper Operable Ventilation Outlets

The Aula Magna building is one of the representations of natural ventilation conceptions in the notion of energy saving the responsive design. The glazing DSF is involved with the natural ventilation pattern, where a stack effect is supplied to the building without any fan assistance or heat exchanger. There are motorized windows placed at the top and bottom of the façade (URL 21). These windows automatically activate themselves when the temperature in the cavity (70 mm) of double skin exceeds the essential value (Poirazis, 2006). The cavity is installed by sun controls. The venetian blinds are lowered and placed close to the internal glazing layer (Poirazis, 2006). However, the building mostly saves its energy by natural ventilation, a mechanical ventilation system is also applied in the case of heating and cooling the building, when the weather is not appropriate for natural accomplishment (Table 46).

Table 46: Overall assessment of Aula Magna (Author, 2018).

Façade system	▪ Ventilation cavity
Energy	▪ Naturally ventilated buffer space gap
Natural Ventilation	▪ Natural ventilation with motorized windows ▪ Climatic buffer corridor circulates fresh air in the cavity
Operation Mode	▪ Motorized windows at top and the bottom of the façade

4.2.15 Jinao Tower

Table 47: Fundamental investigation of DSF system on Jinao Tower (Author, 2018)

CASE STUDY - 15	JINAO TOWER	
LOCATION	NANJING / CHINA	
DSF TYPE	MULTI STOREY FAÇADE	
DSF ORIENTATION	N-S-E-W	
ARCHITECT	SKIDMORE, OWINGS & MERRILL	
COMPLETION	2013	
PROJECT DESCRIPTION	OFFICE + HOTEL BUILDING	
		**DOUBLE SKIN COMPONENTS** **Frame and Glazing:** 1. Exterior Glazing - Monolithic Lightly Tinted Glass 2. Interior Glazing - Insulated Low-e Double Glazing **Shading Elements:** 1. Sun Shade - Extruded Aluminum Frames **Ventilation Elements:** 1. Aluminum Openings Allow Air Intake And Exhaust

The Jinao Tower building is designed by a reinforced exterior tubular frame and an interior shear wall core. The double skin exterior enclosure begins above the granite-clad tower base, and repeats in 16 m high triangular faced inward and outward sloping sections to the top of the tower. The inner building enclosure is the weather resistant skin separating the building occupants from exterior elements. At occupied spaces (hotel and office floors), it consists of floor to ceiling insulated low-E glass. Glass is held in thermally broken extruded aluminum prefabricated unitized frames.

The exterior aluminum and glass screen triangular sections are defined by extruded aluminum prefabricated unitized frames with monolithic and lightly tinted glass span floor to floor and are connected to preset anchor connected to the steel outriggers. Horizontal aluminum openings (200mm net clear opening) occur at every 16m height. The openings allow air intake and exhaust (Mathias et. al., 2016). The glass screen wall and exterior aluminum accomplish sun shading into the building. In addition, they indicate the air cavity of the façade. The air cavity installs an enhanced insulation for cold winter and hot summer periods.

In order to remove the heated air in the cavity during the hot summer periods; the vented openings in the exterior aluminum and glass screen allocate the wind pressure by lowering the temperatures at the inner wall (Mathias et. al., 2016). In the cool winter periods, built up heat cavity, although partially extracted through the vented openings, increase temperatures along the inner wall. Both in cold winter and hot summer periods, the buffered air temperatures at the inner wall effectively reduce the demands on the base building mechanical systems by up to 20% (Table 48) (Mathias et al., 2016).

Table 48: Overall assessment of Jinao Tower (Author, 2018).

Façade system	▪ Ventilation cavity ▪ Floor to ceiling, double skin façade elements for natural ventilation
Energy	▪ Buffer space gap ▪ Insulated low-E glazed heat insulated sliding windows
Natural Ventilation	▪ Natural ventilation through horizontal formed aluminum panels ▪ Climatic buffer corridor circulates fresh air
Operation Mode	▪ Automatically controlled vents

4.2.16 Sendai Mediatheque

Table 49: Fundamental investigation of DSF system on Sendai Mediatheque (Author, 2018)

CASE STUDY - 16	**SENDAI MEDIATHEQUE**	
LOCATION	SENDAI / JAPAN	
DSF TYPE	MULTI STOREY FAÇADE	
DSF ORIENTATION	S	
ARCHITECT	TOYO ITO & ASSOCIATES, ARCHITECTS	
COMPLETION	2000	
PROJECT DESCRIPTION	LIBRARY AND ART ACTIVITY CENTER	
		**DOUBLE SKIN COMPONENTS** **Frame and Glazing:** 1. Exterior Glazing - Double Paned Glazing 2. Interior Glazing - Single Toughened Glass **Shading Elements:** 1. Sun Shade - None **Ventilation Elements:** 1. Operable Windows

The skin of the exterior elevation of Sendai Mediatheque building is formed by a shaded glass or double paned (URL 35). In fact, the south façade is formed by double paned shaded glass, where the other facades are designed opaque and transparent glass and solid metal panels. Indeed, the south façade is completely wall free, transparent glass. The skin of the north façade is a stainless steel panel. The east and west facades are paneled with glass, opaque glass, and steel.

Since the south façade is the main façade that indicates energy saving, by reducing the heat gain through its cavity, mullions and louvers. In fact, the walls act a mechanical barrier to limit the heat gain and to ventilate the indoor while they are open. Especially during the summer period, façade is entirely open and the air is freely flowing from exterior to in. Into this, the floor and offices are naturally being ventilated with opened windows (Figure 24). However, the façade is closed during the winter periods to insulate the air space.

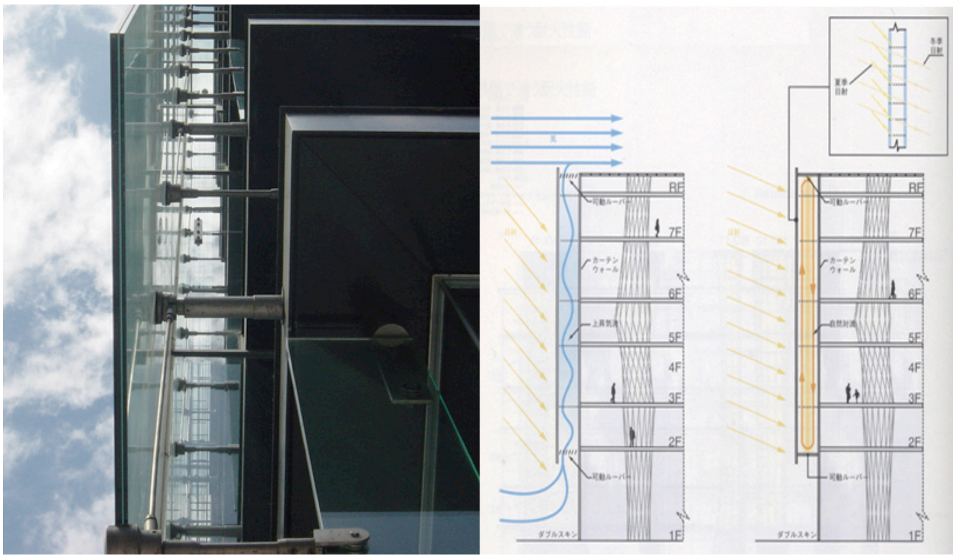


Figure 24: Section Diagram of Natural Ventilation System Down Out Open Windows (URL 36).

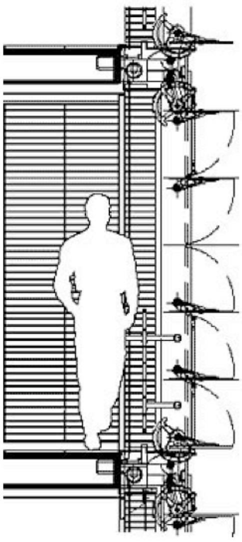
The transparency of the glass affords to obtain of the daylight. Besides, reticular tubes are also installed on the top. The reticular tubes are composed of motorized rotating mirrors. With the impact of rotation, the mirrors reflect the sunlight down, towards the tubes. These tubes convert the reflected sunlight into the light pillars. Apparently, the reticular tubes serve two functions by carrying the mechanical ducts through the building and by drawing the natural air from top to bottom like a wind catcher (URL 37). In addition, the roof is covered by photovoltaic panels to absorb the sun and utilize energy saving (Table 50).

Table 50: Overall assessment of Sendai Mediatheque (Author, 2018).

Façade system	▪ Glass surface with full floor height ▪ Full story height double skin façade elements ▪ Double paned openable glass façade for natural ventilation
Energy	▪ Buffer space gap ▪ Double paned heat insulated glass units ▪ Photovoltaic panels ▪ Roof-top devices to distribute sunlight
Natural Ventilation	• Openings the vents in summer creates a cooling updraft • Climatic buffer corridor circulates fresh air
Operation Modes	▪ Changeable prism glass at the top of the tubes ▪ Operable duct covers ▪ Sliding windows towards buffer space for natural ventilation

4.2.17 Aurora Place

Table 51: Fundamental investigation of DSF system on Aurora Place (Author, 2018).

CASE STUDY - 17	AURORA PLACE	
LOCATION	SYDNEY / AUSTRALIA	
DSF TYPE	CORRIDOR FAÇADE	
DSF ORIENTATION	N-S	
ARCHITECT	RENZO PIANO	
COMPLETION	2000	
PROJECT DESCRIPTION	OFFICE TOWER & RESIDENCES	
		**DOUBLE SKIN COMPONENTS** **Frame and Glazing:** 1. Exterior Glazing - 12 mm Toughened Extra White Glass 2. Interior Glazing - 6 mm Low E Coated Float Glass **Shading Elements:** 1. Sun Shade - Glass & Metal Louvers **Ventilation Elements:** • Operable External Skin • Bottom Hung Windows

The Aurora Place high-rise building has designed by a curved form glazing skin, which is 44 story high (URL 21). The DSF is accomplished in building design, primarily together with glass louvers. The external skin of the double skin façade is assembled with laminated 12 mm tough extra-white glass. A 6 mm thick sheet with a continuous white-fritted dot pattern on the edge and also 6 mm low-E coated float glass is implicated to the glass (URL 21). That means, the opaque areas of the building façade are, in fact, dressed with laminated extra-white glass even though white powder-coated metal sheets are used at the back of the glass. Since extra white glass compromises the facades, the textiles blinds are used to provide the glare and sun control. For better exposition of sun, horizontal metal sunscreens are also implemented to the façades besides the textile blinds (Compagno, 2002). To ventilate the building, inner skin is revealed with fixed glazing units, bottom hung windows and doors (Table 52).

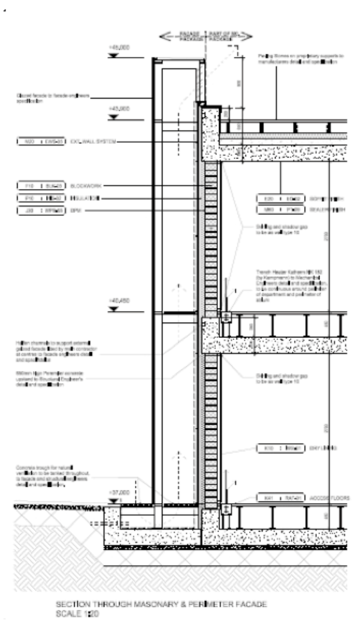
Table 52: Overall assessment of Aurora Place (Author, 2018).

Façade System	▪ Ventilation cavity ▪ Story high, double skin façade elements for natural ventilation
Energy	▪ Buffer space gap ▪ Low-E float glass
Natural Ventilation	▪ Bottom-hung windows ▪ Climatic buffer corridor
Operation Mode	▪ Operable external glass layer ▪ Operable inner windows to prevent fresh air

4.2.18 Wexford County Council Headquarter

Table 53: Fundamental investigation of DSF system on Wexford Country Council Headquarter (Author, 2018).

CASE STUDY - 18	WEXFORD COUNTY COUNCIL HEADQUARTER	
LOCATION	WEXFORD / IRELAND	
DSF TYPE	MULTI-STOREY FAÇADE	
DSF ORIENTATION	N-S-E-W	
ARCHITECT	ROBIN LEE ARCHITECTURE	
COMPLETION	2008	
PROJECT DESCRIPTION	GOVERNMENTAL	



DOUBLE SKIN COMPONENTS

Frame and Glazing:

1. Exterior Glazing - Low Iron Glass
2. Interior Glazing - Double Glazing

Shading Elements:

1. Sun Shade - Semi-reflective Performance Glass Panels

Ventilation Elements:

1. Horizontally Operable Inner Layer
2. Lower and Upper Vents

The Wexford County Council Headquarter is designed through the approach of creating a single cubic glass enclosure for six independent buildings, which is varied with a series of public spaces and administrations. This imposed to consider a varied environmental and comfort control designations in the preparation. As a consequence of the façade design that is concealed in the building, the uniformity of the glass façade is structured through the applied low iron glass on the anodized aluminum mullions. Such a formation impels the façade to act as a sheer envelope for architectural identity, scale and civic status of the building. With its façade design approach the building compromise for inner spaces to be formed in varied qualities such as spatial, formal, functional, environmental control, etc.

