PERFORMANCE OF MOVABLE FAÇADE PANELS IN TERMS OF DYNAMIC DAYLIGHT METRICS FOR A CLASSROOM

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ABSTRACT

PERFORMANCE OF MOVABLE FAÇADE PANELS IN TERMS OF DYNAMIC DAYLIGHT METRICS FOR A CLASSROOM

Although the use of daylight has an important role in educational spaces, uncontrolled use of daylight can lead to some undesirable situations for occupants. It is generally accepted that recommended illuminance values change between 300 lux and 2000 lux in educational spaces. However, it is not possible to get these illuminance range at the same level during the day, as the classrooms have been used all day period. To create more satisfied daylit spaces, movable shading systems become a solution because of their ability of guiding the direct daylight in day period. To evaluate the daylight performance of movable shading systems, dynamic daylight performance metrics have been used.

This thesis focuses on comparing different types of movable shading systems developed as a result of findings of dynamic daylight metrics in a classroom. A classroom in the Department of Architecture in Izmir Institute of Technology was chosen as the case room measured illuminance values. It has been found that the level of illuminance values are much higher than the generally accepted values. The classroom has been modelled virtually and analyzed on a special software programmer in order to examine the findings of the field measurement. Two different types of moveable shading systems have been suggested and used to evaluate the performance of illuminance.

When the results are evaluated, it can be understood that movable shading systems have a significant role on creating satisfied spaces in educational areas. Especially, single oriented shading systems, which represented as model 1 in thesis, are more successful to control direct daylight.

ÖZET

BİR SINIF İÇİN HAREKETLİ CEPHE PANELLERİNİN DİNAMİK GÜNIŞIĞI METRİKLERİ AÇISINDAN BAŞARIMI

Eğitim yapılı ortamlarda gun ışığının kullanılmasının önemli bir rolü olmasıyla beraber, gün ışığının kontrolsüz bir şekilde kullanılması eğitim ortamında bulunanlar açısından istenmeyen durumlara yol açabilmektedir. Bu alanlarda genel olarak tavsiye edilen aydınlık değerleri 300 lux ve 2000 lux arasındadır. Diğer yandan, gün içinde aydınlık değerlerinden eşit olarak yararlanılması, sınıfların tüm gün kullanıldığı düşünüldüğünde mümkün değildir. Dolayısıyla hareketli cephe sistemleri gün içinde gün ışığından en iyi şekilde yaralanılabilmesi için bir çözümdür. Bu sistemlerin gün içindeki performansını ölçmek için ise dinamik gün ışığı metrikleri kullanılmaktadır.

Bu tez, sınıflarda kullanılan farklı hareketli cephe sistemlerini dinamik gün ışığı metrikleri bakımndan karşılaştırmak amacıyla yazılmıştır. Aydınlık değerlerini ölçmek için İzmir Yüksek Teknoloji Enstitüsü Mimarlık fakültesinde bulunan bir sınıf seçilmiştir ve bu sınıfın aydınlık değerlerinin literatürde kabul edilen değerlere göre yüksek olduğu gözlemlenmiştir. Sözü edilen sınıf, sanal ortamda modellenmiş ve gün ışığı similasyon programı kullanılarak analiz edilip gerçek ortamdaki verilerle karşılaştırılmıştır. Bu verileri istenilen değerlere yakınlaştırmak için iki çeşit hareketli cephe önerilmiş ve gün ışığı performansı ölçülmüştür.

Sonuçlar değerlendirildiğinde hareketli cephe sistemlerinin eğitim yapılan ortamlarda kişilere daha rahat öğrenme ortamı sağladığı gözlemlenmiştir. Özellikle bu tezin birinci modelinde gösterilen tek yönelimli cephe sisteminin gün ışığından en iyi şekilde yararlanılmasında başarılı olduğu sonucuna ulaşılmıştır.

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CHAPTER 1

INTRODUCTION

1.1. Problem Definition

Daylight has a crucial role in the design of educational spaces, since daylight increases the success of students, affects positively their health and physical development in schools according to recent studies (Axarli, Tsikaloudaki, 2007). Students can achieve, for example, 26% faster in reading and 20% faster in math with the strong impact of daylighting in their classrooms (Plympton, Conway, Epstein, 2000). Thus, classrooms with well-designed windows and skylight can improve the academic and physical performance of students. In relation with this, the daylight level becomes the first concern for interior spaces. J. Mardaljevic et al. stated in a conference paper in 2012 that useful daylight illuminance (UDI) is a human factors-based metric. It means that UDI is characterized as the yearly event of illuminances over the work plane that is inside a daylight illuminance range considered helpful for tenants. This range is between 300 lux and 2000 lux. On the other hand, most of the time, the range which is between 100 lux and 300 lux creates unsatisfied dark spaces for humans and it is defined as UDI ‘fell-short ‘or UDI-f in studies. Also, it was investigated that the range of workplace demands 300 lux to 500 lux.

Designing a shading system is one of the main solutions for good daylighting in buildings. There are large number of studies about shading systems. In general, we can categorize them in two parts; fixed shading systems and movable shading systems. Generally, fixed shading systems are designed as rectangular planar elements which depend on building location and facade orientation. Some examples of fixed shading systems are overhangs can be found in (Gagne, Andersen, 2010), interior and exterior light shelves which analyzed in (Bauer et al., 2017), fixed louvers can be found in (Mandalaki et al, 2012), fixed solar screens can be found in (Gadelhak, 2013). To compare with movable shading systems, this type of fixed shading systems, especially overhangs, cannot block the sun light effectively because they cannot adapt themselves according to sun position (Lim, Kim, 2010). In addition to this situation, movable facades adjust the different condition changes of interior and exterior environment, to develop the functional requirements of the envelops like daylight availability, noise, strength and stability and aesthetics (Aelenei et al., 2016). Some examples of these movable shading systems are louvers systems (Kirimtat et al., 2016), venetian blinds (Kasinalis et al., 2014), roller shaders (Shen, Tzempelikos, 2017) and movable shading panels (Choi et al, 2017). These movable shading systems have been investigated by different researchers for better understanding of their performance and the importance of their usage in buildings. Shading devices improve energy efficiency in buildings while protecting the interiors overheating and providing adequate daylight level (Kirimtat et al., 2019). According to Yoa, movable shading devices are more successful at controlling sky diffuse radiation than fixed ones (Yao, 2014).

On the other hand, in architectural spaces, daylight is considered as a dynamic source of illumination. Because it can emphasize the gradients of texture and color or create contrast brightness level between geometries (Rockcastle, Andersen, 2012). To evaluate the performance of daylight in interior spaces, some dynamic metrics are used. While these metrics estimate the performance of the daylight, we consider the different conditions like different seasons, the latitude, different times of the day, different sky conditions and building orientations. Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) are two dynamic metrics that analysis based on the time variables (Piderit et al., 2015).

Daylight Autonomy (DA), is an annual daylight metrics. According to Reinhart et. al. (2013), it represents the percentage of the occupied hours of year that a given point in a space above a specified minimum illumination threshold. The most important advantages of DA is that it takes into account the façade orientation, user profiles and possible sky conditions throughout the year (Chien,Tseng, 2013).

Useful Daylight Illuminance (UDI) is a human factor-based metrics that annual occurrence of illuminances across the work plane that are within a range considered useful by occupants (Mardaljevic et al. 2012). It is also based on work plane illuminance. Therefore, the criteria of "useful" vary according to illuminance values. It evaluates the area neither too dark nor too bright. If the spaces have less than 100 lux illuminances, it means that the area is too dark for occupants. Also, if illuminance values are higher than 2000 lux, too bright spaces are occurred to users (Reinhart et al.,2013).

Addition to these metrics, the Illuminating Engineering Society (IES) approved their first human-based daylight metrics which are spatial daylight autonomy (sDA) and annual sunlight exposure (ASE) (Nezamdoost, Ven Den Wymelenberg, 2016).

As described in the review by Costanzo et. al. (2017), Spatial Daylight Autonomy (sDA) is the percentage of floor area that receives over 300 lux for at least 50% and 75 % of building area. The time period of working hours per day that from 8:00 am to 6:00 pm. is studied. There are two different sDA performance criteria. If sDA percentage meets or exceeds 75%, it means that the analysis area is "preferred". In second case, if sDA percentage meets or axceeds 55%, the analysis area accepted as "nominally acceptable".

Annual Sunlight Exposure (ASE) is the percentage of floor area that receives over 1000 lux for more than 250 hour per year. The percentage should be around 7%. There are three different situations in ASE, the first one is that the analysis areas are more then %7, this area reported as "unsatisfactory". If the percentage of ASE less than 7%, it means that the analysis area is "neutral acceptable". If the ASE less than 2%, it is reported as "clearly acceptable".

In this study, different types of movable façade panels design and their performance on daylight in terms of dynamic daylight metrics are researched for a classroom. Although there are lots of researches about movable shading systems, research on movable shading panels for educational spaces is still lacking. More research in this area is needed. So, in first step, the movable shading panels are designed for a classroom and then its performance about daylight are evaluated with simulation method.

1.2. Objective of the Study

Movable systems, as previously mentioned above, are one of the main solutions for good lighting in buildings, because they can adapt to condition changings, also adapt the spaces to these changings. Therefore, the objectives of the thesis are mentioned above.

(i) Focusing the performance of movable shading systems on educational buildings

(ii) To analyze different types of movable shading systems in terms of illuminance values and climate-based metrics

(iii) To present a shading system that is different from other shading types studied in the literature

To achieve these purposes, firstly, the model of case classroom was simulated in terms of illuminance values and the results of simulation were compared with field-measurements. Then, two different movable shading systems were modelled, and different orientated panels of these movable shading were compared to each other with illuminance simulation method.

1.3. General Method of the Research and Outline

In this thesis, the study is explained in 5 different chapters. The first chapter includes the explanations about importance of daylight in educational spaces, the purposes of the study and summarizing the following chapters.

In the second chapter, related literature about daylight in buildings, daylighting strategies for classrooms, different daylight metrics, daylighting features of movable shading systems, different type of movable shading systems and specific examples, also recent daylight studies about movable shading systems are investigated, respectively.

In the third chapter, firstly the geometrical and surface properties of case classroom, which is in Izmir Institute of Technology, were explained. After that, the simulation modelling process of case model, case model with shading model and case model with shading model 2 were introduced, separately.

In the fourth chapter, firstly, the field-measurement and simulation results of case classroom were compared for validation. Then, the simulation results of two different movable shading positioned different angles, which run out on equinox and solstice days at 12:00 pm, were evaluated in terms of illuminance values, DA, UDI annual, sDA and ASE.

In chapter five, the simulation results are summarized, and an optimal movable shading system design is explained according to daylight simulation results. Then, discussions and conclusions of the study are explained, and the thesis is summarized, briefly.

CHAPTER 2

LITERATURE REVIEW

This chapter includes general explanations about daylighting in classrooms and daylighting features of movable façade systems. In the first part of the literature review, the importance of using daylight in classrooms is explained. Then, dynamic daylight performance metrics are mentioned to understand the evolution of daylight performance. In second part of this chapter, daylighting features of movable facades and different type of movable shading systems are explained in detail in order to make better use of daylight in classrooms Then, different example of movable shading systems are mentioned. Finally, recent daylight researches on movable shading systems are explained, briefly shown in Figure 2.1.

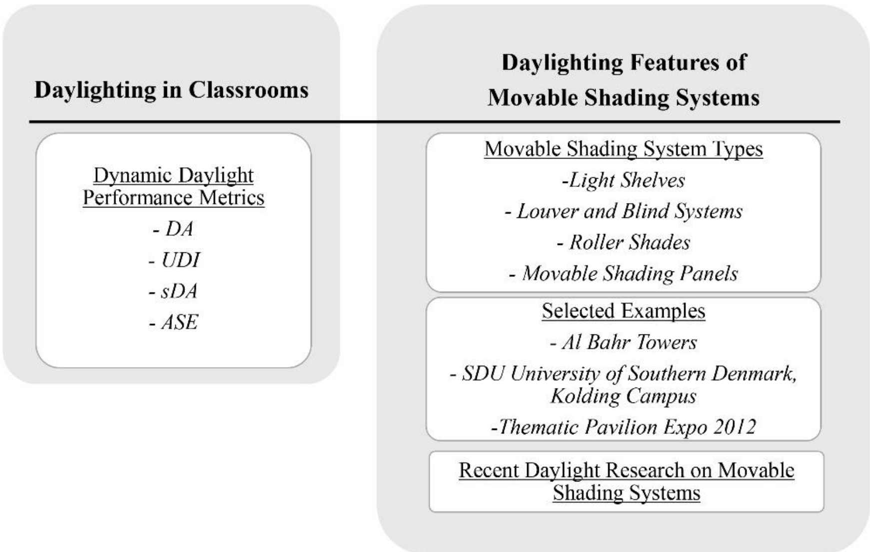

Figure 2.1. Schematic explanation of litearture review

2.1. Daylighting in Buildings

Recent studies show that, good daylight strategy in educational spaces has lots of benefits on students in terms of their mental and physical health. Because controlling illuminance levels has significant role on learning environment. Good daylighting in classrooms can protect eyes from glare, decreases attention span, increases body temperature and supports teacher-student relationship (McCreery, Hill, 2005).

Other than psychological and physiological reasons, educational spaces have priority than other buildings in terms of daylight performance. Because the educational spaces use all day periods and sufficient usage of daylight effects the electrical lighting and energy consumption (Erlalelitepe et al., 2011). For these purposes, there are three main recommendation about good daylighting in classrooms. They are creating balance of brightness throughout the room, getting right proportion of direct and indirect sun light and protecting area from glare which causes by sky and sun. To provide these conditions, level of illuminance should be between 300 lux and 2000 lux according to CIBS Lighting code. On the other hand, most of the time, the range which is between 100 lux and 300 lux creates unsatisfied dark spaces for humans and it is defined as UDI ‘fell-short ‘or UDI-f in studies. Also, it was investigated that the range of workplace demands 300 lux to 500 lux. (Wu, Ng, 2003).

To create good daylit educational environment, the classroom should have some features. Building orientation is the first step of designing well-daylit classroom. North and south façade of the buildings can be controlled more easily than west and east facades, which results in heat gain. Secondly, window area and material are important. The windows need to be designed for providing light to enable a building to function. Accordingly, a building actually needs qualified daylight rather than high level or intense one. Therefore, the initial step of designing process is to decide on a qualified sunlight level. It is also suggested that the material of glass and window type and window to wall ratio have significant role (CIBSE, 1999) (Plympton et al., 2000).

