DOUBLE-SKIN FACADE OPTIONS FOR OPTIMUM DAYLIGHT QUALITY: AN OFFICE CASE IN İZMİR

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ABSTRACT

DOUBLE-SKIN FACADE OPTIONS FOR OPTIMUM DAYLIGHT QUALITY: AN OFFICE CASE IN İZMİR

DSF buildings have been designed and used mainly for the purposes of improving human comfort and decreasing energy consumption in new and renovated structures. However, there has been scarce studies in literature concerning daylighting in DSF buildings in comparison to thermal and ventilation systems. Actually, lighting is responsible for %30 to %40 of all the energy utilized in office buildings. This value is remarkable to take into consideration the daylight efficiency of DSF building at the design phase.

This study examines the effect of double-skin facades system variables on daylight performance. In accordance with this purpose, an office in Izmir Institute of Technology (Iztech) has been selected and primarily, it has been tested to measure the reliability of the daylight simulation software (Relux) to be used. Later, the effect of the second skin on daylight performance has been analyzed by comparing single skin glass curtain wall and double skin facade simulations. Various components generally used in the double-skin facades have been detected and their effects on daylight level have been studied. These components are glass types, replacement of internal and external facade layers and the depth of cavity. The simulation findings have been distributed to various comparison groups and the ratios of meeting 300 lx – 500 lx value suggested in office buildings have been analyzed.

When the obtained results are examined, it can be understood that the daylight can be used at an optimal level with some interventions that can be applied in the design process of the double-skin facades.

ÖZET

OPTIMUM GÜNIŞIĞI KALİTESİNİ SAĞLAMAK İÇİN ÇİFT CİDARLI CEPHE SEÇENEKLERİ: İZMİR'DE BİR OFİS ÖRNEĞİ

Günümüzde, çift cidarlı cephe sistemleri yaygın olarak kullanılmaktadır. Bu cephe sistemi, doğal kaynakları etkili kullanarak insan konforunu artırmakta ve enerji tüketimini azaltmaktadır. Literatürde mevcut çift cidarlı cephe sistemlerini incelediğimizde öncelikli olarak havalandırma tüketim değerlerini azaltmaya yönelik tasarlandığı ve günışığının etkin kullanılması üzerine yeterli çalışma yapılmadığı görülmektedir. Ofis binalarının enerji tüketim değerlerine baktığımızda kullanılan enerji 30% ile 40% oranında yapay aydınlatma için kullanılmaktadır. Bu tüketim değeri göz ardı edilemeyecek kadar yüksektir ve çift cidarlı cephelerin tasarım aşamasında göz önünde bulundurulması için araştırılmalıdır.

Bu çalışma, çift cidarlı cephelerin sistem değişkenlerinin gün ışığı performansı üzerinde etkisini incelemektedir. Bu amaç doğrultusunda, İzmir Yüksek Teknoloji Enstitüsü Mimarlık Fakültesi'nde bulunan bir ofis seçilmiş, kullanılacak günışığı simülasyon programının (Relux) güvenilirliğini ölçmek için simülasyon sonuçlarıyla saha ölçümleri karşılaştırılarak test edilmiş ve sonuçlar tutarlı çıkmıştır. Daha sonra tek katmanlı cam giydirme cephe ile çift cidarlı cephe simülasyonları karşılaştırılarak gelen ikinci cidarın günışığı performansı üzerindeki etkisi analiz edilmiştir. Çift cidarlı cephelerde genellikle kullanılan farklı bileşenler saptanmış ve bunların aydınlık düzeyi üzerindeki etkisi irdelenmiştir. Bu bileşenler, sistemde kullanılan cam çeşitleri, iç ve dışta bulunan cephe katmanının yer değiştirmesi ve iki cidar arasındaki hava boşluğudur. Benzetim bulguları farklı karşılaştırma gruplarına ayrılarak ofis binalarında önerilen 300 lx – 500 lx değerini karşılama oranları analiz edilmiştir.

Elde edilen sonuçlara bakıldığında, Çift cidarlı cephelerin tasarım aşamasında yapılabilecek bazı müdahalelerle günışığından optimal düzeyde fayda sağlanabilmektedir.

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CHAPTER 1

INTRODUCTION

1.1. Argument and Theoretical Frame

Worldwide awareness about energy efficiency and sustainability in building industry presently focuses on double skin facades (Cheung, 2005). With the development of reinforced concrete and steel construction systems, the outer walls ceased to be an element of the load-bearing system, and became the elements that divide the interior and exterior. Moreover, these systems establish the relationship between the interior and exterior of the building in the best way, providing energy efficiency as well (Alakavuk, 2010). In other words, double skin facades combine transparent facade of the modern buildings with energy efficiency (Karim, 2011). Nowadays, DSF systems are being designed to primarily reduce energy consumption; as well as it improves aesthetics, acoustics, thermal insulation, natural ventilation and wind pressure effect reduction (Shameri et.al, 2013). However, daylight quality pay less attention during Double skin facades system design process. Recently, many office building designed with DSF systems, thus, examine the optimum daylight quality for offices on these systems is really important case. The aim of this study is to review the literature from the last decade of studies about Double skin facade in office buildings design and figure out new double skin facade options take consideration optimum daylight quality.

In literature, double skin facades are defined frequently. For example, Belgian Building Research Institute defines DSF as a system forming one active facade or more layers. It can be either impermeable or air penetrable. Active or passive ventilation systems are integrated with each other. Claessens and DeHerde state that second skin is an addition to an existing surface and this additional surface is mostly transparent. In addition, the buffer zone between two layers isolates the building. The heated air at the buffer zone is used for heating purposes. According to Compagno (2002), the double skin facades are formed by editing facade with glass. Sun breakers are placed in the gap between the two surfaces. Those gaps protect the structure from bad weather conditions and air pollution. Another perspective for defining the concept of DSF systems was suggested by Hendriksen (2000). He asserts that purpose of designing double skin facades is generally to obtain transparency through large glazed openings. In addition, double skin facades vary in terms of internal ventilation methods and decreased energy consumption of the building (Shameri et.al, 2013). Steiff Factory built in 1903 in Giengen, Germany go down in history as being the first building with DSF. The building was designed as a toy factory by the owner's nephew, Richard Steiff. The leading factor in design is to benefit from daylight as much as possible despite the cold climatic conditions (Crespo, A. M. L, 1999).

As a continuation of DSF, Otto Wagner's Post Office Savings Bank in Vienna in Austria was built between 1904 and 1912. The building has a double skin skylight above the main banking hall. By the end of the 1920s, the double skin facades were improved. In 1928, Moisei Ginzburg used double-skinned facade at the Narkomfin building of mass housing in Russia. Le Corbusier also designed Centrosoyus in Moscow, and a year later he built Cite de Refuge, 1929 and Immeuble Clarte, in Paris, in 1930. Until the late 1970s and early 1980s, the double skin facade systems were not very much developed and used (Poirazis, 2006). However, after energy crisis occurred in 1970s, effective use of natural resources has gained great importance, and the idea of sustainability were born. In connection with this advancement, double skin facade systems become a trend again, because they combine natural sources and technologies with aesthetics (Khoshroonejad, 2010).

A DSF system may have positive and negative effects compared to single facade systems. Positive effects of DSF minimizing heat losses due to the facade, allowing to open the windows even in the upper floors of tall buildings and it reducing air conditioning systems consumption in terms of cost and power. Moreover, a DSF serves better sound insulation compared to a single-skin facades, and consume less energy than the single-skin facades. On the other hand, negative effects of DSF are high construction cost, lack of ventilation between two facade layers, reduction of available space for offices, disintegrated sound between layers, and extra energy load as a consequence of layers' ventilation (Ünal, 2006).

1.2. Problem Statement

Interest of fully glazed, transparent facade has risen lately as architects and clients embrace the style and construction methods have made it possible. The planned utilization of natural light in office buildings has turned into a vital procedure to improve energy efficiency minimizing lighting, heating, and cooling loads. Daylight can be utilized to reduce lighting energy use and the heat gains associated with electric lighting. The effective usage of daylighting can dramatically decrease the total electricity load. In multi-story buildings, 40% of total heat loss takes place due to the building skin. Double skin facades (DSF) are one of the techniques used for avoiding from heat loss and commonly used in office buildings. The double skin facades have been developed for minimizing energy losses and benefiting from the energy used in the buildings at a maximum level. This system provides heat losses reduction by providing ventilation, and it enables to receive maximum amount of daylight (Oesterle et al, 2001).

Use of daylight is the strategy for low energy consumption in modern architecture. Also, its benefits extend beyond architecture and energy. It affects human health and worker performance positively (Waldner et al., 2007). Sun daylight illumination is variable between 5000 lx and 40000 lx according to different sky conditions. These values are more prominent for satisfactory indoor lighting requests. Average indoor horizontal illuminance should be between 300 lx and 500 lx for workspaces (K. Robertson, 2004).

Studies regarding the use of daylight in buildings have a significant role in the field of architecture. When direct daylight is properly designed as a light source in buildings, it creates dynamic spaces which supports human health, and reduces the energy consumption of the building. Double skin facade systems have high transparency levels. Because double skin facade has more glass surface, it also expands the possibility of natural lighting. So, with the increase in the amount of transparent surface, you can reduce the costs of artificial lighting by utilizing the maximum degree of sunlight (Arons et. al, 2000).

In the designing process of double skin facades, the importance of optimum daylight quality must be taken into consideration. Sunlight taken into building must be under control. If sunlight taken into the building remain uncontrolled, it can produce glare and excessive heat. Glaring is a disturbing sensation caused by high or non-uniform distributions of brightness in the field of view. The physiological mechanisms of glare discomfort are not well understood. Assessment of discomfort glare is based on size, illuminance, the number of glare sources, source-task-eye geometry (or glare source locations within the field of view), and background luminance (Ruck, N, 2000). On the other hand, taking less daylight into the building causes to problem such as high rates of energy consumption because of the utilization of artificial lighting alternatives (Ghonimi, 2017). In past, primary reasons for the invention of double skin facades were to obtain better daylighting performance (Crespo, A. M. L, 1999). Studies about the use of daylight in DSF systems in office design has an important role in the field of architecture. However, daylight strategies in DSF building studies are quite rare. Daylight performance of DSF has received less attention compared to the thermal and ventilation performance, and only a few studies were conducted in this field. Although all of these arguments are legitimate and have important empirical support, more research is needed to understand the most efficient daylight strategy in DSF buildings.

1.3 The Purpose of Study

The available literature concerning DSF systems neglects to provide an optimum solution for daylighting. Thus, the purpose of this study is to examine several DSF system variables which has an effect on daylight performance while designing a double skin facade. Objectives can be stated as follows; (i) to measure the illuminance of an actual office space with Relux and to analyze accuracy of Relux comparing the simulation results with real measurements of office space; (ii) to test the impact of glass types and configurations used in DSF system on illuminance; (iii) to analyze DSF depth of cavity effect; (iv) to analyze DSF layers orientation.

To achieve these purposes, firstly, a simulation of existing office space was prepared and field measurement numbers were compared for validation. After that, several DSF system variables were modeled and illuminance simulations with ray-tracing method were run to better understand glass type, depth of cavity and glass configurations effect at an case study office building in İzmir. In future studies, different variables, as well as DSF buildings located in various places can be evaluated.

1.4 Disposition of Thesis

The overall outline and thesis method are discussed briefly in this section. The remainder of the thesis is organized as into six sections which the first one is Introduction. The first section gives a brief overview of double skin facades importance of efficient usage of daylight at office buildings. According to this informations, necessity of study presented clearly.

In the Chapter two, related literature about history of double skin facades, previous studies about double skin facade systems and daylight strategies of double skin facades at offices are described. Furthermore, double skin facade classification described and some examples given by figures from previous studies.

In the Chapter three, firstly accuracy of simulation software (Relux) was tested by case study office which is choosen at Izmir Institute of Technology (Iztech) Architecture Faculty. These test showed field measurements and simulation outputs results are accurate. Following the validatation part, main simulation setups constant and variable parametres defined respectively. Constant parametres are location, orientation of building, model geometry, surface properties, date and time examined clearly. Variable parametres which are depth of cavity, shading devices, glass types and layer orientation were introduced.

In the fourth chapter, the daylight comparison of double and single skin facades is the first step towards understand how the different type of facade effects the distribution and availability of daylight. Then double skin facade setups simulations were made according to different variables and results presented. In order to understand the effects of depth of cavity, different glazing types and layer orientation. Simulation outputs were separated into different comparison groups and outcomes were obtained with the help of line graphs and bar charts. In the last part of this chapter, an optimal double skin facade design suggesting according to all simulation results.

In the Chapter five, several DSF system variables effect on daylight performance while designing phase is obtained with make comparisons previous studies in the literature. The contribution of this study to the literature is clearly indicated in the last part of this chapter.

Last chapter, summarizes the results of this work and draws conclusions. The thesis summarized briefly, limitation and delimitation of study and some future research suggested.

CHAPTER 2

LITERATURE REVIEW

In literature phase, explanations about the history of Double Skin Facades, their technical charaterization and components; and daylight strategies are summarized through previous studies and existing knowledge.

2.1 History of Double Skin Facade

Double Skin facade (DSF) buildings have been developed and used in both new and renovated buildings to increase human comfort and decrease energy consumption (Khoshroonejad, 2010). Since the 20th century, the outer shell is not use for only protection; it also includes an aesthetic understanding and energy efficient. The size, form and number of windows are not limited by the structure as before. The first building with double skin facade system was the Steiff Factory Building, except vernacular architecture. It was built in Giengen, Germany (Alakavuk,2010) (Figure 1).

Figure 2.1. The Steiff Toy Factory in the illustrated catalogue of the Eisenwerk München AG in 1905 (Source:Fissabre and Niethammer, 2009).

The structure was designed and implemented as a toy factory by Richard Steiff in 1903. Factors affecting the design of the building, the desire to benefit from the maximum light from the day, the climate conditions and the strong winds in the region is the desire to protect the structure. Building have three floors, the ground floor used as a building warehouse, the second and the third floors used as working areas. Building is 30m long, 12m wide and 9.4m high, and its' outer shell consisting of a continuous double skin facade with flat roof. The building's external cover was an innovative construction consisting of a double skin facade of total floor-to-ceiling glazed. The interior glazing of this facade extends from the upper edge of the floor to the lower edge of the ceiling, whereas the exterior facade covers the building's total height. Glazed facade carry just wind pressure and its own load. This building system is very primitive and underdeveloped compared to lately doublu skin facade systems (Alessi,2008). (Figure 2)

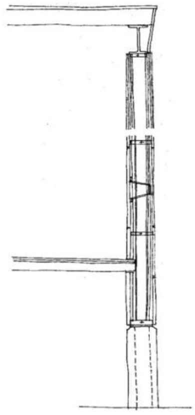


Figure 2.2. Steiff Factory facade section (Source:Alessi, 2008).

The main design purpose of building is maximum benefit from daylight for reduction of electricity consumption and thoughts about well illuminated working area could raise productivity. However, government planning authorities concern about workers go blind in a glass house. Thus, certain drapes located facade corners for protect workers from excessive sun radiation in summer, which is called glare. The gap between the two surfaces of the shell -which is called cavity lately - is 25 cm. There are inspection hole in various places for maintenance and repair of system (Streicher, 2007) .

Double skin facades continued with Post Bank building which is designed by Otto Wagner, Vienna in 1904. It was built in two stages between 1904-1912. There is a double skin skylight above the main hall of building. Steel structure was used for connecting glass and aluminum skylight. Skylight designed as double skin for minimizing heat losses. The building renovated in the '70s for improving lighting, new air-conditioning ducts and changing functions of the building. However, skylight is standing still as originial double skin system (Poirazis 2006).

Figure 2.3. Post Office Savings Bank interior view (Source:Mathur, 2010).

In the late 1920s, the double skin facades were further developed and used in more buildings for aesthetics priorities. (Streicher,2007) Moisei Ginzburg, made experiments in the use of double skin facades during construction of the Narkomfin housing project in Russia, 1928. The main facade of the building consists of two skins. The purpose of using the DSF system is to minimize the heat losses of the structure in the building. According to this aim, the system has been developed by adding windows to both sides of the system. Although the structure has been largely destroyed over the years, it is still being used (Haspel, 2007).

Double skin facades were developed by gaining new priorities such as aesthetics, decreasing cooling and heating loads. If double skin facades designed in properly, it is possible to satisfy all occupant requirements in terms of cooling, heating, lighting. (Fissabre et al., 2009). Le Corbusier is one of the architects who led the development of this system. Le Corbusieur used the double skin facade system in a building called Centrosoyus in Moscow at 1928. Approximately one year later, he used double skin facade systems in facades of Cite de Refuge and Immeuble Clarte projects. The most important difference that makes this system different from the others is the natural ventilation of the space between the building surfaces.

Double facade systems were not extensively developed and applied until the late 1970s and early 1980s (Poirazis,2006). Environmental and human factors were largely rejected until the energy crisis at 1973. With the emergence of energy crisis in 1970s, it has been tried to reduce the use of fossil source energy such as petroleum, coal and natural gas as much as possible and to use renewable energy sources such as solar, wind and geothermal energy. According to this development, double skin facade began to gain importance. Double skin facades are preferred because they use renewable energy sources, reduce the energy costs of the building and even produce some of the energy required for the building with the use of photovoltaic panels in some applications. The concept of DSF has been developed day by day due to increasing demand. (Alakavuk, 2010)

In the period between 1970-80 's double skin facade systems in modern architecture became trend again. The examples given in this study are composed of the buildings which are designed as efficient daylight performance. The first modern version of building which is incorporated Le Corbusier’s DSF Concepts was built in this process by Cannon Design is the Occidental Chemical Center office building in New York.

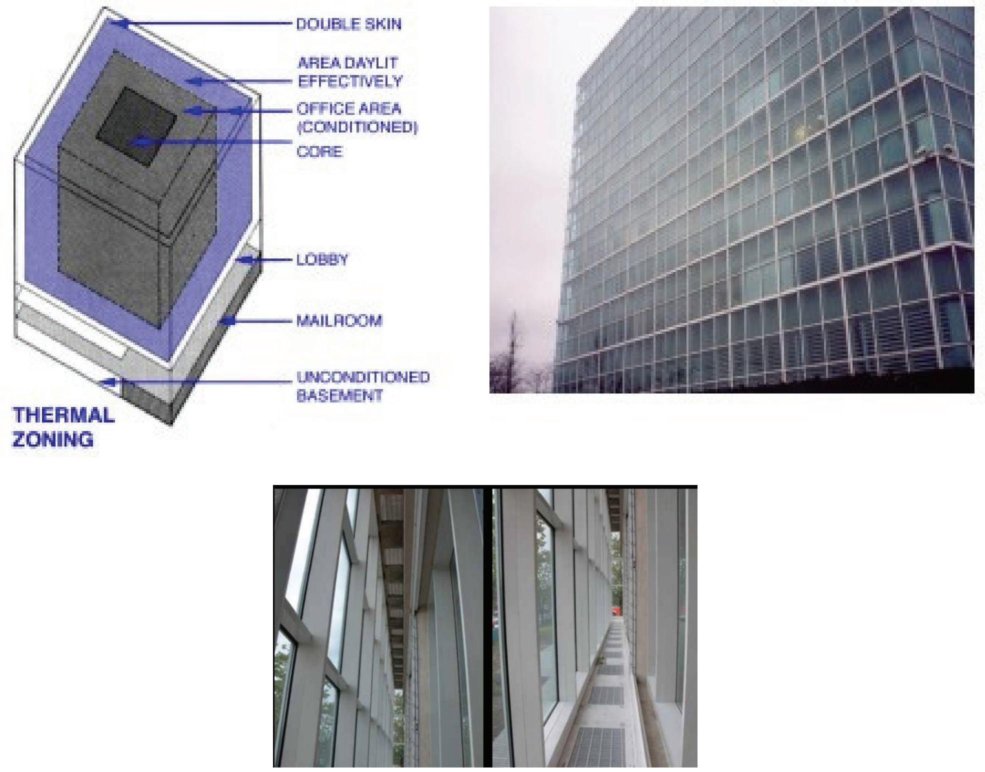


Figure 2.4. Occidental Chemical Center (Source:Harrison, 2003).

In the building, the gap between inner and outer layer is 30 cm. Venetian blinds placed in front of inner layer for protect people sun’ negative effects such as glare. Ventilation chimney helps to exhausting of heated air from building. Accordingly, this natural air movement the gap between the sides is naturally ventilated (Harrison,2003). Most studies stated that this building has the first real double skin facade.

By continuous the examples in the historical process of double Skin Facades, The Lloyd"s Building designed by Richard Rogers in London in 1978, it was completed in 1986. In the middle of the building, there is an atrium with 14 floors and 76 metres. The ventilated facade consists of 3 layers of solar-controlled windows which is allow the reflect artificial light from the interior. (Chang et.al, 2011).

In the 1980s, Europe and The USA government give incentive bonus energy efficient buildings. Thus, there is an increase the choice of double skin facades due to this state support. By the 1990's energy costs were limited by regulations in some European countries. It is observed that double skin facades used in high-level buildings without exception. The most prominent building among these buildings is the Commerzbank Building in Frankfurt, designed by Norman Foster at 1994. It is one of the best example of low energy cost building.

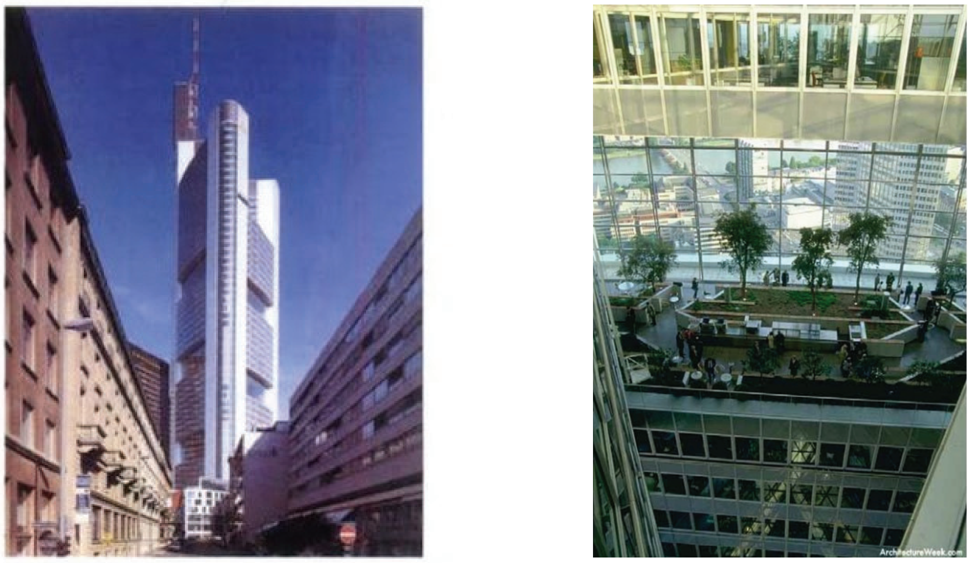


Figure 2.5. Commerzbank interior and exterior view and section of floors (Source:Gissen,2002).

The building has rounded equilateral triangular plan, there is a central atrium (garden) which have double skin facade. Ventilation and lighting are provided by the this atrium. Every office in the tower is daylit and has openable windows. This provide the occupants to control their own environment under external conditions. Design results half of energy consumption at the tower.

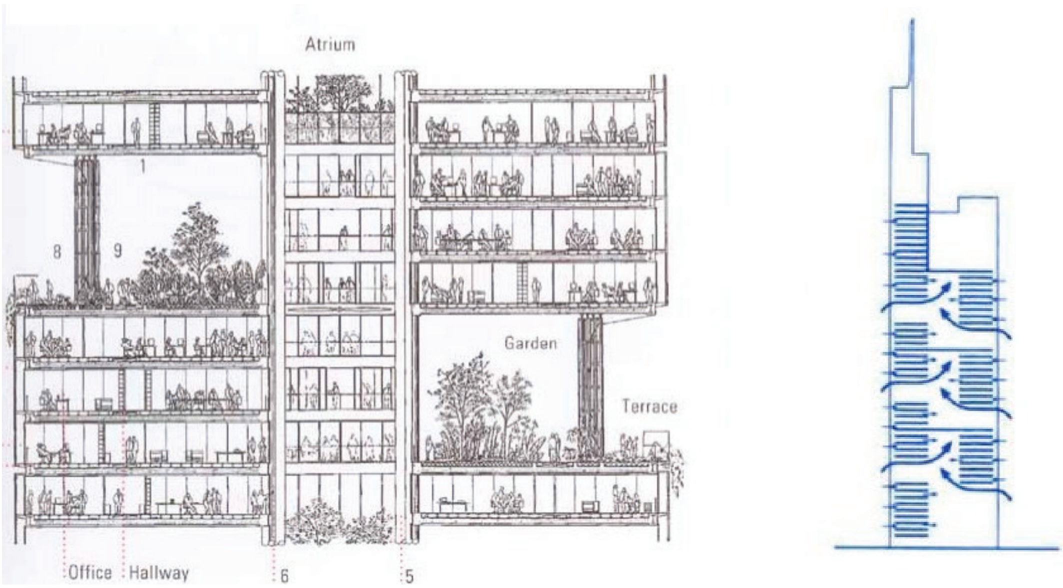


Figure 2.6. Commerzbank section (Source:Daniels,1997).

Plan consist of three section as an arm shape. There is an central triangular atrium which is beyond height of the building. Central triangular atrium run the height of building, Each 12 story standing like village and it consist of four story section. Each section holds a four level high open sky garden that changes orientation from one arm of the triangle to the next at every section, spiraling the height of the building until it reaches the top of the building on the 60th floor. This double skin building (Gissen,2002)

Another classic double skin facade building would be RWE AG Tower in Essen, Germany, which was designed by Ingenhoven and Overdiek Partners. The building cavity closed vertical and horizantal at each story and both outer and inner skin is openable for cleaning purpose (Boake, 2003). DSF cavity is 500 mm. Louver blinds located mid of skins and it remotely controlled. The blinds are protected from the wind and rain by the outer facade and avoid heat transmitting to the room. Also, it helps shading and decreasing heat reflection. In addition, the interior facade contains a set of roller shades made of fireproof cloth (Bayram,2003).

A special window frame was designed for this building which is called "fish mouth". This window has special holes between the coats for providing air inlet and outlet. The air taken into the "fish-mouth" is heated at the gap, and the rising air is thrown out of the fish-mouth window frame (Figure 2.7). The direction of the fish- mouth must be cross changed to prevent the excreted dirty air from being sucked back from an upper floor (BBRI, 2004).