The doubled skin cubic glass enclosures optimized high degree energy efficiency. The external skin of the façade is composed of glass wraps. In principle, the DSF provides to manage the indoor temperature by controlling the air. In other words, the façade is signified by tempering the incoming air to the building. By this way, the building is being cooled during the hot summers and insulated during the cold winter days. Commonly, the cavity of the double skin delineates a buffer zone, which is wrapping the thermal degree. Meanwhile, the glass panels of the external layer strains the undesired sun energy. The double glazed windows at the inner layer maximize the air penetration through inner and external area. For instance, the central area of the building needs minimum heat during the winter period. This is only to protect the fabric and prevent heat reduction (Table 54) (URL 38).

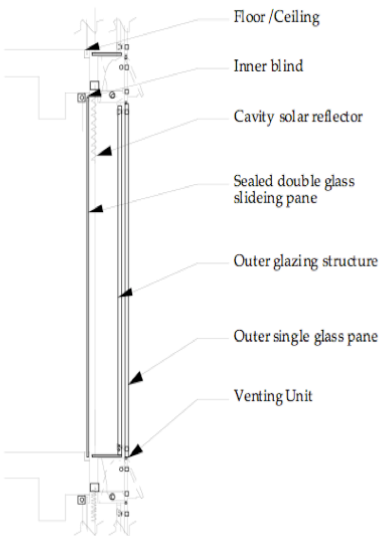
Table 54: Overall assessment of Wexford Country Council Headquarter (Author, 2018).

Façade System	▪ Single layer façade on southeast and southwest ▪ Story high, double skin façade elements for natural ventilation
Energy	▪ Buffer space moderates the cross ventilation ▪ Semi- reflective performance glass panels
Natural Ventilation	▪ Operable windows ▪ Climatic buffer corridor
Operation Mode	▪ Operable inner window slider to gain fresh air

4.2.19 Print Media Academy

Table 55: Fundamental investigation of DSF system on Print Media Academy (Author, 2018).

CASE STUDY - 19	PRINT MEDIA ACADEMY	
LOCATION	HEIDELBURG / GERMANY	
DSF TYPE	BOX WINDOW FAÇADE	
DSF ORIENTATION	NE-NW	
ARCHITECT	SCHRODER ARCHITECKTEN AND STUDIO ARCHITEKTEN BECHTLOFF	
COMPLETION	2000	
PROJECT DESCRIPTION	OFFICE & CONFERENCE CENTER	



DOUBLE SKIN COMPONENTS

Frame and Glazing:

1. Exterior Glazing - Single Glass Pane
2. Interior Glazing - Sealed Double Glazing

Shading Elements:

1. Sun Shade - Metallic Adjustable Blind

Ventilation Elements:

1. Operable Upswing Glass Louvers

The Print Media Academy building in Heidelberg, Germany utilizes two types of glass façade systems. Both systems are managed through a central building control that monitors the building's interior, exterior, weather conditions, as well as user variables. The first façade system type relates to the atrium, the second to the office and lecture and laboratory spaces.

The atrium offers a large common space, extending to the roof, connecting the building with elevators and escalators that, extends up to the roof. Contained within the atrium is two large cylinders that contain conference spaces. The office and lecture rooms are accessed from the atrium space at each floor by a catwalk. These rooms have floor to ceiling glazing on both the exterior facade as well as at the atrium side, and are divided by wall partitions from each other (Mahmod, 2011).

The office component of the building facade utilizes a more complex system of cross-ventilated double skin glazed unit. A double glass pane of the inertial skin and a single glazed pane of the external skin form the box unit. The cavity with 46 cm width between these two panes is formed with tinny adaptable blinds. This design with a few other components offers the user several options that is complimented with a central building control that manages the general building environment (Boake et. al., 2001).

The sun heat gain is managed in two methods. The first system is the cross-ventilation control. It restrains the air cavity between the inner and outer glazing. There are sets of upswing glass louvers that are opened to transmit the heat flow from outside to the cavity, and from the cavity to outside. Through such a process the building skin/envelope is cooled.

The aluminum blind system is the second system that indicates a control on sun heat gain. These blinds are inserted into the cavity and they can be rolled down through a specific angle depending on the angle of sun direction. The sun heat is reflected by aluminum blinds that are positioned in the box unit. As a result, the buffer zone is heated. Afterward, the installed louver ventilating system impels on minimizing heat loss or gain from the cavity. Localized user control of the box unit, manage only qualities of natural ventilation and lighting.

The existence of operable window sliders on the inner skin provides fresh air. The sliders had drawn the fresh air from cavity and offices to a better swapping. In addition to the sliders' activation on fresh air optimization. The central system acts on controlling the speed of the airflow into the cavity. Here, the operable exterior glass louvers interact alongside the central system by harmonizing the building temperature and pressure. This also avoids undermining of the environmental comfort due to varied weather conditions. The slider also provides for maintenance access to the inner portion of the skin.

The occupant using of a roll down screen manages natural lighting. This screen is located on the occupant side of the inner window. The blinds are not maintained by the central system (Table 56) (Boake et. al., 2001).

Table 56: Overall assessment of Print Media Academy (Author, 2018).

Façade System	▪ Single layer façade on southeast and southwest ▪ Storey high, double skin façade elements for natural ventilation
Energy	▪ Buffer space moderates the cross ventilation ▪ Low-E float glass
Natural Ventilation	▪ Operable windows ▪ Climatic buffer corridor
Operation Mode	▪ Mechanical aluminum blind system ▪ Operable inner window slider to gain fresh air

4.2.20 Kista Science Tower

Table 57: Fundamental investigation of DSF system on Kista Science Tower (Author, 2018).

CASE STUDY - 20	KISTA SCIENCE TOWER	
LOCATION	STOCKHOLM / SWEEDEN	
DSF TYPE	CORRIDOR FAÇADE	
DSF ORIENTATION	N	
ARCHITECT	WHITE ARKITEKTER	
COMPLETION	2003	
PROJECT DESCRIPTION	OFFICE & CONFERENCE CENTER	
		DOUBLE SKIN COMPONENTS **Frame and Glazing:** 1. Exterior Glazing - Non-colored Single Pane 2. Interior Glazing - Double-pane Sealed Glazing with Low-e glass **Shading Elements:** 1. Sun Shade - Perforated Venetian Blinds **Ventilation Elements:** 1. Upper Venting Unit 2. Lower Venting Unit

The Kista Science Tower is composed of double skin facades and a single skin façade. Two facades of the building are double skin, while one of them is single skin. The DSF is a corridor type that establishes diagonal ventilation for the building (URL 21). As noticed in other examples, maintenance walkways for each floor are located into the cavity. Moreover, the cavity is also perforated among venetian blinds to sun and heat control. Especially, to control the heat loss, the venetian blinds are inserted on the north façade. Non-colored and non-openable window system is applied to the external skin of the double facades. While, the inner skin is created with non-colored double-pane sealed glazing units with Low-E glass. Uniquely, the building obtains heat control with active cooling beams and optimized ventilation with heat recovery. For instance, the inner temperature in winter is 22 °C, while the outdoor is ±1.5 °C; and the inner temperature in summer is 24 °C, while the outdoor is +26 °C (Table 58).

Table 58: Overall assessment of Kista Science Tower (Author, 2018).

Façade System	▪ Story high, double skin façade elements for natural ventilation
Energy	▪ Non-colored double-pane sealed glazing ▪ Low E glass ▪ Venetian blinds
Natural Ventilation	▪ Climatic corridor
Operation Mode	▪ Active cooling beams ▪ Operable inner window slider to gain fresh air

4.2 Summary of Cases

In this section, data obtained as a result of analyzing façade systems of 20 sample buildings from different locations with temperate climatical conditions in order to determine the specific construction descriptions of each selected case, and to find out the variation of applied DSF elements together that are presented in Table 59.

Inquiry parameters that are used to create the functional evaluation table regarding different DSF elements are thermal comfort, natural ventilation, natural lighting, sun control, and sound control. As it is seen from the examination including the correlation of the specimen structures that have four types of double skin façade construction, the structures contribute to energy efficiency and ideal cooling capacities. Then again, commotion control and proficient use of sunlight are favored capacities relying upon the proposed reason and an area of the structures. Together with this, it is seen that natural ventilation is utilized by ventilation type of façade cavity and in this way indoor space for a wide range of façades. If there should arise an occurrence of deficient natural ventilation, mechanical ventilation is furthermore initiated.

For the extensive part of the selected cases, airflow in DSF system is obtained through the principle of consisting of outdoor air supply, exhaust, curtain, and buffer zone. Concerning glass types utilized for internal and external skin assemblies, low-E and toughened planar glass is generally favored for inner layer clear glass (low-ferrous flat glass) and laminated glass with high sun radiation transmittance for the outer layer.

Deliberating the distinctive types of the double skin façades of the selected structures dissected, it is seen that most of windows in the internal layer are planned as opening while those in the external layer are as fixed windows. Next, the evaluation proposes that the windows in the internal layer of the structures with double skin façade are likewise planned as fixed windows so as to provide a buffer space.

On the other hand, considering the dimensions and geometry of the air cavity, it is seen that they are planned as a wide air cavity (20-200 cm) for all the 4 types of the DSF types. Airflow in the cavity is vertically oriented in all of the selected cases. Only for the cases with box-window double skin façade, cross airflow exists additionally to avert blending of unclean air with clean air. Favored as shading components for the vast majority of the example structures, louvers are positioned rather into façade cavity. For many of the selected structures; service and maintenance occasions are provided depending on the strategy of the façade system.

Table 59: Summarized data of examined case studies (Author, 2018)

CASE STUDY NO.	EXTERNAL LAYER	INTERNAL LAYER	SHADING ELEMENT	VENTILATION ELEMENT	DSF TYPE
1	Blue-Green Tinted Insulating Glass	Single Glazing	Metal Louvers	1. Lower Operable Ventilation 2. Ventilation Service Grills 3. Upper Operable Ventilation	MS
2	Insulating Glass	Double Glazing	1. Aluminum Louvers 2. Glass Visors	1. Lower Operable Damper 2. Upper Operable Glass Louvers	MS
3	Translucent Glass Louvers	Double Glazing	Translucent Motorized External Glass Louvers	1.Vertical Chimneys 2. Low-Resistance Propeller Fans Located On Top	SB
4	Toughened Single Glazing	Triple Glazed Sun Tinted Glass	Perforated Metal Louvers	1.Lower Operable Vents 2.Upper Operable Vents	MS
5	Laminated Glass	Tinted Double Glazed Glass	Perforated Aluminum Louvers	1. Openable Glass Screen 2. Ventilation Chimneys 3. Venting Flaps	SB
6	Toughened Planar Glazing	Double Glazing	Aluminium Louvers	1. Operable Openings 2. Floor To Ceiling Captious Openings	MS
7	Toughened Planar Glazing	Low-e Double Glazing	Aluminum Venetian Blinds	Automatically Controlled Damper	C
8	Uncoated Clear Glass	Thermal Insulated Glass	Aluminium Louvers	Control Flaps	C
9	Laminated Glass	Double Glazing	Perforated Aluminum Louvers	1. Opening Fins 2. Inner Walls Contains Operable Windows 3. Exhaust Air Window on Top	MS
10	8mm Low-e Coating	6mm Low-e Coating	Aluminium Venetian Blinds	1.Mechanically Ventilated Cavity 2. Operable External Layer	MS
11	10mm Single Toughened Glass	Double Glazing	Glass Louvers	1. Lower Operable Ventilation 2. Ventilation Service Grills 3. Upper Operable Ventilation	MS
12	8/15/6 mm Low-e Double Glazing	8mm Low-e Heat Insulated Coating	Aluminium Venetian Blinds	Mechanically Ventilated Cavity	MS
13	Insulated Double Glazing	Clear Single Pane Glazing	Motorized Aluminum Louvers	Mechanically Ventilated Cavity	MS
14	Insulated Double Glazing	Insulated Low-e Double Glazing	Glass Louvers Aluminium Venetian Blinds	1. Lower Operable Ventilation Inlets 2. Upper Operable Ventilation Outlets	MS
15	Monolithic Lightly Tinted Glass	Insulated Low-E Double Glazing	Extruded Aluminum Frames	Aluminum Openings	MS
16	Double Paned Glazing	Single Toughened Glass	None	Operable Windows	MS
17	12 mm Toughened Extra White Glass	6 mm Low E Coated Float Glass	Glass Louvers Metal Louvers	1. Operable External Skin 2. Bottom Hung Windows	C
18	Low Iron Glass	Double Glazing	Semi-reflective Performance Glass Panels	1. Horizontally Operable Inner Layer 2. Lower and Upper Vents	MS
19	Single Glass Pane	Sealed Double Glazing	Metallic Adjustable Blinds	Operable Upswing Glass Louvers	BW
20	8mm Clear Double Glazing Glass	10mm Fixed Clear Glass	Aluminium Louver Blinds	1.Upper Venting Unit 2.Lower Venting Unit	BW