Accordingly, in the research made by Axarli and Tsikaloudaki (2007), different window locations, clerestories, roof openings and light shelves were examined in terms of indoor daylight quality in school buildings. Therefore, they created a typical classroom as a reference model which has three different windows in south façade with overhangs located outside of the façade. Then, they presented five different models that have different daylighting systems. There is a shelf that divides each window into a view area below and clerestory above in the first model. It is used for projecting towards both the interior and exterior part of the window. In second model, the increased the glazed area to the 25 % of the floor area. Lateral windows provided daylighting with the help of light shelves that are located on the classroom’s façade. There were also some other vertical south oriented skylights positioned on the roof at a distance of 3.5 m. In third model, different from model 2, the roof extension beyond the skylight. In model four, lateral windows provide daylight. They are located on the classroom's façade. There are also additional vertical, north-orientated clerestories positioned on the opposite wall. The roof is inclined across the classroom's width. In the last model, lateral windows provide daylight with light shelves located on the classroom's façade. They positioned tilted, north-orientated skylights in two rows on the saw-tooth roof. It is found that a combination of façade and roof apertures performs better than advanced façade systems. In addition, it is better to use skylights, clerestories and double side openings instead of unilateral façade windows.

All in all, the daylight strategies for classrooms depends on daylight availability on the building, physical and geometrical properties of windows and spaces (Ruck et al. 2000). But today, architects offer large glazing areas to use daylight in interior spaces and it causes lots of undesirable situations like; glare and increased cooling demand. To avoid such undesirable situations, architects need to use some evaluation metrics which useful in daylighting performance of spaces (Zomorodian, Tahsildoost, 2019)

2.2. Daylighting Features of Movable Shading Systems

In vernacular architecture, there are lots of examples used as fixed shading device in buildings. They are mostly designed by locally available materials such as clay, tree branches, concrete, wood planks or bamboo. Even if they are successful at shading the building in specific times, they are unable to adapt to changing environmental conditions. (Al Dakheel, Tabet Aoul, 2017). Today, most buildings are designed with large glazed facades with the changing understanding of architectural design. These facades offer many benefits such as increasing solar gains, minimizing heating loads and increasing daylight penetration, minimizing need for artificial lighting. Yet, they also introduce problems. For example, cooling demands increase because of solar radiation, especially in hot climates. The large glazed surfaces are also the major cause of increased glare and visual discomfort in buildings. (Grynning et al.,2014).

Due to the technological developments, architects are trying to design more intelligent systems for buildings like movable façade systems. The most effective area in this regard is the improvement of the use daylight in buildings. Using daylight in effective way, also reduce energy consumption which comes from usage of artificial lighting and heating or cooling systems (El-Dabaa, Bahaa, 2016). According to Aelenei, there are lots of different terms that satisfy in the context of building facades such as movable, controllable, kinetic, dynamic, active, responsive, transformable and intelligent. On the other hand, all of them have served different type of façade system concepts such as adaptive glazing, solar façade and daylighting systems (Aelenei et al., 2016). Although there are many different terms about façade systems, in this study we prefer to use the term of movable façade with the function of daylighting system.

The selection of the type of movable shading devices has also crucial role. They can adopt to the building from exterior, interior or between glass. As the location of the façade to be fitted may change, the direction of the façade elements can be changed. In the study of Sadek, three main oriented shading devices, which are horizontal, vertical and screen shading, have been simulated to improvement on daylight and energy. The horizontal shading devices designed as simple sun breakers with the 45-degree rotation angle. The same approach was obtained vertical shadings. Finally, screen shading designed as perforated solar screen with round holes that have 90% opening ratio. The results show that horizontal shadings achieved the best result among all aims comprised with other shadings and they saved 18% energy of total energy consumption (Sadek, Mahrous, 2018).

In brief, movable shading devices offer the possibility to control solar gains and daylight penetration according to time of day and seasons minimizing the problems associated with glazed facades. They are becoming an important component of building façade design allowing the optimization and control of solar radiation and daylight (Grynning et al.,2014). Also, they aim to create communication and interaction between changing internal/ external environmental conditions and user behavior. At the same time, they provide the building aesthetic (Al Thobaiti, 2014). Generally, movable shading systems are used with the purpose of improving the visual environment and reducing cooling demand and energy consumption. The different types of movable shading devices that have been studied in literature were: light shelves, louver and blind systems, roller shades and movable shading panels.

2.2.1. Movable Shading System Types

This section introduces different types of movable façade systems named light shelves, louver and blind systems, roller shades and movable shading panels, respectively.

2.2.1.1. Light Shelves

Light shelves are the most common daylight protection system used in contemporary buildings. Especially in literature, this type of façade systems are accepted as the most effective façade systems in terms effective daylight usage. They are the simplest systems that placed to a window in eye level as horizontal surface as shown in Figure 2.2. They are integrated into buildings on externally and/or internally. It is capable of controlling and redistributing incoming daylight. Even if they are used as static systems in buildings, they have started to be used as movable systems today. Some significant factors have affected the performance of light shelves. The performance depends on climate and location of the building, room dimensions, window orientation, light shelf's dimensions, reflections of inner spaces. (Kontadakis et al. 2018).

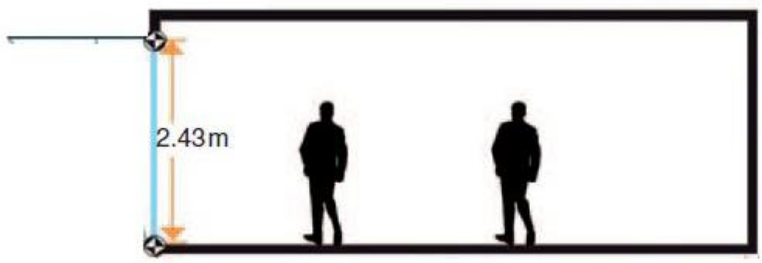

Figure 2. 2. An example of movable light shelf (Source: Lim et. al., 2012)

Several studies have conducted to understand the effect of light selves (Figure 2.2) on building performance. Lim et al. (2012) focuses on daylight performance for visual comfort on existing typical government office in Malaysia with different shading elements. The results showed that light shelf has successfully reduced to high work plane daylight level and it is the best option in terms of reducing in glare on vertical plane with specific orientation of the shelves. Moazzeni and Ghiabaklou (2016) aimed to investigate the impact of light shelf geometry parameters on daylight efficiency and visual comfort in different orientations in a classroom. According to result of DIVA simulation software, although light shelves more effective on west and south orientation, the 30-degree angled external light shelves on this orientation creates disturbing visual comfort. In addition, it cannot perform well in other orientation because of less direct sunlight. But in general, they determined that light shelves have great potential using daylight in educational spaces. In another example of using light shelves in educational spaces, Meresi (2016) evaluated different cases of a combination of light shelves and movable semi-transparent external blinds to efficiently exploit daylight in a typical Greek classroom with south orientation. According to the results, it is analyzed that the combination of the light shelves and semi-transparent blinds have increased the usage of daylight in back of the spaces and decreased the daylight near the window. Grobe et al. (2017) have compared light shelves with different types of shading systems designed for educational space in Izmir with simulation-based research. The results show that light shelves are more efficient according to the other shading systems in terms of to provide uniform and high illuminance to the spaces in specific periods. In the study of Lee et al. (2017) different type of façade shading systems are simulated to understand the differences between useful daylight illuminance (UDI) considers the conditions between 100 lux and 2000 lux and daylight autonomy (DA) metrics considers the condition of 300 lux and more in classrooms. In detail, results show that light shelves have decreased in DA values and increase in the UDI values and create more satisfied spaces.

2.2.1.2. Louver and Blind Systems

Louver systems are another common example of shading system that protect the building from glare and redirect daylight. Louver systems can be integrated into building horizontally and/or vertically and they are located on the exterior or/and interior of windows. They partly or fully block the view to the exterior spaces depending on slat angle and position. Although exterior louver systems are mostly produced by steel, painted aluminum, or plastic (PVC) for high durability and low maintenance; interior louvers are made by PVC. The direction of the louvers depends on the sun position and the direction of the building. Generally, vertical louver systems are used on east and west facing direction opposite to horizontal louver systems used on all building orientation. Mostly, they are used in commercial and educational buildings in order to control solar radiation and improve the comfort conditions in interior spaces. They can be operated by manually or automatically. They are successful at maximizing solar irradiation during winter and minimizing solar gains during summer. If the slats of fixed louvers systems are directed to downwards in sunny sky condition, they produce effective shading areas. Opposite to this situation, in cloudy sky conditions they reduce indoor daylight level. On the other hand, the performance of the movable louver systems has affected by density, direction, width and rotation angles of the slats in all sky conditions. But in general, they allow penetration of necessary natural daylight into interior spaces (Ruck et al., 2000) . An example illustration of louver and blind systems is shown in Figure 2.3.

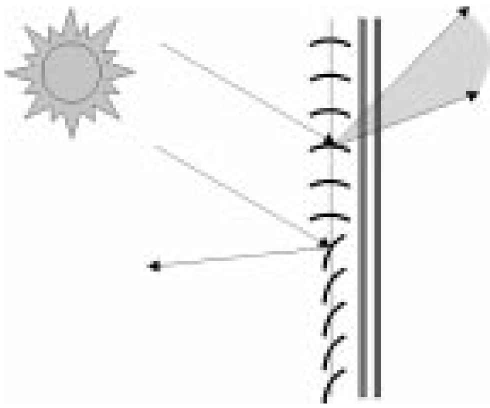

Figure 2. 3. An example of louver and blind system (Source: Ruck et al., 2000)

There are lots of research about louver systems in literature. Mohamed and Gerber (2011) presented a horizontal louver system used for office building for simulate the daylight efficiency of the technology. The horizontal louvers systems located on south façade of the building were simulated by DIVA for Rhino. According to results, this type of systems can improve daylight usage two / two and half times in interior spaces, and this is very important for occupants. On the other hand, author emphasized that, this type of systems demonstrates three important problems which are design domain integration, designing in real world complexity, and minimizing building energy footprints. The research made by Olbina and Beliveau (2009), described two major objectives which are designing new transparent shading device and to analyze its daylight performance. Accordingly, a new transparent louver shading system are designed for office building and their daylighting performance compared with 2 different shading systems, which are opaque and transparent previously patented shading systems, by summation method. The results show that new transparent louver systems provide more sufficient behavior because it provided higher values of daylight autonomy (DA) and achieved autonomous useful daylight illuminance (UDI) than both the commercially available blinds and the previously patented louver systems. Al-Zoubi and Al-Zoubi (2010) aimed to analyze different positions of louver shading systems to find optimal result in good daylighting with minimum energy consumption. They compared 4 different situation which are no shading, vertical louvers, horizontal louvers and horizontal louvers rotated 45 degrees. According to simulation results, shading devices helped the designer to create more satisfied places in terms of daylighting and energy saving. Especially, vertical louver systems provide good daylighting and less energy consumption. Also, it met the expectation on visual requirements.

2.2.1.3. Roller Shades

Roller shades are used to control solar heat gain and create satisfied visual spaces. It is reported that roller shades improve thermal performance especially in summer period. But on the other hand, they may cause negative effects on natural ventilation in transition seasons (Yao,2014). They can be manual or motorized. Interior roller shades are mostly preferred in office buildings because of their important effect on energy demand for space lighting, heating and cooling. Additionally, the most important reason of using roller shades in office building is to block direct sunlight and protect the occupants from glare as shown in schematic view of roller shades in Figure 2.4. (Tzempelikos, Shen, 2013). Recent studies show that external movable roller shades improve thermal performance. They do not need to be used only in fully open or fully closed positions. They can move to an intermediate level according to occupants' needs, sun position or sky conditions. Therefore, they are a significant option when solving problems of visual discomfort and overheating.

In the study of Tzempelikos et al. (2007), movable roller shades, used in educational buildings, compared with blind systems in terms of daylight and thermal performances. The results show that roller shades are more successful at protection from glare and easy control availability by occupants. Konstantzos et al. (2015) made detailed experimental and simulation study on two glare systems integrated with closed and controlled roller shades in private office spaces. To understand the performance, daylight glare probability (DGP) was analyzed. The results show that, advanced shading control systems can protect the spaces from glare while maintaining interior illuminance levels. Also, motorized or dynamic roller shades are more useful to control direct sunlight and eliminating glare problems in comparison to static roller shades.

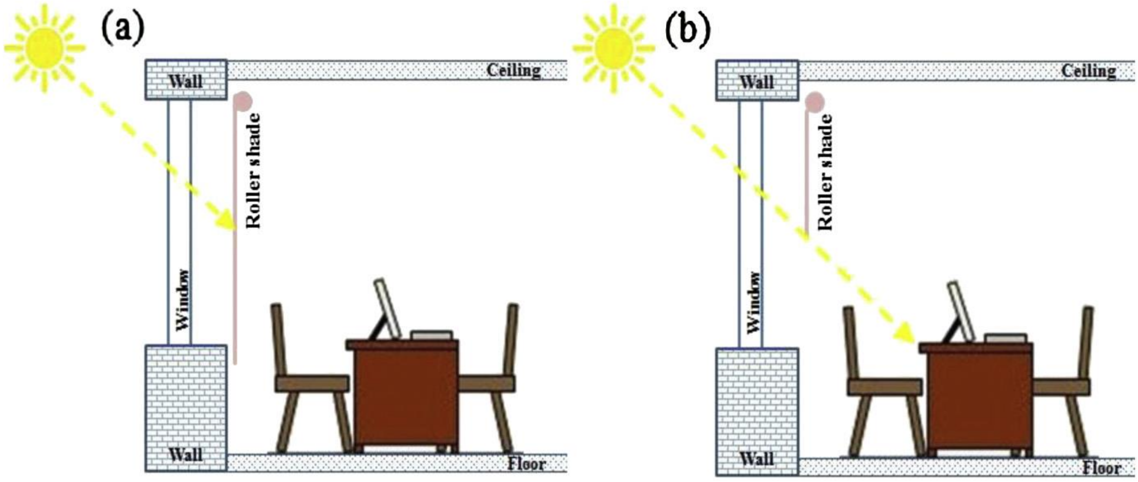

Figure 2. 4. Schematic view of Roller Shades (Source: Tzempelikos and Shen, 2013)

2.2.1.4. Movable Shading Panels

Recent researches show that movable shading panel design has a significant role to design alternatives in early design stage (Nielsen et al., 2011). Like other type of movable shading types, movable shading panels have benefits on daylighting and thermal performance. They are often integrated into the exterior façade of high-rise buildings to serve different services. While they become a part of the structure, also they separate the interior spaces from outer climate conditions. According to the intended purposes, the material of movable shading panels can be covered with different types of materials such as; glass, metal, timber and membrane as shown in Figure 2.5. This type of changings do not only define the building architectural aesthetic, but also increase the performance of the buildings (Srisuwan 2017). Also, they can be arranged as adaptive, responsive and kinetic structures.