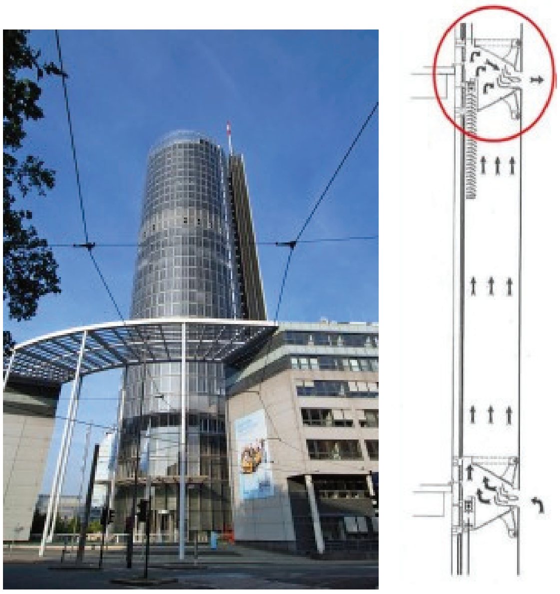


Figure 2.7. RWE AG Building Exterior and Fish-Mouth Window Detail (Source:Wigginton,2002).

Berlaymont building was first built in the 1960s. In the mid-1990s, it was seen that the Berlaymont building needed a complete renovation, due to the outdated infrastructure, sealing and insulation problems, the lack of daylight and a large asbestos threat. Thus, The European Commission has indicated a number of sustainable improvement criteria: First, the original structure must be protected as much as possible. Second, the building should be a turning point in terms of energy efficiency by using renewable building, ease of maintenance and optimum natural light access to the building (Figure 2.8).

Figure 2.8. The Berlaymont Building in Brussels, Belgium, with moveable glass louvers as the outside facade layer (Source:Beckers,2000).

According to this requirements building designed as an double skin facade. The interior of the facade is made of silicon-filled insulation glass with full floor height, while the outer part has 21.000 m2 movable glass blinds and metal bottom structure located (Figure 2.9). There is an automation which is connected air sensors to move louvers. The facade shutters changes the position depend on the position of sun, temperture and wind speed. This providing proper natural lighting inside the building and protect building from overheating (Klosowski, 2017).

Figure 2.9. The Berlaymont Building in Brussels, Belgium, exterior views (Source:Lancour,2005*)*.

Building external skin is made of a whole of suspended frameworks on which are fixed the glazed plates (200 cm out of 50 cm). Thickness of glazed plates changes between 8 mm to 12 mm according to wind pressure.Exterior skin have 2 glass leafs which enclose a multi-layer perforated whit film for better reflect the light. On the Interior skin the louvers prevent a dark face to allow visibility through inside. In fact, because of the contrasts between luminosity , the view from within to the outside is possible, but otherwise impossible (Lancour,2005).

The last 30 years, there are many buildings designed as double Skin, around the world according to previous studies on improving the performance of DSF systems. In fact, this system is landmark of the architectral and technological design with energy efficiency.

2.2 Technical Aspects of Double Skin Facade System

Double skin facades consist of several different functional levels; the outer pane, the inner pane and the space between this panes which is called cavity. The main components of all double skin systems can be listed as follows:

1- Outer shell

2- Cavity (buffer zone)

3- Inner shell

4- Shading devices (R. Waldner et al., 2007).

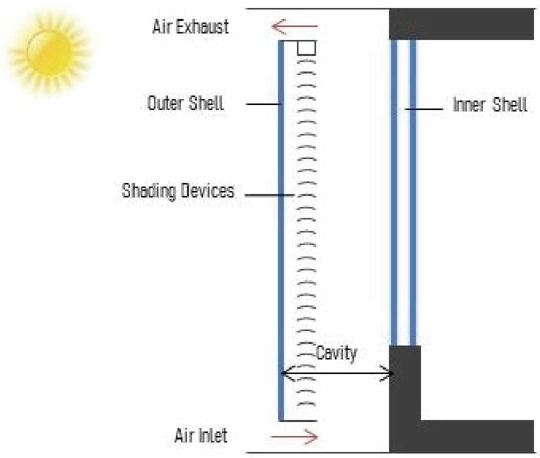


Figure 2.10. Double Skin Facade system components.

The glass properties used in the double skin facades affect both the heat permeability and the taking of sunlight into the building. According to increase in glass surface area also increased the possibility of natural lighting. Thus, direct sunlight can cause some problems such as glare. Shading devices used for avoiding this kind of problems and get in sunlight into the buildings controlled. Another system feature can be stated as ventilation system (Hamza, 2008). However, the subject of this study is related double skin facades of daylight performance, ventilation system consciously ignored.

The energy efficiency performance of the double skin facade may vary due to configuration differences (Meyer,2003). In general, options for system configuration include the following;

- Size and depth of space (cavity)
- Applied facade type
- Glass layer properties and layout
- Shading device features and location
- Ventilation system

2.2.1 Cavity

In double skin facades; cavity can be closed entirely which is called buffer mode. Another alternative is external air curtain mode which is naturally ventilated with the top and the bottom opennings open to outside (Kalyanova et. al, 2009). The buffer zone between the two shells can be thought of as the new external environment of the construction environment and significantly affect the indoor climate (Tenhunen,2000). Cavity can be used for natural, fan supported or mechanical ventilation strategy. The glass skins consist of single or double glazing layers with a distance from 20 cm to 200 cm. Distance of between two layers can vary according to design strategy. Cavity dimension effect sound insulation and daylighting transmittance (Åke,2007). Sun shading devices located at the cavity for improving high transparent facade performance. The presence of shading devices in the cavity, make easier their maintenance and cleaning, and hence the dust effect that reduces the performance of these components can be reduced. (Gavan et. Al, 2008).

Another important criterion in the size of the cavity is; in the cases where the cavity size is more than 50 cm, it is possible to walk on the cat walks placed in the cavity for cleaning and maintenance of the facade layers. This ensures that maintenance and cleaning are carried out comfortably. In cases where the gap size is less than 50 cm; the glass in the inner layer design openable for the maintenance and cleaning of the facade. However, this design increases cost of facade (Kocaman, 2002).

2.2.2 Glass Type

Glass can be defined as; inorganic based, amorphous structured,material which does not have a fixed melting point, fluent at very high tempertures, shows the properties of liquids and act like solid without crystallization at normal temperatures, silicate system (Toydemir, 1990).

Starting from second half of the 20th century innovations start on glass processing. As a result of this development, glass is no longer just a material used in windows. It became a structure shell which can provide heat and sound insulation, control the brightness of the sun and protect building agains the external factors. Choose of glass depending on the needs of the building. Glass can be define in terms of visual comfort; providing adequate level of illumination, avoiding glare and provide sufficient visual relationship with the outside. In addition, the glass must comply with the minumum energy consumption (Ünal,2006).

In the selection of the type of glass the factors to be considered in terms of solar control which are; total heat transfer coefficient (U Value), heat transmittance resistance (R), solar heat gain coefficient (SHGC), light transmittency, light reflectance and shading coefficiency.

Consideration of the selection of glass; the number of glass layers, the gap width between these layers, the type of gas used in the cavity, the type of glass(Reflective, float, low-e, tempered) and colour of glass. However, when evaluating the lighting performance, it is only the color and the type of glass effective in these matters. Because they affect the light transmittancy (İlhan,2005). The types of glass used in the facades are as follows;

a.Float Glass

The surfaces of the flat glass are extremely smooth, undisturbed and bright, and there is no need for any further polishing or similar treatment. Float glasses can have a thickness between 2-19 mm. The largest dimensions are 3.20 m x 6.00 m and the smallest dimensions are 1.50 m x 1.00 m. They are produced in such a way that they provide perfect visual perception without any problems with lighting such as glare. The float glass can be produced with metal oxide coating, so that the amount of light reflected back can be reduced by up to 1%. The metal oxide coating is formed by re-baking the float glass after immersion in the pool of metal oxide components to be coated. The glasses obtained in this way can be resistant to thermal insides, moisture and chemicals (Ünal,2006). Float glass have high daylight transmittency values. Besides of that it have poor performance at heat insulation (Table 2.1).

Table 2.1. Ultra clear float glass performance table (Source:Şişecam,2019).

Ultra Clear Float Glass	**Daylight (EN410)**		**Solar Energy (EN 410)**		
	Transmittance %	**Reflectance Outdoor %**	**Reflectance Outdoor %**	**Direct Transmittance %**	**Solar Factor %**
4 mm	91	8	8	90	90
5 mm	91	8	8	90	90
6 mm	91	8	8	89	90
8 mm	90	8	8	88	89
10 mm	90	8	8	87	88
12 mm	90	8	8	86	87

b.High Reflective Glass and Tinted Glass

High reflective glasses used for privacy and and obtain a homogeneous front view. This innovative glass combines a beautiful reflective appearance with excellent solar control properties. In flat glasses, solar control efficiency is expressed by the shading coefficient. It would be misleading to decide on solar control efficiency by looking only at the light permeability of the glass. If such coatings are applied to colored glasses, the shading coefficient can be reduced to a value of 0.22 in single glass applications. Parallel to this, the light permeability is reduced to an extremely low value of 0.08. For this reason, while increasing the daylight control efficiency of high reflective glasses, it must be considered not to deviate from the intended use. On the other glass type is tinted glass. It's light transmittance varies from 14% (in a very dark gray) to 75% (in lightest tints) and 85% which is clear glass. High reflective glasses can be used as single glazing or insulating glass unit outside layer (Ünal,2006). High reflective transperent glasses values stated at below (Table 2.2).

Table 2.2. High reflective glass performance table (Source:Şişecam,2019).

Daylight (EN410)		**Solar Energy (EN 410)**				
Transmitt. %	**Reflectance Outdoor %**	**Reflectance Outdoor %**	**Absorption %**	**Direct Transmitt. %**	**Solar Factor %**	**Shading Coefficient**
Single Glazing - 4 mm						
34	44	31	24	45	51	0,59
Single Glazing - 6 mm						
34	43	28	29	43	51	0,59
Insulating Glass Unit With Clear Float Inner Pane						
31	44	30	36	34	42	0,48

c.Tempered Glass

This glass used for increasing resistance of the material agains pressure, impact and heat. After the glass is cut and roasted to the desired dimensions, it is being heated to close to the melting point and then quenching suddenly. When it broken, glasses divided into little pieces, and because of this feature, they are used indoors and in the outer layer of the double skin facades. Tempered glasses can be laminated, in order to increase safety even more. This kind of glasses dont have effect at daylighting transmittancy values and heat insulation. Tempered glass common usage at facades which are exposed to heavy wind pressures or intense heat or cold.

d.Insulating Glass

Insulating glasses widely used at DSF buildings for reducing heat loses and maximum daylight purposes. This glass consist of two or more panes of glass with an air gap in between. This air gap can be fill with different gases (Argon or Krypton) for more sufficient heat insulation. Insulating glass system can be made of reflective and low-e glass. Low-E glasses are produced by making a coating with a transparent metal and / or metal oxide character, which is capable of reflecting the outside or outside of the glass surface. They reduce the thermal conductivity coefficients of the glass surfaces.

Greenhouse effect can occur in summer, when transparent glass is used in dsf system. Low-E coated glass reflects the heat of the interior, reflected back to interior. Thus, in winter, the warm air kept in the interior and in summer, the cold air kept in the interior.According to this, amount of energy spent in the summer cooling of the building and in the winter the amount of energy spent in heating the building is reduced. By choosing Low-E coated glass at dsf systems, the greenhouse effect decreased and energy decreased for cooling . Solar Low-E reduce the temperature of the sunlight while get in daylight into the building. Low diffusion heat and solar control (Solar Low-E) coated glass provides thermal insulation in addition to the daylight control feature (Gratia et.al, 2007).

Low-E glass have a lower diffusive coating which is allows visible and invisible radiation energy (shortwave) get inside. Also, longer wavy radiation from room temperature energy of 85-95% backward reflecting the external environment and reduce heat loss (Table 2.3).

Table 2.3. Insulated glass double glazing performance table (Source:Şişecam,2019).

Product	Daylight (EN410)		Solar Energy (EN 410)	
	Transmittance %	Reflectance Outdoor %	Solar Factor %	Shading Coefficient
4 mm Clear Float Glass + 16 mm (cavity)+4 mm Şişecam Clear Float Glass	80	14	75	0,86
4 mm Low-E Glass + 16 mm (cavity)+4 mm Şişecam Clear Float Glass	78	11	57	0,66
4 mm Clear Float Glass+ 16 mm (cavity)+4 mm Şişecam Low-E Glass	78	12	61	0,7
(4+0,76+4) mm Laminated Low-E Glass + 16mm (cavity)+4 mm Şişecam Clear Float Glass	76	11	51	0,59
4 mm Clear Float Glass + 16 mm (cavity)+(4+0,76+4) mm Şişecam Laminated Low-E Glass	76	12	60	0,69
4 mm Low-E Glass + 16 mm (cavity)+4 mm Şişecam Clear Float Glass (*)+ 16 mm (cavity)+4 mm Şişecam Low-E Glass	69	14	49	0,59

Developments in surface coating is capable of responding to minimum heat loss principles and provides maximum light transmittance with high waveform reflection. Low-E lenses reduce the diffusion value of the glass surface from 0.87 to 0.04, thereby reducing long-wave radiation to 20% without decreasing light transmission (Compagno,2002).

2.2.3 Shading Devices

After the development of the DSF Systems, shading devices were placed in the space between the facade shells. Shading devices are used to block direct sunlight into the building or reflect back the unwanted sunlight through the building shell. The shading devices are placed in the cavity in order to control the solar heat gain on the double skin facades. The solar control elements are classified as fixed, hand-operated and controlled by the building automation system according to the operating principles. The wide-sized blinds are generally connected to the building automation system. By using shading devices, unwanted solar heat gain is controlled especially in summer and it has a positive effect on the cooling load of the building. Also, undesirable direct sunlight can controlled and avoid the glare. The sun breakers are usually placed close to the inside or outside skin of the building so that the building does not interfere with actions such as maintenance and repair on the facade during the process of use (Özler, M. E., 2003).

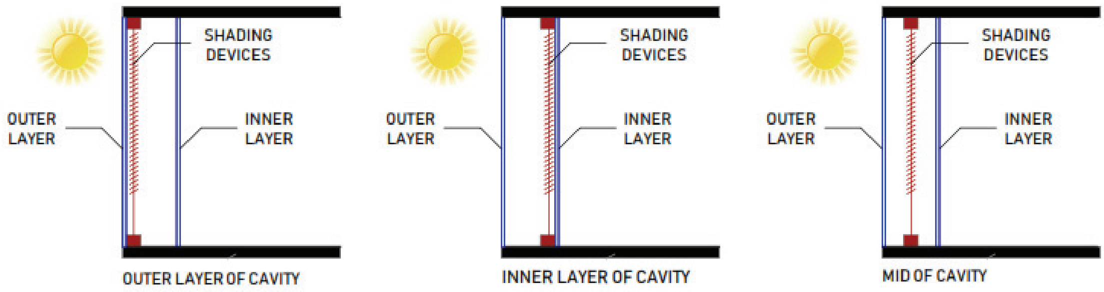


Figure 2.11. Blinds possible locations at double skin facades

To control the overheating, different types of shading devices should be used to control the heat gain of the space. Light-deflecting elements can be used for controlling the lighting which is high in summer and is a reason for the large part of the cooling load of the space (Compagno,2002). Oesterle underlined that, combination of glass and sunshading components must be studied while DSF building design phase (Oesterle, et al, 2001). Cavity physical behaviour can be change by blinds type, characteristics, position (external/internal/intermediate) and orientation (Santamouris, 2007). Three main types of solar control elements are used on DSF Systems.

a.Translucent Blinds

They are mostly made of fabric or plastic based material. It is used more frequently in the regions where the sun comes directly to facade for protect building excessive solar effect. They are placed into the cavity or inside of the inner shell. When they completely close they interrupt the visual relationship of the inside to outside.

In the Halenseestrasse Building which is designed by Hilde Léon and Konrad Wohlage, the fabric blinds placed on the inside of the outer shell protect the building from the direct sunlight and the sunlight get in building controlled (Örkmez, 2012).

Figure 2.12. Halenseestrasse Building shading device and cavity view (Source:Örkmez, 2012).

b.Louver Blinds

Fixed, mirrored louvers are mainly designed for direct sun control. Sun and skylight reflected by the louvers increase daylight levels in the interior. Nearly 10 ° to 40 ° above the horizon, the level of light of day from low - level skies (e.g. from the sky area) is reduced.It consists mostly of aluminum or wood. They are usually placed inside or outside of the inner shell. This shading system is used in the majority of double skin facades. Lamels angles can be variable depends on building location. Louvers can be fixed and mirrored. They control glare but reduce the daylight level (Nabil et.al., 2012)

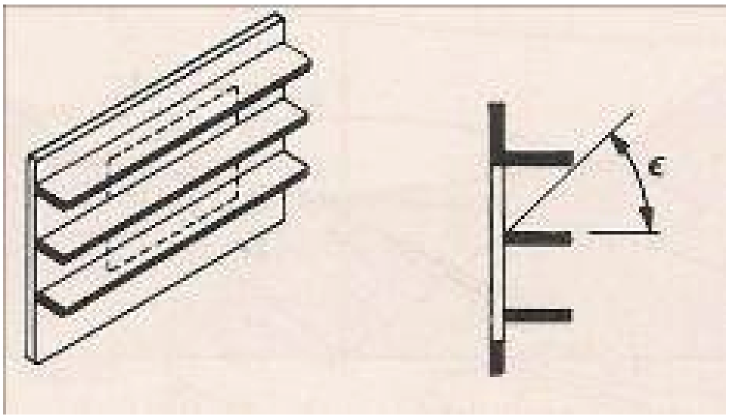


Figure 2.13. Blinds detail (Source:Nabil et.al., 2012).

The headquarters of the Götz building has venetian blinds placed between the layers which is controlling manually by occupants (Figure 2.14). In this building, the shading element is positioned close to the inner layer. This provide convenience in terms of cleaning and maintenance (Örkmez,2012).

Figure 2.14. Headquarters of Götz Building shading device and cavity view (Source:Örkmez,2012)

c.Louver Facade

Louver Facade can be defined as outer layer of DSF consist of moveable shading device. They can be made of perforated aluminum or glass (Alakavuk, 2010). Outer layer act like louver and protect building glare and excessive heat (Figure 2.15)

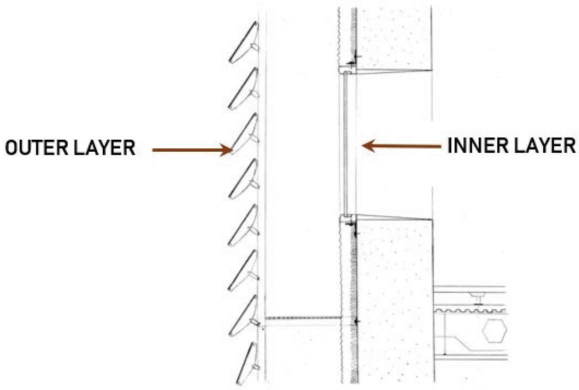


Figure 2.15. Louver facade section.

Jean Nouvel's Torre Agbar Building is good example of louver facade which is built in Barcelona, Spain. İnner and outer layer gap width is 50 cm. The outer skin is made of transparent and translucent horizontal layers of glass, which protect the entire structure against solar radiation and enhance the temperature of the interior (Figure 2.16).

Figure 2.16. Torre Agbar Exterior Views

2.2.4 System Layers Orientation

Generally, Double skin facade system outer skin consist of single glazing and inner skin have insulated glazing. However, the position of the low-e film layer in the glazing system changes as the need for heating and cooling purposes in different climate zones. In cold climates, the low-e film layer is placed on the outer face of the inner glass in double glazed systems. This positioning allows the outside solar radiation to enter the glazing system, thereby providing heat to the structure; The heat generated inside the interior environment is reflected back to the external environment due to its low diffusion and high reflective coating. It is placed on the inner face of the outer glass in hot climates and prevents the heat from entering from the outside by solar radiation and prevents overheating (Henderson et.al, 2010).

2.3 Daylighting Features of Double Skin Facade

DSF systems have high transparency levels. Their development changes the effective use of daylight with the increased amount of glass surfaces. Thus, with the increase in depth of space, it was possible to reduce the artificial lighting costs by taking maximum advantage of daylight (Aarons. Et.al., 2000). In addition, it is possible to contribute to the visual comfort in the interior environment by preventing glare. Daylight control is provided during the day due to sunscreens used in these systems, which are mostly horizontally selected and whose angles can be changed depending on automation and / or user control. It is possible to contribute to the visual comfort in the interior environment by preventing glare (Compagno, 2002).

In DSF systems, daylight performance can be improved by increasing the reflectivity level of glass, using colored glass or thin filmed layer glass. In summer, overheating can be prevented using spectrally selective windows which have optimimised absorption and reflectivity values (Daniels,1997).

2.4 Classification of Double Skin Facade According to Cavity Geometry

Double skin facades, adaptation to daily or seasonal climate conditions, minimizing the energy costs of the building using renewable energy sources, support the creation of the conditions required to achieve the user performance criteria. The amount of energy spent for the heating, natural ventilation, cooling and illumination of the building is reduced by the use of DSF systems. DSF systems are categorized into 4 groups according to the type of cavity, as listed below:

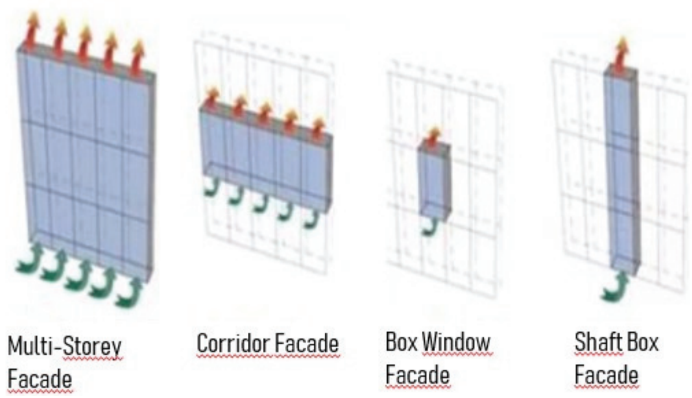


Figure 2.17. DSF System classification according to cavity (Source:Vaglio,2012).

2.4.1 Box Window Facade

Box windows are the oldest form of double skin facades which have close cavity horizontal and vertical at each floor. There is another skin which have single glazing window system applied in front of the inner skin. Generally, the gap between two layers is 200-400 mm.

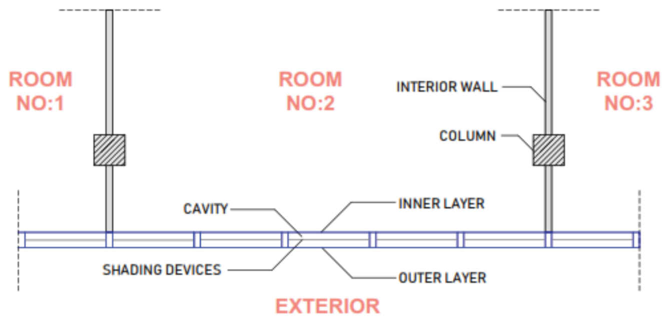


Figure 2.18. Box window double skin facade system plan

Cavity continues only at the window size; there is no connection between the horizontal and vertical windows on the other floors (Figure 2.18 and Figure 2.19)The distinction between these windows prevent sound insulation, block air and smell transfer. Box windows are preferred in buildings where is located noisy areas (Eisele, 2003).

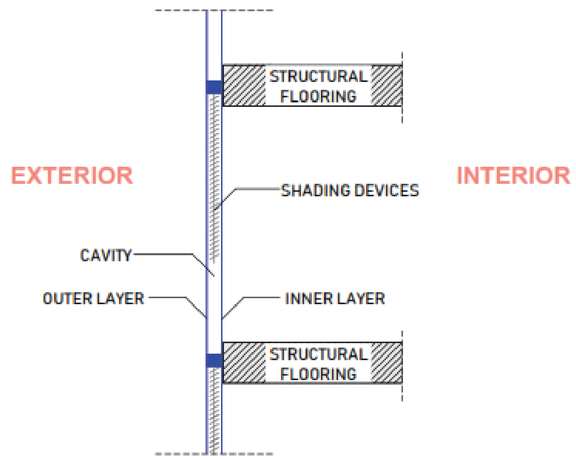


Figure 2.19. Box window double skin facade system section

The heat and chimney effect in the space is limited because of the height of the facade. If ventilation of the system made with external cold air, the heat of the inner shell causes problems such as mist depending on the external surfaces. In the case of high levels of direct sunlight, facade-mounted louvers reduce sunlight. Most of the energy is absorbed or reflected by the louvers. The ventilation of the space is provided by ducted air conditioning system. In this types of DSF system, all types of movable automatic blinds can be applied (Lancour,2005).

Eurotheum Tower Building, which was designed by Novotny Mahner Architects, in Frankfurt is a good example of Box Window Facade (Figure 2.20).

Figure 2.20. Eurotheum Tower building exterior view and blinds (Source:Ünal,2006).

The buildings cavity used for mechanical ventilation. The fresh air is taken from each hole of the facade covered with vertical metal pipes through holes of 75 mm diameter. Hot air is thrown out of the openings at the floor level. These openings are covered with blinds to prevent the entry of the birds and the rain. Facades inner skin consist on manually opened aluminum framed windows. Cavity is 340 mm which have venetian blinds located at mid-point (Ünal,2006).

Advantages of box type double skin facade systems are;

- The outer shell protects the inner shell against wind, rain and snow.
- The vertical and horizontal partitioning of the facade provides a good level of sound insulation.
- Depending on the type of partition, in the fire situation, flame and smoke do not spread into the entire front cavity.
- The interiors can be ventilated naturally by the windows located on the facade (Compagno, 2002).

2.4.2 Corridor Facade

Corridor Facade is one of the common types of DSF. In this type, the cavity is separated horizontally at floor by floor. Air exaust and air inlet located each floor and designed overlap one another. Due to the required on each floor ventilation openings and dividers, it is more complicated than multi-storey double skin facade. Thermal insulation, sound insulation and fire protection in the structure are better than other DSF systems (Oesterle, 2001). There is a catwalk located between inner and outer shell for maintenance and repair. The walkway in the cavity can continue in front of an entire floor without any vertical partitioning (Compagno, 2002).