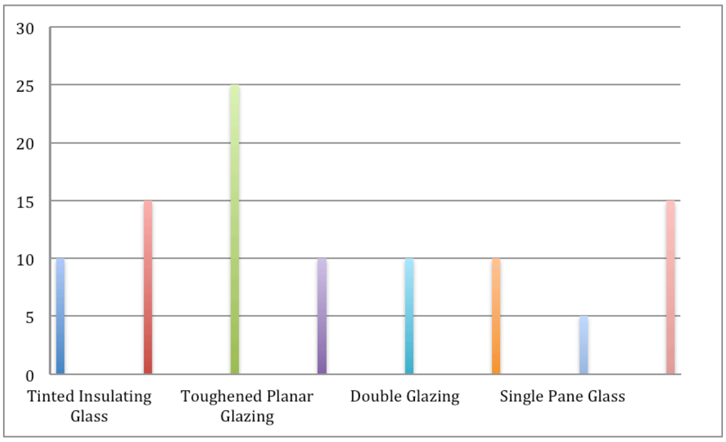


Figure 25: Overall Glass Type Ratio for External Layer of the Selected Cases

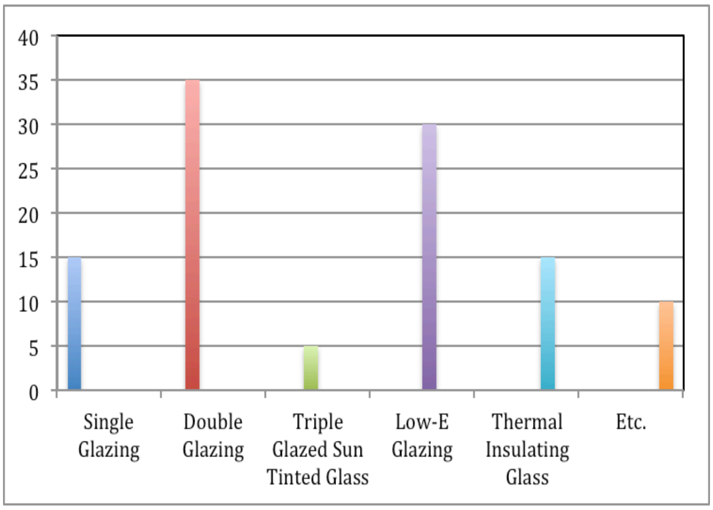


Figure 26: Overall Glass Type Ratio for Internal Layer of the Selected Cases

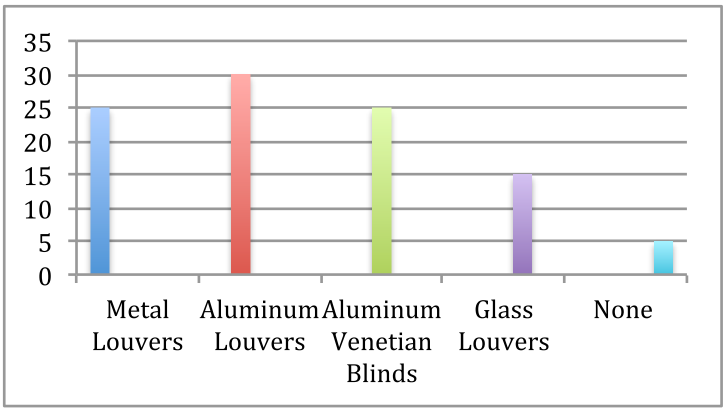


Figure 27: Applied Sun Control Material Ratio for Selected Cases.

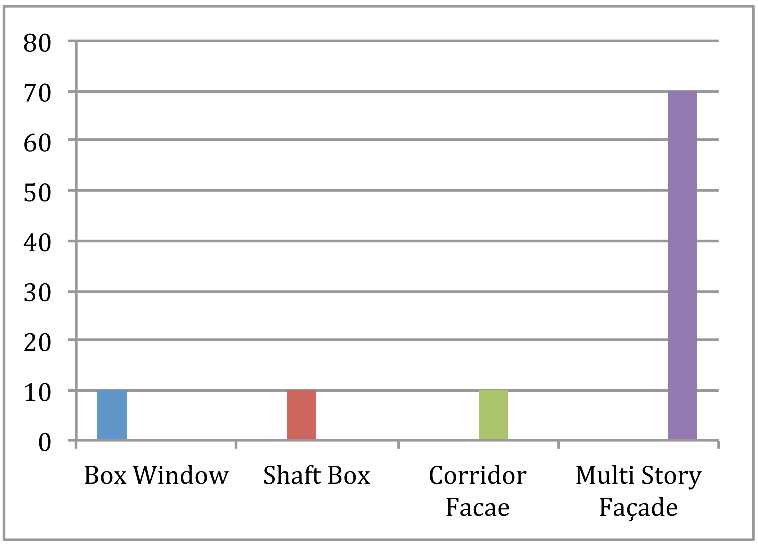


Figure 28: Ratio of DSF Type for Selected Cases.

4.3 Initial Design Stage Evaluation System for Adaptive DSF Systems

There are numerous effectual principles on building facades, therefore, considering all principles may result in inverse interactions for their functionalities. According to this, keeping a certain number of limited principles and their functional optimization may be more appropriate for designing and investigating this research topic.

Interactions between DSF systems and variabilities needs to be investigated for exploring the adaptation principles of DSF systems due to dynamic environmental factors and diverse user requirements for desired comfort levels. Table 60 demonstrates the interactions between DSF system principles and variables.

Table 60: Interaction between DSF principles and variables (✓: positive or negative interaction, ×: no interaction) (Author, 2018)

PRINCIPLES	VARIABLES	Transparency Rate	Transparent Component Type	Opaque Component Type	Sun Control Units	Natural Ventilation
Thermal Comfort		✓	✓	✓	✓	✓
Energy Conservation		✓	✓	✓	✓	×✓
Natural Ventilation		×	×	×	×	✓
Natural Lighting		✓	✓	×	✓	×
Sound Control		×	×	×	✓	×✓

In order to provide comfort zones for occupants, essential comfort aspects (heat, lighting, acoustic, ventilation, etc.) can be utilized from the minimum and maximum limits for specific principles. Hence, occupant comfort level is not possible to obtain, if the indicated comfort requirement limits exceeded.

External environment conditions vary between the seasons and at different times of the day. However, internal comfort conditions must be affected in the least possible level from these vicissitudes. Therefore, façade system between external and internal environment is needed for accommodating against non-static states. These evaluation criteria must provide essential comfort zones accordingly, even more, DSF component alternatives that exceed the comfort limit values can be brought to an acceptable level by making modifications. The possibility of being able to apply changes based on statements on the DSF component alternative increases the effectiveness and operative rate. The flow-chart aims to obtain the assessment of possible variability of DSF systems in the face of dynamic external conditions, for ensuring the comfort level of the internal environment shown in Figure 29.

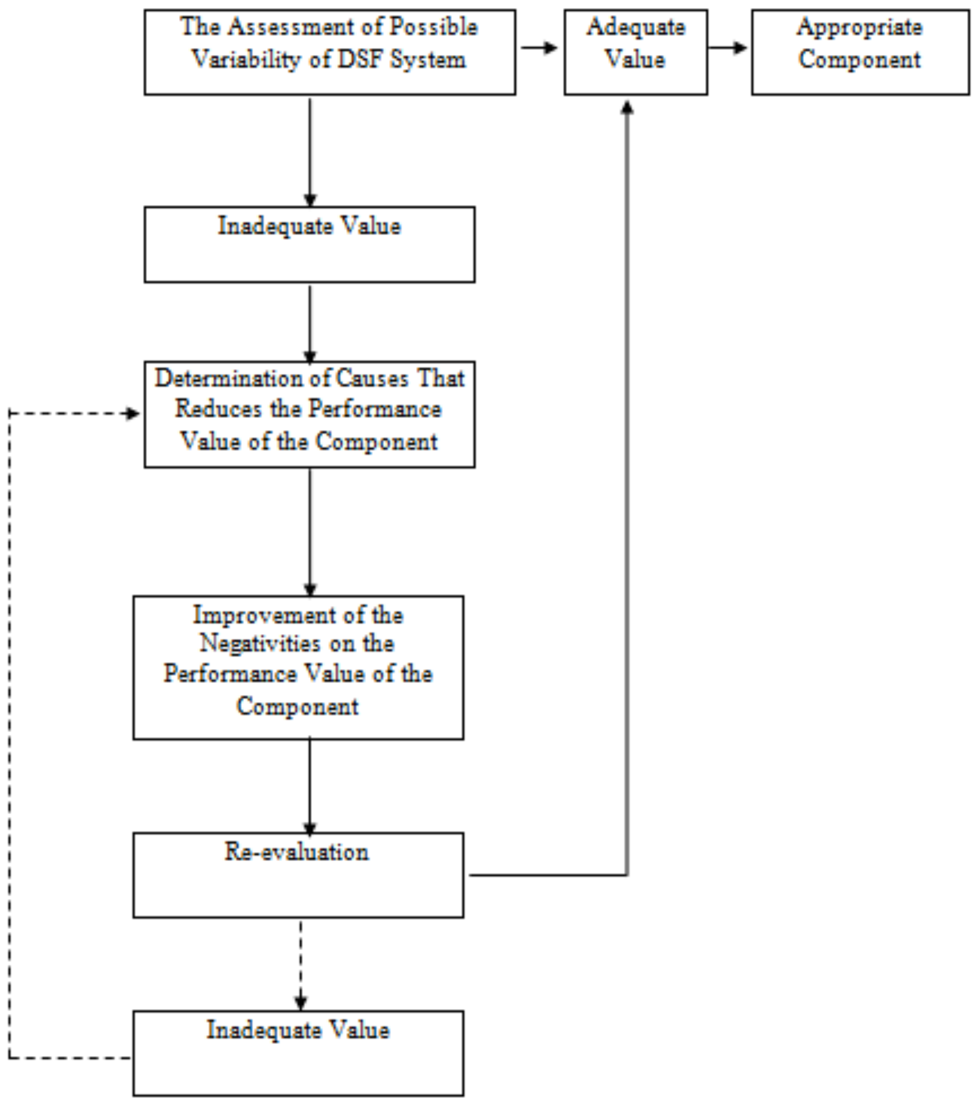


Figure 29: The Assessment of Possible Variability of the DSF System, in the Face of Dynamic External Conditions, for Ensuring the Comfort Level of the Internal Environment (Author, 2018).

According to the case study analysis and literature survey two main components are significant for the establishment of double skin façade systems. These components are glass types and shading devices positioned in to the cavity. To assemble Initial Design Stage Evaluation System for Adaptive DSF Systems the following sections covers the definitions belonging to the performance data of glass and performance data shadings and louvers.

4.3.1 Performance Data of Glass Types

4.3.1.1 Visible Light

Light Transmittance (LT): LT is the percentage/quantity of the visible light close to the normal occurrence, which is conveyed/transmitted throughout the glass (UrL 30).

Light Reflectance (LR): LR is the percentage/quantity of the visible light close to the normal occurrence, which is reflected in the glass (URL 30).

4.3.1.2 Solar Energy

The sun radiant heat admission features of the glasses could be compared through their shading coefficient features.

Total Shading Coefficient (TSC): TSC is the resultant through the comparison of features of any glass with the clear float glass containing an entire energy transmittance of 0.87. It contains a long wavelength and a short wavelength shading coefficient.

Thermal Insulation: Thermal insulation is the U-value (U) or thermal transmittance quantifying the heat loss. According to Système Internationale d'Unités (S.I. units), the U-value is expressed in W/m2K. U-value is the representation of heat fluctuation/flux density through a structure, which is alienated by the diversity/instability in environmental temperatures on any surface of the structure in steady-state conditions (URL 30). In a broader sense, the U-value is utilized to express the speed of heat loss per square meter in the steady-state conditions. It is for a temperature distinction either in C^o, or K^o, between the outer environment and inner environment, which is separated throughout a glass surface or something else.

The determined performance data in the following tables are adjusted by regarding the European Standards (EN). For instance, 90% argon filling is revolved around the data for insulating the glass units. In construction, the 16 mm argon is to fill the cavity. For only triple glazing the cavities are designed as 12 mm (URL 30). According to the EN 673, the U-values must be rounded close to 0.1. And again, the technical data of sun and light energy is defined based on the EN 410. If not, the defined calculations are developed through 4 mm glass (URL 30).

The glass performance values that are used in the thesis are revealed based on companies, which are the worldwide largest glass manufacturing companies (Saint-Gobin Glass/ U.K, PPG Industries and Nippon Sheet Glass Co. Ltd.) in 2017. In the following figures, explain the performance values of their products (Figure 30, 31, 32).