Figure 2. 5. Example of used different material on movable shading panels (Source:Srisuwan,2017)

There are lots of studies about movable shading panels. In study of Sharaidin et. al. (2012), kinetic façade is applied to the surface of the north-west façade of the building located in Australia. Also, it simulated the façade elements in terms of daylighting with different type of kinetic motions. Firstly, they designed a parametric model of movable shading panels in Rhino/ Grasshopper and arranged five different type of kinetic motion which are rotation, elastic, retractable, self-adjusting and sliding. Then, they simulated the effects of these motion to building performance. The results show that self-adjusting and elastic motions are more sufficient to get the benefit from dynamic behavior. The other type of motions, which are rotation, retractable and sliding, have potential on more macro scale behaviors. Nagy et. al (2016) represented their development of adaptive solar façade systems and evaluate the invention in terms of energy saving potential. For simulating the adaptive solar façade, they created two different model in Rhinoceros and Grasshopper. In first model, they simplified design and evaluate energy demand which comes from heating, cooling and lighting on un-real office room. In second model, they designed more detailed model, opposite to first model, to analyze solar electricity production in year. The results of the simulation show that the first model save the %25 energy of total energy and the adaptive solar façade has potential to generate electricity because of directing to the sun.

2.2.2. Selected Examples of Movable Shading Systems

This section focuses on three selected examples of movable façade systems made in last period. These are, Al-Bahr Tower, SDU University of Southern Denmark – Kolding Campus and Thematic Pavilion EXPO 2012, respectively.

2.2.2.1. Al-Bahr Towers

e AL- Bahr Towers designed as two circular towers covered with certain wall by Abulmajid Karanouh. Towers have 150 meters height and each tower have 2 level basement and 24 story office spaces. Towers are covered with dynamic shading systems designed as triangle umbrellas named as mashrabiya (Figure 2.6).

Figure 2.6. Al- Bahr Tower with dynamic Shading Systems (Source: Attia, 2018)

They were designed with parametric geometrical modelling. Totally, there are 1049 mashrabiya in the system. This shading systems are controlled individually or in gropes by central Building Management System. Each unit of the shading systems move as individual devices according to response to light and sun direction for protecting the building from solar radiation. The shading systems are supported by material of steel frames, aluminum dynamic frames and fiberglass mesh infill. The system has only two motions per day; opening and closing (Figure 2.7). These motions depend on angles of the sun. In overcast and windy sky conditions, each mashrabiya opens itself. Even when each unit are closed, occupants can still see the outside spaces. Finally, the project won the 2012 Council on Tall Buildings and Urban Habitat (CTBUH) Innovation Awards. (Attia 2018).

Figure 2.7. Open and closed situation of mashrabiyas. (Source: Attia, 2018)

2.2.2.2. SDU University of Southern Denmark, Kolding Campus

The Kolding Campus building create a powerful relationship between inner life and outside environments with its triangular shaped façade. It is designed by Henning Larsen Architects. Beside of its markable façade, the building has lots of sustainable features. To illustrate, the building has mechanical low-energy ventilation and solar cells and cooling the spaces by water of Kolding River. Dynamic solar shading provides the

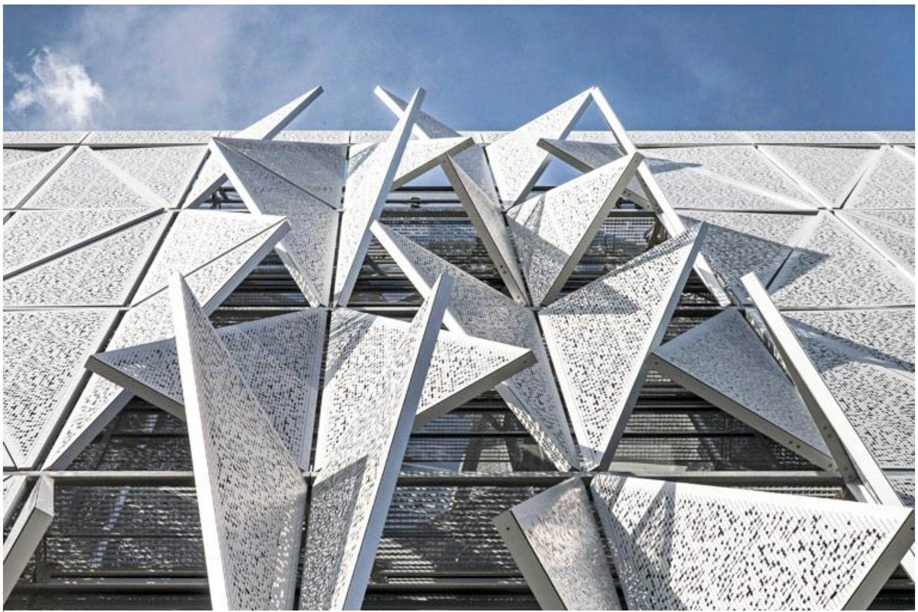

Figure 2. 8. Triangular Dynamic solar shadings of Kolding campus.

user satisfied indoor climate spaces and optimal daylight. It has been designed with triangular units and there are 1600 triangular shutters made by steel (Figure 2.8).

There are three specific position of the façade units; closed, half-open and entirely open, respectively. Since the façade units opened from the building to the outside, they added a motion to the building in 3 dimensions. All unit of the façade have round organic shaped holes. These holes do not only provide play of light on inside spaces but also provide dynamic appearance to the outside of the building (Figure 2.9). For example, in evening times, the light comes from the inside of the building is realized from outside and make the façade more transparent. Also, it has first prize in International Competition in 2008 (Schubert, 2019).

Figure 2. 9. Appearance of façade in evening time of Kolding Campus

2.2.2.3. Thematic Pavilion EXPO 2012

Thematic Pavilion was designed by SOMA for EXPO 2012 in Korea. The theme of the EXPO was the living ocean and cost. Based on this theme, the structure and movable façade system are designed as symbol of gills of a fish and facing the main entrance (Figure 2.10). All movable façade system has 100 individual louvers responded to change of sun direction. The louvers are made by glass-fibre reinforced polymer, so all louvers are strong and flexible. This system has two edges, which are stiff and thin. They have the ability of asymmetrical bending motion with help of actuators located at the top and bottom (Figure 2.11) (Helbig, 2019).

Figure 2. 11. Thematic Pavilion EXPO 2102

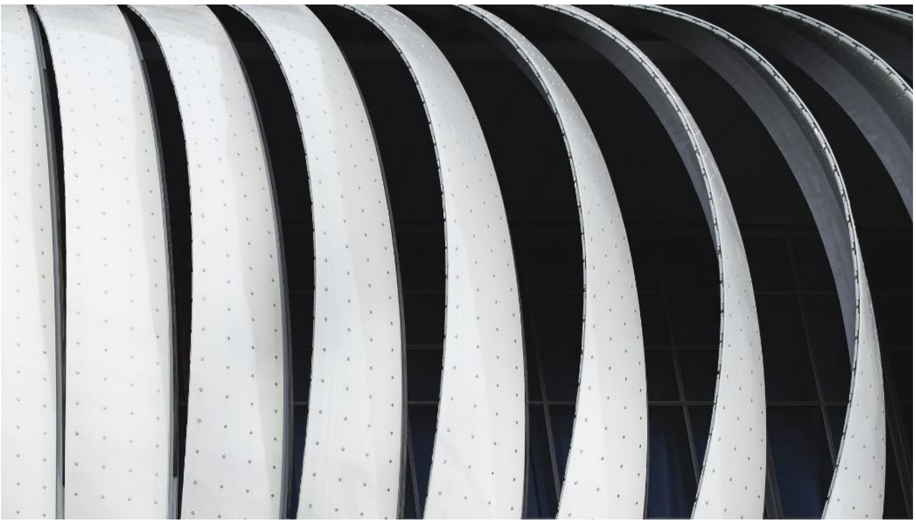

Figure 2. 101. Asymmetrical bending motion of louvers

2.2.3. Recent Daylight Research on Movable Shading Systems

In literature, there are lots of different studies about daylight research on movable shading systems. Table 1.1. shows the list of some different studies in order to date of publication. This section introduces some examples of these studies from daylight simulation stages to the results.

In the study conducted by Kensek and Hansanuwat (2011), a typical office layout located on Dallas, Texas was evaluated in terms of solar thermal, daylighting, ventilation and energy generation with different movable shading systems. To understand the performance differences, firstly they designed four different movable shading systems which are overhang, folding, vertical louver and horizontal louver in Autodesk 3dsMax.

If we concentrate on the analysis of daylight, these four different movable shading elements were analyzed on four different date (March 21, June21, September 21 and December 21) and 3 different time of the day (09:00 am, 12:00pm, 03:00 pm) under sky condition of CIE clear sky. The south façade was used for the test and 18 measurement points were evaluated, totally. The results show that movable shading systems allows sunlight in desired range compared to the non-shaded systems. In detail, it is found that the vertical louver system, at 55%, performed much better in allowing for the largest amount of recommended lighting into the room. The other systems allowed for a high number of points within the recommended range. On the other hand, it is the vertical louver system's ability to track the movement of the sun that was critical to its success in allowing for a more finite control of daylight entering the space. The overhang system performed almost as well with 54% of the points within range during the four times of the year; the overhang allows for a larger amount of window to be influenced by the sun, as opposed to the horizontal folding and louver systems in which the shade system itself can become a hindrance on the light entering the space.

There is another study about exploring the effectiveness of dynamic facades. In a study carried by Wagdy et al. (2016) dynamic solar screen, which is made by modular grid of hollow boxes, applied to façade of office space and its different configurations were computed. In total, 121 different configurations were created and evaluated their daylight performance against to static configuration and venetian blinds with the metrics of sDA and ASE. The aim of the study is maximizing sDA and minimizing ASE. For this purpose, all different configurations were simulated by Radiance software. According to outputs, dynamic configurations increase the percentage of sDA from 17% to 54% and decrease the ASE up to 0%.

Another study carried out by Meresi (2016), analyze the six light shelf types and semi-transparent external blinds to efficiently exploit daylight in classroom located Greece. Firstly, six different shelf types were generated in Ecotect software. Three of these blinds are placed on external part of the façade and the others has internal and external parts. Each blind has ability to rotate 10°, 20° and 30°. Also, semi-transparent movable external blinds studied on three position; rotated 45° and 60°. Each design was compared to each other by Radiance software in terms of illuminance levels in March 21, June 21 and December 21 at 12:00 pm under overcast and clear sky condition. According to illuminance levels, it is seen that combination of light shelves and semi-transparent movable external blinds increase illuminance value by providing shade.

In the study of Varendorff and Garcia-Hansen (2012),5 different skin type options were compared in terms of exterior unobstructed view, direct sunlight and daylight glare probability in summer and winter term. The name of the skin types is, Skin type ‘x’ option one, Skin type ‘x’ option two, Skin type ‘y’ option three, Skin type ‘y’ option four and Skin type ‘z’ option five, respectively. Skin type ‘x’ option one designed with quadrilateral modules sized 350mm x 350 mm, while skin type ‘x’ option two quadrilateral modules have been increased in length by 1.8 times. As opposite to the one-directional orientation in skin type ‘x’ options, skin type ‘y’ option three and four designed as multi directional orientation consist of equal size of triangular modules. Only in skin type ‘y’ option four has triangular shape modules have been raised at the center and create pyramid shape. Finally, skin type ‘z’ option five based on skin option ‘y’ type four but it has surface curvature on panels. According to their results in terms of direct sunlight, all skin types have good performance on shading spaces because they do not allow direct sunlight. But option four performs the best to protect the area from direct sun light. In summer, it allows 5% direct sunlight in interior spaces and this percentage decreases to 1% in wintertime.

In the study conducted by Moazzeni and Ghiabaklou (2016), the educational space located in Tehran was simulated to compare unshaded situation with shaded by light shelf which applied 4 different orientation, separately. Daylight simulation run out by DIVA-Rhino software. According to simulation results, the light shelf has better performance at the south orientation. It increased suitable daylight from 2% to 40% compared with unshaded situation.

2.2.4. Daylight Simulation Tools on Movable Shading Systems

In recent researches, there are lots of simulation tools that evaluate daylight performance of designs. These tools are Radiance, DIVA for Grasshopper, DAYSIM, 3ds Max, Ecotect and Lightscape, from frequently used and less used. Table1.1. also shows the list of different simulation tools.

Radiance is the most frequently used simulation program for the analysis and visualization of lighting in designs. With the selection of input parameters, which are materials, luminaires, time, date and sky conditions, the results of luminance, illuminance and glare are evaluated. Lighting calculations and rendering tools are the primary advantages of the program (Radsite, 2020). In the study conducted by Meresi (2016), the daylight performance of rotated horizontal light shelves, which used on façade of classroom, is evaluated with Radiance simulation tool. Before the main experimental work, the validation of real and virtual environment was also done with Radiance under the same surface properties and sky conditions. After validation, the experimental study was conducted under 6 different stage in terms of different light shelf types and climate conditions and date.

DIVA is a plug-in for Grasshopper that optimized daylight and energy. It has advanced user interface that allow the user to select library materials and schedules. Also, it can create sun path diagrams for any location and sun position. It generates radiation maps and radiance renderings. Addition to radiance analysis, glare analysis can be done with this plug-in (Solemma, 2020). In the study carried out by Gadelhan (2013), daylight performance of office building located in were simulated by DIVA for conducting Daylight Availability Simulations. For daylight performance simulation reference plane was divided in to 0,5m to 0,5m and 117 measurements points have been created 0.8 m above from the ground. Daylight availability simulations of all these measurement points were conducted for weekdays from 08:00 am to 04:00 pm for two different case studies. Finally, two results of daylight performance of two different case studies were compared.

DAYSIM is another daylight analysis software based on Radiance. It allows user to evaluate different type of façade systems from standard venetian blinds to complex façade systems with different selection options on different lighting systems, occupancy sensors. The simulation out puts can be daylight autonomy (DA), useful daylight illuminance (UDI), annual glare and electric lighting energy use (Daysim,2020). In the study carried out by Kasinalis et. al. (2014), the seasonal façade adaptation on building performance was researched under specific multi objective optimization based on building energy and daylight simulation which conducted by DAYSIM for Dutch office building. In study, six different façade designs were compared with non-adapting building shell and according to daylight and energy results the best solution was researched.

3ds Max is also conducted daylight simulation with light meters. As other simulation software, 3ds Max has also coordinates lights, materials, lighting meters and lighting level display and renderings (Autodesk, 2020). In the study of Kensek (2011), 4 different shading systems were analyzed for office building by 3ds Max under CIE clear sky with light meter placed at work plane height. After the selection of best shading systems according to recommended range of illuminance, which is 300 lux-500 lux, the energy analysis was done, and the prototype has been developed.

Ecotect is another daylight simulation tool which used in Rhinoceros/ Garsshopper as in the study of Sharaidin (2012). In the study, kinetic façades were designed with integration of parametric design definitions and environmental software. Ecotect was tested for luminous distribution and and daylight penetration depth inside a space. Ecotect was used as dynamic daylight tool with with Galapagos which used as solver, on different kinds of parameters and strategies to make effective decision in early design stage.