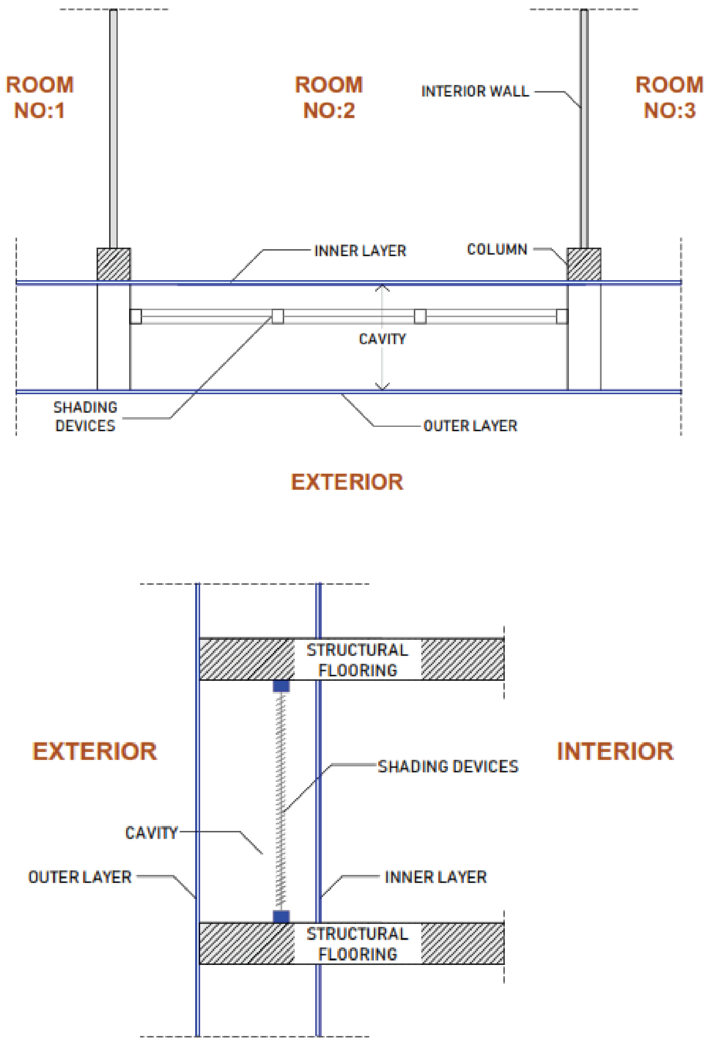


Figure 2.21. Corridor facade double skin facade system plan and section

Petzinka Pink and Partners' Düsseldorf City Gate building designed as a corridor type DSF system in 1997, Germany. The facade cavity is closed on each floor. Building have 16000m² double skin facade area. Air inlet and exaust are made adjacent to the ceiling and floor. The gap is divided at each floor level for avoiding circulation air between the layers. Building ventilated naturally most parts of the year (75-70%). However, when extraordinary weather conditions occured, mechanical ventilation activated. The whole building is enclosed in a glass skin. There is 56 m high atrium located at the center of the building. The outer shell consists of 12mm thick tempered glass. The inner layer consists of laminated low-e glass. The width of the two corridors is 90 and 140 cm. The blinds are connected to the outer shell (Poirazis,2006).

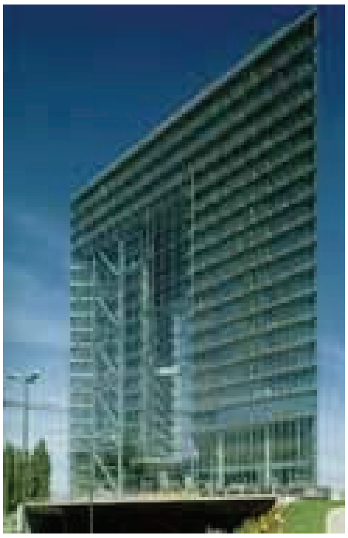


Figure 2.22. Düsseldorf City Gate (Source:Poirazis,2006)

Figure 2.23. Düsseldorf City Gate cavity views (Source:Poirazis,2006).

Feautures of corridor type DSF stated below;

• The outer shell protects the inner shell against the effects of wind, rain and snow.

• Solar control elements can be placed in the front cavity for protection excessive solar radiation.

• It prevents better sound insulation.

• To prevent smoke and flames from spreading in the event of fire, the frontal space can be partitioned vertically with divider elements (Compagno, 2002).

2.4.3 Shaft-Box Facade

Shaft box-type DSF consist of a combination of multi-storey DSF and corridor DSF system. The continuing air gap which is continuing building height act like as a “both sides of the vertical shaft. Even if there is no air flow in the external environment, the natural ventilation of the building is provided due to the chimney effect (Uuttu, 2001). Shaft-box facades are better than corridor facades in terms of providing natural ventilation. In this type, fresh air taken from under part of system between facade layers. Disadvantages of this system can be stated as insufficient fire protection, noise pollution and clean and dirty air mixing together when compared to the other DSF types (Oesterle et al, 2001).

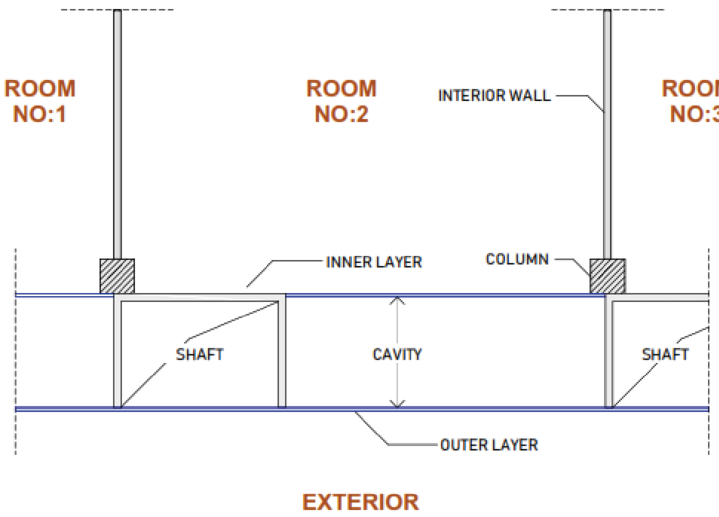


Figure 2.24. Shaft box facade double skin facade system plan.

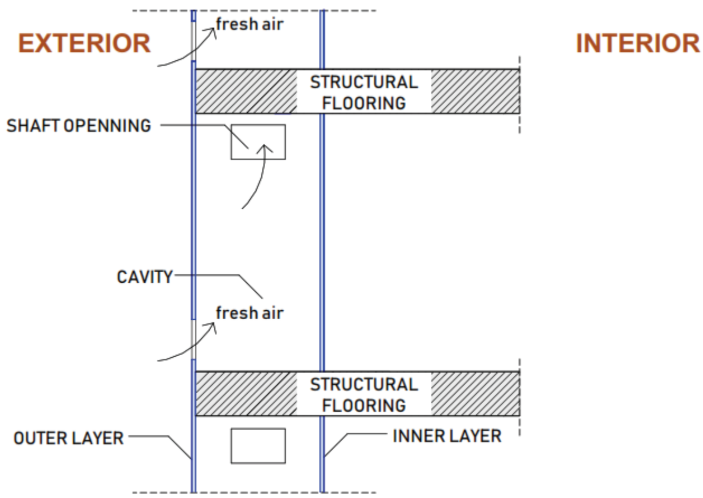


Figure 2.25. Shaft box facade double skin facade system section

Schrammer&Partners renovate Gladbacher Bank as the shaft box facade concept. The outer layer is designed as a frameless glass construction which is consist of hinged horizontal panels. The cavity in the system provides natural ventilation. When the windows in the inner shell are opened, the exhaustion of the dirty air is satisfactory and the balance of the temperature is ensured. Reflective sun-controlled glass is used in the outer layer. The movable shutters were placed in the space between the double shell (Ünal, 2006).

Figure 2.26. Gladbacher Bank exterior views before and after renovation (Source:Ünal, 2006).

Advantages of shaft-box type double skin facades: (Compagno, 2002)

- The outer shell protects the inner shell against the effects of wind, rain and snow. Solar control elements placed in the front cavity for better protection from weather conditions.
- It provides a high level of sound insulation.
- The interiors can be naturally ventilated through windows placed on the inner shell.

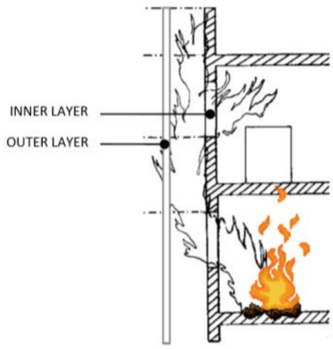


Figure 2.27. Shaft box facade fire situation (Source:Loncour and Deneyer, 2004).

However, this system isn’t good for fire protection (Figure 27). In case of fire, the central shaft is filled with smoke and flames and the air pressure in the shaft rises. Thus, due to the high pressure in the shaft, the smoke may fill into the horizontal spaces (Compagno,2002).

2.4.4 Multi-Storey Facade

In multi-storey double skin facades, the air gap between inner and outer layer is not have any solid boundries horizontally or vertically. Cavity continues through all floors. Walkways can be located at floor level for cleaning and maintenance purposes. However, the walkways are designed as not block air flow (Oesterle,2001).

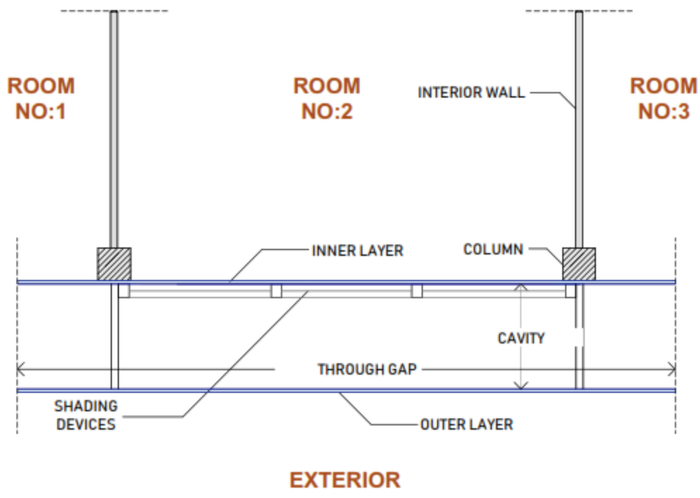


Figure 2.28. Multi-Storey facade plan

This type of facade has an excellent acoustic performance against outside noise. Also, it provide possibility all transperent external cladding. Thus, this facade type prefer at many DSF buildings. It is not possible to open internal windows in generally. There is an special entrance to cavity for cleaning and maintenance. The multi-storey double facades have an uninterrupted space, such facades have disadvantages when the possibility of fire is considered. Therefore, it is necessary to take additional preventions in design stage and material selection (Loncour and Deneyer, 2004).

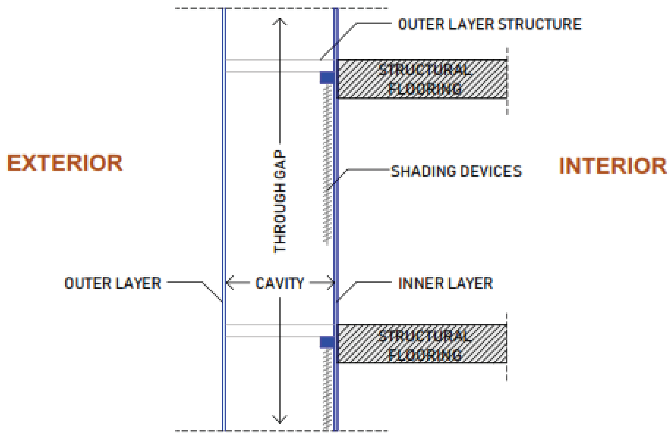


Figure 2.29. Multi-Storey facade section

Norman Foster’s Business Promotion Center built as multi-storey DSF system at Duisburg, Germany,1993. The facade of the building consists of a combination of double skin facade system panels. The building mechanical ventilation system and natural ventilation system works seperately. However, both system operated in way that supports each other. The temperture of the air in the facade system is adjusted according to the outdoor temperature (Ünal,2006)

Figure 2.30. Business Promotion Center Exterior View (Source:Ünal, 2006).

The outer shell consists of single glazed panels and the inner shell consists of low-e glass panels. Cavity dimension is a 200mm between the layers. Each facade consists of 36 panels connected to each other. In order to protect the interior from the sun's undesirable effect, the space between the glass surfaces includes metal blinds with partial holes. These blinds are controled manually by hand. The glass on the inner surface is coated with double layer low e, and there is argon gas in the space between the layers.

The glass on the inner surface can be opened for the cleaning of the system and the control of the metal blinds (Figure 2.30).

The Multi-storey facade outer skin can be consist of movable panels. This type of facade can not be air impermeable even outer panel entirely closed. The difference between this facade and the standart multi-storey facade is that the outer shell consists of movable roller shutters, not in the form of a conventional glass curtain wall. In cases where visual contact with outer space is desired, the roller shutters are placed horizontally. The louvers can be closed when the visual contact is not desired or avoid the direct sunlight.Berlaymont Building is a good example of this type facade. (Figure 2.31).

Figure 2.31. View of the louvers in horizontal position and in vertical position in Berlaymont Building (Source:Waldner et.al,2007).

As a summary of Multi-storey DSF systems features can be stated below;

• The outer shell protects the inner shell against the effects of wind, rain and snow.

• Solar control elements can be located between layers.

• Best sound insulation of DSF system for exterior noise. However, as the frontal space is not have boundries, the sound from the interior diffuses into the frontal space and passes over to other spaces.

• It is not possible to natural ventilation. The reason for this is that the air discharged from the lower floors into the front cavity is absorbed from the windows in the upper floors.

• In case of fire, fumes and flames spread to the front cavity. The flames and hot air in the space can cause the glass break in the inner shell, leading to the spread of fire to other spaces (Compagno,2002).

2.5 Daylighting Strategies for Offices

Daylight can be define as bringing together art and science to illuminate indoor space. Evidence that daylight is desirable can be found in research as well as in observations of human behaviour and the arrangement of office space (Öztürk 2006). Visual comfort, thermal comfort and energy consumption of three inter-related concept. Also, sun have some benefits for human health. It provides us Vitamin D, combats seasonal affective disorder and winter depression (Manav, 2007).

Studies for the use of daylight in building design has an important role in the field of architecture (Robertson, 2004). When the daylight designed correctly as a primary light source, it create places supporting human health and reduce the building's energy needs. Both of these reasons as well as a devolopment of design tools (scale models, mathematical formulas and computer programs) of the building growing interest occured on natural daylight design. (Kazanasmaz, 2009/2014)

Office buildings are one of the building typologies used during day hours. According to this, the effective use of sunlight in these buildings is gaining importance in terms of visual comfort, sustainability and energy efficiency (Yun et. al, 2014). Illuminance is the density of luminous flux at a surface measured in lumens per square meter (lm / m2) or Lux (lx). The natural illumination of daylight depends on sky conditions, between 5000 lx and 40000 lx. Indoor average lighting for workplaces takes 300 lx to 500 lx. According to Leadership in Energy and Environmental Design (LEED) daylight requirements: "Achieve a minimum daylight factor of 2% (excluding all direct sunlight penetration) in 75% of all space occupied for critical visual tasks." "(Robertson,2004)

The use of solar control elements in office building facades is preferred by optimizing the heating, cooling and lighting energy loads in buildings and minimizing the visual comfort problems that may occur due to the sunlight (Maesterle, 2015).

Illuminance of specific visual tasks can be variable according to purpose of office. Level of luminance values are listed below. (Ruffles,2009)

Table 2.4. Recommended lighting level of offices (Source:Ruffles,2009)

Area	**Recommended Lighting Level (lx)**
General	500
Computer Work Stations	300-500
Filing Rooms	300
Print Rooms	300
Drawing Office	500
Drawing Boards	750
CAD Design Areas	300-500

2.6 Selected Studies with DSF

There are some studies about how cavity effect thermal and daylighting performance. Most of them focuses cavity dimension effect thermal performance (Hamza, 2008; Hendriksen et. al, 2000; Örkmez, 2012; Hashemi,2010). One of the limited sources about DSF daylighting can be Ghonimi's study which is the comparison of daylighting performance between single and double skin facade. The variations in the study are single skin facade with 0.15 thickness, double skin facade with 0.15 Thick and 0.3 distances, and double skin facade with 0.35 thick and 0.6 distances. According to his study, daylight performance can be devolaped by adapting DSF. It provide, more plesant quality and quantity performance than the single skin (Ghonimi, 2017).

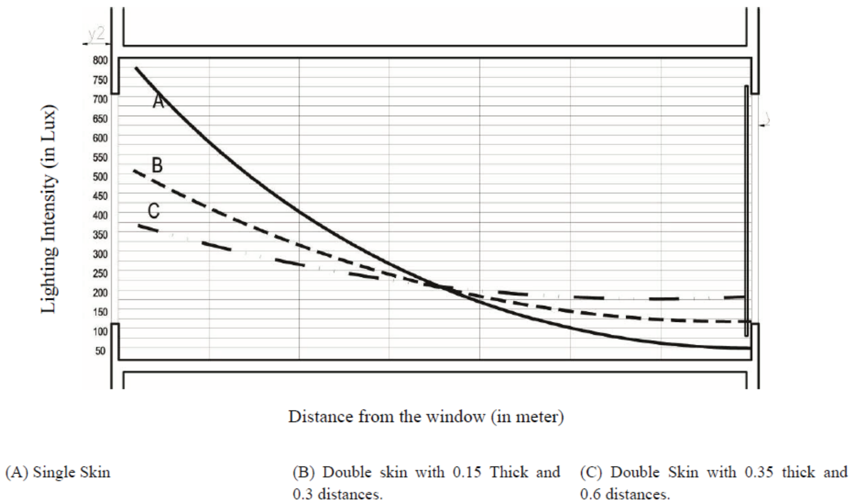


Figure 2.32. A comparison of (average illumination level) for different facade configuration (Source:Ghonimi, 2017).

Another study which is analyzed DSF systems' daylighting performance is Deneyer's case study, presents the lighting of the Berlaymont building. Building facade consists of two ventilated skins which have rotating louvers. It also compares glazed louver with metal louver facade performance. It also shows a comparison. The outside of the louver has a white multilayer film which can reflect light and the inside is dark, so that people can see it and decrease the contrast. The rotation of the louvre is controlled by central management and depends on the position of the sun (date and time). The comparison of measurements of the daylight factor on glass louvers and metal louvers shows the best possibilities (Lancour and Deneyer, 2004)

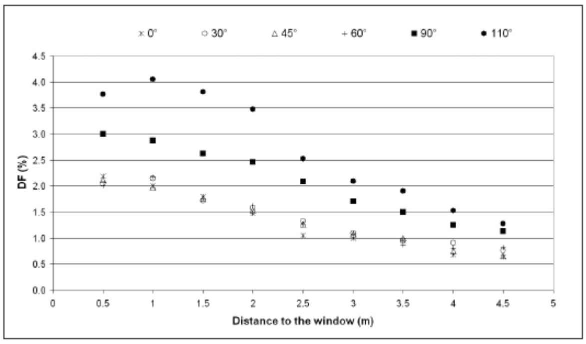


Figure 2.33. 110 Degree glass louver light distribution deep to the space and detail (Source:Loncour and Deneyer, 2004).

There is an another study about investigating the improvement of daylight potential of DSF office buildings. In a study carried out by Vijoen et al. (1997) , daylight performance analyzing by different walkway design options. Studied variables are size, color and perforation of walkway. Radiance Software was used for simulation. According to outputs, approximetely 16% difference in the autonomy of daylight forms a black solid and perforated way to white. The author proposed future studies on the visual comfort effect of design.

Most comprehensive study investigating the effect of double skin facades on daylight could be stated as Elham Motevalian's. In his study, five facade parameter chosen for understand double-skin facade building effect to daylighting. This variables stated as; double skin facade type; facade material including different types of glass and translucent materials; shading device design considering their size, material and position in the cavity; and walkway design within the cavity. Rhino, Grasshopper and DIVA (with Radiance engine) used for simulations. Also, simulations done for three different geographic locations (Los Angeles, New York and Houston). Study results can be stated as; most significant effect catch up with depth of cavity walkway width. Shading device design (material and position) effect could be counted secondly and facade layer glazing types effect is limited (Motevalian,2014).

CHAPTER 3

DOUBLE SKIN FACADE COMPONENTS IN TERMS OF DAYLIGHT PERFORMANCE

3.1 Validation of Model Construction

Validation is an important method for quantitative research. It is utilized to determine that a model is an accurate representation of the existing space. Simulation results compared with real system measurements for testing reliability. The accuracy of a lighting simulation (compared to real system data) is first affected by the errors related to the model properties of the scenario components (materials, measurement equipment etc.). Thus, at the beginning of simulations process, validation has huge importance.

The main objective of this section is to evaluate the accuracy of Relux Software comparing the simulation results with the measured data.

3.1.1 Location and Orientation

An office in Izmir Institute of Technology (Iztech) is chosen as the base case model. The site at İzmir is located on the west side of Turkey, it is on the coast of Aegean Sea. İzmir climate mean mild with dry, hot summers acording to Köppen-Geiger "Csa". Köppen-Geiger classification is based on average monthly values of temperture and precipitation (Peel,2007).

Field measurements were taken in the office which is in Department of Architecture, (Iztech). The office is located on the third floor of Block A (longitude: 26.64 degrees East, latitude: 38.31 degrees North). The location has an altitude of approximately 80.00 m over sea-level . The office have one facade with two openings and it is oriented to North-East. This office is used for the purpose of validation. After the validation phase, the office model is simplified,DSF system features are added to the faade and different variables are analyzed.

3.1.2 Relux Software

Relux Desktop is a freeware simulation tool based in Switzerland which can do daylight as well as artificial light simulations (Relux, 2016). Programme interface provide, creating a new building model with materials, appliances and colors and allows the exportation of 3D models from other applications (Yu, Su et.al. 2014). It is free of charge source for academic researchers and students. Program able to calculate electric light, daylight and energy performance of electric light. Photometrical databases can be import from manufacturers. Relux also supports the broad variety of reflections and transmissions to imitate real-world glazing surfaces and materials. Also demonstrated are outputs such as 3D representation, isolux curves, distribution of luminance, table outputs, 3D mountain plot and solar altitude graph. According to these outputs, user have better persepective of how daylight behaves within the room (Bhavani,2011)

Relux use both raytracing and radiosity in its simulation engine. User could be decide which calculation engine used for Simulation. In this study, it was conducted using Relux Desktop to simulate daylighting performance of DSF with raytracing engine.

Radiosity

Radiosity is an algorithm used to create simulations with the help of shadows and diffused light (Figure 3.1). This method has some limitations in terms of its use to make daylight simulations (diffuse surface, complex description of the sky).Moreover, its main purpose of use should be evaluating basic spaces. On the other hand, it is not useful when it comes to make calculations for the rooms receiving borrowed light. The reason for that is, only the facades facing the exteriors can have window openings. Thus, creating a room which have interior window is not geometrically possible (Iversen et al., 2013).

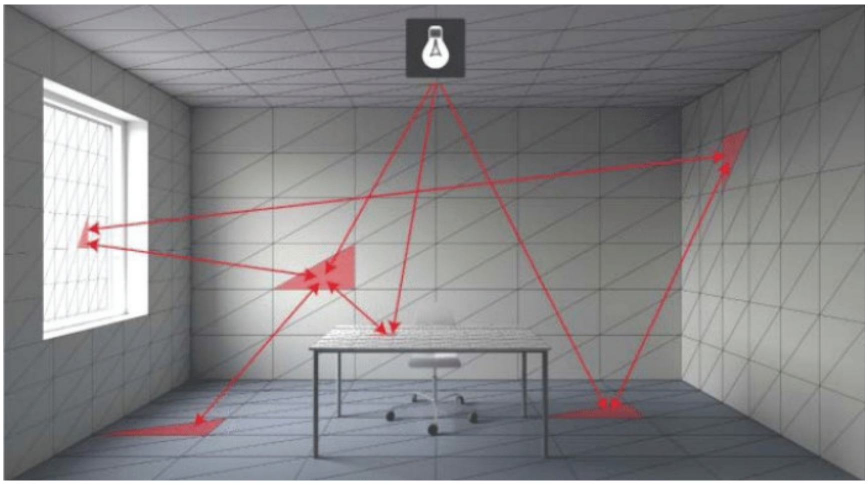


Figure 3.1: Illustration of the radiosity calculation method
(Source:Iversen et al., 2013).

Ray tracing

Ray tracing is basically used to calculate the distribution of a large number of rays in a scene. These rays might be emitted from either light sources (forward ray tracing), or a view point (backward ray tracing). Although backward ray tracing is a faster method due to only calculating the rays arriving to the view point, it also has a constraint. It is not suitable to be used in scenes which does not have an obvious light source, i.e. narrow light well, light pipe. Reflection, transmission and refraction properties of surfaces that allow the use of complex materials in simulations are supported by ray tracing (Iversen et al., 2013).

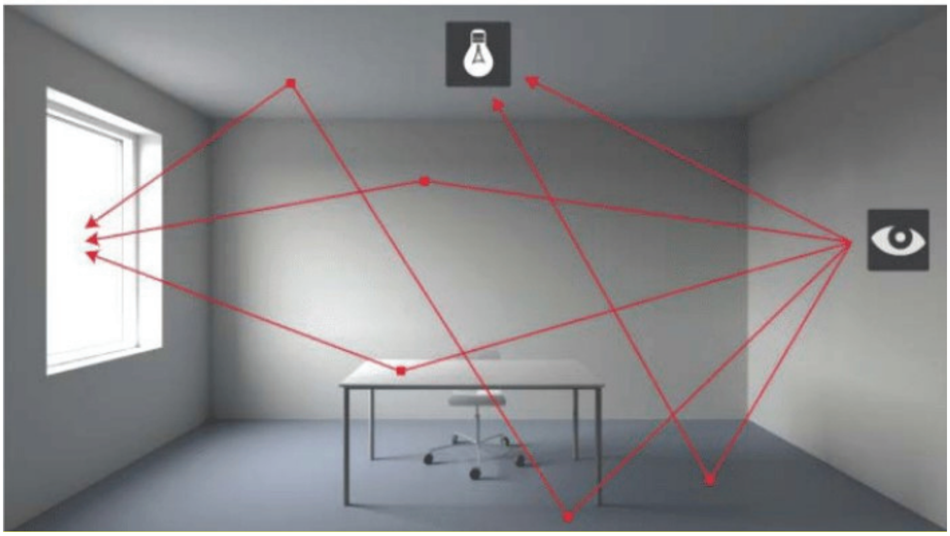


Figure 3.2. Illustration of the backward ray tracing calculation method
(Source:Iversen et al., 2013).