COMPANY NAME	GLASS TYPE	Visible Light Transmission 50%-70%	U-Value Winter 0.9-0.1	U-Value Summer 0.9-0.1	Solar Heat Gain Coefficient (SHGC) 0.9-0.1	Shading Coefficient (SC) 0.9-0.1	Outdoor Visible Light Reflectance	Sound Transmission OITC RATING
Nippon Sheet Glass Co. Ltd.	Tinted Solar Control Glass	64%	0.58	0.56	0.60	0.69	24%	43
	Tinted Solar Control Insulating Glass	48%	0.26	0.25	0.40	0.46	13%	40
	Coated Solar Control Glass With Low-Emissivity Glass	67%	0.38	0.35	0.64	0.74	27%	39
	Coated Solar Control Insulating Glass With Low-Emissivity Glass	60%	0.16	0.13	0.55	0.63	19%	38
	Solar Control Glass With Thermal Insulation	70%	0.11	0.1	0.42	0.49	17%	41
	Solar Control Glass With Triple Thermal Insulation	49%	0.1	0.1	0.26	0.31	7%	34
	Coated Low-Emissivity Glass	83%	0.37	0.34	0.75	0.87	48%	42
	Coated Low-Emissivity Insulating Glass	69%	0.13	0.11	0.64	0.74	26%	40
	Coated Low-Emissivity Triple Insulating Glass	63%	0.1	0.1	0.58	0.67	21%	37

Figure 30: Glass Performance Values of Nippon Sheet Glass Co. Ltd. (Author, 2018).

COMPANY NAME	GLASS TYPE	Visible Light Transmission 50%-70%	U-Value Winter 0.9-0.1	U-Value Summer 0.9-0.1	Solar Heat Gain Coefficient (SHGC) 0.9-0.1	Shading Coefficient (SC) 0.9-0.1	Outdoor Visible Light Reflectance	Sound Transmission OITC RATING
PPG Industries, Inc.	**Uncoated Tinted Insulating Glass**	69%	0.47	0.50	0.50	0.57	13%	41
	Low-E Tinted Insulating Glass	66%	0.32	0.31	0.44	0.50	11%	41
	Solar Control Low-E Tinted Insulating Glass 60	61%	0.29	0.27	0.32	0.37	9%	40
	Solar Control Low-E Tinted Insulating Glass 67	47%	0.29	0.27	0.25	0.29	16%	39
	Solar Control Low-E Clear Insulating Glass 70XL	58%	0.28	0.26	0.27	0.31	10%	38
	Low-E Tinted Reflective Insulating Glass	36%	0.29	0.27	0.21	0.24	25%	38
	Reflective Tinted Insulating Glass	27%	0.47	0.50	0.31	0.36	24%	40
	Reflective Tinted Solar Control Low-E Insulating Glass	24%	0.29	0.27	0.19	0.22	24%	37
	Reflective Solar Control Low-E Insulating Glass	22%	0.28	0.26	0.17	0.20	24%	37

Figure 31: Glass Performance Values of PPG Industries, Inc. (Author, 2018).

COMPANY NAME	GLASS TYPE	Visible Light Transmission 50%-70%	U-Value Winter 0.9-0.1	U-Value Summer 0.9-0.1	Solar Heat Gain Coefficient (SHGC) 0.9-0.1	Shading Coefficient (SC) 0.9-0.1	Outdoor Visible Light Reflectance	Sound Transmission OITC RATING
Saint-Gobain Glass UK.	Coated single glazing	67%	0.57	0.55	0.70	0.80	40%	43
	Coated double glazing (85% argon)	60%	0.12	0.11	0.57	0.65	24%	37
	Solar control low-e insulating glass (90% argon)	68%	0.14	0.11	0.39	0.45	11%	34
	Solar Control Glass With Triple Thermal Insulation	61%	0.10	0.10	0.28	0.32	14%	31
	Low-E glass with thermal insulating glass	79%	0.24	0.20	0.63	0.72	12%	36
	Coated low-e glass	73%	0.26	0.25	0.70	0.80	12%	37
	Clear laminated glazing	84%	0.22	0.20	0.61	0.70	12%	50
	Tinted single laminated glazing	65%	0.22	0.20	0.28	0.33	11%	47

Figure 32: Glass Performance Values of Saint-Gobin Glass (Author, 2018).

4.3.2 Performance Data of Sunshades and Louvers

In today's performance focused building environment, louvers and sunshades means more than decorations for designers. When accurately determined and carefully selected, they can make an extensive involvement in a building's general energy performance.

Building's site location and positioning are the decisive factors for sunshade utilization and eventually, for evaluating what benefits are conceivable. In moderate to hot climates where cooling is a factor, deliberately positioned sunshades can be the first line of barrier against the sun light infiltration for throughout the daytime, generating opportunities for a diversity of competences.

In fact, there are not many studies developed for DSF with sun-shades, yet, there are few studies that captures the sunshadings in DSF systems (Manz, 2004; Safer et al., 2005; Bladinelli, 2009; Zeng et. Al., 2012). Manz (2004) puts a significant attempt to DSF systems residing a metallic shading screen, while Safer et al. (2005) seeks for simplification of flow around the venetian blind louvers by use of porous media approach. Bladinelli (2009) addresses a utilization of integrated moveable shading elements thinking for DSFs following the Safer's porous media approach for venetian louvers. Zeng et al. (2012) developed a research on reducing the computational simulation cost by residing an acceptable outcome for flow patterns, but high variations for predictions of temperature in venetian blind is found. In addition to all, the Gratia and Herde connote an important approach to the use of shading devices with the most efficient positioning in the cavity of DSF (Gratia and Herde, 2007). In such an enhanced approach, they also assemble very important notice on the use of the sun shadings in DSF cavity could pose a fire hazard due to blocking the accessibility in the case of fire emergencies.

Subsequently, the integrated louvers typically feature precise control mechanisms that can rotate 180 degrees horizontally or vertically to distribute and diffuse light with simple louver rotation. Adjusting integrated louvers can control indoor lighting inclinations. Completely open and maximum daylight will infiltrate, angled up, and light will reflect off ceilings creating a diffused effect, then a completely closed and light blockage and a complete privacy can be achieved. They can filter sunlight for thermal and occupant benefits, or reflect light back outside to block UV rays, unwanted glare, and sun heat gain.

Specifically, louver positioning can block sun heat gain while still filtering daylight into interiors. Blocking sun heat gain through glazing guarantees an optimal Solar Heat Gain Coefficient (SHGC), utilizing integrated louvers that ensure simultaneous transparency options. In the summer, adjustable integrated louvers can block direct sunlight to significantly reduce cooling requirements. In the winter, integrated louvers can be angled parallel to the sunrays to leverage sun energy for interior heating. Integrated louvers, therefore, offer variable SHGC that can be adjusted according to seasonal requirements.

If the need for cooling is determined by internal heat gain and not just outside temperature, there is an opportunity for ventilation. Airflow in these applications is frequently created via louvers, allowing free airspace for air to flow while keeping unwanted elements out. Factors such as what is behind the louver or, climate/storm probability, etc., will determine how easily the louvers prevent the egress of rain.

In this study louver performance scoring is based on following information (Figure 33, 34, 35).

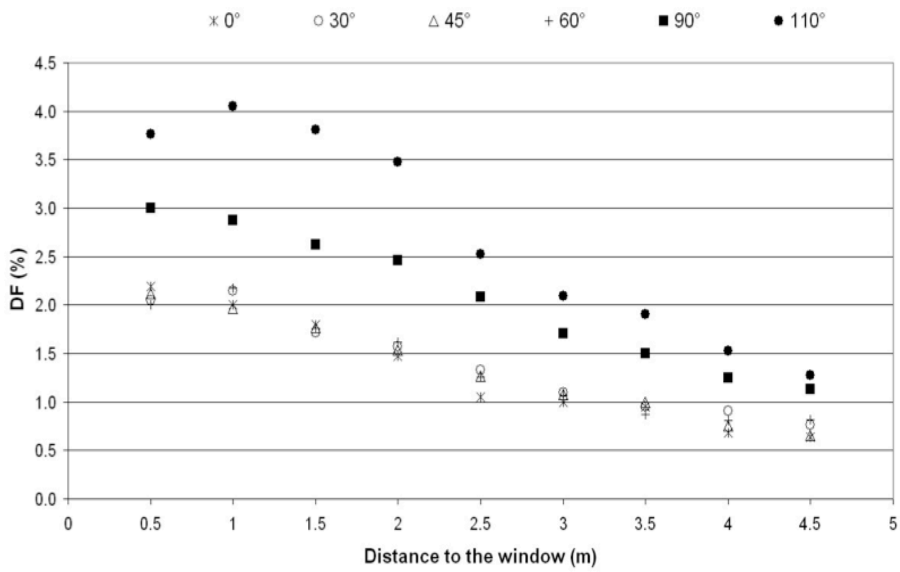


Figure 33: Daylight Factor in Function of the Distance to the Window for Different Slopes of the Louvers.

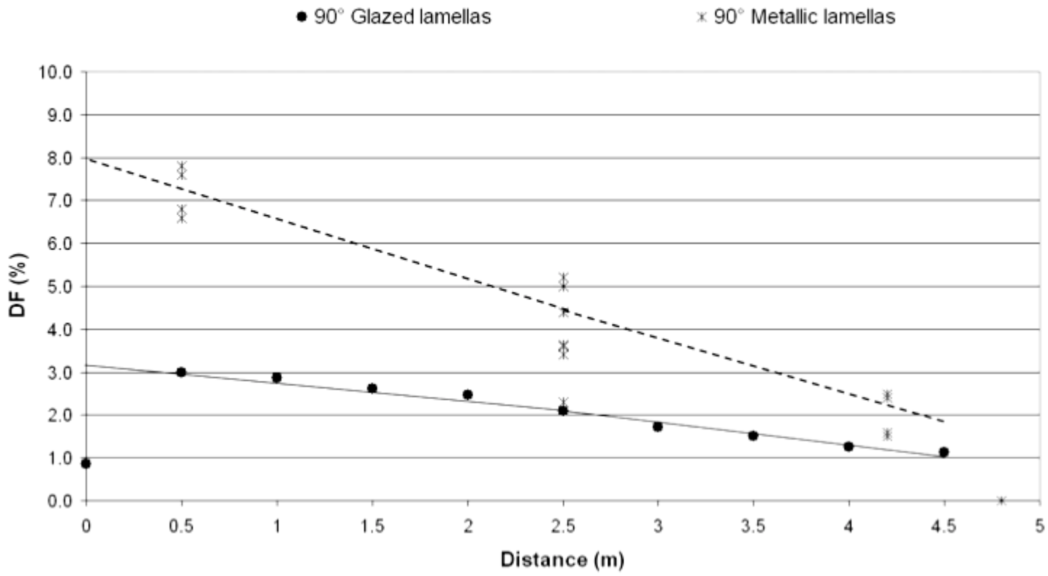


Figure 34: Daylight Factor of the Distance to the window for 90° Louver Slope for Glazed and Metallic Louvers.

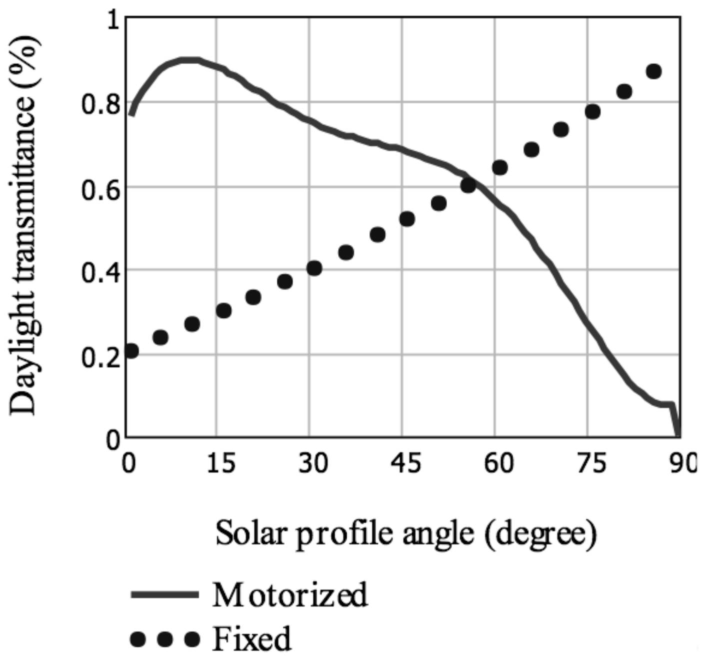


Figure 35: Daylight Transmittance for Adjustable and Fixed Louvers in Altered Slopes.

Subsequently, based on all given data about louver performance installed in DSF systems, results can be summarized as in the following part.

During wintertime: The louvers on the outer layer may be closed to create a buffer zone improving the thermal insulation of the façade. The inner layer is protected from the external environmental effects and the heat exchange coefficient is reduced. The adjustable shading devices allow having maximum transparency and beneficial sun gains, which may reduce the heat loads.

During summer time: The sun gains are reduced in three ways:

- The glass louvers partially reflect the sun radiation reaching the building before it can penetrate the interior spaces.
- The shading devices between the two layers absorb and reflect a large amount of the sun radiation before penetrating the building, and so the cooling loads on the mechanical plant are significantly reduced.
- The ventilation through the cavity provided by the openings in the outer layer has the effect of partially removing the heat absorbed by the shading devices. This effect reduces the amount of heat gain.