Lightascape simulates both natural and artificial lighting in designs. It uses point by point method for calculations and of direct and reflected lighting. The outputs can be in 2D and 3D color, grayscale or puseudo color renderings (Lightscape,2020). In the study conducted by Alzoubi (2010), the daylight performance of office space was simulated by Lightscape in specific date and times for two different shading devices. Acoording to results of average illuminance level on horizontal plane, the best option was selected.

In this study DIVA plug-in used in Rhinoceros/Grasshopper has been used bevause it is user friendly in terms of usage and time. Grasshopper allows to user create lots of variation on same model and DIVA has ability to adapt changings in designs,easily.

Table 1.1. List of some different studies in litearture.

#	Authors (first et.al)	Year	Keywords	Scale / Functionality	Facade Type	Tools (Simulation)	Topic
7	Kleo Axarli	2007	X	Single Space / Classroom	Light Shelf and lateral windows with light shelves	Adeline / Radiance	Daylight
54	Athanassios Tzempelikos	2007	Integrated facade design; Energy simulation; Daylighting; Shading design and control; Electric lighting; Hybrid ventilation	Building Facade / School	Rollershades, movableVenetian blinds, combination of Venetian blinds and rollershades	No simulation program is mentioned.	Daylight Thermal
40	Svetlana Olbina	2009	alternative technology; daylight autonomy; daylighting; facade design; illuminance; optics; shading device; simulation; useful daylight illuminance	Single Space / Office	MovableGlass Louvers	Autodesk software	Daylight performance
4	Hussain H. Alzoubi	2010	Shading device, Daylight Illuminance, Heat gain, Computer simulation, Energy consumption	Single Space / Office	Fixedhorizontal and vertical louvers	Lightscape software	Illumınance control
18	Jaime M. L. Gagne	2010	x	Building	Overhang, vertical louvers	Radiance	Daylight
30	Hong Soo Lim	2010	Blind system, Daylighting, Shading device, Horizontal louver, Solar control , Sun shading	Single Space / Residential	Movable Venetian blinds and fixed overhang	Radiance	Daylight
15	Mohamed El-Sheikh	2011	kinetic facades, parametric design, design integration, daylighting, performative design, design optioneering, realtime feedback	South Facade	Exterior Horizontal Louvers	DIVA	Lighting
23	Karen Kensek	2011	Kinetic façade, Building envelope, Shading device, Performance-based design	Building / Office	overhang, folding, horizontal louver, and vertical louver	eQuest 3D Smax Solar Advisor Model	Solar Thermal Daylight Ventilation Energy Generation
39	Martin Vraa Nielsen	2011	Dynamic solar shading; Integrated simulation; Energy demand; Indoor environment; Office buildings	Single Space / Office	Dynamic solar shading and fixed solar shading	iDbuild	Daylight + Thermal
57	Andrew Varendroff	2012	Daylight, Glare, Simulation, Radiance, Parametric Design	Building / Office	Multi-dimensional Kinetic Shading Devices	Radiance	Illuminance
31	Yaik-Wah Lim	2012	Blinds, Field measurement,Glare,Glazing Light shelf, Simulation	Single Space / Office	1. OverHang 2.light Shelf 3.Light Shelf + Blinds	Radiance	Lighting

(cont. on the next page)

#	Authors (first et.al)	Year	Keywords	Scale / Functionality	Facade Type	Tools (Simulation)	Topic
49	Kamil Sharaidin	2012	Kinetic façades; digital simulations; design considerations; early design stage.	Building / Office	Kinetic Facade	Ecotect	Daylight
17	Mahmoud Gadelhak	2013	High performance facade; daylighting simulation; optimization; form finding; genetic algorithm	Building / Office	FixedLightshelf and fixedsolar screen	DIVA for Rhino	Optimizingthe annual daylighting performance Climate-based simulation
54	Athanasios Tzempelikos	2013	Shading control, Daylighting Facades, Visual comfort Energy consumption	Single Space / Office	Movable Roller Shade	Energy Plus	Lighting + Thermal
22	C. Kasinalis	2014	Climate adaptive building shellSeasonal facade adaptationBuilding performance simulationMulti-objective optimization	Single Space / Office	Venetian blinds	Trnsys+Daysim	Daylight Energy
60	Jian Yao	2014	Building energy Movable solar shade Indoor thermal Visual comfort	Building / Residential	Movable Roller Shade	Energy Plus	Daylight illuminance Indoorthermal comfort
26	Iason Konstantzos	2015	Daylight glare, Visual comfort Shading control, Facades	Single Space / Office	RollerShades	Evalglare / Radiamce	Daylightglare probability (DGP) evaluation
36	Mohammad Hossein Moazzeni	2016	daylight; visual comfort; educational space; light shelf; daylight simulation	Single Space / Classroom	Light Shelf	DIVA	Daylight
35	Aik. Meresi	2016	Daylight, Classrooms, Light shelf, Shading devices, Visual comfort, Greece	Single Space / Classroom	Horizontal Light Shelf (rotataed)	Radiamce	Daylight
37	Zoltan Nagy	2016	Dynamic facade; BIPV; Facade engineering; Photovoltaics; Responsive architecture	Single Space / Office	Dynamic facade System	Grasshopper	Energy
24	Ayca Kırımtat	2016	horizontal louvers, simulation modeling, evolutionary algorithms, multi-objective optimization, parametric modeling	Single Space / Office	Horizontal Louvers	DIVA for Rhino Ladybug Honeybee	Daylight
58	Ayman Wagdy	2016	Daylighting; Parametric analysis; Dynamic Facades; Hourly-based performance	Single Space / Office	Dynamic Sun Screen	DIVA for Rhino	Daylight
8	Carsten Bauer	2017	climate based daylight simulation, daylight metrics, photon mapping, radiance	Single Space / Classroom	interior and exterior light shelf	EvalDRC / Radiance	Daylight

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#	Authors (first et.al)	Year	Keywords	Scale / Functionality	Facade Type	Tools (Simulation)	Topic
19	Lars O. Grobe	2017	X	Single Space / Classroom	Light Shelves with a Ceiling System, Light-Ducts, Blinds, Horizontal and Tilted	Radiance	Daylight
28	Kyung Sun Lee	2017	daylighting control; Daylight Autonomy (DA); Useful Daylight Illuminance (UDI); façade shading; louver; daylight metrics	Single Space / Classroom	Vertical and Horizontal Louvers, Eggcrate louver, Overhang, Light Shelf,	DIVA for Rhino	DA and UDI
10	Su-Ji Choi	2017	External movable shading device, Control algorithm, Shaded fraction, Glare, Illuminance, Energy	Building / Office	External movable shading device	Radiance EenrgyPlus	Energy Glare Illuminance
25	Ayca Kirimtat	2019	Energy Daylight Multi-objective optimization	Single Space / Office	horizontal movable shading pnaels	Radiance EnergyPlus	Daylight Energy

CHAPTER 3

PROCEDURE

In this study, different types of movable shading devices have been simulated in terms of daylight conditions. In the design step of the movable shading systems, computational tools and techniques were used to achieve different alternatives of panel's situation and orientation. This chapter introduces to the general description of case classroom, field measurements and surface properties and simulation process of case classroom model with 2 different movable shading designs, respectively.

3.1. General Description of Case Classroom

In this study, a classroom in Izmir Institute of Technology was chosen as the case room to evaluate its daylight performance by two different types of movable shading systems. The classroom is located on second floor of A block in Department of Architecture. A block is located on highest level of campus and it has coordinates at 38° 19' N, 26° 37' E and at an altitude of approximately 76 m over sea-level. The case classroom has 8.76 meters length, 6.43 meters width, and 3.80 meters height; in total 56.32 square meters. The room is facing to south. And at the south façade of the class, there are 3 different windows scaled 1,80 m wide by 2.03 m height, 1.97 m wide by 2.03 m height and 1.80 m wide by 2,03 m height, respectively and they are elevated 1 m from floor. The windows have no movable or static shading devices as stated before. The detailed geometrical properties of case classroom and windows are given in Table 3.1.

Table 3. 1. Geometrical properties of case room

	Type	**Orientation**	**Length (m)**	**Depth (m)**	**Height (m)**	**Area (m^2)**	
ROOM	Classroom	South	8.76	6.43	3.80	56.32	
	No	**Orientation**	**Height (m)**	**Width (m)**	**Height from floor (m)**	**Total Glazed Area (m^2)**	**WWR (%)**
WINDOWS	1	South	2.03	1.80	1.00	3.65	10
WINDOWS	2	South	2.03	1.97	1.00	3.99	12
WINDOWS	3	South	2.03	1.80	1.00	3.65	10

The case classroom is used by students on weekdays, from 8:00 am to 17:00 pm. Most of time, the area of the classroom has dark atmosphere so artificial lighting is used during lectures. In addition to this, students, who witting near the window, are disturbed from excessive daylight and glare. Figure 3.1 shows interior photos of the case classroom.

Figure 3. 1. Photographs of the case room

3.2. Field Measurements and Surface Properties

To achieve realistic simulation results, the current daylight condition of the room was measured, and surface properties were identified. The illuminance levels were measured by certain points in certain days and times. Totally, 140 measurements points are located as a grid system in the middle of the room. Each measurement points have equal distances; 0.60 m in length and depth. During measurements, all desks and other stuffs were not included. The measurements layout is shown in Figure 3.2.

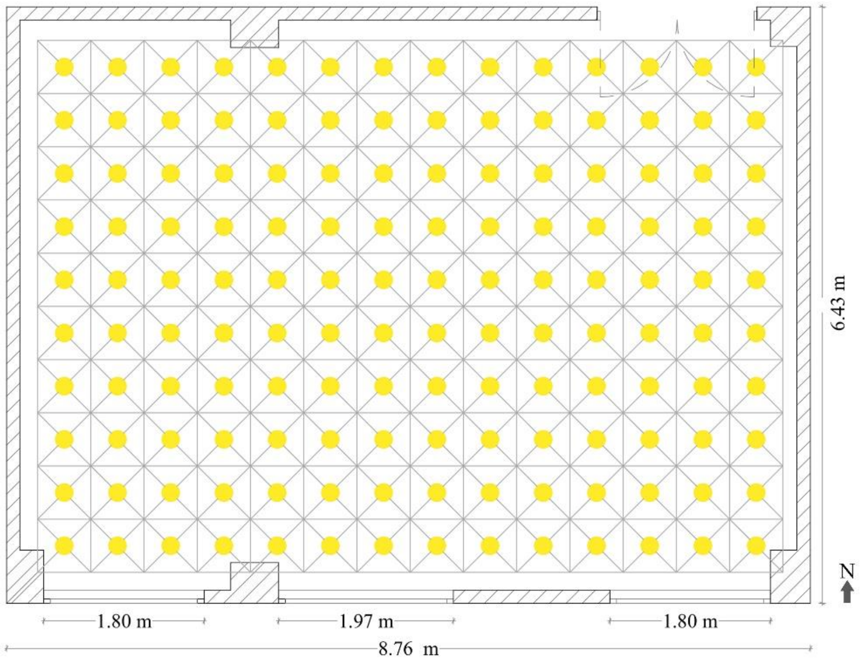


Figure 3. 2. Location of measurement points on the plan.

The on-site measurements were done November 29 under CIE clear sky with the sun. The time of measurements was 15:30 p.m. In the case classroom, the floor is covered with marble and walls are painted with matte white color. To measure illuminance levels of the surfaces, the illuminance meter was used. After measuring illuminance (E) of the surfaces from the specific point, luminance (L) of this specific point was also measured and reflectance (ρ) value of walls, ceiling, and the floor is calculated with equation of Lambertian reflectance (3.1):

$$L = \frac{E \, x \, \rho}{\pi} \tag{3.1}$$

Also, the properties of the window are determined with luminance and illuminance method. As mentioned before, there are no shading elements on window, and they have double layer glazing. To calculate transmittance value of the window, firstly the luminance of a specific point from outside was measured when the window was closed. Then, the luminance value of the same specific point was measured again when windows were opened. Finally, the transmittance value of glazing was calculated with following equation (3.2):

$$\tau = \frac{L\ in}{L\ out} \quad (3.2)$$

Accordingly, the reflectance value of the walls, ceiling, and floor are found as 0.80, 0.90 and 0.70, respectively. Also, the transmittance of glazing is 0.80. The reflectance and transmittance value of materials are shown in Table 3.2.

Table 3. 2. The reflectance and transmittance value of the case room.

Walls Reflectance (%)	Ceiling Reflectance (%)	Floor Reflectance (%)	Windows Transmittance (%)
80	90	70	80

3.3. Simulation Models in Grasshopper

Computer simulation was carried out using Rhinoceros/ Grasshopper. In total, there are 3 different simulation model was designed to compare work plane illuminance level. The process of simulation models is explained below, respectively:

(i) The base case model of the classroom was designed to create virtual model which close to actual classroom in terms of properties of surfaces and room geometry. The simulation of this model run out in terms of illuminance levels on 29th November and result are compared with on-site measurements.

(ii) A new shading model 1, which has single oriented louver shading systems, is designed to case the classroom with layout of same surface properties and room characteristics.

(iii) Another new shading model 2, which has a multi-oriented shading system, is also designed to same case classroom with same method.

At the last stage, 140 measurement was set to be 0.80m above the floor, 0.50 m away from wall surfaces and 0.60 m spacing in case model, shading model 1 and shading model 2. After validation of the case model simulation, illuminance simulations were run on solstice and equinox days at 10:00 pm, 13:00 pm and 16:00 pm under CIE clear sky with sun condition with DIVA tool. Also, camera was in the corner of the room to show the effect of shading models and interior spaces rendering.