3.1.3 Model Geometry and Surface Properties

To achieve a high degree of accuracy of simulation results, model geometry and surface properties were determined carefully. Office has a rectangular plan with dimensions of 5.50 m in width x 5.50 m in length and 3.8 m in height. A total of 15 measurement points were located on a reference plane which is 0.85 m height from floor. Room geometry (space dimensions, window layout) was modeled using architectural drawings of Block A. Workspace location, furniture dimensions and layout changings were determined on site (Figure 3.3).

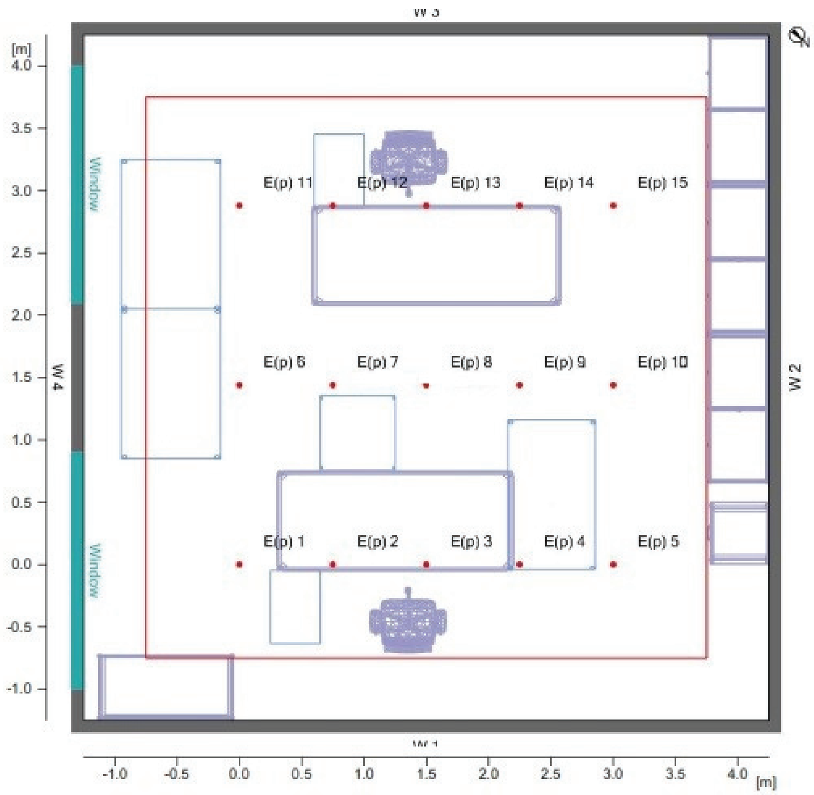


Figure 3.3. Office Plan and Measurement Points

The floor surface is covered with marble , walls are painted with matt color that closed to white; desks are wood in light brown color. The transmission of the window glazing derived from measurements using a luminance meter pointed at an exterior surface from behind and in front of the glazing. The transmittance values calculate as the ratio of the two measurements. Other materials reflections ratios chosen from Relux Software library according to real materials of office. Reflection and Transmittance values are shown in Table 3.1 There are two windows located at two sides of the column;

their dimensions are 190 cm length, 210 cm width and 210 cm height. The window sill is at 100 cm from the floor. The interior materials are fixed for all the simulations. Optical properties of building components are listed in Table 3.1. The model was generated in Relux. Existing office space and office furniture (office desk, computers, chairs, potted plants) were modeled from the software library (Figure 3.4).

Table 3.1. Surface properties of existing office

Floor	Reflectance	60 %
Ceiling	Reflectance	45 %
Walls	Reflectance	45 %
Table	Reflectance	30 %
Window	Transmittance	78 %

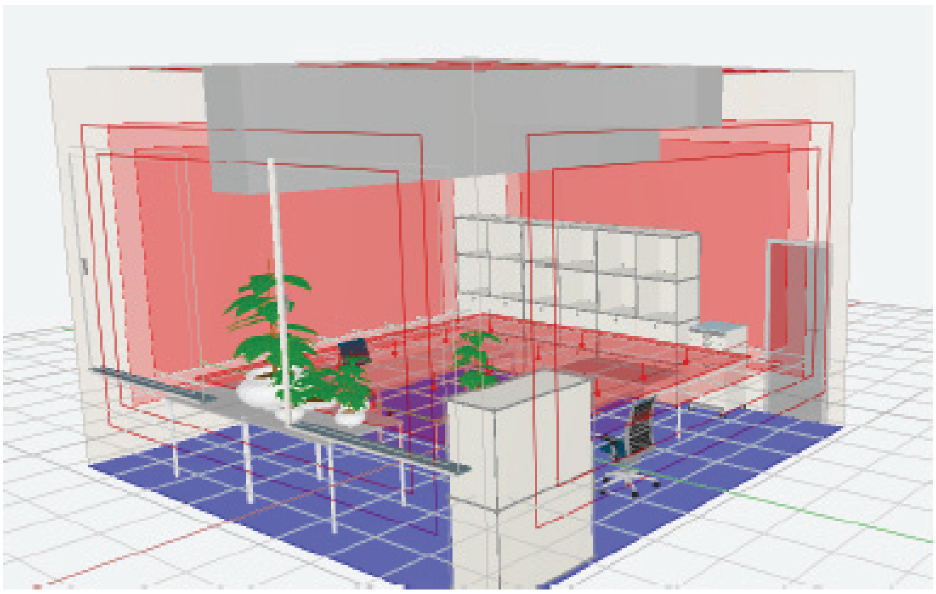


Figure 3.4. Relux Model of Existing Office

Measurement readings were taken using a digital light meter with a silicon photo diode detector according to CIBSE (CIBSE, 2005), on November 20th, at 9.20 am, under overcast sky condition. There were no shading devices at the office. Relux model outputs generated according to this date and measurement readings were compared for the validation set up (Table 3.2).

Table 3.2. Measurement points and Relux simulation output values

POINTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
MEASURED (lx)	811	484	337	229	187	190	386	268	196	181	888	383	316	211	188
RELUX SIMULATION (lx)	1490	736	397	227	151	180	525	259	231	167	1430	775	435	251	156

According to above results, there is a consistency between actual measurements and simulation software's results. The closest points have the highest variation because of the expected variations in Relux sky model and actual sky conditions. Illuminance values decrease gradually from beginning of each column to interiors of room. This means that Relux model and simulation software are working successfully. This numerical data is shown in Table 3.2. for comparison.

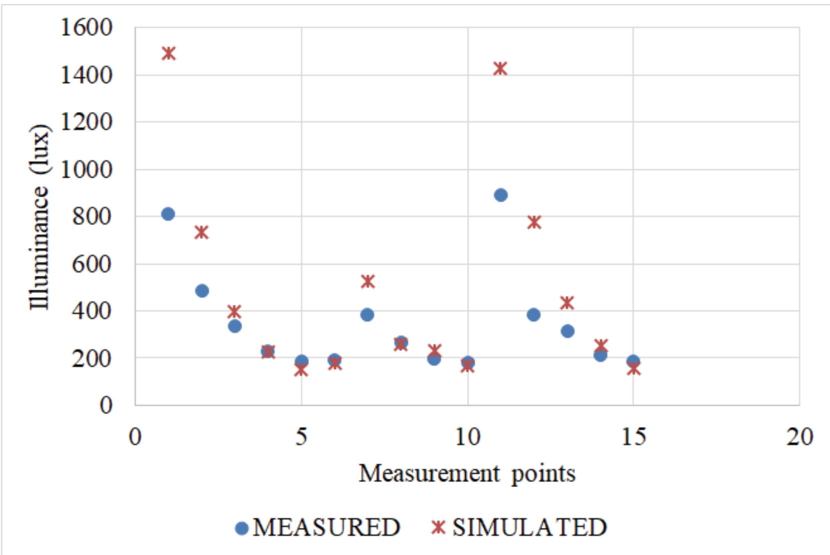


Figure 3.5. Distribution of measured and simulated illuminance

According to coefficient of determination (R^2) , Relux simulation results are 96 % consistent with field measurements. However, some values are higher than actual measurement numbers. This difference results from software can be occurred from simulation tools different sky model usage.

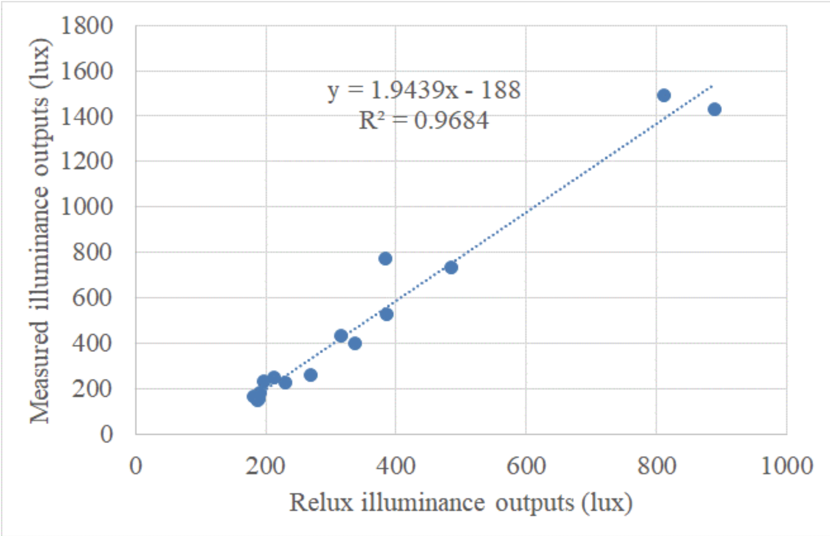


Figure 3.6. Scatter plots of Relux simulation and measurement values

3.2 Defining Variables

After verification of Relux model, the impact of DSF system elements on daylight performance of the office was examined. Architectural design variables which might be effective were determined according to literature. They are stated as below;

- Depth of Cavity: 50 cm, 150 cm, 200 cm
- Glass Type: Single glazing: High transparent glass and Double Glazing: low, medium and high transparent glass
- Shading Devices: Venetian Blinds
- System Layers Orientation: Single glazing inner layer -insulating glazing outer layer and Single glazing outer layer -insulating glazing inner layer

3.2.1 Cavity

Double skin facade skins can be separated from each other with air space called the air corridor in literature. Here in this study, we called it as "cavity". The distance between the glass skins can vary from 20 cm to 2 meters, it is called the depth of the cavity (Moderate,2013) In this study, depth of cavity are chosen as 50 cm, 100 cm and

200 cm. These cavities were named as A, B, and C in Figure 3.7. This denomination is helpful to clarify different simulation set-ups easily. Classification by cavity geometry, study test case was choosed as corridor type double skin facade.

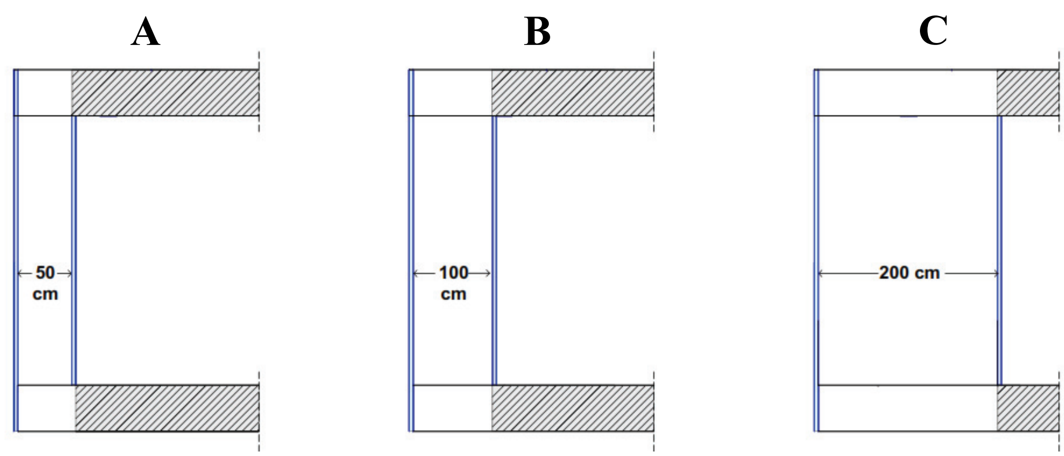


Figure 3.7. Simulation different variations according to cavity distance

3.2.2 Shading Devices

According to some designers, the positioning of the sun shading elements out of the facade is negative in terms of care and aesthetic concerns. The placement of sun-shading elements near the interior is not considered to be an effective solution for the control of solar energy gains (Lancour, 2003) . Two studies suggest to place sun shading elements in the 1/3 section of the cavity close to the outer/external facade to let the air movement inside the cavity efficiently. It needs to be at least 15 cm from the external facade because of maintainance and cleaning purposes (Oesterle, 2001; Poirazis, 2006). A recent one focused on the placement of blinds according to DSF's cooling performance. Shading device very close to the outer pane, inner pane and middle line were tested. The lowest possible cooling consumptions and lowest surface temperature on shading device—blind—was attained in the middle-located-shading. On the other hand, the color of shading blinds were found to be very slightly effective in this sense (Gratia, 2007). So, to be precise, in this study, each blind system consists of 98 lamels and four 100 cm partitions which have 120 mm length at horizontal line, 20 mm thickness and 20 mm spacing. Blinds were modeled as a surface object in Relux and located one third of the cavity depth from the outer facade (Figure 3.8). Their surface material have 60% of reflectance. Blinds were used to reduce the possible unfavorable effects of direct sunlight and provide optimum quality of daylight.

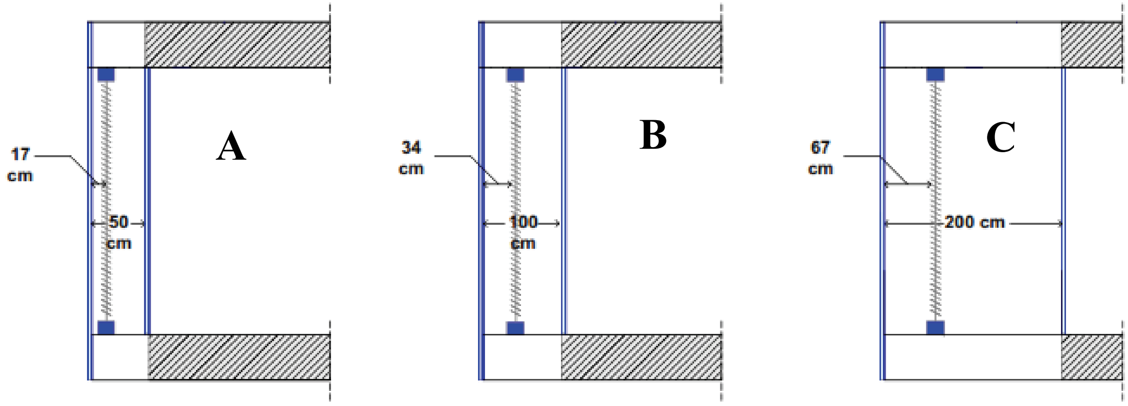


Figure 3.8. DSF set-ups (A – C) according to shading device locations

3.2.3 Glass Type

During the design phase of DSF, a total 5 glass types were selected according to their optical characteristics. These are; number of glass layers, low diffusion coated glass, transparent insulation materials, film layer, gap thickness and gas types between two glasses. It has been stated at previous studies, that when glass types are being selected in DSF design, generally U values are taken into consideration but daylighting features of glass was ignored.

However, the performance criteria for solar control, light transmittance, color and light reflection of glass units needs to be examined. According to this aim, many different glass types and combinations were implemented at Şişecam Online Performance Calculator . This calculator provides information about daylight properties, solar energy properties, thermal conductiviy and sound insulation values. Different combinations of inner pane, cavity and outer pane can be employed seperately. In this study, the selection was made by taking into consideration of daylight properties. Transmittance values, daylight reflectance indoor and outdoor panes was examined.

The commonly used glazing type in literature is found to be one skin consisting of single glazing, other skin choosen as insulating glass double or triple glazing. Thus, one glass type is choosen as single clear glass (90% transmittance value) and second double glazing choosen from Table 3.3. as insulated glass. 12 mm air choosed gap which is between inner and outer pane.

Table 3.3. Insulating Glazing Values (Source:Şişecam Performance Calculator,2019)

	Outer Pane	Inner Pane	Daylight Transmittance	Daylight Reflectance Outdoor	Daylight Reflectance Indoor
Solar Low	Solar Low-E Cam 4 mm Neutral	Clear Float Glass 3 mm	72%	10%	11%
Colored Glass	Clear Glass 4 mm Dark Grey	Clear Float Glass 3 mm	52%	8%	13%
	Tinted Float Glass 3.2 mm Dark Grey	Clear Float Glass 3 mm	19%	5%	11%
	Tinted Float Glass 4 mm Dark Grey	Clear Float Glass 3 mm	14%	4%	11%
	Tinted Float Glass 8 mm Dark Grey	Clear Float Glass 3 mm	2%	4%	11%
	Clear Glass 4 mm Green	Clear Float Glass 3 mm	72%	12%	14%
Laminated Glass	Laminated Glass (5+0,38+5) mm Neutral 55.1	Clear Float Glass 3 mm	80%	14%	14%
	Laminated Glass (8+1,52+8) mm Neutral 88.4	Clear Float Glass 3 mm	78%	14%	14%
	Laminated Glass (10+1,52+10) mm Neutral 1010.4	Clear Float Glass 3 mm	77%	14%	14%
Ultra	**Şişecam Clear Float Glass 4 mm Clear**	**Clear Float Glass 3 mm**	**83%**	**15%**	**15%**
Solar Low E	Tempered solar Low-E Glass 6 mm Neutral 70/37	Clear Float Glass 3 mm	70%	15%	17%
	Tempered solar Low-E Glass 4 mm Neutral 62/44	**Clear Float Glass 3 mm**	**63%**	**21%**	**21%**
	Tempered solar Low-E Glass 6 mm Bronze 31/25	**Clear Float Glass 3 mm**	**32%**	**13%**	**24%**
	Tempered solar Low-E Glass 6 mm Dark Grey 28/26	Clear Float Glass 3 mm	28%	11%	26%

As seen from Table 3.3. transperency levels of glass can be varied from 2% to %83 by changing their colour, thickness and tempered. In accordance with the purpose of this study, three glazing types were determined as the double glazing layer. Selected glazings stated as bold in Table 3.3. To understand the possible effects of glass type to the performance of DSF better, low, medium and high transmittance values were determined for glasses. Their configurations are stated in Figure 3.9.

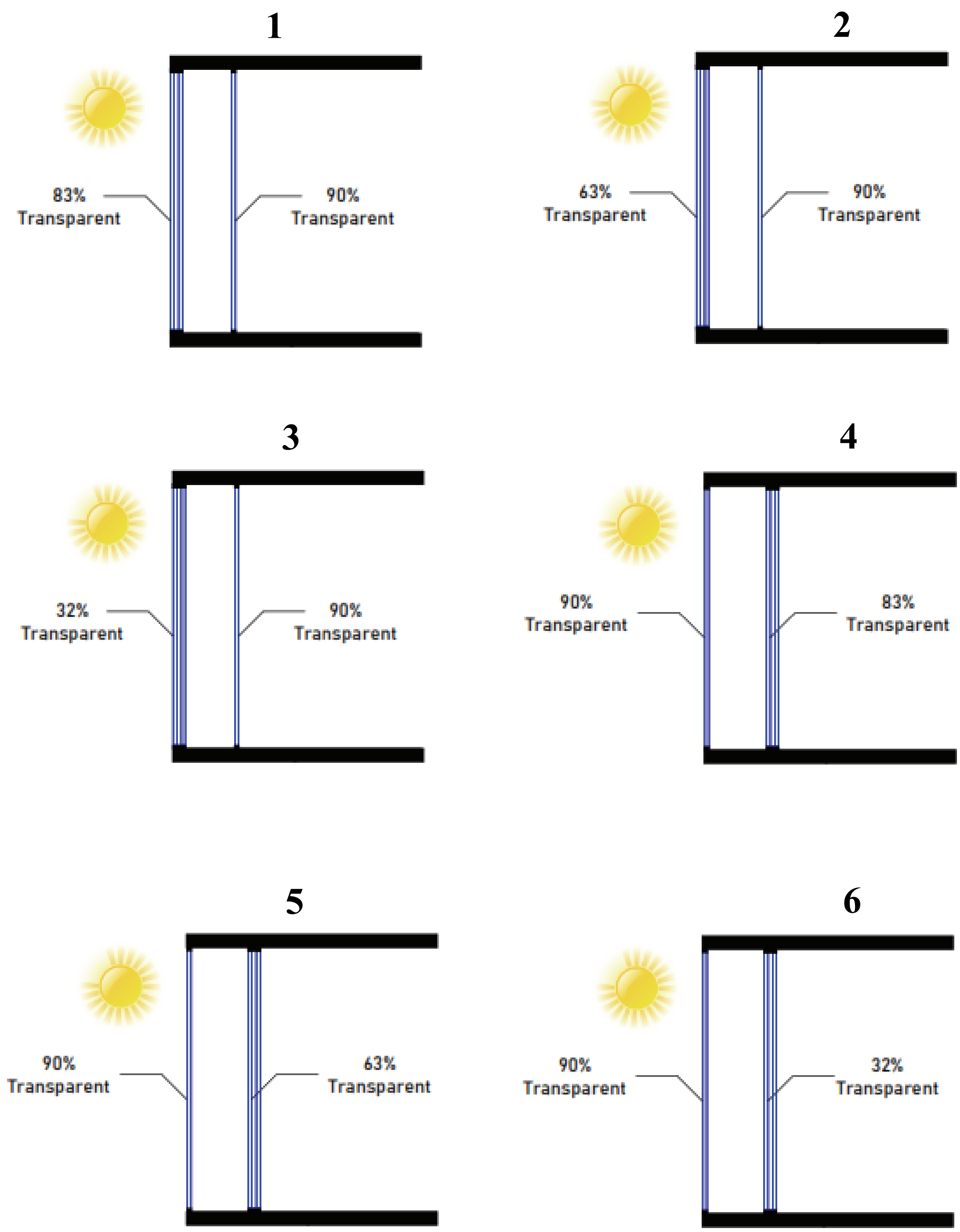


Figure 3.9. DSF set-ups (1 – 6) according to glass types.

3.2.4 Layer Orientation

Limited number of studies stated that, natural light percentage indoors decreases with the added external layer. If the additional layer is single-glazed, reduction is at least 10% . If the highly transparent type of glass is used, a specific reduction can only be 7-8%, and this is an acceptable value (Ünal, 2006).

All sets of simulations employ clear glass with 90% transmittance for the outer pane. The inner layers as stated in the previous section are Tempered Solar Low-E Glass 4mm Neutral, Tempered Solar Low-E Glass 6mm Bronze, and Ultra Clear Glass, having transmittance values as 83%, 63%, 32% respectively. To test the effects of inner and outer layer location, glass configurations have been determined as in Figure 3.10.

Figure 3.10. Layer orientations

3.3 Model Application Through Simulation

Simulations (and models, too) are abstractions of reality. In architecure, simulations are the specific application of models to arrive at some outcome. Simulation method provide standards against compared to other research methods. Simulations are suitable for constructing and understanding field research at study of research design (Trochim, et al.). According to Pidd(2003) computer simulation is creation of a model for understand and experiment system before it built up in a reality. They allow comparison of models with experiment and provide means assesing validity of a model. A simulation model is basically considered as "what-if" analysis (Kellern et al., 1999).

A high degree of accuracy of simulation results, model geometry and surface properties determined carefully as explained in Section 3.1.2. Subsequently, the Relux model was refined excluding some furniture and features inside. The number of calculation points were increased to be 49 calculation points on reference plane to capture detailed evaluation of daylight distribution inside the room. They were similarly placed at least 0.5 m away from the surface of the walls. The distances between the points were 1.44 m in the x-direction and 0.75 m in the y-direction (Figure 3.11). In the initial phase of the model application, the software also has been tested to find out if it takes to account the second skin for more reliable results. At the end, second skin designed with exporting 3dmax object to Relux which is explained in detail in the next chapter as the base case model.

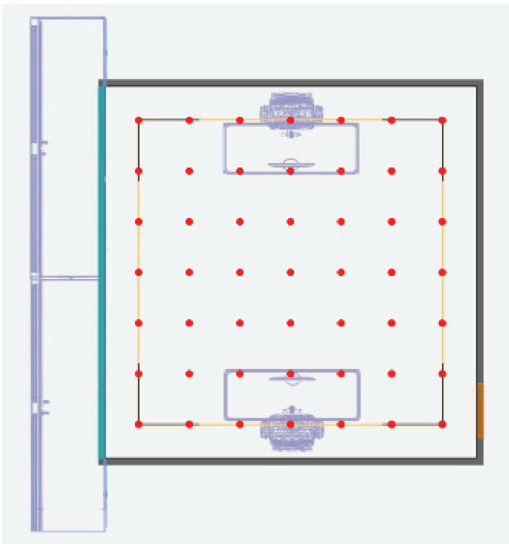


Figure 3.11. Double Skin Facade plan

Figure 3.12. 3D view of Relux Model showing Double Skin Facade

Material selection was determined from ray tracing materials, transparency values were chosen from the actual material properties given in Table 3.4. Daylight simulations were calculated by raytracing method and all setups were simulated at equinox date, 21. March, at 12:30 pm under CIE intermediate sky with sun conditions.

Table 3.4. Simulation material properties

Floor	Reflectance	60 %
Ceiling	Reflectance	45 %
Walls	Reflectance	45 %
Table	Reflectance	30 %
Window	Transmittance	90%, 83%, 63%, 32%

Simulation set-ups were identified as A,B,C according to cavity. After that, different transparent glazing types were integrated to the setups which are 90%, 83%, 63% and %32. These glazing configurations were named as 1, 2, 3, 4, 5, 6. (Table 3.5.)