Chapter 5

IMPLEMENTATION OF PROPOSED ASSESSMENT METHOD FOR INITIAL DESIGN PHASE OF DSF SYSTEMS

This section presents the evaluation of DSF elements according to their functional performances in thermal comfort, natural ventilation, natural lighting, sun control and sound control by applying the cross ranking method and fuzzy logic set theory.

The functioning diagram of the proposed evaluation method exposed in schematic form to enlighten the complete progression in figure 36.

Investigated double skin façade systems and their façade components throughout the selected cases according to their objectives/functions (thermal comfort, natural ventilation, natural lighting, sun control, sound control) to be evaluated by Cross 5 point scale scoring in Table 61, in terms of the first step of the assessment method.

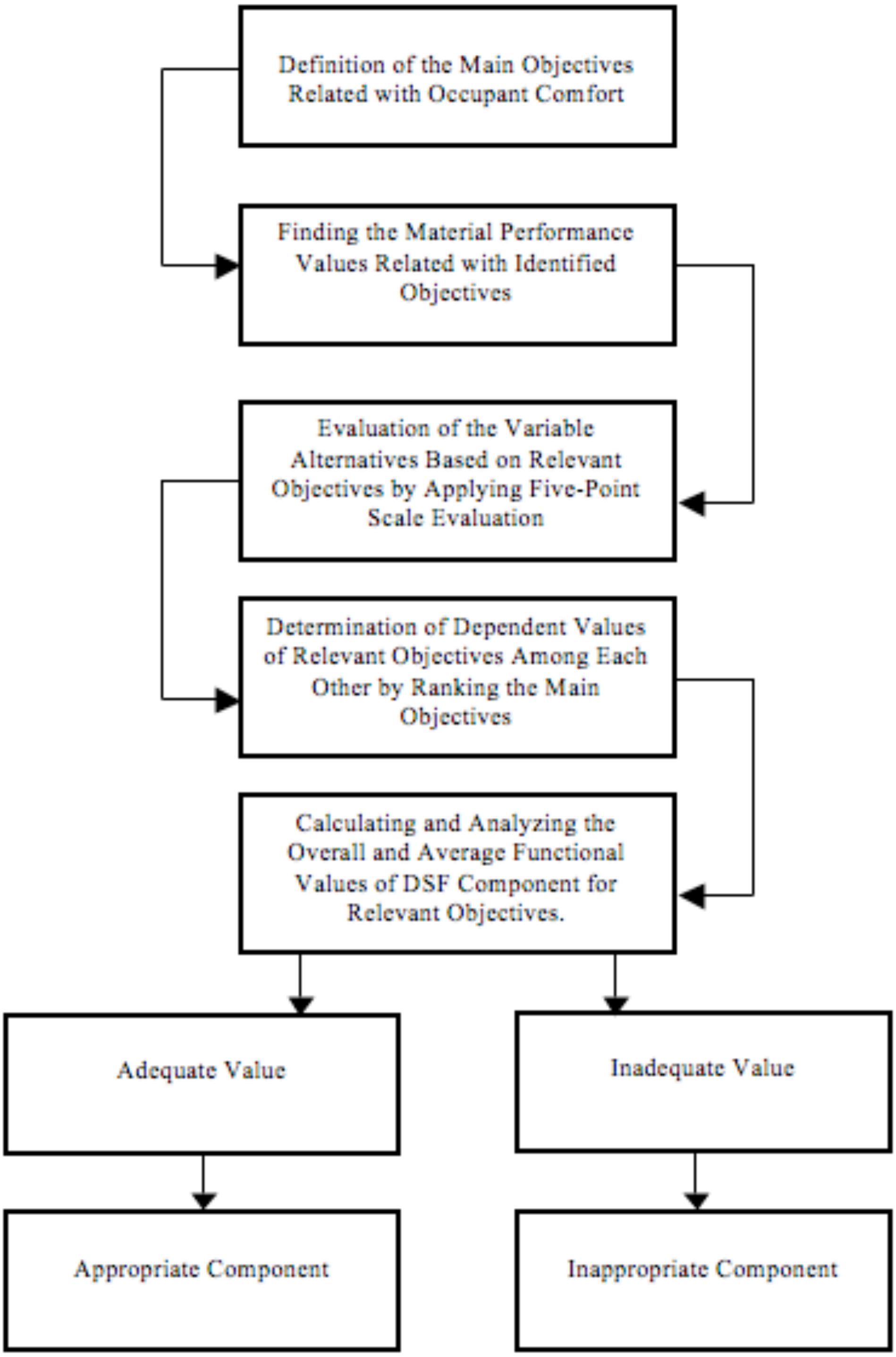


Figure 36: Functioning Diagram of the Proposed Evaluation Method (Author, 2018).

Table 61: Functional / Performance evaluation of DSF components (Author, 2018).

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		**THERMAL COMFORT** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**NATURAL VENTILATION** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**NATURAL LIGHTING** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**SUN CONTROL** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**SOUND CONTROL** Functional Evaluation of the Double Skin Façade Element					**Functional Value**
	Code No.	DSF Element Situation	0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4	
			Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent	
1. Laminated Single Glazed Glass	1A	Laminated Single Glazed Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	1B	Laminated Single Glazed Glass / **Closed**						**4**						**0**						**3**						**2**						**2**
2. Low-e Coating Double Glazing	2A	Low-e Coating Double Glazing / **Open**						**1**						**4**						**4**						**0**						**1**
	2B	Low-e Coating Double Glazing / **Closed**						**3**						**0**						**3**						**2**						**2**
3. Insulating Glass	3A	Insulating Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	3B	Insulating Glass / **Closed**						**4**						**0**						**3**						**2**						**3**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		THERMAL COMFORT Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL VENTILATION Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL LIGHTING Functional Evaluation of the Double Skin Façade Element					Functional Value	SUN CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value	SOUND CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value
	Code No.	DSF Element Situation	0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4	
			Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent	
4. Tinted Solar Control Glass	4A	Tinted Solar Control Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	4B	Tinted Solar Control Glass / **Closed**						**2**						**0**						**3**						**2**						**3**
5. Tinted Solar Control Insulating Glass	5A	Tinted Solar Control Insulating Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	5B	Tinted Solar Control Insulating Glass / **Closed**						**3**						**0**						**1**						**3**						**3**
6. Coated Solar Control Glass With Low-Emissivity Glass	6A	Coated Solar Control Glass With Low-Emissivity Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	6B	Coated Solar Control Glass With Low-Emissivity Glass / **Closed**						**3**						**0**						**3**						**2**						**4**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		THERMAL COMFORT Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL VENTILATION Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL LIGHTING Functional Evaluation of the Double Skin Façade Element					Functional Value	SUN CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value	SOUND CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value
	Code No.	DSF Element Situation	0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4	
			Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent	
7. Coated Solar Control Insulating Glass With Low-Emissivity Glass	7A	Coated Solar Control Insulating Glass With Low-Emissivity Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	7B	Coated Solar Control Insulating Glass With Low-Emissivity Glass /**Closed**						**4**						**0**						**2**						**2**						**4**
8. Solar Control Glass With Thermal Insulation	8A	Solar Control Glass With Thermal Insulation / **Open**						**1**						**4**						**4**						**0**						**1**
	8B	Solar Control Glass With Thermal Insulation / **Closed**						**4**						**0**						**3**						**3**						**3**
9. Solar Control Glass With Triple Thermal Insulation	9A	Solar Control Glass With Triple Thermal Insulation / **Open**						**1**						**4**						**4**						**0**						**1**
	9B	Solar Control Glass With Triple Thermal Insulation / **Closed**						**4**						**0**						**1**						**3**						**4**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		THERMAL COMFORT Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL VENTILATION Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL LIGHTING Functional Evaluation of the Double Skin Façade Element					Functional Value	SUN CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value	SOUND CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value
	Code No.	DSF Element Situation	0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent	
10. Coated Low-Emissivity Glass	10A	Coated Low-Emissivity Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	10B	Coated Low-Emissivity Glass / **Closed**						**3**						**0**						**3**						**1**						**3**
11. Coated Low-Emissivity Insulating Glass	11A	Coated Low-Emissivity Insulating Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	11B	Coated Low-Emissivity Insulating Glass / **Closed**						**4**						**0**						**3**						**2**						**3**
12. Coated Low-Emissivity Triple Insulating Glass	12A	Coated Low-Emissivity Triple Insulating Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	12B	Coated Low-Emissivity Triple Insulating Glass / **Closed**						**4**						**0**						**3**						**2**						**4**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		**THERMAL COMFORT** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**NATURAL VENTILATION** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**NATURAL LIGHTING** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**SUN CONTROL** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**SOUND CONTROL** Functional Evaluation of the Double Skin Façade Element					**Functional Value**
	Code No.	DSF Element Situation	0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4	
			Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent	
13. Uncoated Tinted Insulating Glass	13A	Uncoated Tinted Insulating Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	13B	Uncoated Tinted Insulating Glass / **Closed**						**3**						**0**						**3**						**2**						**3**
14. Low-E Tinted Insulating Glass	14A	Low-E Tinted Insulating Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	14B	Low-E Tinted Insulating Glass / **Closed**						**3**						**0**						**3**						**2**						**3**
15. Solar Control Low-E Tinted Insulating Glass 60	15A	Solar Control Low-E Tinted Insulating Glass 60/ **Open**						**1**						**4**						**4**						**0**						**1**
	15B	Solar Control Low-E Tinted Insulating Glass 60/ **Closed**						**3**						**0**						**3**						**3**						**3**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		**THERMAL COMFORT** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**NATURAL VENTILATION** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**NATURAL LIGHTING** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**SUN CONTROL** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**SOUND CONTROL** Functional Evaluation of the Double Skin Façade Element					**Functional Value**
	Code No.	DSF Element Situation	0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent	
16. Solar Control Low-E Tinted Insulating Glass 67	16A	Solar Control Low-E Tinted Insulating Glass 67/ **Open**						**1**						**4**						**4**						**0**						**1**
	16B	Solar Control Low-E Tinted Insulating Glass 67/ **Closed**						**3**						**0**						**1**						**3**						**4**
17. Solar Control Low-E Clear Insulating Glass 70XL	17A	Solar Control Low-E Clear Insulating Glass 70XL / **Open**						**1**						**4**						**4**						**0**						**1**
	17B	Solar Control Low-E Clear Insulating Glass 70XL / **Closed**						**3**						**0**						**2**						**3**						**4**
18. Low-E Tinted Reflective Insulating Glass	18A	Low-E Tinted Reflective Insulating Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	18B	Low-E Tinted Reflective Insulating Glass / **Closed**						**3**						**0**						**1**						**3**						**4**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		THERMAL COMFORT Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL VENTILATION Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL LIGHTING Functional Evaluation of the Double Skin Façade Element					Functional Value	SUN CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value	SOUND CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value
	Code No.	DSF Element Situation	0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4	
			Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent	
19. Reflective Tinted Insulating Glass	19A	Reflective Tinted Insulating Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	19B	Reflective Tinted Insulating Glass /**Closed**						**3**						**0**						**1**						**3**						**3**
20. Reflective Tinted Solar Control Low-E Insulating Glass	20A	Reflective Tinted Solar Control Low-E Insulating Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	20B	Reflective Tinted Solar Control Low-E Insulating Glass /**Closed**						**3**						**0**						**1**						**4**						**4**
21. Reflective Solar Control Low-E Insulating Glass	21A	Reflective Solar Control Low-E Insulating Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	21B	Reflective Solar Control Low-E Insulating Glass /**Closed**						**3**						**0**						**0**						**4**						**4**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		THERMAL COMFORT Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL VENTILATION Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL LIGHTING Functional Evaluation of the Double Skin Façade Element					Functional Value	SUN CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value	SOUND CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value
	Code No.	DSF Element Situation	0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent	
22. Coated single glazing	22A	Coated single glazing / **Open**						**1**						**4**						**4**						**0**						**1**
	22B	Coated single glazing / **Closed**						**2**						**0**						**3**						**1**						**3**
23. Coated double glazing (85% argon)	23A	Coated double glazing (85% argon)/ **Open**						**1**						**4**						**4**						**0**						**1**
	23B	Coated double glazing (85% argon)/ **Closed**						**4**						**0**						**2**						**2**						**4**
24. Solar control low-e insulating glass (90% argon)	24A	Solar control low-e insulating glass (90% argon)/ **Open**						**1**						**4**						**4**						**0**						**1**
	24B	Solar control low-e insulating glass (90% argon)/ **Closed**						**4**						**0**						**3**						**3**						**4**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		**THERMAL COMFORT** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**NATURAL VENTILATION** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**NATURAL LIGHTING** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**SUN CONTROL** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**SOUND CONTROL** Functional Evaluation of the Double Skin Façade Element					**Functional Value**
	Code No.	DSF Element Situation	0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent	
25. Solar Control Glass With Triple Thermal Insulation	25A	Solar Control Glass With Triple Thermal Insulation / **Open**		■				**1**					■	**4**					■	**4**	■					**0**		■				**1**
	25B	Solar Control Glass With Triple Thermal Insulation / **Closed**					■	**4**	■					**0**			■			**2**				■		**3**					■	**4**
26. Low-E glass with thermal insulating glass	26A	Low-E glass with thermal insulating glass/ **Open**		■				**1**					■	**4**					■	**4**	■					**0**		■				**1**
	26B	Low-E glass with thermal insulating glass/ **Closed**				■		**3**	■					**0**				■		**3**			■			**2**					■	**4**
27. Coated low-e glass	27A	Coated low-e glass/ **Open**		■				**1**					■	**4**					■	**4**	■					**0**		■				**1**
	27B	Coated low-e glass / **Closed**				■		**3**	■					**0**				■		**3**		■				**1**					■	**4**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		THERMAL COMFORT Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL VENTILATION Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL LIGHTING Functional Evaluation of the Double Skin Façade Element					Functional Value	SUN CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value	SOUND CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value
	Code No.	DSF Element Situation	0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent	
28. Gas (argon) Filled Insulated Glass	28A	Gas (argon) Filled Insulated Glass / **Open**						**1**						**4**						**4**						**0**						**1**
	28B	Gas (argon) Filled Insulated Glass / **Closed**						**3**						**0**						**2**						**3**						**4**
29. Single Glazing (Outer Layer) + Double Glazed Panels (Inner Layer)	29A	Single Glazing (Outer Layer) + Double Glazed Panels (Inner Layer) / **Open**						**1**						**4**						**3**						**1**						**0**
	29B	Single Glazing (Outer Layer) + Double Glazed Panels (Inner Layer) **Closed**						**2**						**1**						**1**						**2**						**3**
30. Triple Glazed Low-e Coating and Gas in Cavity	30A	Triple Glazed Low-e Coating and Gas in Cavity/ **Open**						**1**						**4**						**4**						**0**						**0**
	30B	Triple Glazed Low-e Coating and Gas in Cavity/ **Closed**						**3**						**0**						**2**						**2**						**3**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		THERMAL COMFORT Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL VENTILATION Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL LIGHTING Functional Evaluation of the Double Skin Façade Element					Functional Value	SUN CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value	SOUND CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value
	Code No.	DSF Element Situation	0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent	
31. Ventilation Gaps	31A	Ventilation Gaps/ **Open**						**1**						**3**						**0**						**0**						**1**
	31B	Ventilation Gaps/ **Closed**						**3**						**1**						**0**						**0**						**2**
32. Air Flaps	32A	Air Flaps / **Open**						**2**						**3**						**1**						**0**						**1**
	32B	Air Flaps / **Closed**						**3**						**1**						**0**						**0**						**2**
	32C	Air Flaps/ **Closed** Inner Layer Window / **Open**						**1**						**1**						**3**						**1**						**2**
	32D	Air Flaps / **Closed** Inner Layer Window / **Closed**						**3**						**0**						**1**						**2**						**3**
	32E	Air Flaps / **Open** Inner Layer Window / **Closed**						**1**						**2**						**3**						**2**						**2**
	32F	Air Flaps / **Open** Inner Layer Window / **Open**						**3**						**4**						**4**						**0**						**1**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		**THERMAL COMFORT** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**NATURAL VENTILATION** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**NATURAL LIGHTING** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**SUN CONTROL** Functional Evaluation of the Double Skin Façade Element					**Functional Value**	**SOUND CONTROL** Functional Evaluation of the Double Skin Façade Element					**Functional Value**
	Code No.	DSF Element Situation	0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent		0 Inadequate	1 Weak	2 Satisfactory	3 Good	4 Excellent	
33. Air Flaps with Fans	33A	Air Flaps/ **Open** Fans/ **On**						**1**						**4**						**1**						**0**						**0**
	33B	Air Flaps/ **Open** Fans **/ Off**						**2**						**2**						**1**						**0**						**1**
	33C	Air Flaps / **Closed** Fans / **On**						**4**						**2**						**0**						**0**						**1**
	33D	Air Flaps / **Closed** Fans / **Off**						**3**						**0**						**0**						**0**						**3**
34. Glass Louvers (Outer Layer)	34A	Glass Louvers (Outer Layer) / **Open**						**1**						**3**						**3**						**1**						**0**
	34B	Glass Louvers (Outer Layer) / **Closed**						**2**						**0**						**1**						**2**						**2**
35. Glass Louvers (Inner Layer)	35A	Glass Louvers (Inner Layer) / **Open**						**1**						**0**						**4**						**1**						**1**
	35B	Glass Louvers (Inner Layer) / **Closed**						**3**						**0**						**2**						**2**						**3**