3.3.1. The Base Case Model

The simulation model of the case classroom was designed in Rhinoceros/ Grasshopper. The main aim of the case model is comparing the simulation results with the on-site measurements. Because to achieve more realistic results, the model of the case classroom must be close to actual classroom environment. So, after the model the case classroom geometrically, the reflectance and transmittance properties of surfaces were assigned from the material properties in grasshopper as shown in Figure 3.3. As mentioned before, simulation was run on November 29 at 15:00 pm under CIE clear sky with sun condition with DIVA tool. Therefore, the weather data file imported to Grasshopper to make simulation according to location and climatic conditions of Izmir (Figure 3.4). In final step, 140 measurement points were designed as measurement plane with 0.6 m spacing between each point and above 0.8 m from floor (see Figure 3.2)

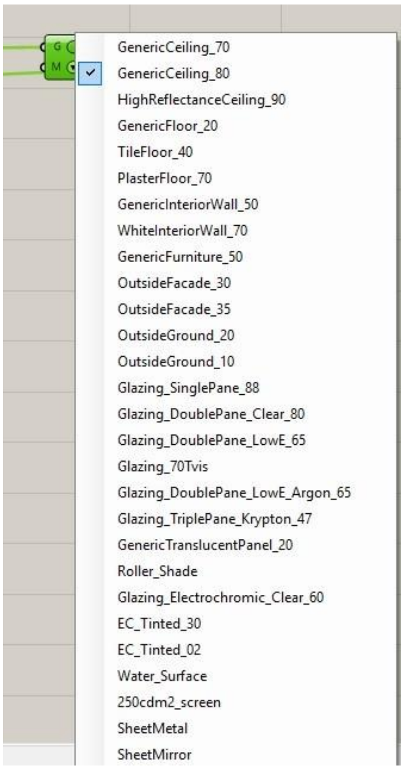


Figure 3. 3. Material properties selection in Grasshopper

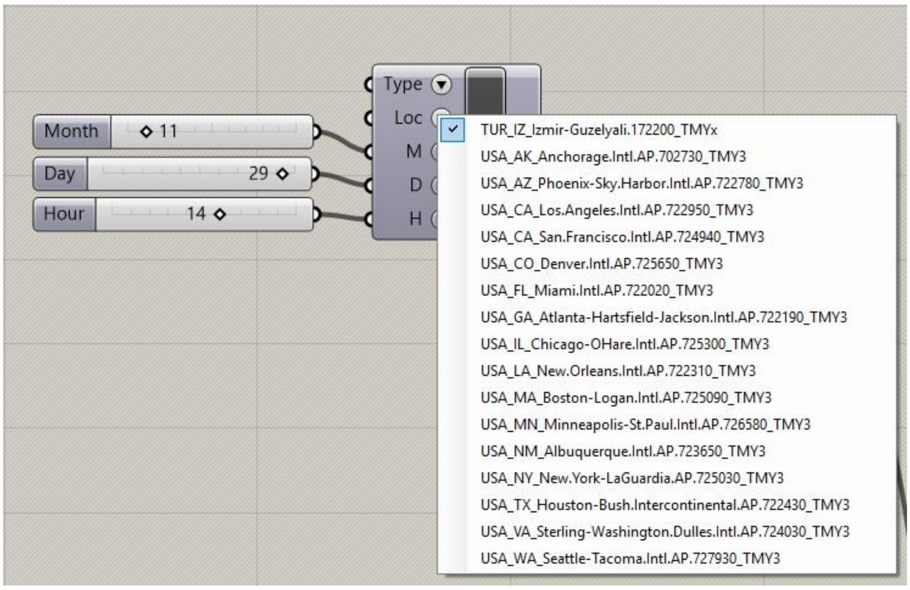


Figure 3. 4. Location and weather data selection in Grasshopper

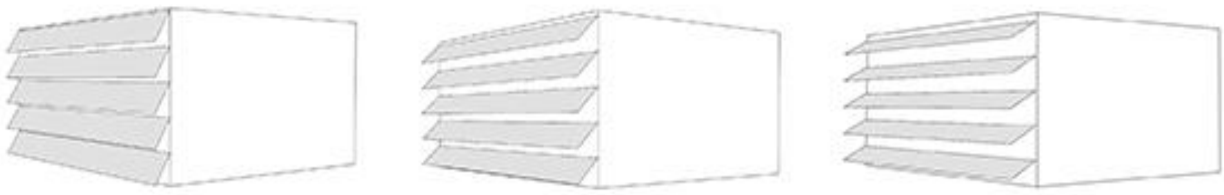
3.3.2. Case Classroom with Shading Model 1

On-site measurements show that there is no balanced illuminance distribution in the case classroom. The illuminance values decrease rapidly as you move away from the window, while excessive illuminance values corresponding to the window. According to on-site measurements, the shading model 1 was designed to achieve good daylighting performance.

As the first step, the case classroom model is designed with real geometrical properties of classroom which dimensioned 8.76 meters length, 6.43 meters width, and 3.80 meters height. But to understand the performance of the shading model 1, the south façade of the model, which has 3 different windows, was designed as fully glazed. The reflectance of walls, ceiling, and floor was defined as 0.80, 0.90 and 0.70, respectively. Also, the transmittance of glazing is 0.80 seen in Table 3.3. In second step, the border of the glazing was divided into 5 points which have equal distance in Y-axis. These points are mutually connected to each other in X-axis as third step to creating horizontal shading panels. These horizontal shading panels have ability to rotate to 30, 45 and 90 degrees seen in Figure 3.5. And the reflectance of shading panels is defined as 0.35. The general process of designing shading model 1 is shown in Figure 3.6.

Table 3. 3. Surface properties of case classroom with shading model 1

Walls Reflectance (%)	Ceiling Reflectance (%)	Floor Reflectance (%)	Shading Reflectance (%)	Glazing Transmittance (%)
80	90	70	35	80



30 ° rotation angle 45 ° rotation angle 60 ° rotation angle

Figure 3. 5. Different position of shading panels of model 1.

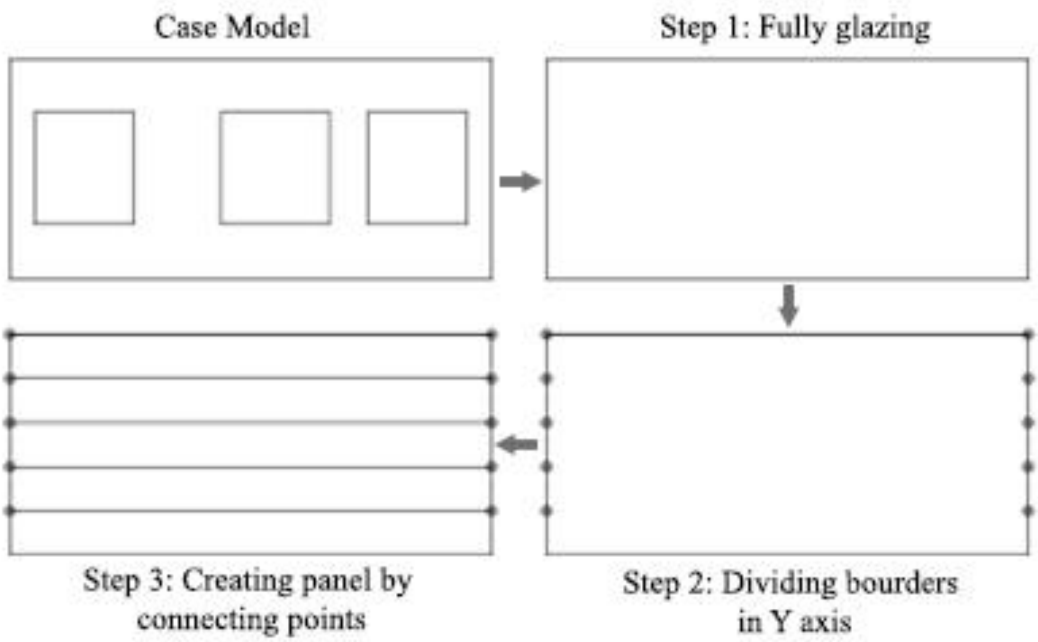


Figure 3. 6. Design process of shading model 1

3.3.3. Case Classroom with Shading Model 2

The shading model 1 designed as one-oriented shading panels. To understand the effects of orientation on daylighting performance, shading model 2 designed as multi-oriented shading panels. Although the steps in the design process are similar to model 1, there are differences in shape and orientation.

In the first step, the case classroom model is designed with real geometrical properties of classroom as in shading model 1. Also, the south façade of the model, which has 3 different windows, was designed as fully glazed. The reflectance of walls, ceiling, and floor were defined same with case model and shading model 1(Table 3.3). In second step, the border of the glazing was divided into 5 points which have equal distance in X and Y axis and square grid was created. And the center point of these squares was found. Then, 2 corner points of each square and center points were connected with line to create panels dividing each unit square into 4 triangles. At final stage, which is steps 4 and 5, these shading panels were duplicated into X and Y axis and whole shading model 2 was designed as shown in Figure 3.7. Each triangular panel has rotation ability to 30, 45 and 60 degrees and these rotations add mobility to the façade. Figure 3.8 shows the front view of these rotations and the perspective views are seen in Figure 3.9.

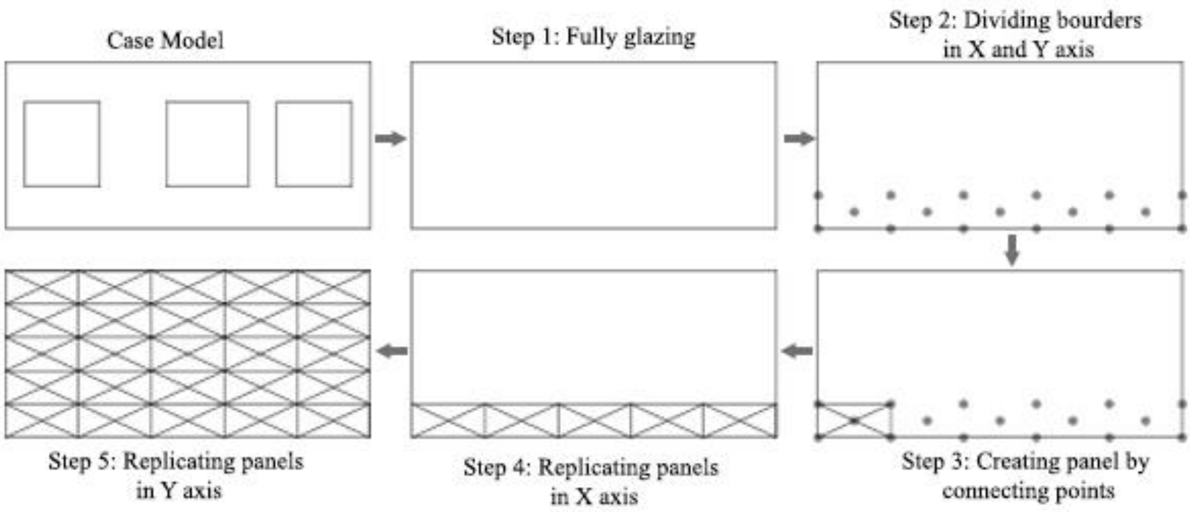


Figure 3. 7. Design process of shading model 2

30 ° rotation angle

45 ° rotation angle

60 ° rotation angle

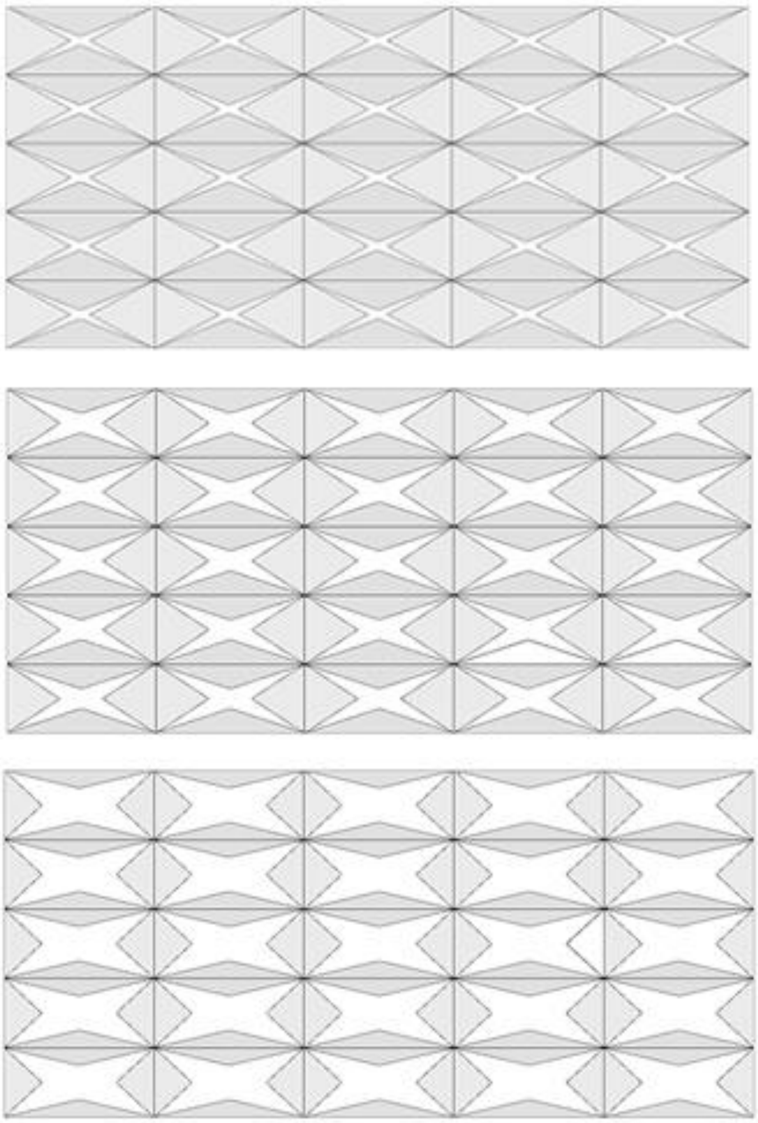
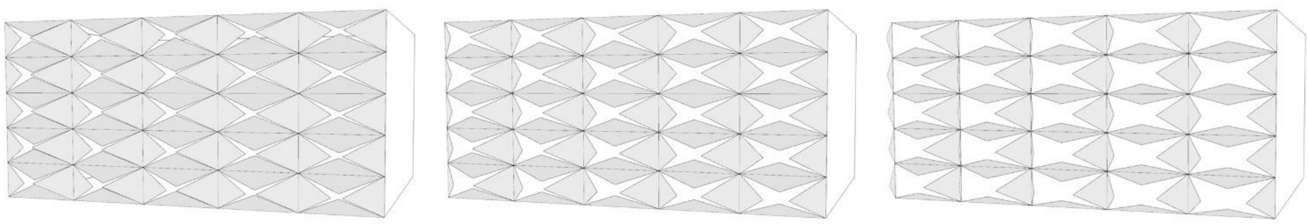


Figure 3.8. Front view of different rotation of shading panels



30 ° rotation angle 45 ° rotation angle 60 ° rotation angle

Figure 3.9. Perspective view of different rotation of shading panels

CHAPTER 4

RESULTS

This chapter represents the daylight performance simulation results under 3 sections. Section 4.1 shows the field measurements readings and simulation model. Section 4.2 involves the UDI, sDA, ASE and illuminance values of the classroom with shading model 1. Also, section 4.3 explains the UDI, ASE and illuminance values of the classroom with shading model 2.

4.1. Field Measurements and Validation of Simulation Model

As mentioned before, the illuminance values of the case classroom, which has 8.76 meters length, 6.43 meters width and 3.80 meters height, were measured by illuminance meter from 140 measurement points. After on-site measurements, in the scope of the research, the case classroom was designed in Rhinoceros /Grasshopper software. The reflectance and transmittance of surfaces assigned same with the values in Figure 3.3. Also, no shading devices were located. Then, on-site illuminance measurements of classroom, which evaluated on 29^{th} November at 15:00 pm under CIE clear sky with sun condition, were run in DIVA. And the camera was located into simulation model to show the physical effect of daylight in classroom.