Table 3.5. Simulation set-ups 1-6 glass configuration and glass features

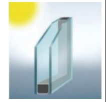
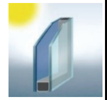
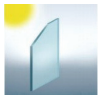
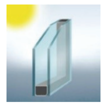
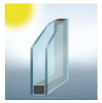
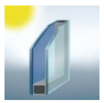
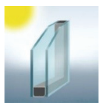
	First Skin								Second Skin- Glass Configuration							
No	Outer Pane	Gap	Inner Pane	Daylight Transmittance	Daylight Reflectance Outdoor	Daylight Reflectance Indoor	Shading Coefficient	İmage	Outer Pane	Gap	Inner Pane	Daylight Transmittance	Daylight Reflectance Outdoor	Daylight Reflectance Indoor	Shading Coefficient	İmage
1	Şişecam Clear Float Glass 4 mm Clear	Unavalible	Unavalible	90%	8%	8%	1,00		Şişecam Ultra Clear Float Glass 4 mm Ultra Clear	12 mm Cavity (Air)	Şişecam Clear Float Glass 3 mm Clear	83%	15%	15%	0,94	
2	Şişecam Clear Float Glass 4 mm Clear	Unavalible	Unavalible	90%	8%	8%	1,00		Şişecam Temperable Solar Control LowE Glass 4 mm Neutral 62/44 (Surface #2)	12 mm Cavity (Air)	Şişecam Clear Float Glass 3 mm Clear	63%	21%	21%	0,52	
3	Şişecam Clear Float Glass 4 mm Clear	Unavalible	Unavalible	90%	8%	8%	1,00		Şişecam Temperlenebilir Solar Low-E Cam 6 mm Bronz 31/25 (2. Yüzey)	12 mm Cavity (Air)	Şişecam Renksiz Düzcam 3 mm Renksiz	32%	13%	24%		
4	Şişecam Ultra Clear Float Glass 4 mm Ultra Clear	12 mm Cavity (Air)	Şişecam Clear Float Glass 3 mm Clear	83%	15%	15%	0,94		Şişecam Clear Float Glass 4 mm Clear	Unavalible	Unavalible	90%	8%	8%	1,00	
5	Şişecam Temperable Solar Control LowE Glass 4 mm Neutral 62/44 (Surface #2)	12 mm Cavity (Air)	Şişecam Clear Float Glass 3 mm Clear	63%	21%	21%	0,52		Şişecam Clear Float Glass 4 mm Clear	Unavalible	Unavalible	90%	8%	8%	1,00	
6	Şişecam Temperlenebilir Solar Low-E Cam 6 mm Bronz 31/25 (2. Yüzey)	12 mm Cavity (Air)	Şişecam Renksiz Düzcam 3 mm Renksiz	32%	13%	24%			Şişecam Clear Float Glass 4 mm Clear	Unavalible	Unavalible	90%	8%	8%	1,00	

Table 3.6. Study simulation set-up

			Glazing Type Transparency Values					
			1	**2**	**3**	**4**	**5**	**6**
			Inner Layer : 90% Outer Layer: 83%	Inner Layer: 90% Outer Layer: 63%	Inner Layer: 90% Outer Layer: 32%	Inner Layer: 83% Outer Layer: 90%	Inner Layer: 63% Outer Layer: 90%	Inner Layer: 32% Outer Layer: 90%
Depth of Cavity	**A**	50 cm	SET UP- A1	SET UP- A2	SET UP- A3	SET UP- A4	SET UP- A5	SET UP- A6
	B	100 cm	SET UP-B1	SET UP-B2	SET UP-B3	SET UP-B4	SET UP-B5	SET UP-B6
	C	200 cm	SET UP-C1	SET UP-C2	SET UP-C3	SET UP-C4	SET UP-C5	SET UP-C6

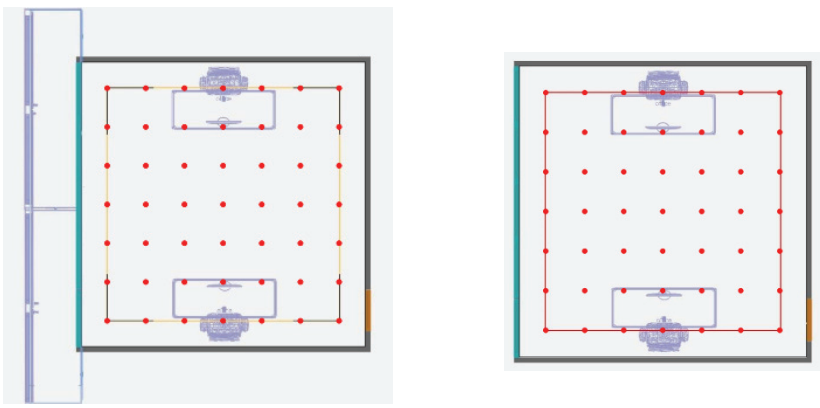
CHAPTER 4

RESULTS

The main objective of this chapter is understand the different double skin facade design parametres by benefit efficient daylight. This chapter involves three subsections; findings daylight performance of double and single skin facade, different double skin facade features effect of daylight performance and suggesting an optimal double skin facade design according to all simulation results. The second section is divided into three parts for test the effect of depth of cavity, glazing types and layer orientation.

4.1 Base Case: Single Skin Facade versus Double Skin Facade

As a preliminary work, the office room was designed in Relux in the same location and dimension. Office has 5.5 m length and 5.5 m width and 3.8 m height. Office was designed more simply than the model which is tested and explained in section "3.1. Validation Model Construction". No shading devices were located at the office. Wall, ceiling, and floor reflectance values are the same with validation model. Double skin facade was designed as a 3dmax object and located outside the room. It has 100 cm depth (Figure 4.1 and Figure 4.2). The comparison of daylight performance of single-skin and double skin facades is the initial step to understand how the shift in facade type affects the distribution and availability of daylight inside the room.



(a) (b)

Figure 4.1. Single (a) and double skin (b) facade plans

(a) (b)

Figure 4.2. 3D views of single (a) and double skin (b) facade

According to calculation of Relux Software, daylight illuminance values change in the range of 3180-49300 lx using radiosity method; utilizing raytracing method, illuminance varies within this range of 738-3090 lx in the single skin facade model. This range is 1180-3520 lx in the double skin facade set-up; using raytracing method, illuminance varies from 896lx to 2350 lx. The values of the 49 calculation points in the reference plane are shown in the following table (Table 4.1 to Table 4.4). The highest values are underlined as blue, the lowest values are underlined with yellow.

Table 4.1. Illuminance Values in Single Skin Facade Model (Radiosity)

SINGLE SKIN			Columns (x Axis)						
			1	2	3	4	5	6	7
	Rows (y Axis)	1	8550	6290	5340	3690	3790	3490	3180
		2	47800	11700	5660	4240	4170	3800	3480
		3	48100	7130	6030	5150	4510	4010	3650
		4	48400	26300	6270	5380	4660	4130	3760
		5	48700	27900	6410	5400	4650	4110	3750
		6	49300	25500	6510	4640	4390	4010	3620
		7	43000	8450	6510	4470	4210	3750	3340

Relux Software radiosity daylight illuminance values are quite high and inconsistent for single skin model. It is seen that,especially first two vertical columns values can cause excessive heat and glare for single skin model. Illuminance values decrease proportionally while going back side of the room but still remains at very high values for recommended illuminance values for offices (Table 4.1). Double skin model radiosity daylight values are not extremely high while comparing single skin model

(Table 4.2). However, it can be concluded that, radiosity method illuminance values are not convenient for this study.

Table 4.2. Illuminance Values in Double Skin Facade Model (Radiosity)

DOUBLE SKIN		Columns (x Axis)						
		1	2	3	4	5	6	7
Rows (y Axis)	1	2100	1740	1520	1180	1250	1220	1180
	2	2350	1970	1650	1260	1330	1270	1240
	3	2500	2170	1820	1580	1420	1330	1280
	4	2740	2380	1970	1670	1470	1370	1320
	5	3040	2550	2090	1740	1510	1390	1330
	6	3520	2730	2170	1550	1460	1390	1320
	7	3400	2780	2210	1520	1460	1350	1280

Simulation outputs by ray-tracing method are more close to the measured data which is stated in validation phase. Thus, raytracing method data was chosen for comparing the single versus double skin facade daylight levels.

Table 4.3. Illuminance Values in Single Skin Facade Model (Ray-tracing)

SINGLE SKIN		Columns (x Axis)						
		1	2	3	4	5	6	7
Rows (y Axis)	1	2770	1900	1480	976	921	813	738
	2	2960	2160	1660	1170	1050	908	826
	3	3040	2270	1770	1400	1170	983	875
	4	3090	2330	1820	1470	1220	1020	898
	5	3040	3040	2320	1820	1460	1210	902
	6	3030	3030	2290	1800	1290	1140	886
	7	2970	2190	1720	1160	1040	919	823

Table 4.4. Illuminance Values in Double Skin Facade Model (Ray-tracing)

DOUBLE SKIN		Columns (x Axis)						
		1	2	3	4	5	6	7
Rows (y Axis)	1	1550	1290	1150	896	968	948	912
	2	1670	1430	1240	964	1020	967	952
	3	1710	1510	1340	1200	1090	1030	991
	4	1850	1600	1410	1250	1120	1050	1020
	5	2100	1780	1520	1300	1170	1070	1020
	6	2350	1880	1570	1160	1140	1060	1010
	7	2130	1810	1570	1140	1130	1070	979

While analyze double skin facade effect of illuminance values, it is seen at ray-tracing method results, illuminance in double skin facade becomes approximately 25-30 % lower than the values in single skin model. However, this effect of double skin facade decreases through inner of room. Even it slightly rises the illuminance near the rear wall to support the uniformity of the room (Figure 4.3).

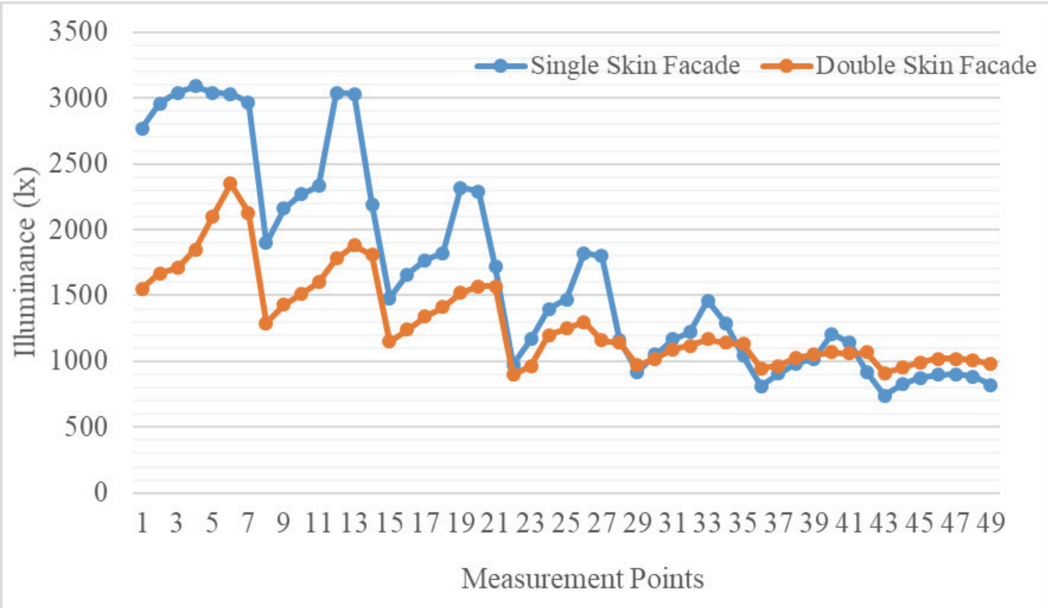
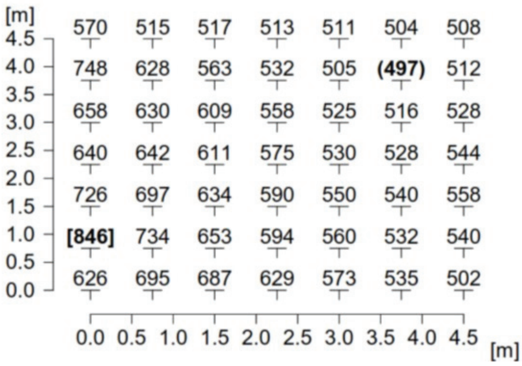


Figure 4.3. Daylight distribution in single-skin and double skin facade (ray tracing)

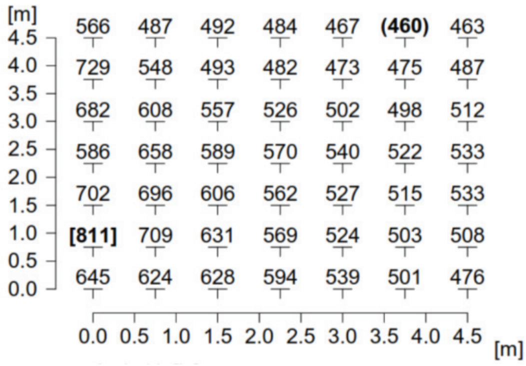
4.2 Double Skin Facade Setups

In this study, double skin facade variations investigated for providing recommended illuminance values for office buildings (between 300 lx to 500 lx). According to Base Case simulation results, it is easily seen that, Ray-tracing method results more reliable than radiosity. Thus, ray-tracing method was used for this study. A total of 18 simulation setups were made whose detailed features are given in Chapter 3. Illuminance values of setups for 49 points are given in Figure 4.4. , Figure 4.5. and Figure 4.6. Maximum and minumum illuminance values are remarked as bold.

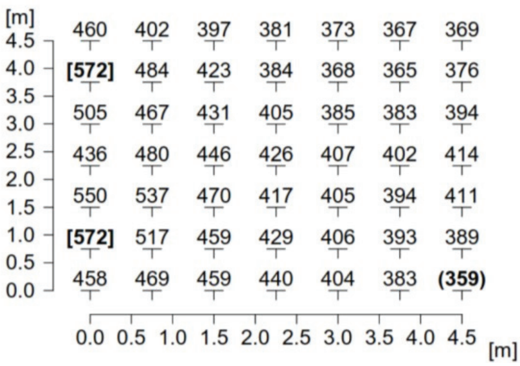
SET UP A-1



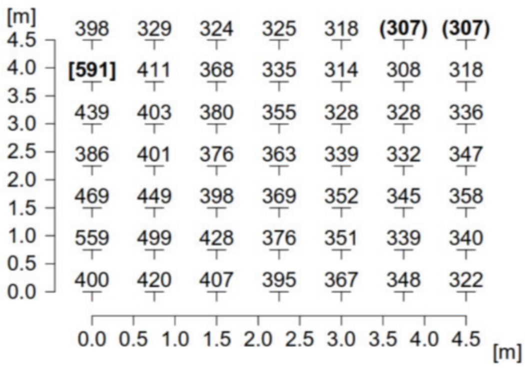
SET UP A-4



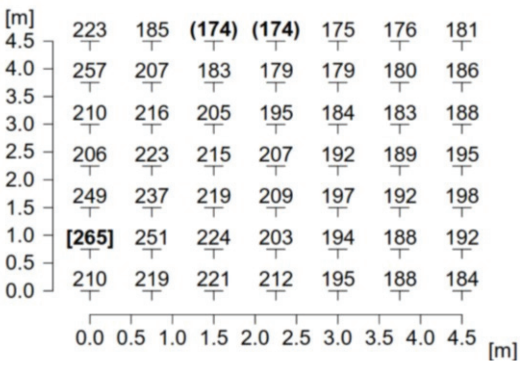
SET UP A-2



SET UP A-5



SET UP A-3



SET UP A-6

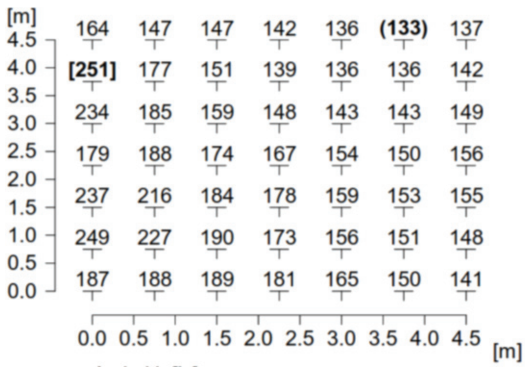


Figure 4.4. Set up A 1-6 illuminance values

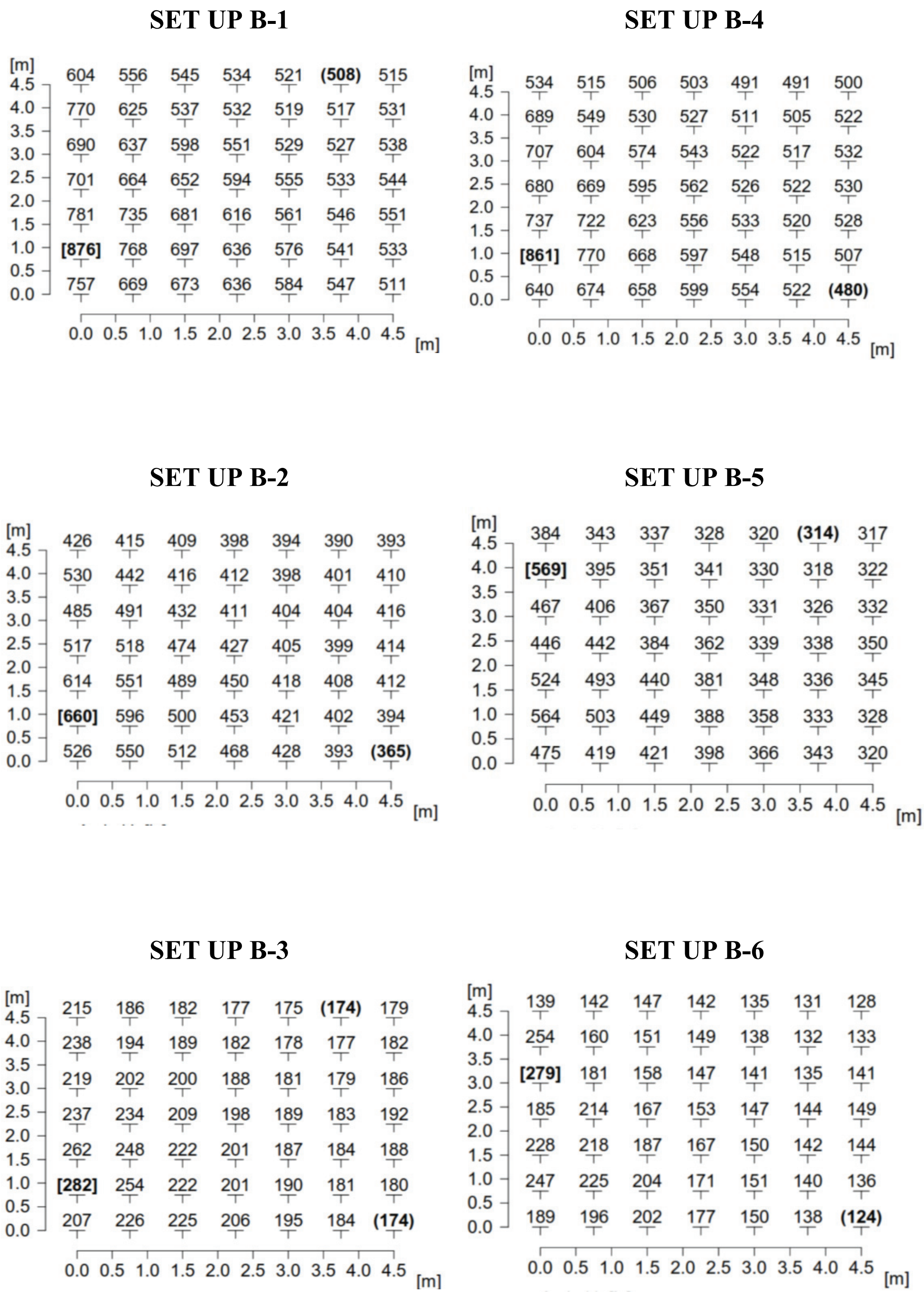


Figure 4.5. Set up B 1-6 illuminance values

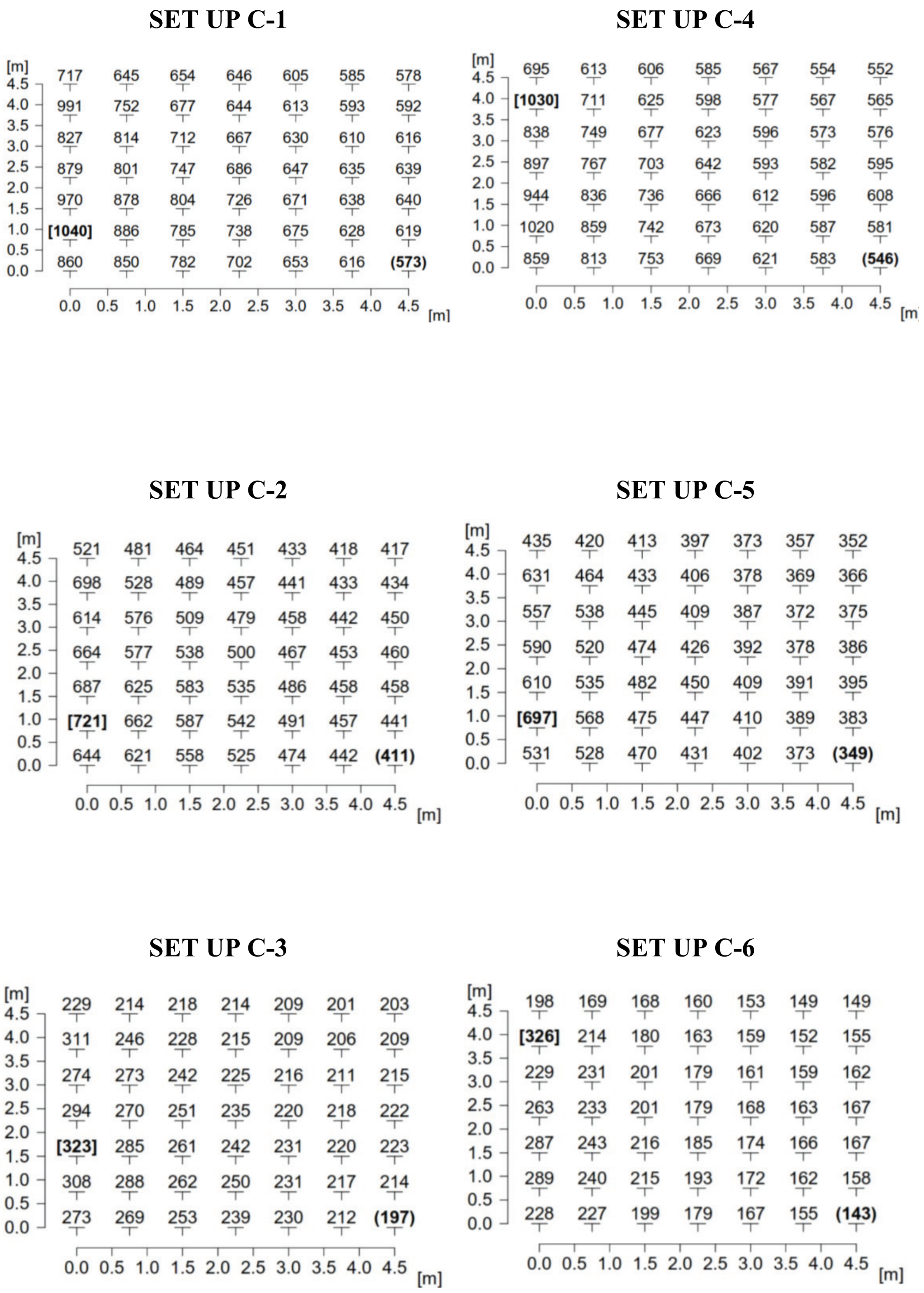


Figure 4.6. Set up C 1-6 illuminance values

These simulations were grouped and some parameters were kept constant for comparison. In accordance with the purpose of the study, the results are discussed in 3 subsections. These are ; effects of depth of cavity , effects of different glazing types and effects of layers orientation of double skin facades.

Firstly, to examine the depth of cavity effect; the glass transmittancy values are fixed for each group, and one layer orientation is compared. The set up comparison variations are shown in the Figure 4.7.

Analysis Depth Of Cavity Effect			
1. Group	Set up A-1	Set up B-1	Set up C-1
2. Group	Set up A-2	Set up B-2	Set up C-2
3. Group	Set up A-3	Set up B-3	Set up C-3

Figure 4.7. Set up comparison variations for analyzing depth of cavity

In the second part of results, to understand the impact of different types of glazing usage at double skin facade design; cavity is fixed for each group and one layer orientation is compared which is stated Figure 4.8. The 83% , 63%, 32% transmitted glass types effects are compared in terms of daylight illuminance.

Analysis Glazing Types Effect			
1. Group	Set up A-1	Set up A-2	Set up A-3
2. Group	Set up B-1	Set up B-2	Set up B-3
3. Group	Set up C-1	Set up C-2	Set up C-3

Figure 4.8. Set up comparison variations for analyzing glazing types

Another double skin facade feature, layer orientation is examined at each depth of cavity (a-50 cm, b-100 cm and c-200 cm) and at transmittance values of inner and outer skin switch between each other (Figure 4.9).

Layers Orientation (depth is 50 cm)		
1. Group	Set up- A1	Set up- A4
2. Group	Set up- A2	Set up- A5
3. Group	Set up- A3	Set up- A6

(a)

Layers Orientation (depth is 100 cm)		
4. Group	Set up- B1	Set up- B5
5. Group	Set up- B2	Set up- B6
6. Group	Set up- B3	Set up- B7

(b)

Layers Orientation (depth is 200 cm)		
7. Group	Set up- C1	Set up- C4
8. Group	Set up- C2	Set up- C5
9. Group	Set up- C3	Set up- C6

(c)

Figure 4.9. Set up comparison variations for analyzing layers orientation

Following part of study, illuminance values compared by 49 points with line graphs and bar charts used for minumum, maximum and average numbers.

4.2.1. Effects of Depth of Cavity

In all simulations to understand the effect according to depth of cavity, these items have been considered as fixed:

- Building interior materials
- Inner layer glass transmittance value changes as 83%, 63%, %32 and outer layer glass transmittance value is 90%
- Date and Hour: 21 March 12:30
- Recomended office illuminance range: 300 lx -500 lx

In this section the depth of cavity effect on daylight performance is investigated. According to different depth of cavity set up results which is presented in Figure 4.4, Figure 4.5. and Figure 4.6. , graphs generated for comparing illuminance values. Recommended office lighting level considered as 300-500 lx for all setups.

The first graph below, shows distrubution of different depth of cavity values at 49 measurement points for 1st comparison group (see in Figure 4.11). Overall, first comparison group minumum and maximum illuminance values have been found out as 497-846 lx, 508-876 lx, 573-1040 lx respectively for 50 cm, 100 cm and 200 cm depth of cavity (Figure 4.10). Despite the fact that the number of measurements points whose illuminance values satisfy the recommended office numbers, it was observed that higher illuminance values at the measurements points near the window can cause glare.