DSF COMPONENT TYPE	Adaptation of Double Skin Façade Element		THERMAL COMFORT Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL VENTILATION Functional Evaluation of the Double Skin Façade Element					Functional Value	NATURAL LIGHTING Functional Evaluation of the Double Skin Façade Element					Functional Value	SUN CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value	SOUND CONTROL Functional Evaluation of the Double Skin Façade Element					Functional Value
			0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4		0	1	2	3	4	
	Code No.	DSF Element Situation	Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent		Inadequate	Weak	Satisfactory	Good	Excellent	
37. Aluminum Louvers (Outer Layer)	37A	Aluminum Louvers (Outer Layer) / **Open**						**1**						**1**						**2**						**1**						**1**
	37B	Aluminum Louvers (Outer Layer) / **Closed**						**3**						**0**						**0**						**4**						**3**
38. Aluminum Louvers (Inner Layer)	38A	Aluminum Louvers (Inner Layer) / **Open**						**1**						**3**						**3**						**1**						**0**
	38B	Aluminum Louvers (Inner Layer) / **Closed**						**2**						**0**						**1**						**4**						**4**

Intended purpose of ranking the objectives of DSF is totally related to existing conditions. DSF objectives values among each other may vary according to external conditions, occupant needs, and location of the façade. The most accurate ranking of the objectives can be obtained by evaluating these aspects. However, in the scope of thesis occupant comfort is accepted as the main priority. Table 62 demonstrates the comparison method among the main objectives of DSF related to occupant comfort, to provide the second phase of the overall evaluation method as granting the dependent values of objectives.

Table 62: Ranking the main objectives of the DSF (Author, 2018).

Objectives	Thermal Comfort	Natural Ventilation	Natural Lighting	Sun Control	Sound Control	**Total Value**
Thermal Comfort		1	1	1	1	**4**
Natural Ventilation	0		1/2	1/2	1	**2**
Natural Lighting	0	1/2		1/2	1/2	**1.5**
Sun Control	0	1/2	1/2		1/2	**1.5**
Sound Control	0	0	1/2	1/2		**1**

In the last phase of the evaluation, data that obtained in the previous steps of the evaluation process is used to reach the total performance values of the DSF system components. Table 63 demonstrates the overall performance values of DSF system components by merging functional values and dependent values of DSF components.

OPV= PVT+PVV+PVL+PVS+PVSD………………………………………… Eq (3)

OPV= $(FV_T \times DV_T) + (FV_V \times DV_V) + (FV_L \times DV_L) + (FV_S \times DV_S) + (FV_{SD} \times DV_{SD})$……………………………………………………………………….. Eq (4)

AVPV= (PVT+PVV+PVL+PVS+PVSD) / 2………………………………….. Eq (5)

Table 63: Assessment of DSF components (Authors, 2018).

DSF COMPONENT TYPE NO.	THERMAL COMFORT		PVT	NATURAL VENTILATION		PVV	NATURAL LIGHTING		PVL	SUN CONTROL		PVS	SOUND CONTROL		PVSD	OPV	AVPV
	Functional Value	Dependent Value		Functional Value	Dependent Value		Functional Value	Dependent Value		Functional Value	Dependent Value		Functional Value	Dependent Value			
1	1-4	0.40	**0.40 1.60**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-2	0.15	**0.00 0.30**	1-2	0.10	**0.10 0.20**	0.95 3.50	2.22
2	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-2	0.15	**0.00 0.30**	1-2	0.10	**0.10 0.20**	0.95 3.10	2.02
3	1-4	0.40	**0.40 1.60**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-2	0.15	**0.00 0.30**	1-3	0.10	**0.10 0.30**	0.95 3.60	2.27
4	1-2	0.40	**0.40 0.80**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-2	0.15	**0.00 0.30**	1-3	0.10	**0.10 0.30**	0.95 2.80	1.87
5	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	1-4	0.15	**0.15 0.60**	0-3	0.15	**0.00 0.45**	1-3	0.10	**0.10 0.30**	0.65 3.35	2.00
6	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-2	0.15	**0.00 0.30**	1-4	0.10	**0.10 0.40**	0.95 3.30	2.12
7	1-4	0.40	**0.40 1.60**	0-4	0.20	**0.00 0.80**	2-4	0.15	**0.30 0.60**	0-2	0.15	**0.00 0.30**	1-4	0.10	**0.10 0.40**	0.80 3.70	2.25
8	1-4	0.40	**0.40 1.60**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-3	0.15	**0.00 0.45**	1-3	0.10	**0.10 0.30**	0.95 3.75	2.35
9	1-4	0.40	**0.40 1.60**	0-4	0.20	**0.00 0.80**	1-4	0.15	**0.15 0.60**	0-3	0.15	**0.00 0.45**	1-4	0.10	**0.10 0.40**	0.65 3.85	2.25
10	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-2	0.15	**0.00 0.30**	1-3	0.10	**0.10 0.30**	0.95 3.20	2.07
11	1-4	0.40	**0.40 1.60**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-1	0.15	**0.00 0.15**	1-3	0.10	**0.10 0.30**	0.95 3.45	2.20
12	1-4	0.40	**0.40 1.60**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-2	0.15	**0.00 0.30**	1-4	0.10	**0.10 0.40**	0.95 3.70	2.32
13	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-2	0.15	**0.00 0.30**	1-3	0.10	**0.10 0.30**	0.95 3.20	2.07

DSF COMPONENT TYPE NO.	THERMAL COMFORT		PVT	NATURAL VENTILATION		PVV	NATURAL LIGHTING		PVL	SUN CONTROL		PVS	SOUND CONTROL		PVSD	OPV	AVPV
	Functional Value	Dependent Value		Functional Value	Dependent Value		Functional Value	Dependent Value		Functional Value	Dependent Value		Functional Value	Dependent Value			
14	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-2	0.15	**0.00 0.30**	1-3	0.10	**0.10 0.30**	0.95 3.20	2.07
15	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-3	0.15	**0.00 0.45**	1-3	0.10	**0.10 0.30**	0.95 3.35	2.15
16	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	1-4	0.15	**0.15 0.60**	0-3	0.15	**0.00 0.45**	1-4	0.10	**0.10 0.40**	0.65 3.45	2.05
17	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	2-4	0.15	**0.30 0.60**	0-3	0.15	**0.00 0.45**	1-4	0.10	**0.10 0.40**	0.80 3.45	2.12
18	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	1-4	0.15	**0.15 0.60**	0-3	0.15	**0.00 0.45**	1-4	0.10	**0.10 0.40**	0.65 3.45	2.05
19	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	1-4	0.15	**0.15 0.60**	0-3	0.15	**0.00 0.45**	1-3	0.10	**0.10 0.30**	0.65 3.35	2.05
20	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	1-4	0.15	**0.15 0.60**	0-4	0.15	**0.00 0.60**	1-4	0.10	**0.10 0.40**	0.65 3.60	2.12
21	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.00 0.80**	0-4	0.15	**0.00 0.60**	0-4	0.15	**0.00 0.60**	1-4	0.10	**0.10 0.40**	0.50 3.60	2.05
22	1-2	0.40	**0.40 0.80**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-1	0.15	**0.00 0.15**	1-3	0.10	**0.10 0.30**	0.95 2.85	1.90
23	1-4	0.40	**0.40 1.60**	0-4	0.20	**0.00 0.80**	2-4	0.15	**0.30 0.60**	0-2	0.15	**0.00 0.30**	1-4	0.10	**0.10 0.40**	0.80 3.70	2.25
24	1-4	0.40	**0.40 1.60**	0-4	0.20	**0.00 0.80**	3-4	0.15	**0.45 0.60**	0-3	0.15	**0.00 0.45**	1-4	0.10	**0.10 0.40**	0.95 3.85	2.40
25	1-4	0.40	**0.40 1.60**	0-4	0.20	**0.00 0.80**	2-4	0.15	**0.30 0.60**	0-3	0.15	**0.00 0.45**	1-4	0.10	**0.10 0.40**	0.80 3.85	2.32
26	1-3	0.40	**0.40 1.20**	0-4	0.20	**0.40 0.80**	3-4	0.15	**0.45 0.60**	0-2	0.15	**0.00 0.30**	1-4	0.10	**0.10 0.40**	1.35 3.30	2.32

5.1 On Functional Evaluations/Rankings of DSF Components

This section of the study presents the summary for rankings of the double skin façade components related to the assessment according to their performance values and dependent values of objectives.

1. Laminated Single Glazed Glass

During the assessment, two situations of the component is considered. Laminated single glazed glass offers an excellent performance value for thermal comfort, a good performance value for the natural lighting, a satisfactory performance value both for sun control and sound control, but an inadequate performance value for natural ventilation when the component is in the closed state mode. In contrary, when the component is in the open state mode it offers an excellent performance value for both of the natural ventilation and lighting, a weak performance value for sound and thermal comfort, and an inadequate performance level for sun control.