In total, 140 measurement points were evaluated in on-site measurement and case classroom simulation modeled in grasshopper. Accordingly, the illuminance values of these 140 measurements points were compared to understand the validation of the case classroom simulation model. In this case, the coefficient of determination (R^2) value is 51% for simulation of 29^{th} November as shown in Figure 4.1. It is seen that there is acceptable accuracy while DIVA simulation results and field measurements are compared. Also, MBE values and CV(RMSD) are calculated indicate the averaged error and deviation of measured to simulated illuminance values as seen in Table 4.1. When we look at the results compared, it is seen that the illuminance results of on-site measurements and the simulation model are close to each other as seen in Figure 4.2. Therefore, validation has been achieved.

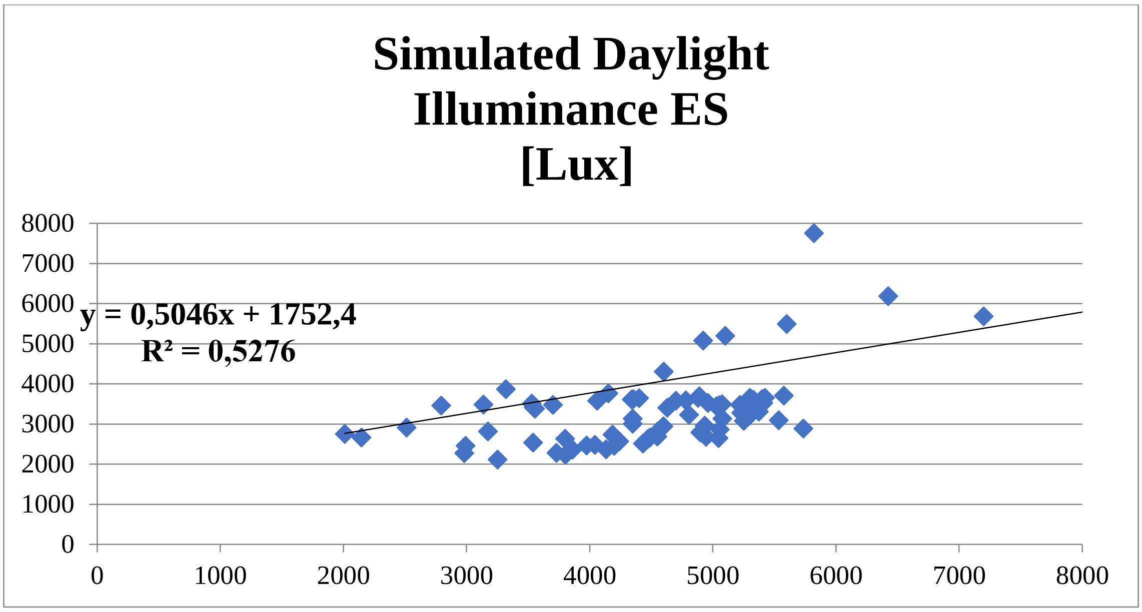


Figure 4. 1. Validation of simulation results of the measurement points

Table 4.1. The averaged error and deviation of measured to simulated illuminance values

	R^2	MBE	CV (RMSD)
November 29, 15:00 pm	0.52	20%	30,5 %

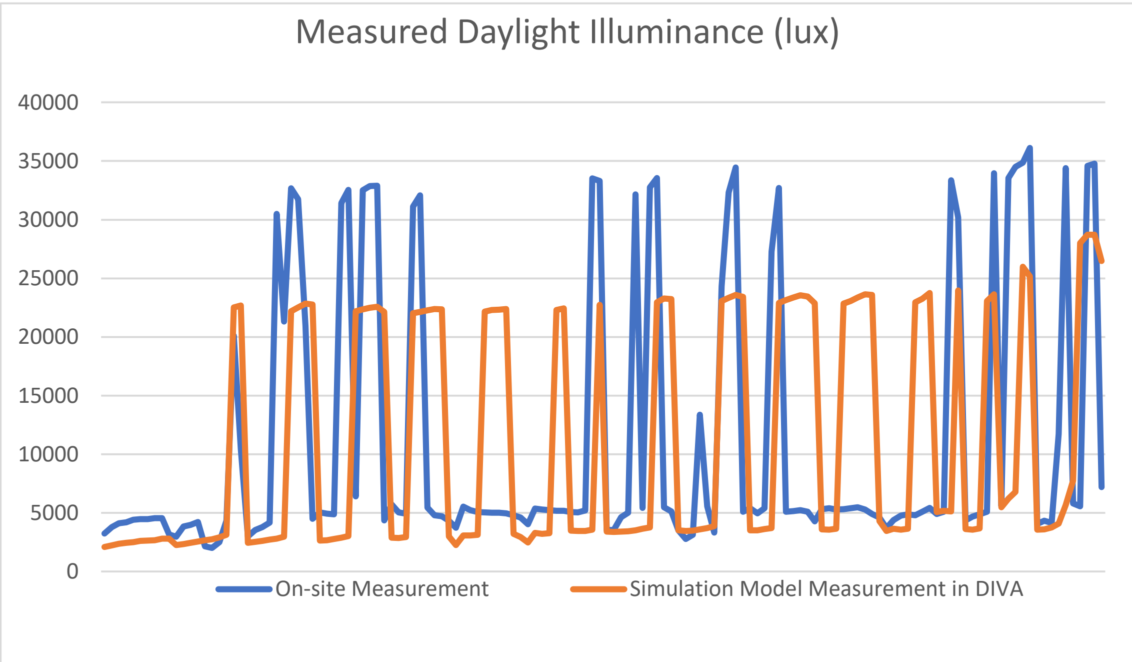


Figure 4. 2. The comparison of illuminance values between on-site and simulation model

But in either case, which are on-site measurements and simulation model, it was observed that the results of illuminance values were more than desired. In standard, the range of illuminance values should be between 300 lux and 2000 lux. To show the over-illuminating on the spaces the photograph of class and render by DIVA are shown in Figure 4.3. After this comparison, shading models 1 and 2 were designed to evaluate daylight performance and create more satisfied spaces.

(a) (b)

Figure 4. 3. Daylight effects in classroom (a) and simulation model (b)

4.2. Results of Simulation Models

Simulation model of case classroom with shading model 1 and shading model 2 are designed separately in Rhinoceros/grasshopper. After designing model with specific geometrical and surface properties stated in Section 3.1, the 140 measurement points are
(a)
located. The material properties and weather data selection are assigned same with the case classroom seen in Figure 3.3 and Figure 3.4.

After preperations of model, each model is simulated by DIVA in specific dates and times to evaluate daylight performance by climate-based daylight metrics. These are Daylight Autonomy (DA), Useful Daylight Illuminance (UDI), Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). Daylight Autonomy (DA) is a dynamic daylight metric presented a percentage of annual daylight hours of specific points in area. The threshold of DA is 300 lux. Useful Daylight Illuminance (UDI) summarises overall daylight performance of a space. The lower and upper thresholds of

UDI 100 lux and 2000 lux, respectively. UDI is a daylight availability metric represented percentage of the occupied time (Kevin et al.,2019). Spatial Daylight Autonomy (sDA) is another annual metrics represents the percentage of occupied time during year specific point on horizontal working plane that receives lower daylight illuminance threshold of 300 lux. The minimum acceptable percentage of sDA is %50. Annual Sunlight Exposure (ASE) represents the percentage of area that receives more than 1000 lux direct sunlight over 250 occupied hours of year. The percentage of ASE should be around %10 (Sterner). Addition to climate-based daylight metrics all simulation model were evaluated in terms of illuminnace values of measurement points and the interior space of models were rendered for physical view of daylighting distribution in specific times

4.2.1. Simulation Results of Case Model

In Section 4.1, the validation of the case simulation model was achieved according to simulation results that evaluated in 29th November at 15:00 pm. In this section, The case simulation model with unshading situation was evaluated on equinox and solsticee day to understand the daylight performance and effect of 2 different shading models. The comporison was made between March 21, June 21, September 23 and December 21 at 12:00 pm.According to calculation of illuminance value in raytracing of DIVA, Illuminance values increase considerably in the areas corresponding to the windows, while falling away from wndows. The illuminance results of 140 measurement points for equinox date are seen in Table 4.2. and 4.3. The highest values are highlighted with red and the lowest are highlighted with blues.

Looking at the results in March 21 and September 23 at 12:00 pm, the illuminance values change between 1064 lux-48464 lux and 1152lux-56696 lux, respectively. It shows that illuminance values are really higher than required values, which should be between 300 lux and 2000 lux. It is seen that, especially the values which are calculated by windows are really high and create unsatisfied spaces to occupants. Also illuminance values falls while move away from windows, they are close to required upper threshold.

According to illuminance values on solstice days, which are June 21 and December 21, at 12:00 pm, evaluations are same with the results of equinox days. The raytracing illuminance values changed between 492 lux-44848 lux in June 21 and 2120 lux - 32232 lux in December 21. The lowest illuminance value is really closed to required lowest threshold in June, but the highest value creates undesirable situations. On the other hand, even lower value in December 21 exceed the lowest 300 lux threshold. So, total has unsatisfied daylight situation for occupants. The raytracing illuminance values of June and December 21 are shown in Table 4.4 and 4.5.

When all results at 12:00 pm, it is seen that in March 21 and September 23, the illuminance value of half of the room is under 2000 lux, while the other half is over 2000 lux value. Especially in December 21, all values are higher than 2000 lux. So, entire of the room has unsatisfied daylight condition for occupants. As opposed to these days, in June 21, a large majority of the spaces have illumination values between 300 lux and 2000 lux as standards demand. In morning and evening time of these days, in March, September and December, the illuminance values have changed between 500 lux and 40000 lux and in June the values are between 400 lux and 2000 lux as similar with the situation of noon time.

In general illuminance values are higher than required range, especially in September 23 seen in Figure 4.4. All illuminance values are rapidly increasing near windows and falling at back spaces of classroom. So, the case classroom model needs to shade by shading systems to create more satisfied spaces to occupants in terms of illuminance values.

Table 4. 2. The raytracing illuminance values in March 21 at 12:00 pm of case model

March 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	1148	1260	1296	1392	1464	1480	1544	1496	1424	1316	1376	1188	1204	1028
2	1212	1304	1416	1376	1484	1552	1620	1508	1540	1432	1444	1324	1200	1064
3	1336	1400	1536	1548	1656	1672	1676	1600	1644	1620	1596	1424	1272	1240
4	1816	1732	1888	1896	1936	2040	2072	2008	1976	2016	1892	1712	1636	1528
5	2172	2348	2264	2056	2136	2472	2520	2484	2508	2264	2328	2232	2136	1948
6	2984	2964	2788	2816	2744	3040	3128	3024	2936	2736	3040	3064	2744	2380
7	4572	4268	3704	3416	3464	3944	4240	4456	3980	3896	4240	4024	3716	3396
8	43700	43120	12192	3944	4272	34888	42964	42756	12380	4588	35088	42644	42636	11800
9	46984	46296	14124	4304	3848	36096	45692	45444	14440	5188	36684	45592	45208	12944
10	47960	48464	46532	3536	2376	35720	47644	48088	46132	3564	35716	47648	47840	15648

Table 4. 3. The raytracing illuminance values in September 23 at 12:00 pm of case model

September 23, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	1160	1280	1344	1456	1520	1548	1600	1560	1504	1408	1448	1280	1268	1096
2	1228	1348	1472	1464	1564	1632	1688	1604	1620	1536	1532	1420	1296	1152
3	1364	1448	1592	1628	1728	1748	1764	1696	1720	1704	1676	1524	1388	1324
4	1752	1736	1868	1888	1928	2036	2076	2028	1992	2000	1920	1764	1700	1600
5	2080	2204	2180	2040	2112	2336	2404	2392	2360	2200	2244	2168	2104	1960
6	2724	2704	2592	1592	2532	2740	2816	2756	2676	2520	2724	2760	2572	2348
7	6812	6552	3496	1984	5616	5948	6408	6584	3652	5912	6136	6284	6152	3376
8	54280	53592	13364	3360	3400	43408	53248	53240	13364	3656	43552	53048	53176	13192
9	56696	55672	17288	3584	3068	44004	54888	54848	14768	4016	44364	54812	54780	13936
10	56592	56695	55544	2988	2128	43556	55944	56256	55232	2920	40916	55888	56128	18076

Table 4. 4. The raytracing illuminance values in June 21 at 12:00 pm of case model

June 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	528	560	576	616	644	652	672	660	620	576	624	548	576	512
2	524	568	608	576	620	644	672	632	644	604	628	580	536	492
3	556	560	624	632	676	672	680	636	660	672	664	584	544	548
4	720	696	720	728	728	780	800	764	772	772	748	680	672	656
5	816	872	868	784	808	900	948	936	936	856	896	872	856	824
6	1064	1072	1068	1104	1056	1104	1112	1092	1096	1044	1152	1160	1080	984
7	1512	1472	1400	1344	1344	1408	1456	1572	1496	1488	1568	1456	1380	1368
8	2244	2228	1956	1656	1692	1912	2172	2216	2800	1868	2080	2168	2204	1980
9	3552	3624	2860	2068	1812	2528	3436	3424	3148	2468	2904	3484	3460	2648
10	44632	44816	16624	1948	1232	30196	44600	44848	16544	2036	30360	44640	44648	16136

Table 4.5. The raytracing illuminance values in December 21 at 12:00 pm of case model

December 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	2428	2616	2704	2848	3020	3064	3160	3072	2992	2808	2842	2512	2412	2120
2	2516	2544	2660	2676	2832	2952	3064	2880	2936	2744	2760	2548	2316	2132
3	2704	2676	2756	2772	2940	2944	3016	2860	2908	2880	2844	2592	2360	2328
4	2852	12328	12388	2972	18924	19160	28488	12540	12364	18984	18880	27956	11984	11864
5	29412	28932	12660	3024	18972	19480	28880	12940	12816	19024	19256	28504	12508	12220
6	30492	29664	13064	3500	19328	19840	29316	29220	12948	19152	19824	29040	12976	12368
7	31500	30404	13640	3576	3560	20180	29608	29764	13344	3888	20116	29412	29184	13052
8	32028	31268	14248	3524	3568	20308	30536	30424	13916	3708	20400	30272	30304	13480
9	32232	31920	30564	3348	2860	20076	30976	31136	30288	3624	20224	30980	31108	13744
10	30804	31488	30624	2496	1864	3248	30780	31140	30408	2376	3192	30696	30944	29816

According to result of climate-based daylight metrics, the percentage of floor area of sDA is 100% because the all measurement points provide value of 300 lux throughout the year. The percentage of floor area of ASE is %75 so %75 of total area exposed more than 1000 lux per year seen in Table 4.6. Although the percentage of sDA is acceptable, the percentage of ASE is higher than accepted seen in Table 4.5. Also, it is seen from the Figure 4.5 and 4.6, the useful daylight illuminance range change between 21% and %96 and the range of DA range change between 92% and 97%. It means that all specific areas of space meet with daylight and illuminance values are generally more than 300 lux in year.