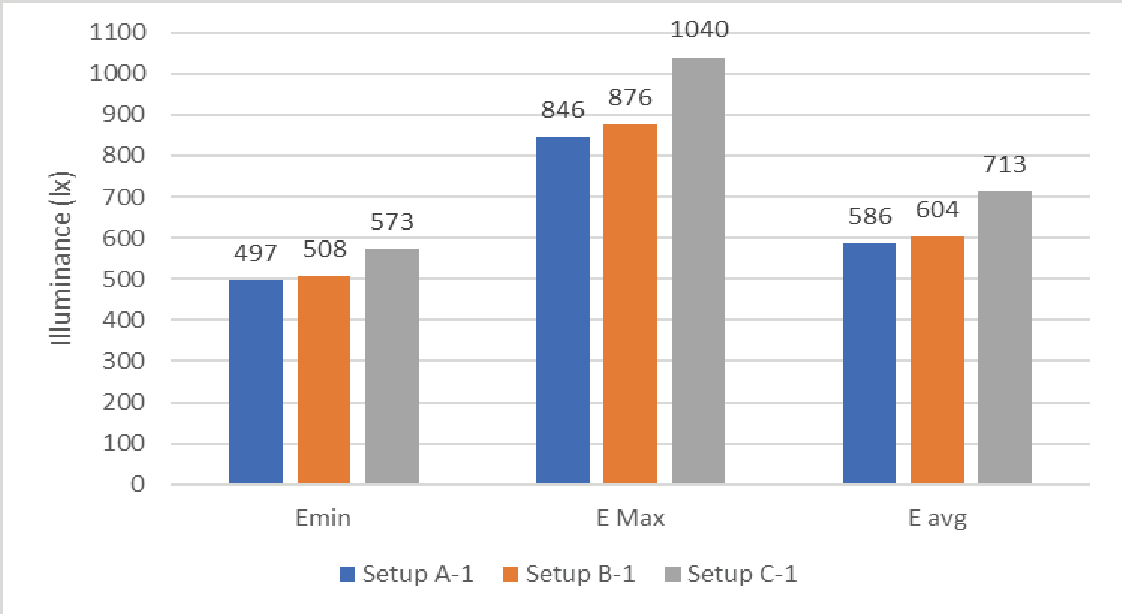


Figure 4.10. Setup A-1, setup B-1, setup C-1 lowest, highest and average illuminance values comparison graph

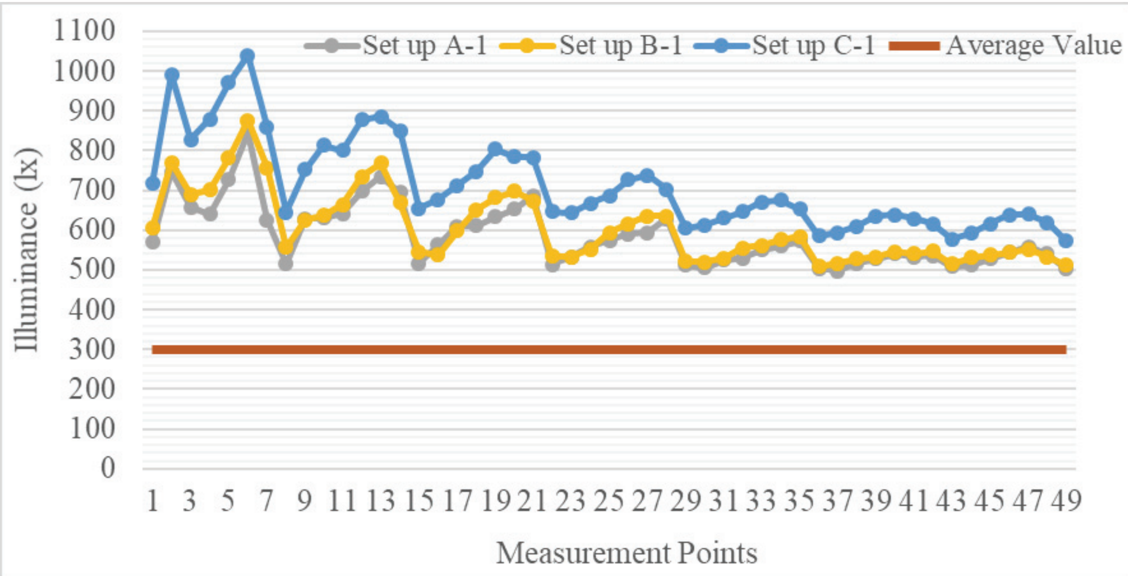


Figure 4.11. Setup A-1, setup B-1, setup C-1 and recommended office illuminance values of comparison graph

Therefore, while comparing 50 cm (setup A-1) and 100 cm (setup B-1) cavity setups did not show a big alteration, which changes between 2% to 4%. However, comparison between 100 cm (setup B-1) and 200 cm (setup C-1) depth of cavity changes 13% to 19% and while comparing 200 cm results numbers varies between 15% to 23%.

According to the summarized data shown in Figure 4.10. and 4.11. , illuminance values can be decreased by extend the gap between inner and outer layer at double skin facades. For this comparison group Setup A-1 (depth of cavity:50 cm) performance is better than other setups. It provide offices recommended illuminance value and comprehensible higher at some measurement points.

Another setup comparison group has inner layer glass transmittance value 63%, and outer layer glass transmittance value 90%. Illuminance level for 50 cm depth of cavity range from 359 lx to 572 lx while the range was 365 lx to 660 lx, in the case of 100 cm depth of cavity and 411 lx to 721 lx for 200 cm cavity length setup B-3. The second comparison group values are illustrated on Figure 4.12. and Figure 4.13.

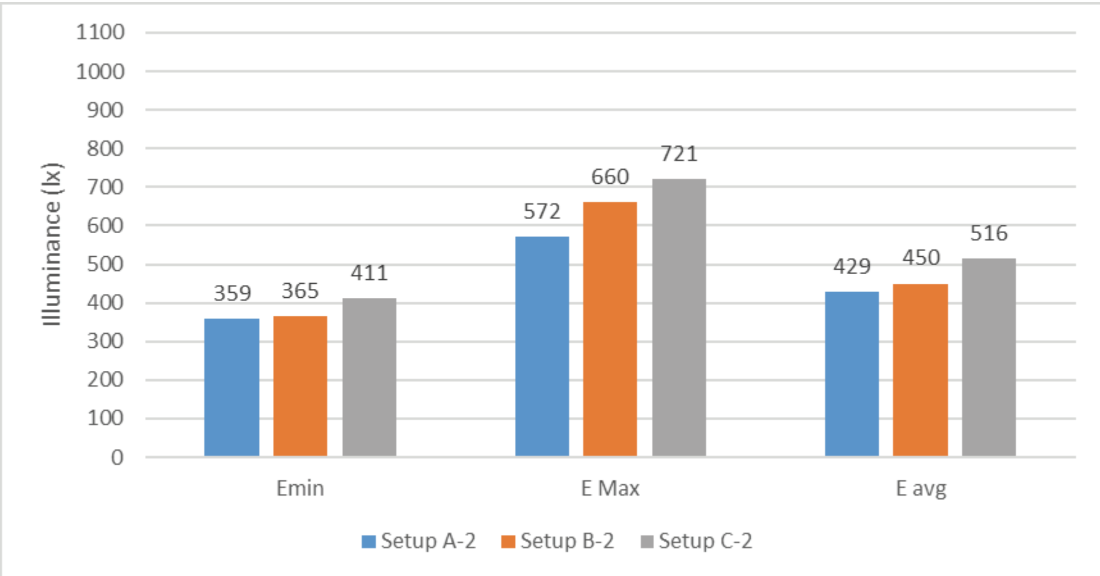


Figure 4.12. Setup A-2, setup B-2, setup C-2 lowest, highest and average illuminance values comparison graph

In Figure 4.13 above, the target illuminance (300-500 lx) for each measurement point was achieved. As the cavity width increase form 50 to 100 cm the amount of daylight decreases 5%. By changing the depth of cavity 100 cm to 200 cm lenght, illuminance has increased by 15%. All setups for 2nd comparison group, meets the optimal illuminance numbers for offices (300-500 lx) and it is not give excessive illuminance values which can cause harmful effects of sunlight like glare.

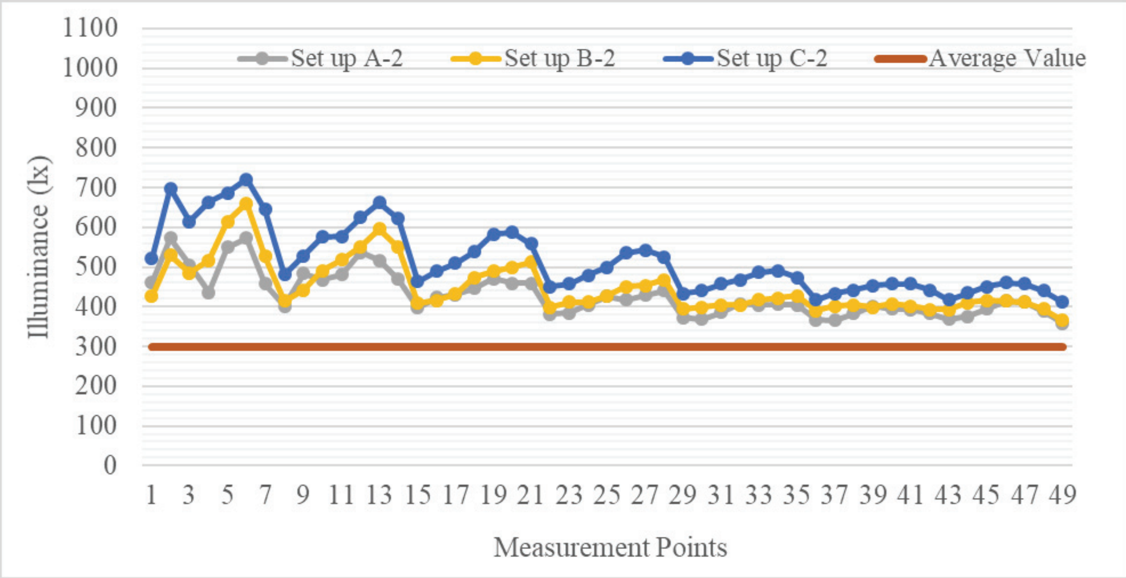


Figure 4.13. Setup A-2, setup B-2, setup C-2 and recommended office illuminance values of comparison graph

Last group which have outer layer glass transmittancy 90%, inner layer transmittancy 32% daylight values found distinctively low. According to all setups results for this comparison group, maximum illuminance value is 323 lx and minumum number is 174 lx (Figure 4.14). Although the lower values of daylight, the depth of cavity effect remained identical.

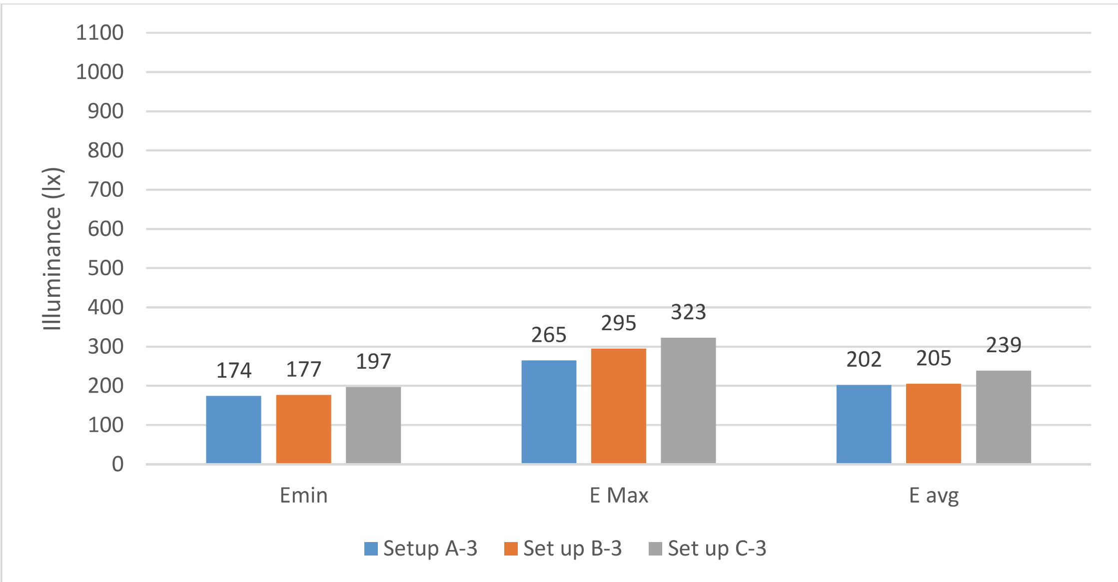


Figure 4.14. Setup A-3, setup B-3, setup C-3 lowest, highest and average illuminance values comparison graph

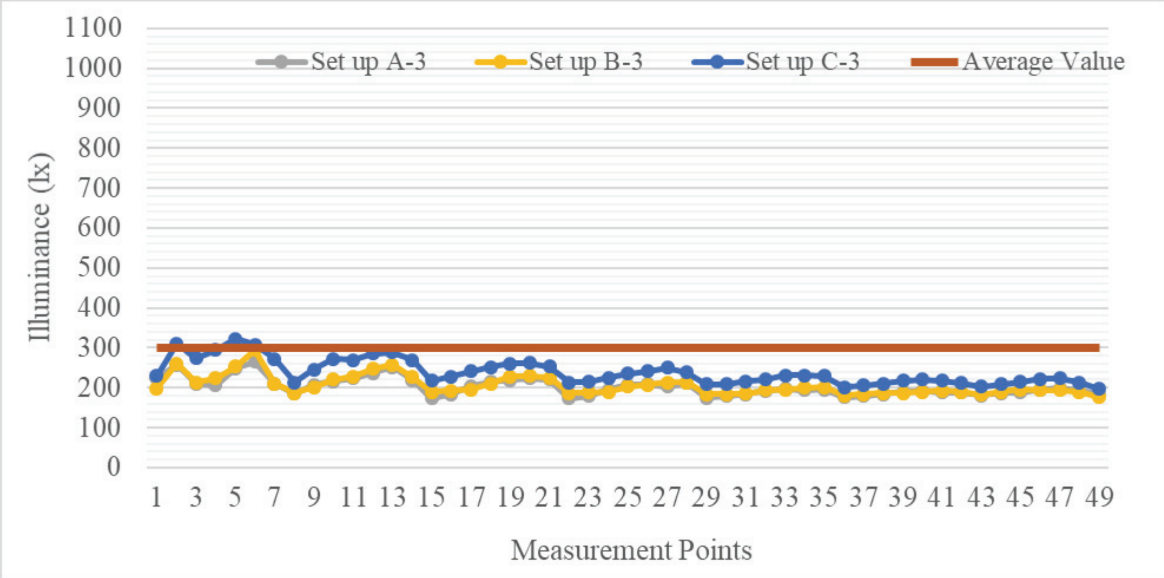


Figure 4.15. Setup A-3, setup B-3, setup C-3 and recommended office illuminance values of comparison graph

The graph at the first sight indicates that the almost all measurement points illuminance values of the last comparison group is not fulfill recommended illuminance level for offices. However, there is consistancy for comparing depth of cavity effect. Changing the cavity of the double skin facade system from 50 cm (setup A-3) to 100 cm (setup B-3) illuminance reduce about %2 and from 100 cm to 200 cm (setup C-3) it decreased %11 (Figure 4.15).

4.2.2. Effects of Different Glazing Types

In all simulations to understand the effect according to different glazing types, these items have been considered as fixed:

- Building interior materials
- Date and Hour: 21 March 12:30
- Depth of cavity for each comparison group (A: 50 cm - B:100 cm – C:200 cm)
- Recomended office illuminance range: 300 lx -500 lx
- Outer Layer Glazing Transmittance value 90%

Different glazing types effect on daylight examined in this section. According to various glazed surfaces which have 83%, 63% and %32 transmittancy values compared within constant depth of cavity. Outer layer of double skin facade glazing material transmittance value keep constant which is 90%.

In first case of this part of study, 50 cm lenght cavity fixed. Illuminance distribution of all setups outputs regularly reduced by decrease transmittancy values of glazing. Minumum illuminance values can be stated respectively 497 lx, 359 lx, 174 lx for inner glazing transmittancy 83%, 63% and %32. Maximum level of illuminance are 846 lx, 572 lx and 265 lx.

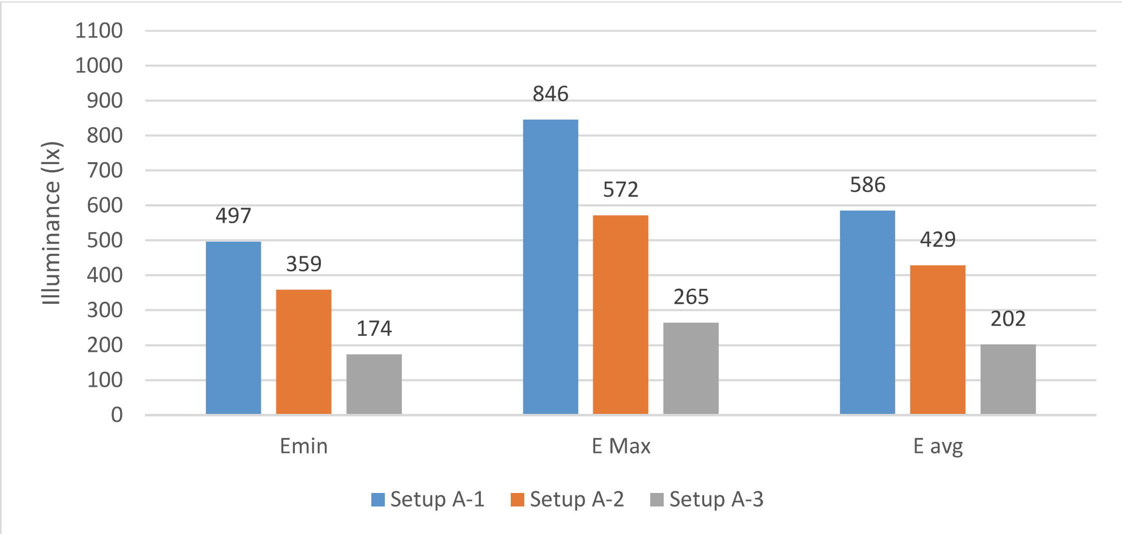


Figure 4.16. Setup A-1, setup A-2, setup A-3 lowest, highest and average illuminance values comparison graph

While comparing effect of glazing materials at double skin facades, it is seen easily from above graph (Figure 4.17.), illuminance values decreases 2 times for setup A-2 and by using very low reflected glass (32%), it decreases by 4 times. When the low reflected glass used, the luminosity values go down inappropriate values for the office buildings.

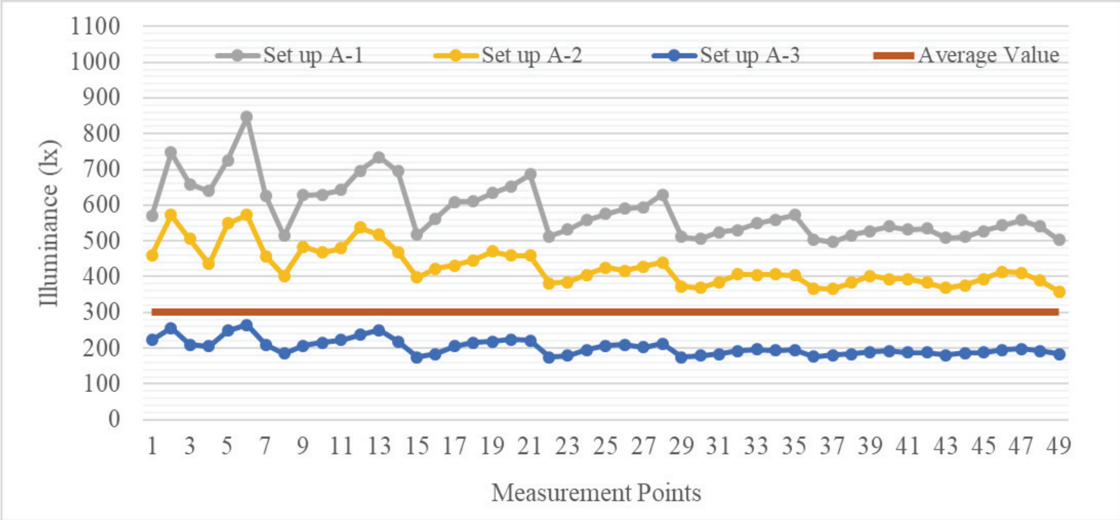


Figure 4.17. Setup A-1, setup A-2, setup A-3 and recommended office illuminance values of comparison graph

Secondly, three setup compared which has 100 cm lenght cavity. It is observe that, maximum level of illuminance values changes from 876 lx to 295 lx by changing glazing transmittancy. The results show that illuminance levels of double skin facades can be make adequate by choosing right glazing material (Figure 4.18).

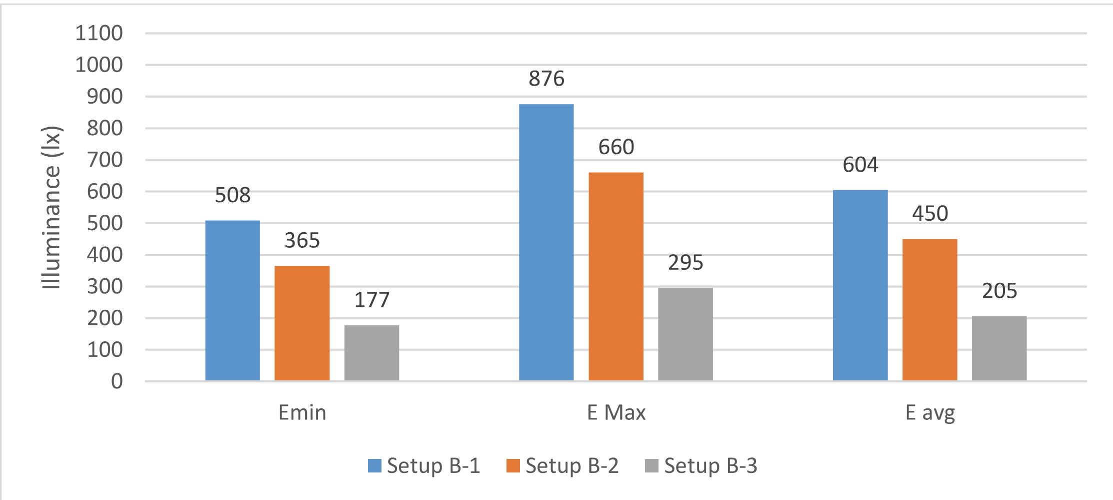


Figure 4.18. Setup B-1, setup B-2, setup B-3 lowest, highest and average illuminance values comparison graph

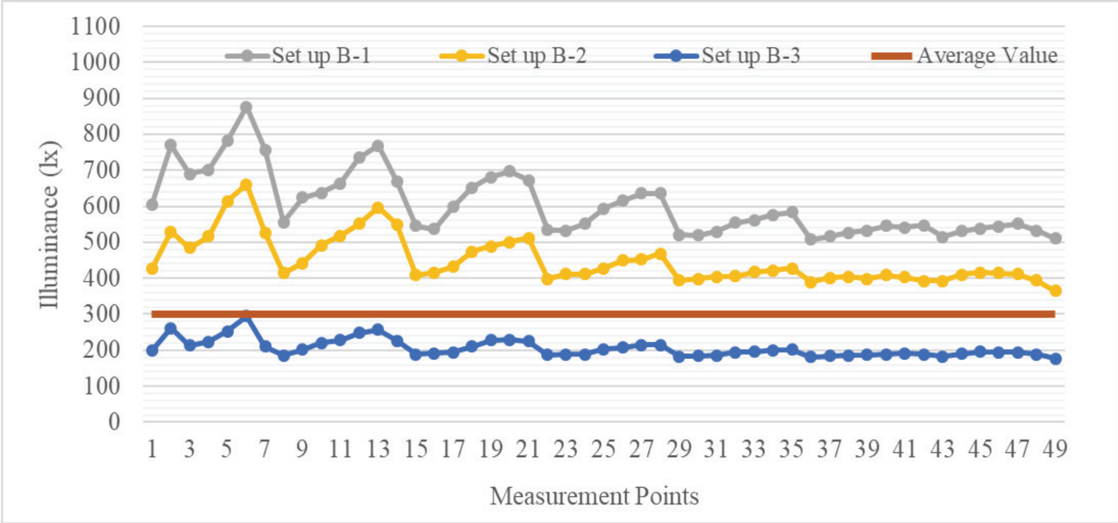


Figure 4.19. Setup B-1, setup B-2, setup B-3 and recommended office illuminance values of comparison graph

While looking 49 measurement points attitude for this comparison group (100 cm depth of cavity) It is seen easily, illuminance levels are harmoniously changes. By changing inner glazing transmittancy 83% to 63% illuminance values drop off %34. However, when inner glazing transmittancy designate from 83% to 32% daylight harvesting sharply decrease three times lower values (Figure 4.19).

Last comparison group for understanding different glazing types impact to double skin facade system have 200 cm depth of cavity. Illuminance values appears more higher than other comparison groups. Maximum values catching up by using 83% transmitted glass as usual, which is 1040 lx. When looking for average levels of illuminance for each setup; 63% transmitted glazing satisfy recommended illuminance level for offices, 83% transmitted glazing can be occur sunlight negative effect which is glare. Setup C-3 which have 32% transmittancy does not fulfill between 300 lx to 500 lx almost all measurements points.