For the overall performance value, the component suggests performance values above good level in the closed state mode and inadequate value when it is in the open state mode. After the average performance value evaluation, the component can be observed to give above satisfactory performance value for the occupant comfort.

2. Low-E Coating Double Glazing

Related to the assessments of low emissivity coating double-glazing, it offers excellent performance values both for natural ventilation and lighting, weak performance values for thermal comfort and sound control, inadequate performance values for sun control objectives in an open state mode. In the close state mode, it proposes a good performance value for thermal comfort and natural lighting; while its sun and sound control performances are in satisfactory level, but it provides an inadequate performance value for natural ventilation.

For the overall performance value, the component suggests performance values just above good level in the closed state mode and just below weak value when it is in the open state mode. As the average performance value evaluated, the component can be observed with a satisfactory performance value for occupant comfort.

3. Insulating Glass

Assessing the insulating glass, in an open state mode the component offers excellent performance values both for natural ventilation and lighting, opposed to that the component has weak performance values for sound control and thermal comfort and an inadequate value for sun control. Besides, it has an excellent performance value for thermal comfort, and good performance values for both natural lighting and sound control in the closed state mode.

For the overall performance value, the component suggests performance values above good level in the closed state mode and just below the weak value when it is in the open state mode. As the average performance value evaluated, the component can be observed above a satisfactory performance value for occupant comfort.

4. Tinted Solar Control Glass

Related to the assessment, tinted sun control glass provides excellent performance values for natural lighting and ventilation opposed to weak performance values for thermal comfort and sound control when the component set to open state mode.
On the other hand, it provides a satisfactory value for thermal comfort and a good performance value for sound control in the closed state mode.

For the overall performance value, the component suggests performance values just below the good level in the closed state mode and just below the weak value when it is in the open state mode. As the average performance value evaluated, the component can be observed just below the satisfactory performance value for occupant comfort.

5. Tinted Solar Control Insulating Glass

Tinted sun control insulating glass has weak performance values for thermal comfort and sound control as well as inadequate performance value for sun control. However, it provides excellent performance values for natural lighting and ventilation when it is in the open state mode. It also maintains good performance values for sound control and natural lighting, and satisfactory performance values for both thermal comfort and sun control when it is set in the closed state mode.

As for the overall performance value, the component suggests performance values above good level in the closed state mode and just above the inadequate value when it is in the open state mode. As the average performance value evaluated, the component can be observed with a satisfactory performance value for occupant comfort.

6. Coated Solar Control Glass with Low Emissivity Glass

In a closed state mode, coated sun control glass with low emissivity glass delivers good performance values in thermal comfort and natural lighting and excellent sound control. Nonetheless, in an open state mode, opposing to the values that it has in the closed state mode, it provides weak performance value for thermal comfort and sound control. On the other hand, it provides excellent performance for natural ventilation and lighting.

When an overall performance assessed, the component submits performance values within the range of above the good level and just above the inadequate value. As the average performance value evaluated, component can be observed with a satisfactory performance value for occupant comfort.

7. Coated Solar Control Insulating Glass with Low Emissivity Glass

During the closed state mode component provides, excellent thermal comfort and sound control with satisfactory sun control and natural lighting opposing to the inadequate level of natural ventilation performance. In the open state mode it allows air circulation and sun infiltration into the indoor spaces that carries excellent natural ventilation and lighting performance values.

As for the overall performance value, the component submits performance values within the range of below the excellent level and just below the weak value. As the average performance value evaluated, component can be observed just above the satisfactory performance value for occupant comfort.

8. Solar Control Glass with Thermal Insulation

In the open state mode, sun control glass with thermal insulation delivers excellent performance values for natural ventilation and natural lighting conflicting to that it has a weak thermal comfort sound control level and an inadequate sun control performance. In the closed state mode, the component has pleasing values to achieve human comfort standards such as; good natural lighting, sound, and sun control performance levels besides an excellent thermal comfort performance.

For the overall performance value, the component submits performance values within the range of below the excellent level and weak values. As the average performance value evaluated, the component can be observed just above the satisfactory performance value for occupant comfort.

9. Solar Control Glass with Triple Thermal Insulation

In the open state mode, natural lighting and ventilation values are excellent, but opposing to that in the closed state mode those values having weak and inadequate levels for the component performance. In addition to that, sun control glass with triple thermal insulation brings excellent performance values on thermal comfort and sound protection in close state mode with good sun control performance.

For the overall performance value, the component submits performance values within the range of the excellent level and above the inadequate value. As the average performance value evaluated, the component can be observed just above the satisfactory performance value for occupant comfort.

10. Coated Low Emissivity Glass

In the closed state mode, coated low-E glass provides good performance values for thermal comfort, natural lighting, and sound control. Besides, it devises a weak sun control performance. Instead, in the open state mode, the component brings excellent natural ventilation and lighting performances.

For the overall performance value, the component submits performance values within the range of just above the good level and weak values. As the average performance value evaluated, the component can be detected with just above the satisfactory performance value for occupant comfort.

11. Coated Low Emissivity Insulating Glass

In the open state mode, component demonstrates weak thermal and sound control performances contrasting to the values in natural ventilation and lighting performances that are excellent. The component brings a good thermal comfort, natural lighting, and sound control performances in the closed mode.

For the overall performance value, the component submits performance value within the range of above the good level and weak values. As the average performance value evaluated, the component can be detected with just above the satisfactory performance value for occupant comfort.

12. Coated Low Emissivity Triple Insulating Glass

In the open mode of the component, natural ventilation and lighting performance values are excellent. In this case, performance values of thermal comfort are weak in while sun control performance is at the inadequate levels. Reversely to the open mode, component provides excellent performance values on thermal comfort and sound protection with good natural lighting performance in the closed mode. It also has a satisfactory sun control performance.

For the overall performance value, the component submits performance value within the range of just below the excellent level and weak values. As the average performance value evaluated, the component can be detected with above the satisfactory performance value for occupant comfort.

13. Uncoated Tinted Insulating Glass

Uncoated tinted insulating glass performs good thermal comfort, natural lighting, and sound protection with a satisfactory sun control ranks in the closed mode. Opposing to that, thermal comfort and sound control performances are weak, when the component is in the open mode.

For the overall performance value, the component submits performance value within the range of the good level and weak values. As the average performance value evaluated, the component can be detected with a satisfactory performance value for occupant comfort.

14. Low Emissivity Tinted Insulating Glass

In the closed mode, low-E tinted insulating glass provides a satisfactory level of sun control and good levels of natural lighting, sound control, and thermal comfort performances. Against the open mode, thermal comfort level and sound control is at weak levels, neither sun control performance is satisfactory.

For the overall performance value, the component proposes performance values within the variety of the good level and weak values. As the average of the performance value evaluated, the component can be detected with a satisfactory performance value (2.07) for occupant comfort.

15. Solar Control Low Emissivity Tinted Insulating Glass 60

For thermal comfort, natural lighting, sun control, and sound control, component offers good performance levels in the closed mode. On the other hand, natural ventilation and lighting performances are excellent in the open mode.

For the overall performance value, the component proposes performance values within the variety of the good level and weak values. As the average of the performance value evaluated, the component can be detected with a satisfactory performance value (2.15) for occupant comfort.

16. Solar Control Low Emissivity Tinted Insulating Glass 67

This item allows excellent natural lighting and ventilation when the component is in the open mode. This mode brings inadequate performance level for sun control. In a closed mode, sound control level is excellent and it provides good performance levels for thermal comfort and sun control.

For the overall performance value, the component proposes performance values within the variety of above the good level and weak values. As the average of the performance value evaluated, the component can be detected with a satisfactory performance value (2.05) for occupant comfort.

17. Solar Control Low Emissivity Clear Insulating Glass 70XL

The component offers an excellent sound control performance, as well as good thermal control and sun control performances with a satisfactory natural lighting performance when it is in the closed mode. On the other hand, when it is in the open mode, the component delivers excellent natural lighting and ventilation. Besides, thermal comfort and sound control performances are weak.

For the overall performance value, the component proposes performance values within the variety of above the good level and weak values. As the average of the performance value evaluated, the component can be detected with a satisfactory performance value (2.12) for occupant comfort.

18. Low Emissivity Tinted Reflective Insulating Glass

The component offers an excellent sound control performance, good thermal control and sun control performances with a weak natural lighting when it is in the closed mode. Opposing to that, when the component is in the open state mode, it delivers excellent natural lighting and ventilation. Besides, thermal comfort and sound control performances are weak.

For the overall performance value, the component proposes performance values within the variety of above the good level and weak values. As the average of the performance value evaluated, the component can be detected with a satisfactory performance value (2.05) for occupant comfort.

19. Reflective Tinted Insulating Glass

As for thermal comfort, natural lighting, sun control and sound control. The component offers good performance levels in the closed mode. On the other hand, natural ventilation and lighting performances are excellent in the open mode.

For the overall performance value, component proposes performance values within the variety of above the good level and weak values. As the average of the performance value evaluated, the component can be detected with a satisfactory performance value (2.05) for occupant comfort.

20. Reflective Tinted Solar Control Low Emissivity Insulating Glass

When the component is in the open state mode, it offers excellent natural lighting and ventilation. Besides, thermal comfort and sound control performances are weak. However, sun control and sound control performances are excellent in the closed mode. Moreover, it provides a good performance value for thermal comfort.

For the overall performance value, the component proposes performance values within the variety of above the good level and weak values. As the average of the performance value evaluated, the component can be detected with a satisfactory performance value (2.12) for occupant comfort.

21. Reflective Solar Control Low Emissivity Insulating Glass

Sun control and sound control performance of the component in closed mode is excellent, and it offers a good thermal comfort level. Strikingly, in the open state thermal comfort and sound control performances at the weak levels. Nevertheless, it contributes to natural ventilation and lighting at excellent levels.

For the overall performance value, the component proposes performance values within the variety of above the good level and weak values. As the average of the performance value evaluated, the component can be detected with a satisfactory performance value (2.05) for occupant comfort.

22. Coated Single Glazing

Coated single glazing offers good performance levels for natural lighting and sound control with a satisfactory performance level of thermal comfort in closed mode. In contrast, thermal comfort and sound control performance levels are weak. Still, natural ventilation and lighting performances are at the excellent levels in the open mode.

For the overall performance value, the component proposes performance values within the variety of just below the good level and weak values. As the average of the performance value evaluated, the component can be detected with just below the satisfactory performance value (1.90) for occupant comfort.

23. Coated Double Glazing (85% Argon)

Thermal comfort and sound control performance levels of the component are excellent, while it offers satisfactory levels of natural lighting and sun control performances in the closed mode.

For the overall performance value, the component proposes performance values within the variety of above the good level and weak values. As the average of the performance value evaluated, the component can be detected with a satisfactory performance value (2.25) for occupant comfort.

24. Solar Control Low Emissivity Insulating Glass (90% Argon)

In the closed state mode, thermal comfort and sound control performances of the component is excellent, while natural lighting and sun control performance is at good levels. Strikingly, natural ventilation performance is inadequate.

For the overall performance value, the component proposes performance values within the variety of just below the excellent level and weak values. As the average of the performance value evaluated, the component can be detected with above the satisfactory performance value (2.40) for occupant comfort.

25. Solar Control Glass with Triple Thermal Insulation

It performs excellent levels of thermal comfort and sound control with a good sun control performance when component is in the close state mode. Correspondingly, it provides a satisfactory level of natural lighting performance. Furthermore, natural lighting and ventilation performances are excellent in the open state mode. However, thermal performance and sound control is at weak levels. Moreover, it has an inadequate level of sun control performance.

For the overall performance value, the component proposes performance values within the variety of just below the excellent level and weak values. As the average of the performance value evaluated, the component can be detected with above the satisfactory performance value (2.32) for occupant comfort.

26. Low Emissivity Glass with Thermal Insulating Glass

While the component is in the closed mode, sound performance is excellent, thermal comfort and natural lighting performances are good, and sun control performance is at a satisfactory level. In contrast, when is set in the open mode thermal performance and sound control performance cannot put enough contribution to achieving occupant comfort.

For the overall performance value, the component proposes performance values within the variety of above the good level and above weak values. As the average of the performance value evaluated, the component can be detected with above the satisfactory performance value (2.32) for occupant comfort.

27. Coated Low Emissivity Glass

In an open mode of the component natural lighting and ventilation performance are excellent, because component allows air circulation and sun infiltration for indoor spaces. Consequently, thermal comfort and sound protection contribution to occupant comfort stays on weak levels. When coated low-E glass set in the closed mode, thermal comfort and natural lighting performances are at good levels. In addition, sound control performance achieves to an excellent level.

For the overall performance value, the component proposes performance values within the variety of the good level and above weak value. As the average of the performance value evaluated, the component can be detected with above the satisfactory performance value (2.25) for occupant comfort.