Table 4. 6. The percentage of sDA and ASE daylight metrics of case model

sDA (%)	ASE(%)
100	75

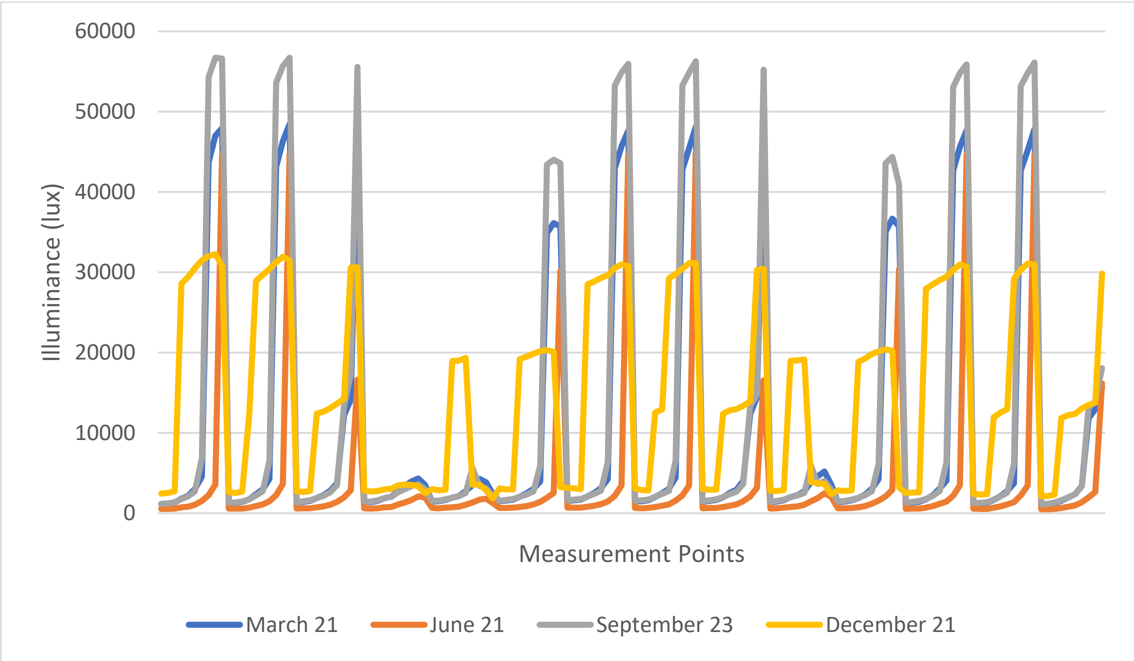


Figure 4. 4. The all illuminnace result on equinox and sosltice days at 12:00 pm

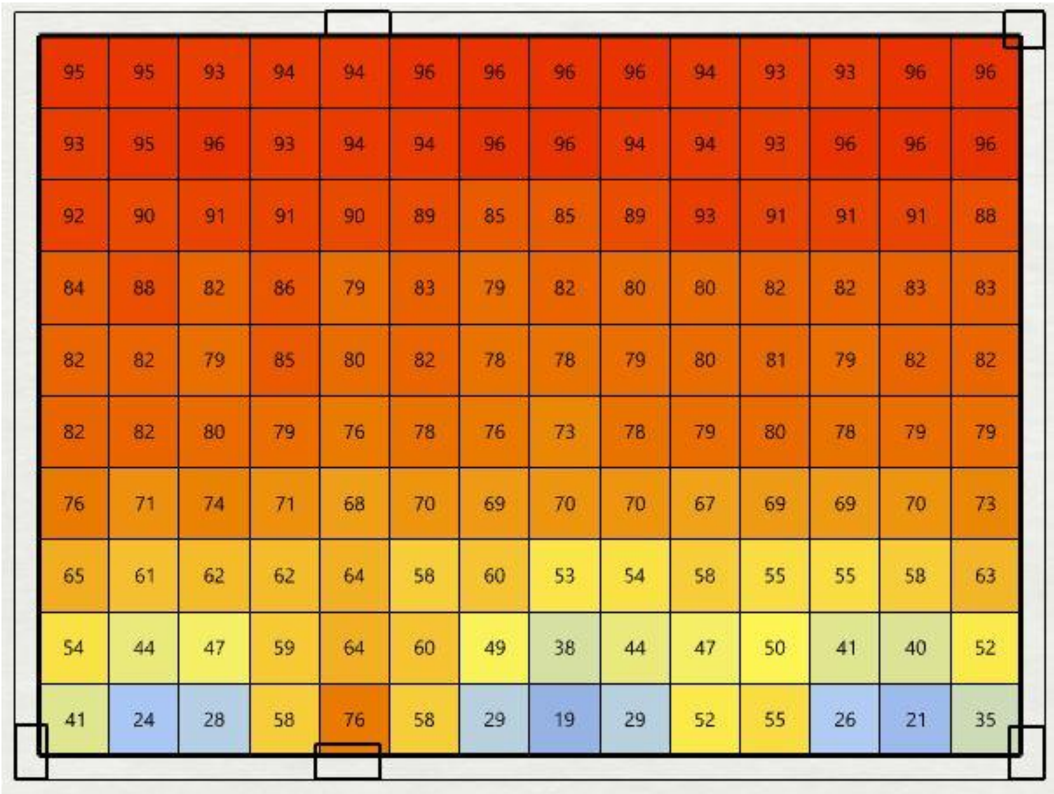


Figure 4. 5. Distribution of daylight illuminance range of spaces (UDI) in year of case model.

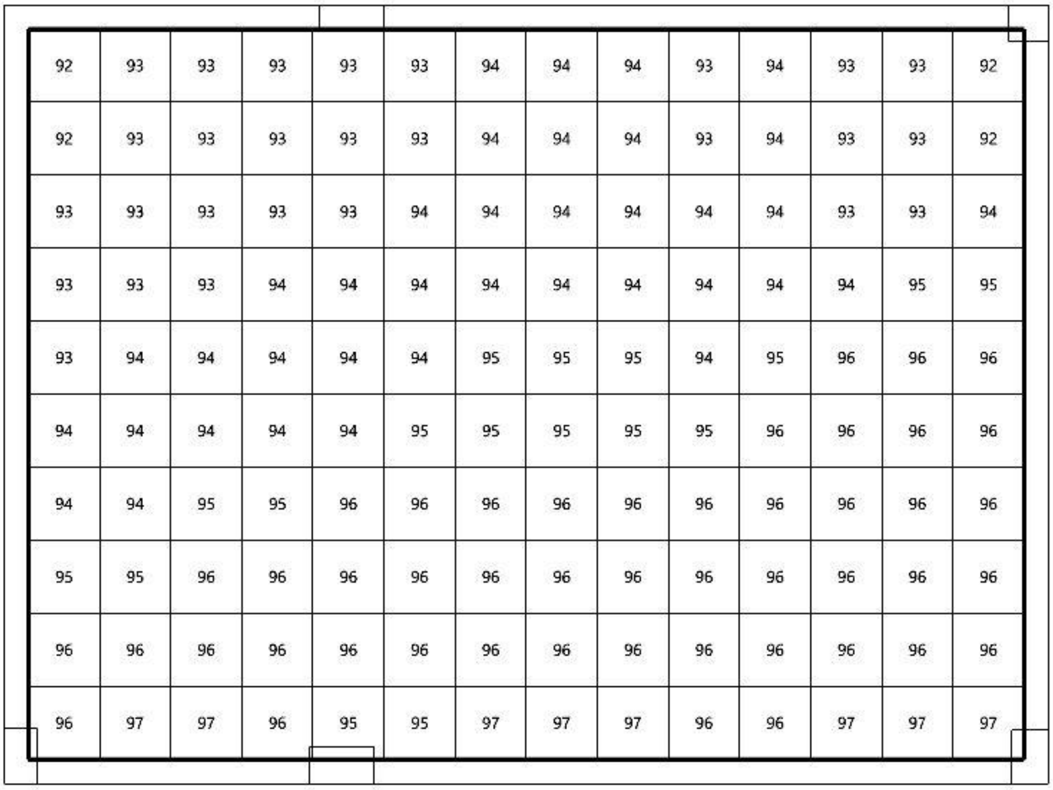


Figure 4. 6. Distribution of annual daylight hours of spaces (DA) in year of case

4.2.2. Simulation Results of Shading Model 1

According to results of the case model simulation, the classroom needs to shade by movable shading systems. So, the first movable shading model was designed as described in Section 3.2. To understand the effect of the position of the shading systems to the classroom, performance of 3 different orientation, which are 30 degrees, 45 degrees and 60 degrees of rotation angle, were evaluated in terms of daylight performance. As mentioned before, the comporison was made between March 21, June 21, September 23 and December 21 at 12:00 pm. Also, the UDI, sDA, ASE and illuminance values are evaluated for each position of shading model 1, respectively.

4.2.2.1. Results of Shading Model 1 Positioned 30 Degree

The results of illuminance values in March 21, June 21, September 23 and December 21 at 12:00 pm are explained and shown below, respectively. The highest values are highlighted with red and the lowest values are highlighted with blue as mentioned before.

İn March 21, the illuminance values have changed between 60 and 836 lux as shown in Table 4.7. So, total is of the classroom have dark interior spaces. Because, almost whole areas have lower value than 300 lux. İn June 21, illuminance values start with 44 lux at the back side of the classroom and increase to 444 lux getting closer to the windows, rapidly as seen in Table 4.8. So, the areas which located near the windows have an average value, while other areas create dark spaces to occupants. İn September 23, seen in Table 4.8, the areas are divided into 3 different areas according to range of illuminance values. In the first space, which are away from the windows, the illuminances values are between 64 and 112 lux. In the middle space, the range changes between 100 lux and 216 lux. The last space, which is located near to the windows, have range between 232 and 640 lux. So, the illuminance values have changed between 64 lux and 640 lux, in total and this situation cerates dark environment across the classroom. Similar to result of September, in December 21, classroom have 3 different zone in terms of illuminance range. On that zones, values are changed between 80-108 lux, 120-232 lux and 272-704 lux, respectively. It is shown in Table 4.10.

On the other hand, useful daylight illuminance (UDI) range has changed 3% and 96%. While the back side of the classroom has percent between 3% and 36%. Because of the low illuminance value on the back side of the classroom, these areas occupied time between 3 and 36 percentage in year. In the areas, which close to the windows, this percentage become in a range between 30% and 96% because the illuminance values are higher than the back spaces of the classroom in this areas According to result of the daylight autonomy (DA) , generally all of the results of the illuminance values of back side of the field has lower value than 300 lux. So, the DA percentage is 0% in that places. Only the areas, which have higher value than 300 lux in year, has percentages between 6% and %79. UDI and DA results are shown as a grid in Figure 4.8 and 4.9, respectively.

All in all, shading model 1 positioned 30 degrees does not create enough daylight to occupants in year because generally the illuminance values are lower than 300 lux. But on the other hand, there is no too bright areas in spaces. So, the shading model 1 (30°) protects the classroom from direct sunlight but it is more than wanted.

Table 4.7. The raytracing illuminance values in March 21 at 12:00 pm of Shading Model 1 (30°)

Shading Model 1 (30°) March 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	64	64	76	88	72	100	84	100	96	88	80	72	60	60
2	64	64	84	88	84	72	92	92	76	84	76	72	72	68
3	60	80	68	72	88	76	80	84	80	80	80	80	72	64
4	72	84	76	80	84	96	92	96	88	92	92	92	92	80
5	88	88	96	104	96	112	120	120	112	120	104	92	100	100
6	96	120	160	116	104	104	104	108	132	120	152	132	132	112
7	108	116	136	144	152	128	136	160	128	136	144	160	208	160
8	164	196	192	188	184	156	160	168	172	192	232	260	336	196
9	272	296	224	188	188	192	192	176	204	216	256	312	536	29916
10	512	368	248	260	244	224	212	204	236	236	220	352	468	836

Table 4.8. The raytracing illuminance values in June 21 at 12:00 pm of Shading Model 1 (30°)

Shading Model 1 (30°) June 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	48	56	60	68	60	72	68	76	72	64	64	56	48	44
2	52	48	64	64	64	56	64	68	56	56	56	52	52	48
3	48	56	52	52	56	56	56	56	52	56	56	56	52	48
4	52	56	52	52	56	56	56	64	56	56	56	56	60	48
5	64	60	64	64	56	64	64	64	64	64	64	60	60	56
6	68	72	88	64	56	56	52	56	68	60	72	68	76	64
7	68	72	72	72	76	56	68	72	56	64	68	76	100	92
8	100	112	104	96	88	68	64	72	76	84	108	116	148	104
9	156	168	112	88	84	80	80	72	84	96	128	160	272	228
10	312	212	120	120	104	88	80	72	96	100	88	188	296	444

Table 4.9. The raytracing illuminance values in September 23 at 12:00 pm of Shading Model 1 (30°)

Shading Model 1 (30°) September 23, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	68	72	80	88	80	104	92	104	100	96	88	80	68	64
2	72	72	88	92	92	84	96	100	88	92	84	80	80	76
3	68	88	76	84	96	88	92	96	92	96	96	88	80	76
4	84	92	88	96	100	112	104	112	104	104	108	108	104	92
5	100	100	108	120	116	124	136	136	132	128	120	112	116	116
6	112	136	164	136	128	136	132	136	152	144	164	152	2788	128
7	128	140	160	172	176	160	168	184	164	168	176	188	208	176
8	180	208	216	216	216	196	200	212	208	224	244	256	288	208
9	272	296	256	232	232	236	240	224	252	256	280	312	436	37040
10	456	376	296	312	300	284	276	272	300	296	280	372	424	640

Table 4.10. The raytracing illuminance values in December 21 at 12:00 pm of Shading Model 1 (30°)

Shading Model 1 (30°) December 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	80	84	92	108	104	128	108	120	124	120	116	104	96	80
2	88	76	100	112	112	112	128	116	108	116	112	104	108	104
3	80	96	104	108	128	104	116	124	112	112	120	120	104	100
4	96	116	128	120	144	132	140	144	148	132	136	128	124	108
5	120	136	160	148	156	164	184	184	176	176	168	144	160	140
6	144	184	224	196	176	188	192	184	204	200	208	204	192	152
7	168	208	232	240	256	224	252	252	248	232	232	236	284	232
8	232	272	288	312	312	292	288	308	304	304	320	328	332	16068
9	336	368	356	336	356	352	352	336	356	348	388	384	476	432
10	528	504	440	484	464	440	416	400	448	448	408	500	488	704

4	4	9	23	16	28	21	31	29	24	19	9	5	3
4	3	20	26	23	18	27	31	17	21	17	11	8	9
6	15	14	20	26	18	24	20	18	19	19	24	15	9
17	24	24	22	27	33	29	36	29	27	26	25	29	14
30	31	36	43	35	43	43	41	44	42	35	32	31	27
37	45	67	45	42	37	38	38	49	47	47	40	41	33
43	47	49	58	64	45	57	55	43	46	53	48	66	55
69	81	80	79	72	58	55	56	58	58	78	75	83	62
89	90	83	73	69	69	68	58	64	72	84	86	89	89
91	96	85	82	75	72	62	56	73	75	68	91	93	89

Figure 4. 7. Distribution of daylight illuminance range of spaces (UDI) in year of shading model 1 (30°)

0	0	0	1	2	6	0	0	6	3	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	1
1	1	0	0	0	0	0	0	0	0	0	0	2	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	8	6	0	11	0	0	0	0	11	0	6	8	0
0	0	8	11	9	0	1	1	0	7	12	8	2	0
6	10	12	15	18	8	2	4	7	11	12	13	15	6
26	41	30	15	24	13	13	11	12	23	27	32	50	32
76	66	32	30	26	30	20	17	32	23	18	47	64	79

Figure 4. 8. Distribution of annual daylight hours of spaces (DA) in year of case model shading model 1 (30°)

4.2.2.2. Results of Shading Model 1 Positioned 45 Degree

To compare the different positions of shading model 1, the panels rotated to 45 degrees. In addition, simulations run out on equinox and solsticee days at 12:00 pm.