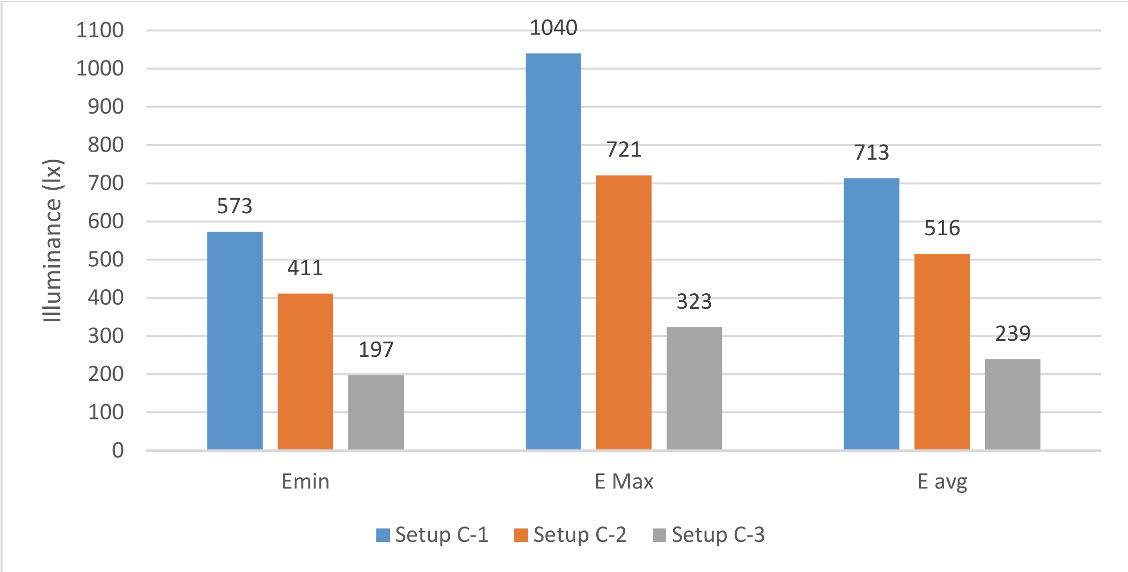


Figure 4.20. Setup C-1, setup C-2, setup C-3 lowest, highest and average illuminance values comparison graph

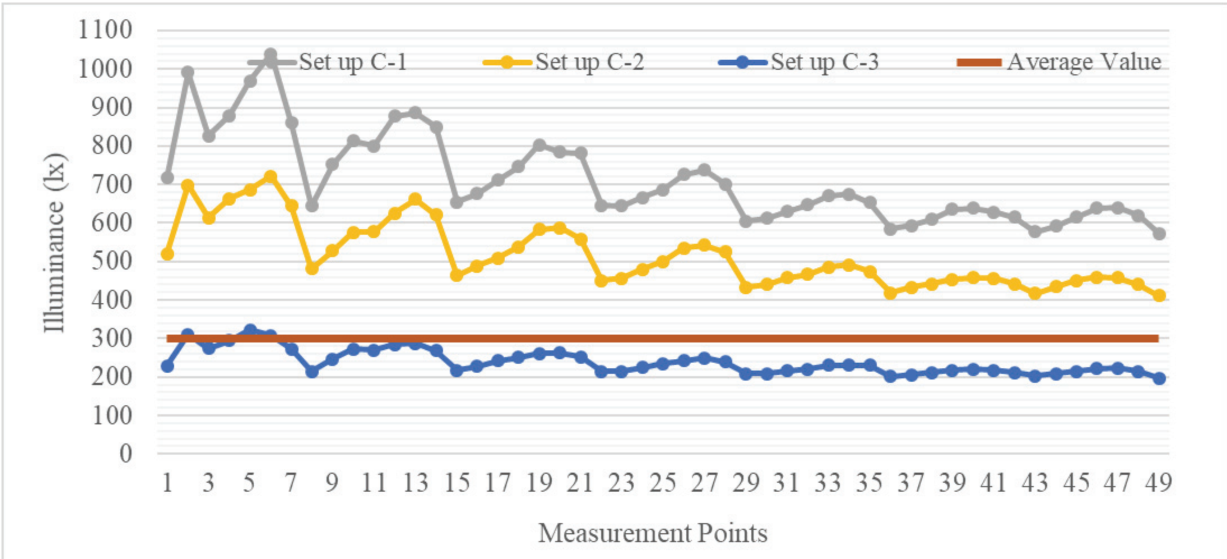


Figure 4.21. Setup C-1, setup C-2, setup C-3 and recommended office illuminance values of comparison graph

The line graph shows all points have more higher illuminance values for third comparison group. Likewise, illuminance values strongly decrease for 32% transmitted glazing materail. When comparing setup C-1 and setup C-2 values fall off twice times. Looking at other setup which is consist of 32% transmitted glass, illuminance values sharply drop off three times.

4.2.3. Effects of Layer Orientation

In order to test the layer orientation effect of daylight at double skin facades, Some parameters kept constant for each setup, these are;

- Building interior materials
- Date and Hour: 21 March 12:30
- Depth of cavity for each comparison group (A: 50 cm - B:100 cm – C:200 cm)
- Recomended office illuminance range: 300 lx -500 lx

This section deals with understand double skin facade illuminance level attitude by inner and outer layer location changing. Each comparison was grouped seperately for different cavity lenght.

First one is stated below graph for layer orientation of double skin facade system effect daylight for 50 cm depth of cavity. It is seen that, average daylight illuminance value increase %5 by switch transmittancy of glass 90% to 83% If the glass permeability value choosen as 63% and 90% illuminance number decline 15% by change inner and outer layer location. Moreover, the situation which 32% and 90% transmitted glazing replacement, results changes 20% for 50 cm depth of cavity (Figure 4.22).

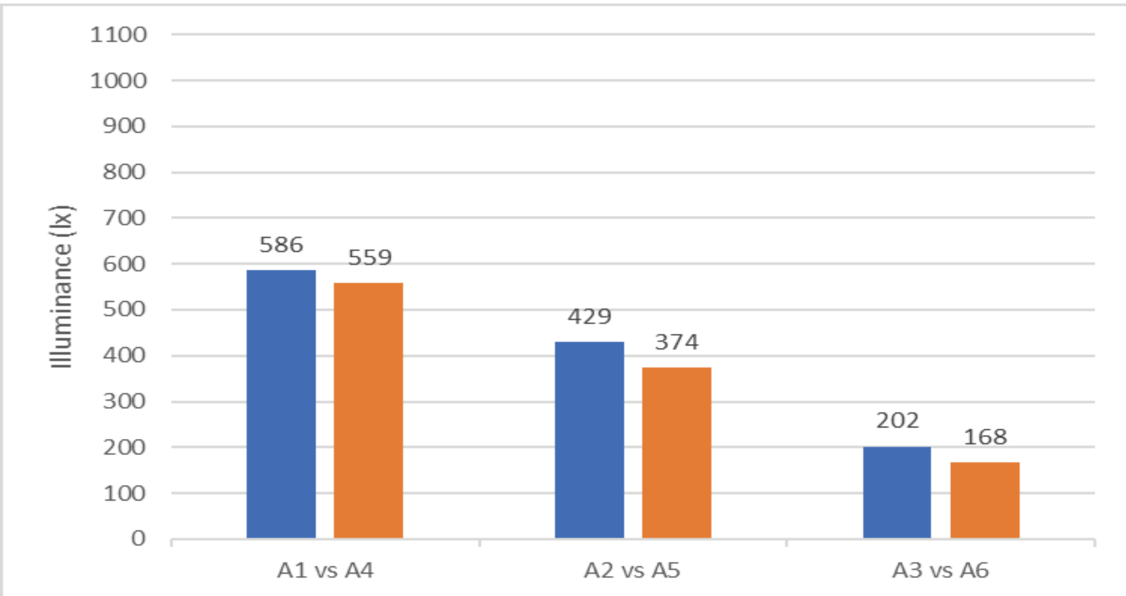


Figure 4.22. Average iluminance values comparison for layer orientation according to 50 cm depth of cavity

The purpose of comparing illuminance values act for 49 measurements points below graphs generated. It is seen the illuminance level increases or decreases consistently at every point in the existing office. Illuminance values for 32% transmitted glazing(setup A-3 and A-6) do not meet the recommended office lighting which is 300-500 lx at each point and remain very low (Figure 4.23, Figure 4.24, Figure 4.25).

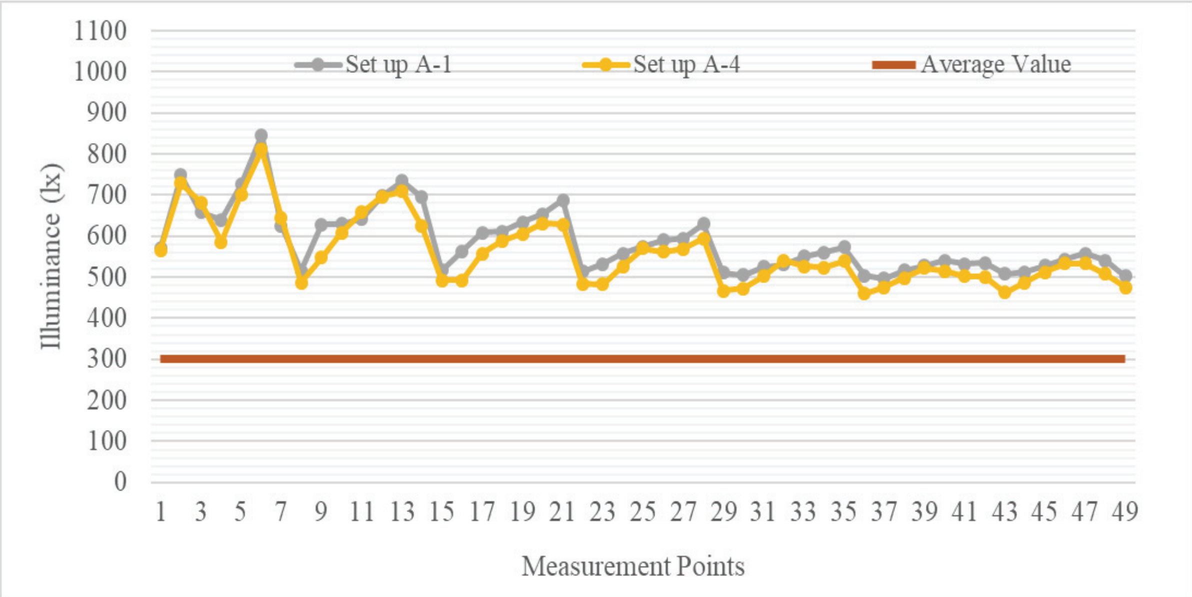


Figure 4.23. Setup A-1, setup A-4 and recommended office illuminance values of comparison graph

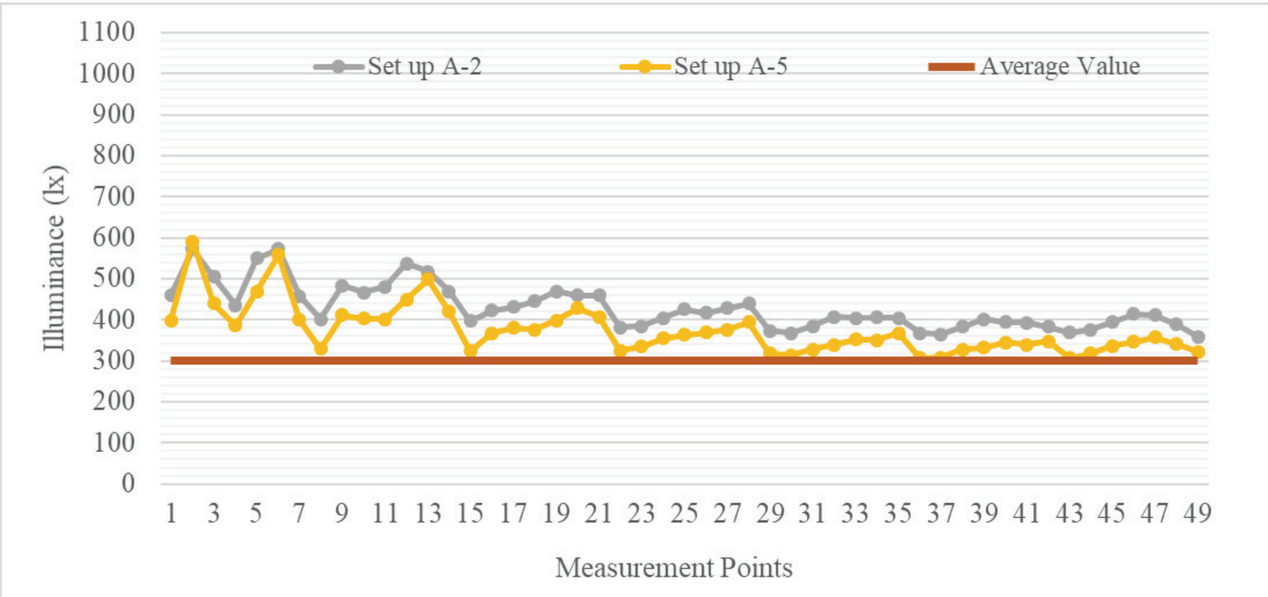


Figure 4.24. Setup A-2, setup A-5 and recommended office illuminance values of comparison graph

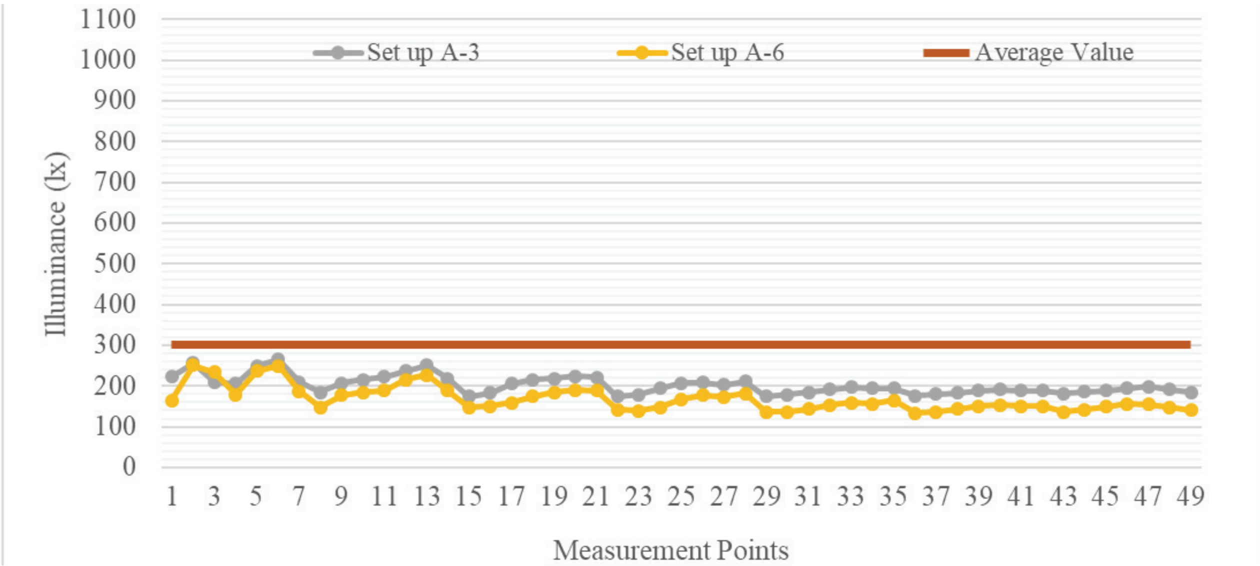


Figure 4.25. Setup A-3, setup A-6 and recommended office illuminance values of comparison graph

The next set of simulation comparison has been done for 100 cm cavity lenght. Average illuminance results show that 90% and 83% transmitted glass orientation effect illuminance remain constant (5%) as well as it is same 50 cm depth of cavity. While looking 90% and %63 transmitted glazed skins orientation effect, this ratio changes 18%. Maximum difference seen at distrubiton of 32% and %90 transmitted glazing which is reach 25% (Figure 4.26).

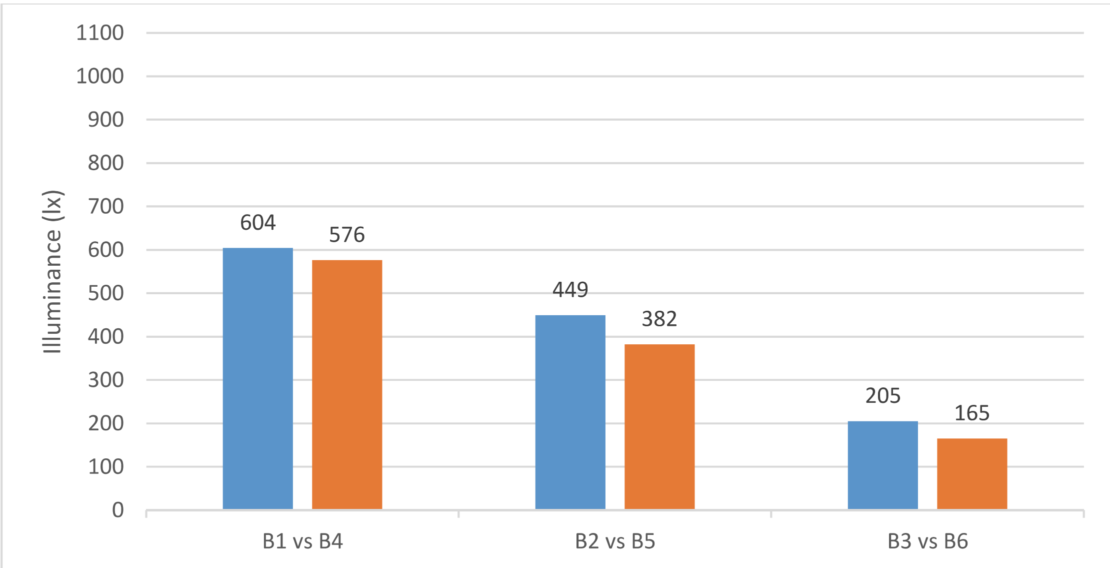


Figure 4.26. Average iluminance values comparison for layer orientation according to 100 cm depth of cavity

It is observe that illuminance values were close to the previous comparison group. The variation, which is 83% and %90 transmitted glazing alteration ,reccomended illuminance values provided at every measurement point. Furthermore, this rate decreases at 63% and 90% transmitted glazing switch, still yet it does not fall below 300 lx. However, at 32% transmittancy value glass orientation changing with 90% transmitted glazing, 300 lx does not meet at any point, it is lower than the recommended illuminance values for offices (Figure 4.27, Figure 4.28, Figure 4.29).

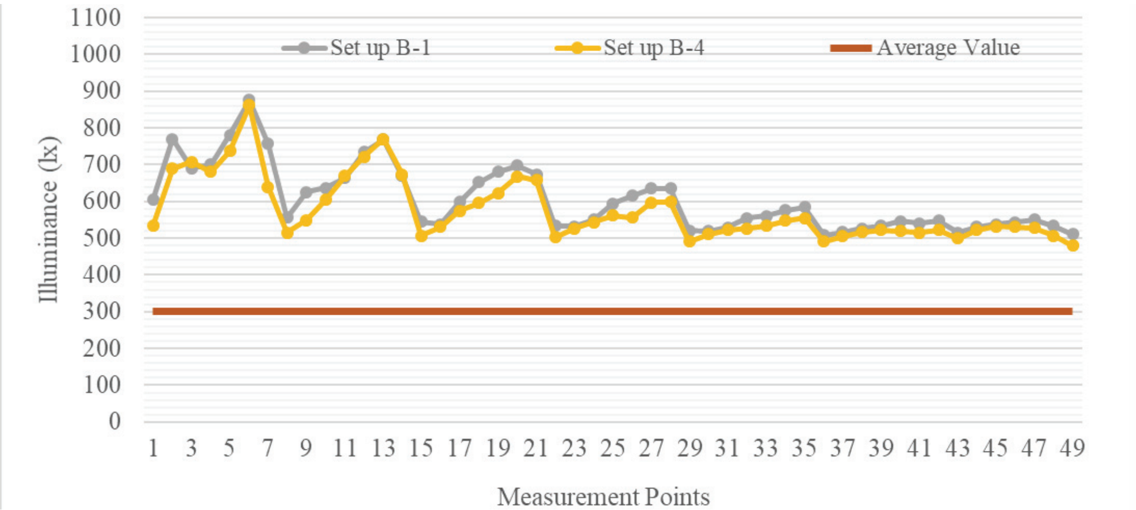


Figure 4.27. Setup B-1, setup B-4 and recommended office illuminance values of comparison graph

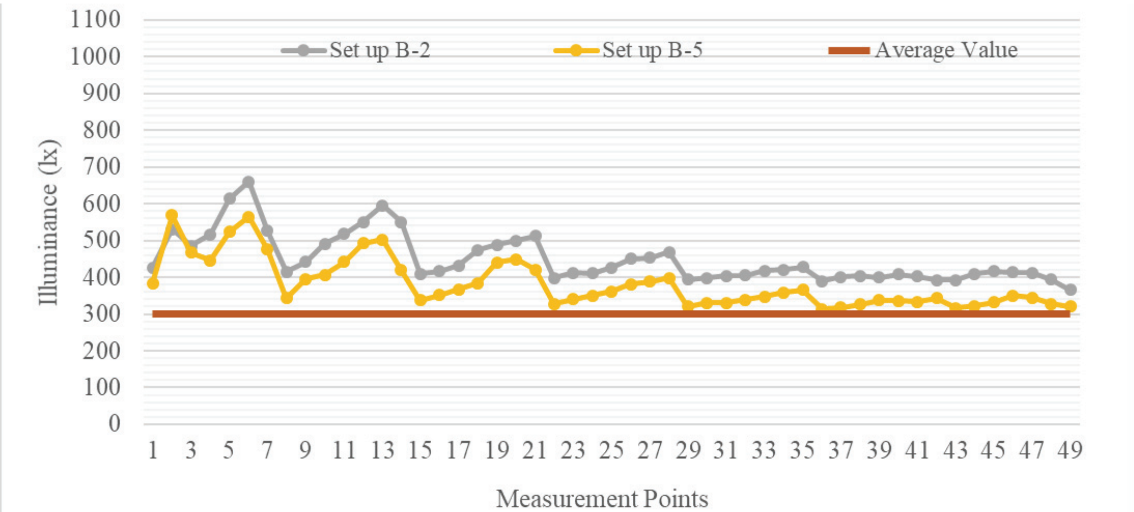


Figure 4.28. Setup B-2, setup B-5 and recommended office illuminance values of comparison graph

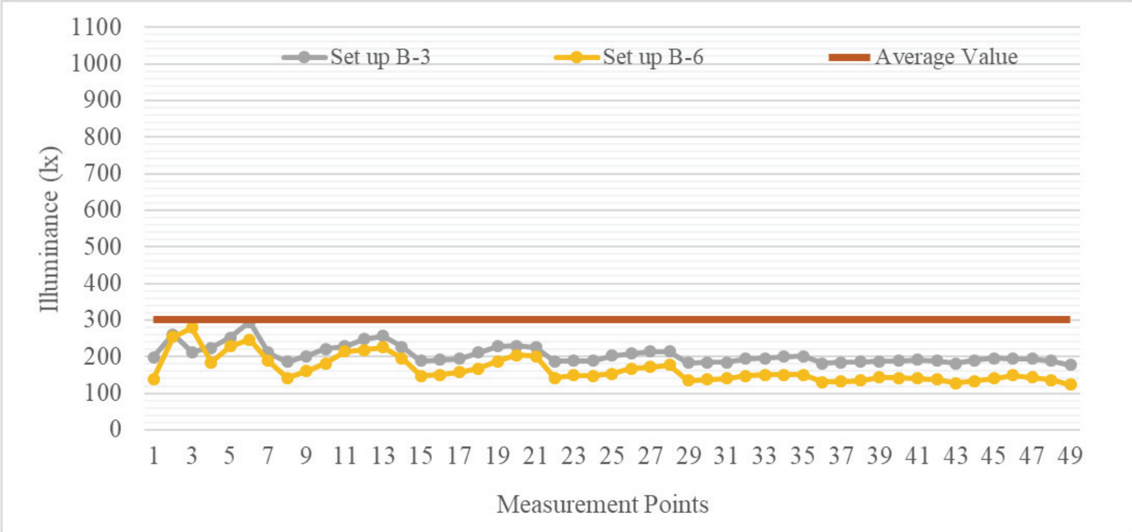


Figure 4.29. Setup B-2, setup B-5 and recommended office illuminance values of comparison graph

Last comparison group for obtain layer orientation effect which have 200 cm lenght depth of cavity. According to simulation models, average illuminance results are higher than other ones. However, there is still constancy for increase incidence which have been found out as 5%, 16% and 25% respectively for 90%-83%, 90%-63% and 90%-32% transmitted glazing layer orientations by switching orientations between eachother (Figure 4.30).

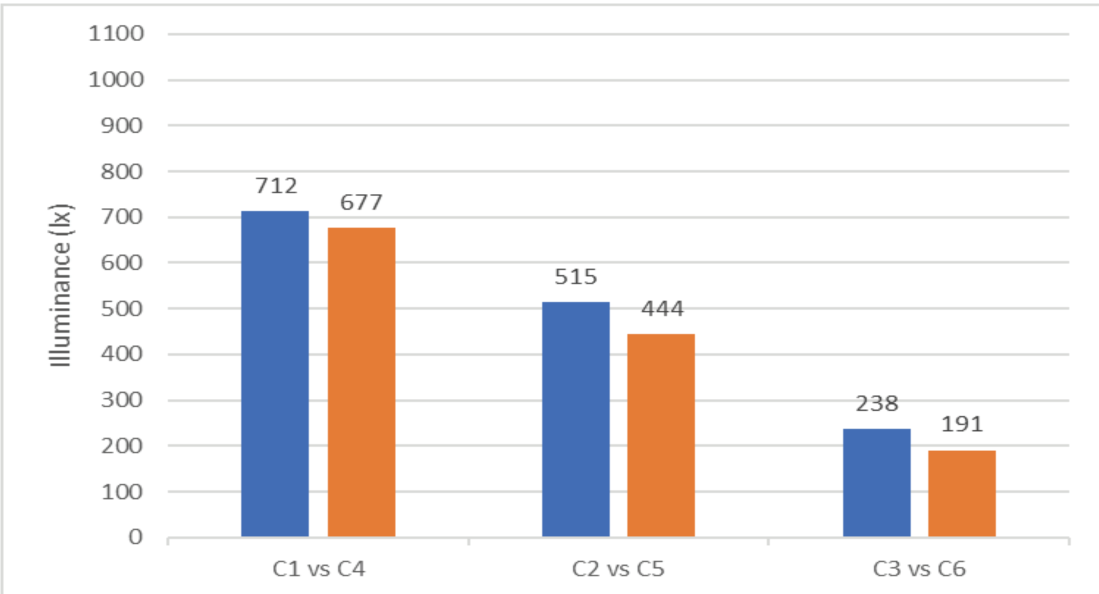


Figure 4.30. Average iluminance values comparison for layer orientation according to 200 cm depth of cavity

This comparison group illuminance results are much higher than other simulations. Notwithstanding higher values, results are constantly changing for each measurement points. Results are not fulfill recommended illuminance value for office buildings for 83% and 90% transmitted glazing, it can cause glare. The appropriate values can be captured by using 63% and 90% transmitted glazing materials.