28. Gas Filled Insulated Glass

In the open state mode, natural lighting performance is excellent. However, sun control performance is inadequate. Additionally, sound control and thermal comfort performances are weak. In the closed state mode component serves excellent sound control performance and good thermal comfort and sun control contributions. Natural lighting performance also set to satisfactory level.

For the overall performance value, the component proposes performance values within the variety of above the good level and above weak values. As the average of the performance value evaluated, the component can be detected with above the satisfactory performance value (2.32) for occupant comfort.

29. Single Glazing (Outer Layer) + Double Glazed Panels (Inner Layer)

Thermal comfort and sun control performance levels are satisfactory. Besides sound control performance can reach to an excellent level. However, natural ventilation performance is inadequate.

For the overall performance value, the component proposes performance values within the variety of above the satisfactory level and weak values. As the average of the performance value evaluated, the component can be detected with below weak performance value (1.77) for occupant comfort.

30. Triple Glazed Low-E Coating and Gas in Cavity

Natural lighting and sun control performances are at the satisfactory levels, furthermore, both sound control and thermal comfort performances are excellent when the component is in the closed mode.

As an overall performance value, component proposes performance value within the variety of above good level and above weak value. As an average of the performance value assisted with evaluation, component can be detected with above the satisfactory performance value (2.15) for occupant comfort.

31. Ventilation Gaps

The performance value of ventilation gaps to accomplish occupant comfort is at the satisfactory levels for thermal comfort and natural ventilation. But, strikingly, they have inadequate performance level for natural lighting and sun control.

For the overall performance value, the component proposes performance values within the variety of the satisfactory level and above the inadequate value. As the average of the performance value evaluated, the component can be detected with above the weak performance value (1.35) for occupant comfort.

32. Air Flaps

Air flaps can act on various modes in the system. As the average performance values can be of numerous modes, ranking of the air flaps explained as follows; thermal comfort performance and natural lighting performances are at the satisfactory levels, natural ventilation and sound control performances are just below the average. However, sun control performance is at an inadequate level.

For the overall performance value, the component proposes performance values within the variety of above the good level and above weak values. As the average of the performance value evaluated, the component can be detected with satisfactory performance value (2.05) for occupant comfort.

33. Air Flaps with Fans

Fan supported air flaps can be seen in several modes as well. Relating to the ranking of numerous modes, the average performance values are at the satisfactory levels for thermal comfort and natural ventilation, at the weak levels for sound control and natural lighting, and at the inadequate level for sun control.

For the overall performance value, the component proposes performance values within the variety of just below the good level and above weak values. As the average of the performance value evaluated, the component can be detected with below the satisfactory performance value (1.82) for occupant comfort.

34. Glass Louvers (Outer Layer)

When the glass louvers that positioned closed to the outer layer, thermal comfort, sun control, and sound control performances are at the satisfactory levels in the closed mode. Nevertheless, in the open state mode natural ventilation and lighting performance can extend up to excellent levels.

For the overall performance value, the component proposes performance values within the variety of above the satisfactory level and weak values. As the average of the performance value evaluated, the component can be detected with a weak performance value (1.52) for occupant comfort.

35. Glass Louvers (Inner Layer)

In the closed mode, thermal comfort and sound protection performance levels are good and performances for natural lighting and sun control is satisfactory. In the open mode, thermal comfort, sun control, and sound control performances are weak. Opposing to that, natural ventilation lighting performance is excellent.

For the overall performance value, the component proposes performance values within the variety of above the good level and weak values. As the average of the performance value evaluated, the component can be detected with above the weak performance value (1.67) for occupant comfort.

36. Glass Louvers (Outer Layer) + Inner Layer Window Variations

Thermal comfort and sound control performance levels can be accepted as above satisfactory. Natural lighting performance is good. Natural ventilation and sun control performance averages are above weak.

As an overall performance value, component proposes performance value within the variety of above good level and above weak value. As an average of the performance value assisted with evaluation, component can be detected with above the satisfactory performance value (2.52) for occupant comfort.

37. Aluminum Louvers (Outer Layer)

When the aluminum louvers are in the closed mode, sun control performance is at the excellent level. Both sound control and thermal comfort performances are at the good levels. Notwithstanding, natural ventilation and lighting performances are at the inadequate levels. If the component is in the open mode, natural lighting performance is satisfactory. On the other hand thermal comfort, natural ventilation, sun control, and sound control performances are at the weak levels.

For the overall performance value, the component proposes performance values within the variety of above the satisfactory level and below weak values. As the average of the performance value evaluated, the component can be detected with a weak performance value (1.62) for occupant comfort.

38. Aluminum Louvers (Inner Layer)

In the open mode, aluminum louvers perform good values for natural ventilation and natural lighting. On the other hand, in the closed mode, sun control and sound control performances are excellent while thermal comfort performance is satisfactory.

For the overall performance value, the component proposes performance values within the variety of just below the good level and below weak values. As the average of the performance value evaluated, the component can be detected with just below the satisfactory performance value (1.77) for occupant comfort.

Chapter 6

CONCLUSION

In this study, double skin facades reflected as a system, which assists the structures for achieving certain levels of occupant comfort by reacting to the climatical circumstances. Subsequently, within the scope of the thesis different types and classifications of double skin systems are described and elaborated.

The study exposed that the human comfort is accomplished in terms of certain principles as thermal comfort, natural ventilation, natural lighting (in terms of effective use of daylight), sun control, and acoustic comfort. Next, compulsory necessities for human comfort issues and their values are defined accordingly, to achieve human comfort standards. This work also revealed that these standards could be achieved in aesthetical intentions of the architects through double skin façade systems as well.

In this regard, the study was embarking on to explain the notion of DSF systems and to introduce the different classifications for discovering the elements of DSF systems and their contributions to achieving comfort standards.

Accordingly, the main aim of the thesis is to find out an assessment model for various DSF elements and conditions, which can be used in initial design phase to enlighten the designers about selecting the appropriate elements for their DSF configurations. Four objectives were determined for the focal purpose of the study.

- To decide the climatical zones with diverse variables, which help to understand the adaptation flexibility of the DSF systems.
- To find out the DSF elements those are taking a part in accomplishing the principles of comfort standards by analyzing different cases.
- To find out the performance values of DSF components on each principle of comfort standards.
- To find out the overall performance values of DSF components and conditions according to different variables.

The thesis was structured in three key parts. The first part was a systematic review of the literature as theoretical framework, which can be found in Chapter 2 and Chapter 3. Thereafter, in Chapter 4, analyzing the selected cases belong to certain climatical zones for finding out DSF components which have been used in the projects and their participation in occupant comfort established the second part of the thesis. Conclusively, to present the proposed assessment method to find out the overall performance values of DSF components according to different variables and its application was comprehended in Chapter 5.

6.1 Outcomes of the Research

The classification of the research findings collected under three main sub-headings as:

- Findings of the human comfort standards theory
- Findings of the DSF theory

- Finding of the ranking analysis

6.1.1 Outcomes of the Human Comfort Standards Theory

The study exposed that four expansive subjects sustain human comfort: thermal comfort, visual comfort, auditory comfort, and climate change. The outcomes of these subjects are discussed below

Thermal Comfort

Thermal comfort is explained in two main categories as physical factors and individual factors. Physical factors can be justified by four parameters as relative humidity, airspeed, mean radiant temperature, and air temperature. Protection with clothing and movement level of the human being can be explained as individual parameters for thermal comfort.

The study also exposed that one of the fundamental attributes of the buildings is to establish a required thermal indoor climate for occupants.

The research found out that for the operation of current methods of environmental systems and for the improvement of completely novel systems, consistent measurable circumstances can be used to achieve rational calculations.

Afterwards, the recommended indoor design parameters in winter conditions and summer conditions are also revealed as the average temperature range should be between 20-24 °C, relative humidity level between 30-35% in winter conditions; 23-26 °C average temperature and 40-60% relative humidity level in summer conditions.

Visual Comfort

The study exposed that preferences of the occupants' for lighting conditions for indoors are wide-ranging and one set lighting level is not able to satisfy all of the occupants. In addition to this, visual comfort is depending on some focal principles such as contrast, glare and light levels. Here, it is also revealed that the appropriate illuminance levels differ for different indoors with special uses. This range is determined in between the values of 100lux and 2000lux.

Auditory Comfort

This study also exposed that the human hearing range stated within the 20 Hz to 20 kHz, however, it becomes more sensitive to the sounds between 1 kHz to 4 kHz. This study also revealed that the auditors could detect sounds at 3 kHz as low as 0 db SPL (sound pressure level). Nevertheless, the comfortable hearing limit of human is stated in the study is 40 dB SPL in 100 Hz.

Comfort and Climate Change

The study revealed that current environmental problems would be intensified when uniform indoor climate tried to be obtained with mechanical heating or cooling systems. Novel design principles might be necessitated to operate under various climatic conditions for the buildings.

This research also exposed that, for the future designs, to attribute the energy consumption, passive design features such as conservatories need to be considered. Because to improve the energy efficiency in building designs, strategies coping with the climate alteration need to be proposed.

6.1.2 Outcomes of the DSF Theory

Considering the outcomes of the double skin facades, the thesis exposed conspicuous information about the "double skin façade" concept and its contribution to the occupant comfort in building indoors. In this regard, sufficient adaptability/flexibility of DSF systems confronted with climatic variations are emphasized. The fundamental components/issues of the DSF through the historical background is classified in three main parts:

- The configuration of the envelope,
- The transparency of the bordering surfaces,
- The airflow within the cavity between the external and internal layers of the system.

In the study, according to the common attitude of other researchers, double skin facades considered to be compromising of three different layers as external glazing, internal glazing, and intermediate cavity.

There were four main classifications of DSF stand out from the definitions of various authors according to the geometry of the air cavity as box window type, shaft box type, corridor façade, multi-story double skin façade.

Regarding the objectives of occupant comfort, the assessment of the DSF system investigated through thermal performance, natural ventilation, natural lighting, sun control and sound control in double skin façade systems. To be able to have improved thermal performance in DSF systems, the capability of the air cavity and the shading devices positioned within the cavity as well as the openings that enable the air circulation on the internal glazing play a significant role. In addition, the use of spectrally selective glazing enables enhancing sun heat transmission, and this makes the selection of the glazing extremely critical for DSF systems. The natural airflow of the cavity mostly depends on climatical conditions. The naturally ventilated façade can be utilized as an air insulation space for an acclimatized inner space and can supply opening for bringing fresh air for indoors. An expanded glazed surface of double skin facades enhances the admittance of natural lighting to the indoor. Another important essential of natural lighting for indoors is the ratio between floor height and floor area. Solar control can be provided with shading devices and by accurate calculations on sun and optical properties of the selected materials. Few others scholars studied the effects of an extra absorptive material hooked on the buffer zone to improve sound insulation concerning the acoustic assets of naturally ventilated double skin facades.

In this section of the thesis, the advantages and disadvantages of the DSF concepts were highlighted. With respect to the common understanding of the scholars, lower construction cost, acoustic insulation, thermal insulation, nighttime ventilation, energy savings, reduced environmental impacts, better protection of the shading or lighting devices, reduction of the wind pressure effects, transparency in architectural design, natural ventilation, thermal comfort, fire escape and low U-value and g-value are listed as advantages. On the other side, higher construction cost, fire protection, reduction of floor area, additional maintenance and operational costs, overheating problem, increased airflow speed, increased weight of the structure, daylight, and acoustic insulation are listed as disadvantages of DSF.

6.1.3 Findings of the Ranking Analysis

In the first step of the assessment method, double skin façade components and various type of glazing performances investigated and ranked according to cross-scale. Consequently, performance values of each component can be found according to their objectives such as thermal comfort, natural ventilation, natural lighting, sun control and sound control. Throughout this phase, functional values of all specified double skin façade components have been stated for each objective that double skin facades system should respond.

In the second step of the evaluation method, according to the comparison between the main objectives of the double skin façade related to the occupant comfort. Their dependent values have been granted as thermal comfort 40%, natural ventilation 20%, natural lighting 15%, sun control 15% and sound control 10%.

In the last step of the evaluation, overall (the minimum and maximum functional values) and average (the functional value of a DSF component according to the min. and max. functional values) performance values of the DSF components have been conceded. Consequently, relatively minor samples are not able to reach comfort level for occupants. However, most of the samples offer the average comfort zone for the occupants. Nevertheless, the appropriate combinations of the components according to the needs can improve the comfort zone.

6.2 Recommendations for Future Studies

Various decisive arguments can be accentuated for future studies. These are listed below as;

- There were certain challenges for finding out statistical values, proposed assessment method can contribute more wisely by using the actual data through experimental environment, which may allow more definite results.

- In the study, functional/performance values of various DSF components for several objectives are ranked individually, but in an experimental environment, different combinations and configurations of numerous components can be tested together as a system.

- It is relevant to investigate application of different components instead of using only one component for all objectives of DSF. These components application can be selected through their functional values for different objectives, therefore, can create more flexibility to provide occupant comfort for indoors.

- Giving dependent values for objectives may show variations according to external conditions of the specific site and orientation of the facades or functions of the indoor spaces. Hence, the designer should decide the dependent values of the objectives on the initial design phase accordingly.

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