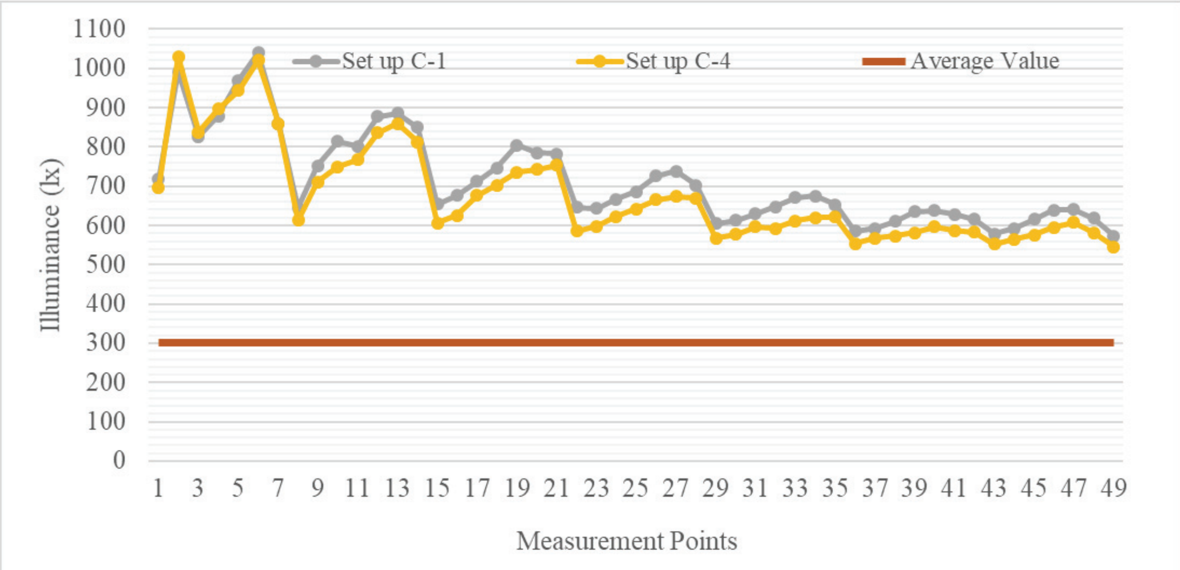


Figure 4.31. Setup C-1, setup C-4 and recommended office illuminance values of comparison graph

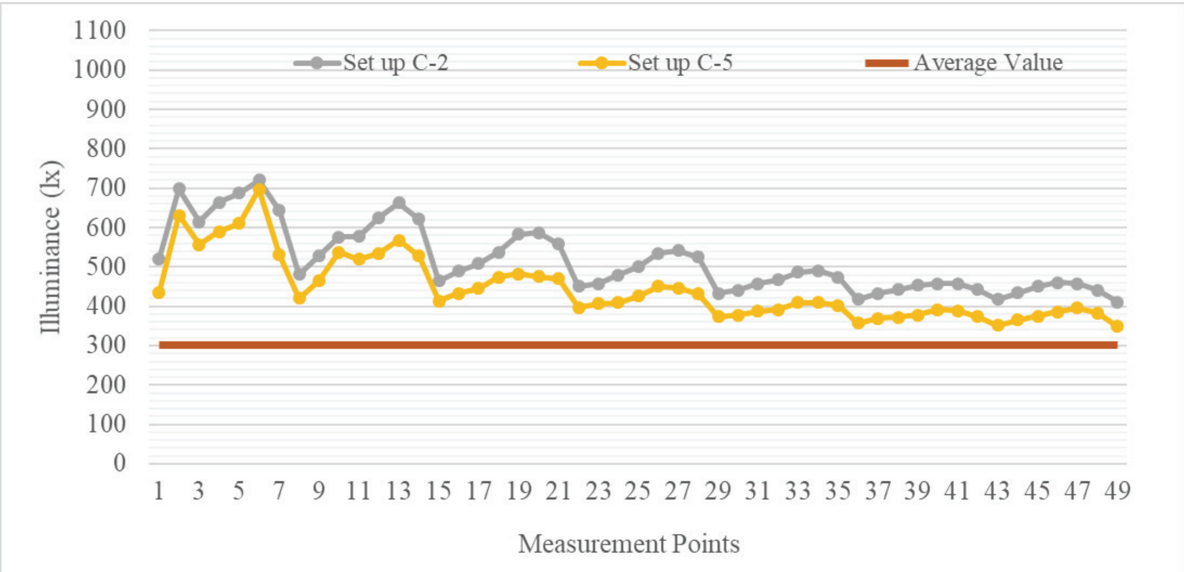


Figure 4.32. Setup C-2, setup C-5 and recommended office illuminance values of comparison graph

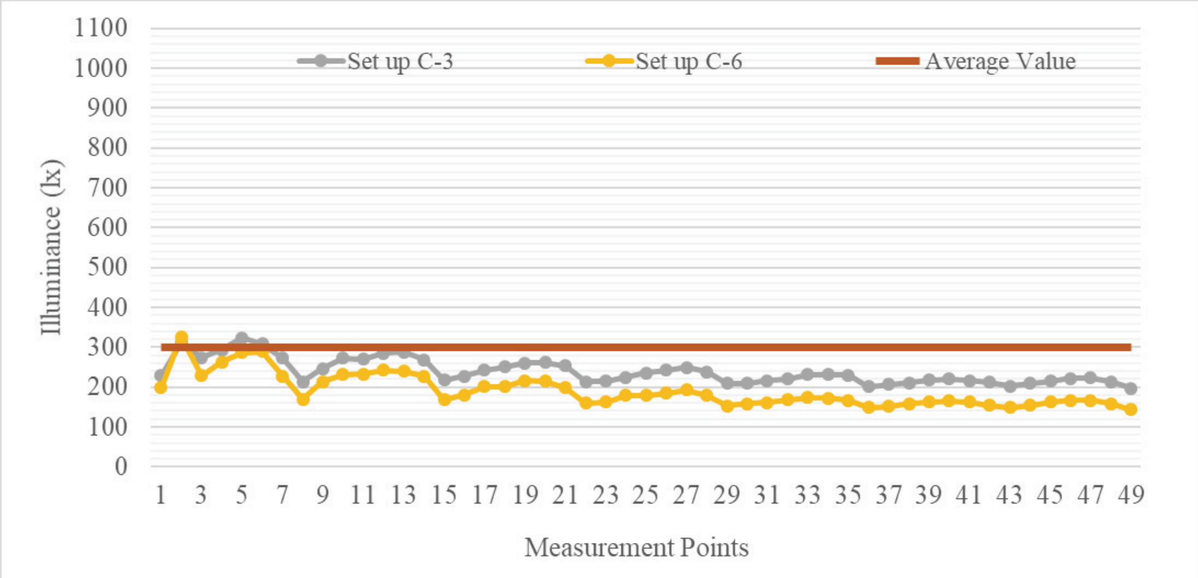


Figure 4.33. Setup C-3, setup C-6 and recommended office illuminance values of comparison graph

4.3. Optimal DSF Design by Efficient Use of Daylight

In this section, based on the findings of three different sub-sections, it was intended to give information about the double skin facade design that meets the optimum illumination values. The recommended lighting level in office buildings is between 300 lx to 500 lx. In cases this values found out higher than 500 lx, it causes negative efffect of sunlight which is glare. Glare adversely affects user comfort negatively and reduces productivity. Shading devices can be used for avoid sunlight undesired effect. Where the illuminance values emerge lower than 300 lx, artificial lighting has to be used which is increase energy consumption. The following graph shows the average values of the 18 etup simulations . The reccomended illuminance values marked with lineer dots.

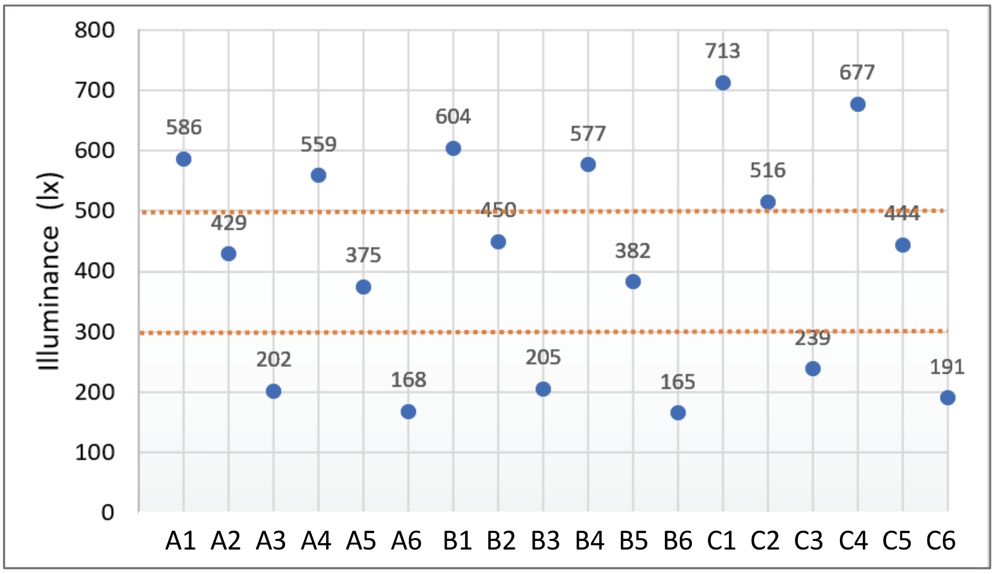


Figure 4.34. Setup A 1-6 and B 1-6 and C 1-6 Illuminance average values

Among the 18 different setups that have been simulated the highest illuminance value found out at setup C-1 which have 90% transmitted outer skin and 83% inner skin transmitted glass and 200 cm depth of cavity. It is seen that Setup B-6 and A-6 results have the lowest illuminance values which have 32% transmitted material for outer skin, 90% transmitted material for inner skin and respectively 100 cm and 50 cm depth of cavity. Therefore, it can be concluded that 63% transmitted glazing material daylight performance is better than other materials. In double skin facade design stage, select of very low or very high transmitted glazing types must be avoided for convenient daylight performance. Likewise, other double skin facade system variable, depth of cavity effect is increasing 5% by changing lenght 50 cm to 100 cm and it rises approximately 15% by changing lenght 100 cm to 200 cm. Last system variable which is layer orientation impact of double skin facade daylight performance changes more for lower valued transmitted glazing materials.

CHAPTER 5

DISCUSSION

Our knowledge of Double skin facade daylight performance is largely based on very limited data. The main aim of the research was consequently testing the effects of DSF system variables on daylight performance. With the knowledge of various effects of DSF variables on daylight performance, it is possible to make some interventions to obtain optimal benefit from the sunlight while designing the Double skin facades for offices. However, the problems faced related to finding the method and the suitable simulation program during the study have been also examined. It is aimed for this to be a guideline for the researchers planning to study on double skin facades daylight performance in the future.

In the initial stage of the study, it has been seen that the double skin facade daylight performance has not been analyzed in the literature by using Relux Software. In fact, it has been considered at the validation section of the study that Relux software daylight performance results are reliable compared to field measurements. Thus, it has been decided to use Relux for investigating DSF daylight performance. However, the software's user manual does not have any practical information about how the double skin facade model could be designed. At this point, many variations have been tried to design second skin for experimental setups which has been proved at the base case. It is concluded that if second skin is designed as an "object", simulation software outputs become accurate for double skin facade daylight performance. Relux simulation tool can analyze daylight performance by using radiosity and ray tracing method. As it can also be seen in the tables given comparatively in the study, the illuminance values are very high especially on the parts closer to the facade when the radiosity method is used. The results obtained from the base case are as follows;

(i) The second skin (another layer) must be designed as an "object "when analyzing the double skin facade in the Relux program.

(ii) When using radiosity method for single skin facade illuminance values are extremely high at 2 columns which is near the window, values are reduced while going back side of the room constantly but still really high for offices.

(iii) The simulation results must be obtained by using raytracing method instead of the radiosity method so that fair results can be obtained.

(iv) When the daylight performance of the double skin facade wall systems and the single-skin wall systems almost all of it consisting of a glass surface, adding a second layer to the facade reduces the daylight brightness value around 25%.

Outcomes from the base case which is stated above also indicated by Oesterle study. He stated that, Double skin facade effects daylight illuminance values approximately %30 without any sun shading devices. However, effect of DSF system decreases with increasing depth of room. Even this simple system of double skin facade, it can help to eliminate negative effects of daylight which are brightness or glare at near the window. He suggested further studies on combination of material choice and shading device design can be study.

When we look at the literature, an important criterion when designing a building effective on energy must be receiving the daylight to the building in a controlled manner. Because the daylight directly received into the building may cause problems such as glare or excessive heat. As Ghonimi has specified in the results of the study he has previously done, not being able to receive the daylight sufficiently into the building causes unnecessary energy consumption since it increases the need for artificial lighting. Therefore, as it can be understood from the study in the literature, an optimal value must be aimed at when receiving daylight into the building and these values clearly take place in the literature in accordance with the usage purposes of the buildings. In this study, the 300 lx and 500 lx range which is the recommended value for office building used for determine optimal illuminance value.

After validation and base case sections, several double skin facade system components examined. Primarily, the effect of the space between the two system layers (depth of cavity) in double skin facades have been examined. As a result of the comparison of the simulation models being applied, it has been understood that increasing the facade space between the two skins from 50 cm to 100 cm affects the daylight brightness value by 2-5%. However, if it is increased from 100 cm to 200 cm, this effect reaches up to approximately 11-19%.

The variable searched secondly is the transmittance values of the glasses used in the system. The transmittance value of the external layer has been kept stable for all models (90%) and the transmittance values of the internal layer have been determined as 83%-63% and 32%. The interpretation of the numeric data of simulation models are as follows:

(i) When the space between the two skins is 50 cm, the average illuminance value of the room becomes 586 lx if a glass with 83% luminous transmittance is used. On the other hand, when a glass with 63% transmittance value is used, it drops to 429 lx. However, this value meets the optimal level necessary for the offices at all points. When the glass with very low transmittance value is used, the average brightness value becomes 202 and the brightness level necessary for the offices cannot be obtained in any of the measurement points.

(ii) When the space between the two skins is 100 cm, the brightness levels increase in certain ratios as compared to the space of 50 cm. The average brightness values of the office model for the glasses with the transmittance value of 83%, 63%, and 32% have been detected as 604 lx, 450 lx, and 205 lx respectively.

(iii) When the space between the two skins of the double skin facade is 200 cm, although the brightness levels are higher than other comparison groups as compared to the comparison that has been made, still the brightness values necessary for offices only in several points closer to the glass surface can be obtained for the glass type with 32% of transmittance value

(iv) Starting from the results of these 3 different comparison groups, it has been understood that it is not possible to intervene later on after the building has been constructed in the case that the glass type with low transmittance value (32%). In the cases that this glass type is used, the office lighting gets to be made by artificial lighting and this causes a situation where the energy is not being used effectively. It has been understood that when the glass type with high transmittance value (83%), an improvement can be made by using shading equipment although the high values are obtained from the optimal brightness levels. When the glass type is chosen as 63%, the 300-500 lux range which is suitable for office buildings can be obtained in almost all facade layers of space variations. In the researches on the suitable glass type during the design process of the double skin facades, the necessity to use the glasses with a transmittance level close to this value must be considered.

Another facade component that the study examines the effect of the double skin facades on daylight performance is layer orientation. Various depth of cavity has been researched by dividing into different groups. The results given below apply for each depth of cavity since similar results have been obtained for various spaces:

(i) When the transmittance value between the internal and external layer has been chosen close to each other, the effect on the daylight stays at the ratio of 5% and an obvious difference is not seen (83% and %90 transmitted glazing).

(ii) When the transmittance of the glass types used for both skins is kept stable as 90% and 63% and only the orientations are changed as internal and external, the difference between the brightness levels reaches up to 15%.

(iii) When the transmittance values of the glass types are chosen as 32% and 90% and the places of the double skin facade layers are changed, the daylight brightness level changes by 20%-25%.

This study aims, examining the purpose of the first appeared double skin facade building and bringing light to the necessity of considering the daylight performance during the design processes of these facades. The first purpose intended when the design of the Steiff Factory building which is described as the first double skin facade in the literature is to benefit from the daylight at the maximum. However, the purpose of the double skin facades has given its place to reducing the heating and cooling loads, natural ventilation and esthetic concerns in time. Therefore, the number of studies regarding the natural lighting performance of the double skin facades taking place frequently in the literature is not sufficient and it is generally not taken into consideration during the designing process. Some improvements can be made in the daylight performance with simple interventions to be made when the building is yet in the designing process.

The energy consumption caused by the artificial lighting can be prevented with small interventions that can be made to obtain the optimal daylight values in the office buildings being used between 08:00-18:00 especially for our country where the days with the sun are pretty much. It must also be remembered that the effective usage of daylight increases the efficiency of employees as well as decreasing energy consumption.

There are some limitations of the study, which could be better for investigating the effects of the variables on thermal performance and natural ventilation evaluations together with the daylight performance. Moreover, although the effect of daylight on visual comfort is an important issue, this subject has also not been examined.

In this study, the office buildings have been examined because they are used at day time which gives the opportunity to utilize the maximum effect of daylight. Moreover, DSF systems are commonly used in office buildings.

The study examines the effect of Double Skin Facade system elements variations for daylight quality. In future studies, different variables, different locations could be investigated to examine the daylight performance of double skin facades. Also, daylight autonomy could be investigated and according to results daylight energy saving cost could be underlined at further studies.

CHAPTER 6

CONCLUSION

This study included analysis of Double skin facades system daylight performance with relation to system design variables effect to make possible interventions during design phase of system. Research focused on examinining the effects of DSF systems design variables -- glass types, depth of cavity and layer orientation-- on daylight performance of a North-East facing office.

In literature, daylighting strategies for building design argued many times. Also, DSF systems became popular issue at architectural research. However, these two issues (daylight and DSF systems) not combined at studies detailed. This study has found the deficiency in the literature and aimed to provide a background for future studies.

At the beginning of the study, a validation model was made to determine the appropriate simulation program and field measurements were taken in a sample office and compared with the results of Relux Software. As the results were consistent, this simulation program was used throughout the study. Elimination of approximate results is one of the main reason for common usage of simulation. Computer simulations help to fill the gap between theory and experiment. Also, there are limited information about how to design double skin facades in the Relux. A large number of variations have been tried to design the second skin for experimental setup and decide which method outputs will be suitable for study which have been proven in the base case section.

In order to test reliability of simulation software, field measurements done and compared with simulation tool results. First variable, which is depth of cavity results show that increasing two skins air corridor length from 50 cm to 100 cm has little effect on daylight performance. However, when we increase from 100 cm to 200 cm, this effect reaches 20%. Optimal illuminance values for offices are caught at 100 cm depth of cavity for each measurement points.

Second variable which is glass type is analyzed. The transmittance value of the external skin has been kept constant and internal skin varies 32%, 63% and %83 transmittance value. Changing the transmittancy of the glass used in the double skin facade system affects the daylight performance sharply The situation which 32%

transmitted glass used, illuminance values not met reccomended illuminance values for offices at all measurement points. In this case, there is no possibility to make improvements and artificial lighting must be use for proper lighting. When 63% transmitted glass is used, optimal values are captured for each depth of cavity setups. If 83% transmitted glass used, the values remain high. However, this improvement can be made with the help of shading devices. It is possible to avoid undesirable of daylight which is excessive heat and glare.

Moreover, another analyzed case is layer orientation effect of double skin facade daylight performance. Replacement of inner and outer skin glazing material with eachother had small effect when two skins transmittancy values closer with eachother. If glazing materials transmittancy choosen obviosuly different than eachother, it is seen that illuminance values changes between 20% to 25%.

The study examine the effect of Double Skin Facades system elements variations to daylighting quality and explain which improvements can be done. By using the simulation results and charts, designers will be able to find a suitable solution for optimum daylight quality while designing double skin facade. Double skin facade effects of daylighting is an important study field for architecture it can not be ignored.

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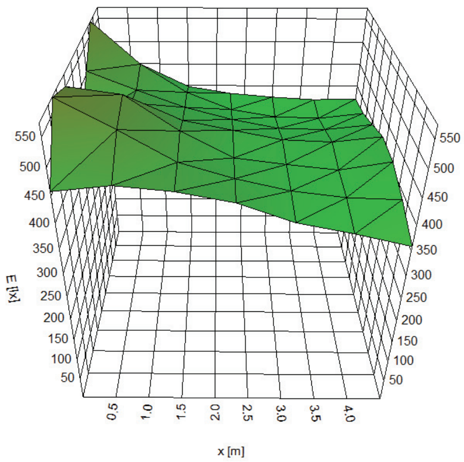
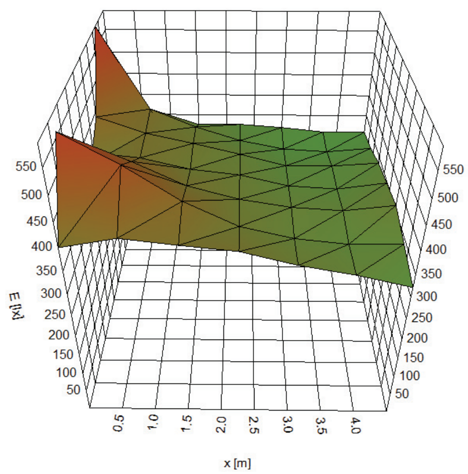
APPENDIX A

RELUX 3D MOUNTAIN PLOTS AND ILLUMINANCE VALUES OF SATISFIED OPTIMUM DAYLIGHT MODELS



Em	: 429 lx
Emin	: 359 lx
Emax	: 572 lx
Emin/Em	: 1 : 1.19 (0.84)
Emin/Emax	: 1 : 1.59 (0.63)

Figure A.1. Set up A-2 : 50 cm depth of cavity, inner layer transmittancy:%90, outer layer transmittancy: %63



Em	: 375 lx
Emin	: 307 lx
Emax	: 591 lx
Emin/Em	: 1 : 1.22 (0.82)
Emin/Emax	: 1 : 1.93 (0.52)

Figure A.2. Set up A-5: 50 cm depth of cavity, inner layer transmittancy %63, outer layer transmittancy %90

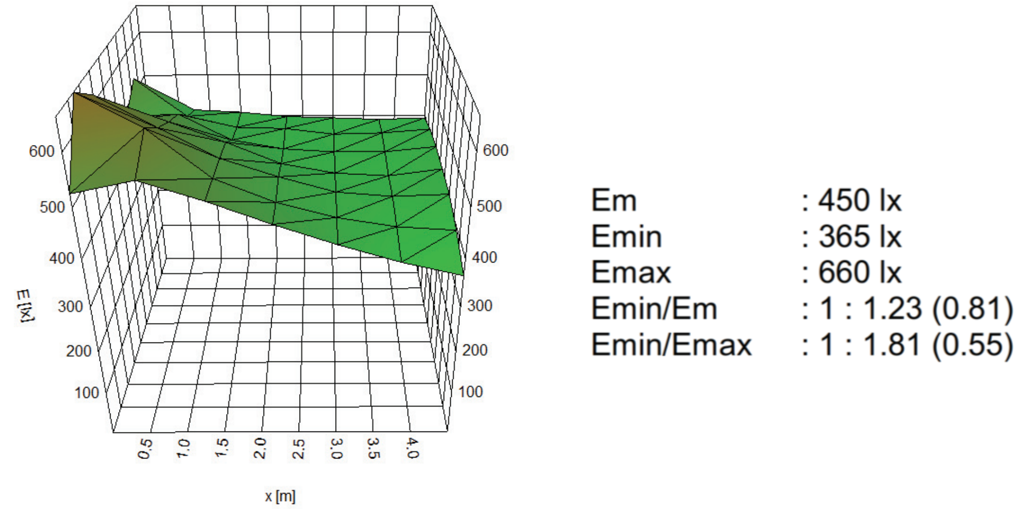


Figure A.3. Set up B-2: 100 cm depth of cavity, inner layer transmittancy:%90, outer layer transmittancy: %63

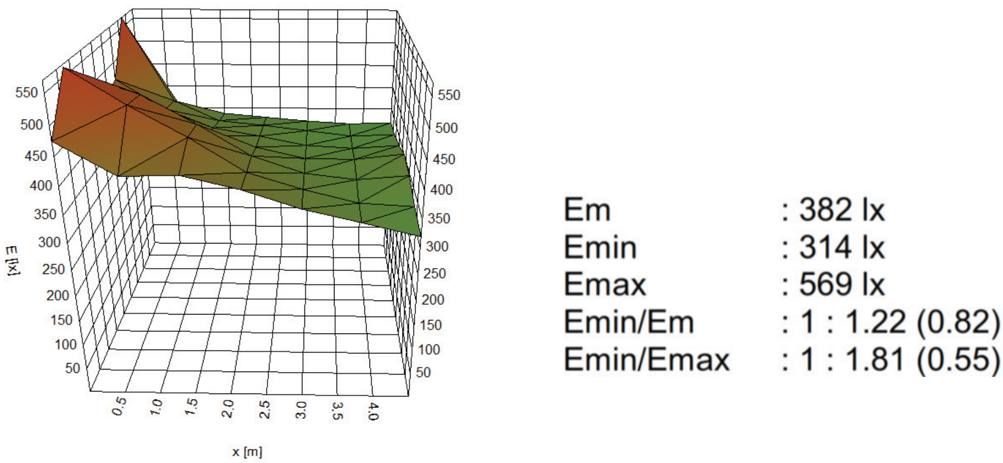
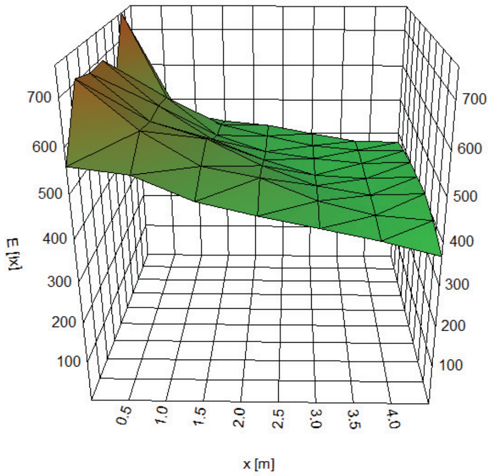


Figure A.4. Set up B-5: 100 cm depth of cavity, inner layer transmittancy %63, outer layer transmittancy %90



Em	: 444 lx
Emin	: 349 lx
Emax	: 697 lx
Emin/Em	: 1 : 1.27 (0.78)
Emin/Emax	: 1 : 2.00 (0.50)

Figure A.5. Set up C-5 200 cm depth of cavity inner layer transmittancy %63, outer layer transmittancy %90