The illuminance values change between 204 lux and 1544 lux in March 21 as in the range we want to achieve seen in Table 4.11. Opposite to March, in June 21, this range decreased to range between 152 lux and 796 lux as shown in Table 4.12. With the fall of these values, the classroom, which have sufficient illuminance value in March, creates dark and unsatisfied spaces to occupants. According to values in September, the area has again enough daylight in interior spaces with the range of 208-2992 lux seen in Table 4.13. The illuminance values are divided into 2 zones in spaces. The values change between 208 lux and 320 lux in first and creates more darker spaces. At second zone, these values increased the range between 340 lux and 2992 lux, so desired daylight levels are achieved. In December 21, the same situation repeated with September. The illuminance values change between 224 lux and 1512 lux and these values shown in Table 4.14. In general, the shading model 1 positioned 45 degrees has sufficient illuminance values in classroom.

According to UDI and DA values of model 1 positioned 45 degrees, the ranges have been changed between 80 % - 96% and 4%-94%, respectively. The cause of the UDI values appear in this range is having enough daylight in classroom in year. So, occupants can easily use the spaces in terms of daylight in year. In terms of the 4% - 94% range of DA show that the back side of the classroom have lower value than 300 lux in year, so these areas have values lees than 50%. The other half of the building have higher value than 300 lux in year, so the percentage increased up to 94% in year. These values of UDI are shown in Figure 4.9 and DA is seen in Figure 4.11.

As a result, the shading model 1 (45°) provides available areas in terms of daylight. It does not only protect the classroom from direct sunlight, but also creates valuable areas which are bright enough throughout the year.

Table 4.11. The raytracing illuminance values in March 21 at 12:00 pm of Shading Model 1 (45°)

Shading Model 1 (45°) March 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	212	248	272	276	288	272	324	332	312	272	288	240	236	192
2	204	204	228	216	248	256	264	256	292	308	256	252	220	176
3	204	204	224	228	280	272	252	240	232	264	208	208	224	216
4	224	232	228	236	232	264	292	236	288	220	248	236	208	196
5	256	264	256	252	244	304	240	292	288	348	300	276	252	244
6	272	276	292	368	308	356	276	368	264	340	400	372	332	284
7	312	296	400	344	384	328	328	392	320	396	388	388	616	352
8	396	448	452	424	376	372	420	388	344	400	468	548	612	404
9	536	620	532	376	424	392	396	492	408	456	528	640	760	30172
10	1088	868	744	680	676	736	744	712	708	728	800	956	984	1544

Table 4.12. The raytracing illuminance values in June 21 at 12:00 pm of Shading Model 1 (45°)

Shading Model 1 (45°) June 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	172	184	200	208	224	212	248	264	240	216	220	196	192	160
2	160	160	176	164	188	196	208	200	208	224	192	184	168	148
3	160	160	160	168	192	188	176	176	176	184	152	152	168	172
4	164	164	160	160	156	172	192	152	200	156	172	168	156	152
5	176	176	160	156	152	188	140	176	172	192	172	160	172	168
6	184	176	168	196	168	192	148	192	144	172	200	196	184	184
7	192	176	216	184	208	160	160	188	160	208	188	200	280	220
8	232	248	240	212	180	168	192	176	152	184	228	264	292	236
9	312	340	280	164	192	156	160	224	164	200	268	336	396	360
10	648	496	400	340	320	360	368	348	344	356	416	532	564	796

Table 4.13. The raytracing illuminance values in September 23 at 12:00 pm of Shading Model 1 (45°)

Shading Model 1 (45°) September 23, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	216	248	268	272	284	272	324	336	312	280	288	248	244	200
2	208	216	232	228	256	268	272	268	304	308	272	264	232	192
3	212	220	240	248	288	288	268	264	256	280	240	232	248	232
4	240	248	256	268	264	288	312	264	320	256	276	264	240	220
5	272	284	284	288	280	332	288	328	320	360	328	308	284	272
6	308	312	332	392	352	400	340	400	320	368	408	392	2992	324
7	344	352	444	404	432	400	404	448	392	436	428	424	568	392
8	424	488	508	496	460	464	504	472	448	488	524	560	584	452
9	560	648	600	484	528	508	512	596	524	564	608	664	736	39952
10	1020	896	820	776	784	844	844	824	820	836	880	992	960	1260

Table 4.14. The raytracing illuminance values in December 21 at 12:00 pm of Shading Model 1 (45°)

Shading Model 1 (45°) December 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	260	316	344	352	384	352	432	428	392	352	400	332	320	252
2	248	264	288	288	328	344	348	340	372	428	344	360	288	224
3	272	280	304	316	388	392	344	332	340	164	288	292	308	312
4	288	332	336	332	328	376	416	348	436	340	356	356	288	280
5	364	372	372	376	392	444	396	448	420	496	432	392	384	376
6	376	400	448	588	480	572	472	560	436	520	544	548	440	384
7	448	468	588	560	644	568	584	640	592	592	584	580	728	472
8	548	612	696	704	684	684	728	700	696	m704	704	740	736	16376
9	732	872	864	728	824	772	784	928	784	820	884	912	960	816
10	1328	1320	1244	1224	1252	1296	1344	1288	1264	1300	1312	1384	1288	1512

88	92	92	92	93	89	93	93	90	93	93	93	93	90
87	87	91	88	92	92	93	93	93	94	93	92	92	85
87	87	88	90	93	93	91	92	91	93	83	87	92	93
88	90	89	89	90	93	93	84	93	87	92	93	91	90
92	92	92	87	84	93	80	91	93	94	91	92	92	93
92	89	89	93	93	94	85	93	81	90	94	91	90	93
93	92	91	88	92	89	89	94	87	92	87	91	95	94
88	94	90	92	89	93	94	94	80	90	92	91	95	90
87	87	92	86	87	84	87	94	84	88	95	92	87	88
84	96	96	95	95	95	95	95	94	95	96	96	95	85

Figure 4.9.Distribution of daylight illuminance range of spaces (UDI) in year of shading model 1 (45°)

5	12	20	21	28	24	33	37	30	22	26	12	12	5
5	5	9	6	16	18	22	22	26	33	19	16	4	4
6	6	9	13	28	23	22	21	16	24	4	5	8	11
10	16	18	15	21	27	33	18	29	18	21	19	6	5
22	25	31	28	23	36	26	35	31	38	33	27	22	19
28	31	33	41	43	44	33	43	28	43	44	39	32	27
36	33	51	50	54	38	44	51	37	52	50	42	61	37
51	63	62	58	49	48	52	49	43	49	54	59	63	43
75	83	78	46	57	45	47	57	46	57	66	75	82	74
94	94	90	84	79	86	82	78	85	78	91	94	93	94

Figure 4.10. Distribution of annual daylight hours of spaces (DA) in year of case model shading model 1 (45°).

4.2.2.3. Results of Shading Model 1 Positioned 60 Degree

The last comparison group for understanding the effect of different positioned shading systems is shading model 1 with 60 degrees. As in previous ones, this model has also evaluated in terms of illuminance value, useful daylight illuminance (UDI) and daylight autonomy (DA). Illuminances values are changed between the values of 320 lux and 17000 lux on equinox and solsticee days at 12:00 pm. İn March 21, this range is between 440 lux and 2368 lux as we wanted to achieve seen in Table 4.15. Like this situation, the all areas have 320 lux-1280 lux range in June and 464lux- 2000 lux in September shown in Table 4.16 and 4.17, respectively. Only in December, the back side of the area daylit more sufficient way with the range of 732-1204 lux but it increased to 17000 lux in some specific points and it disturbs the occupants at specific times shown in Table 4.18.

Regarding to results of UDI and DA of shading model 1 positioned 60°, since the illuminance values are in desired range of 300 lux – 2000 lux, the percentage of occupant times in year changes between 84% and 96% seen in Figure 4.11. In the results of DA, the average percentage of the areas, which located on the far side of the window and have higher value than 300 lux in year, is about 80 %. This percentages increased up to %96 as shown in Figure 4.12.

In general, the shading model 1 with 60° rotation angle has successful to shade the areas with acceptable illuminance values on each specific day. So, this shading system can use on classroom, effectively.

Table 4.15. The raytracing illuminance values in March 21 at 12:00 pm of Shading Model 1 (60°)

Shading Model 1 (60°) March 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	528	560	716	696	676	880	808	632	696	680	680	656	576	520
2	472	512	600	564	576	620	684	608	560	580	592	640	508	480
3	548	500	588	600	632	680	616	696	528	532	616	532	488	440
4	520	580	580	568	572	572	612	668	600	668	584	580	496	524
5	596	596	512	632	688	568	632	652	672	624	720	664	608	620
6	584	676	644	692	604	828	728	664	720	696	676	704	600	592
7	816	824	792	656	756	992	872	804	712	856	848	892	840	764
8	976	1112	984	872	812	848	944	752	872	896	968	1040	1096	944
9	1200	1220	1004	1012	1052	1060	1024	1040	1032	1024	1072	1184	1504	30640
10	1884	1688	1500	1532	1456	1488	1468	1436	1512	1468	1500	1632	1780	2368

Table 4.16. The raytracing illuminance values in June 21 at 12:00 pm of Shading Model 1 (60°)

Shading Model 1 (60°) June 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	392	420	488	488	488	592	560	464	500	480	504	480	448	416
2	364	376	420	400	404	452	472	428	416	424	424	460	400	380
3	392	360	388	408	424	436	416	448	368	376	404	380	364	352
4	364	376	380	372	376	364	388	420	380	420	360	392	356	384
5	400	392	320	376	392	344	360	384	388	376	408	416	388	420
6	384	396	372	384	336	444	396	360	392	384	380	392	376	400
7	488	460	424	360	380	500	428	408	352	456	440	464	456	464
8	552	576	508	440	400	404	472	368	436	452	504	540	544	528
9	700	696	532	528	528	536	504	504	520	520	564	628	780	632
10	1040	932	784	768	712	728	720	700	736	724	768	880	996	1280

Table 4.17. The raytracing illuminance values in September 23 at 12:00 pm of Shading Model 1 (60°)

Shading Model 1 (60°) September 23, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	500	536	656	656	648	812	760	624	668	648	664	632	564	516
2	468	500	572	560	572	620	664	608	560	580	580	632	516	488
3	536	500	572	600	636	664	620	688	556	560	612	552	504	464
4	516	588	592	592	604	600	636	688	620	672	600	608	528	552
5	600	612	556	656	716	624	672	700	704	652	712	692	636	640
6	616	704	692	752	684	848	792	736	768	752	736	744	3300	648
7	828	848	832	764	852	1036	944	880	820	924	900	904	880	812
8	976	1104	1040	972	948	976	1048	924	996	1016	1064	1072	1056	980
9	1204	1260	1132	1164	1208	1216	1200	1200	1200	1164	1188	1224	1400	40428
10	1716	1652	1552	1588	1544	1588	1572	1552	1592	1568	1576	1648	1708	2000

Table 4.18. The raytracing illuminance values in December 21 at 12:00 pm of Shading Model 1 (60°)

Shading Model 1 (60°) December 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	848	888	1096	1156	1100	1372	1280	1020	1132	1128	1104	1056	888	760
2	796	816	992	936	944	1032	1104	1056	896	968	1004	976	828	744
3	872	840	984	1036	1080	1152	1080	1188	936	940	1048	888	824	732
4	1004	1028	1000	1044	984	1048	1080	1176	1048	1160	1008	1016	884	856
5	1088	1032	940	1132	1208	1100	1156	1168	1216	1112	1240	1144	16896	1004
6	1076	1264	1224	1280	1192	1416	1320	1228	1272	1240	1280	1204	1060	972
7	1528	1456	1524	1264	1472	1704	1628	1488	1388	1432	1480	1408	1380	1204
8	1556	1756	1684	1584	1576	1600	1696	1506	1616	1580	1668	1668	1496	17328
9	2024	2000	1812	1944	1984	2000	1956	1932	1912	1884	1872	1852	1960	1628
10	2696	2604	2516	2572	2532	2604	2612	2592	2632	2516	2588	2548	2560	2828

94	94	94	94	94	91	95	95	92	95	96	96	96	96
94	94	94	94	94	93	95	94	94	95	95	96	95	95
92	92	92	93	93	93	93	95	94	94	94	94	94	94
94	94	94	94	94	94	95	95	95	96	95	95	95	96
90	85	89	86	86	86	83	85	86	87	87	91	86	91
94	90	90	93	93	95	95	95	95	94	95	92	92	96
92	93	89	87	89	93	91	93	92	90	88	90	94	93
89	95	90	93	92	95	96	94	95	93	93	90	96	91
88	87	93	96	91	96	96	96	96	92	95	93	87	88
83	96	96	96	96	96	96	96	95	96	96	95	94	84

Figure 4. 11. Distribution of daylight illuminance range of spaces (UDI) in year of shading model 1 (60°).

78	84	90	91	90	93	93	89	92	92	92	91	90	85
73	78	85	79	79	88	91	84	82	81	85	91	82	81
83	76	80	84	85	87	81	91	79	80	81	81	79	78
77	79	80	78	81	77	82	85	81	88	80	82	79	86
85	84	72	83	83	75	81	83	83	82	84	88	83	88
82	83	79	81	77	93	85	81	86	82	82	82	82	86
92	92	90	82	81	94	87	89	77	93	89	93	92	92
93	93	93	92	87	91	94	79	93	90	94	94	93	93
93	94	94	94	94	94	91	94	94	92	94	94	94	94
95	96	95	94	94	94	94	94	94	94	94	95	95	96

Figure 4. 12. Distribution of annual daylight hours of spaces (DA) in year of case model shading model 1 (60°).

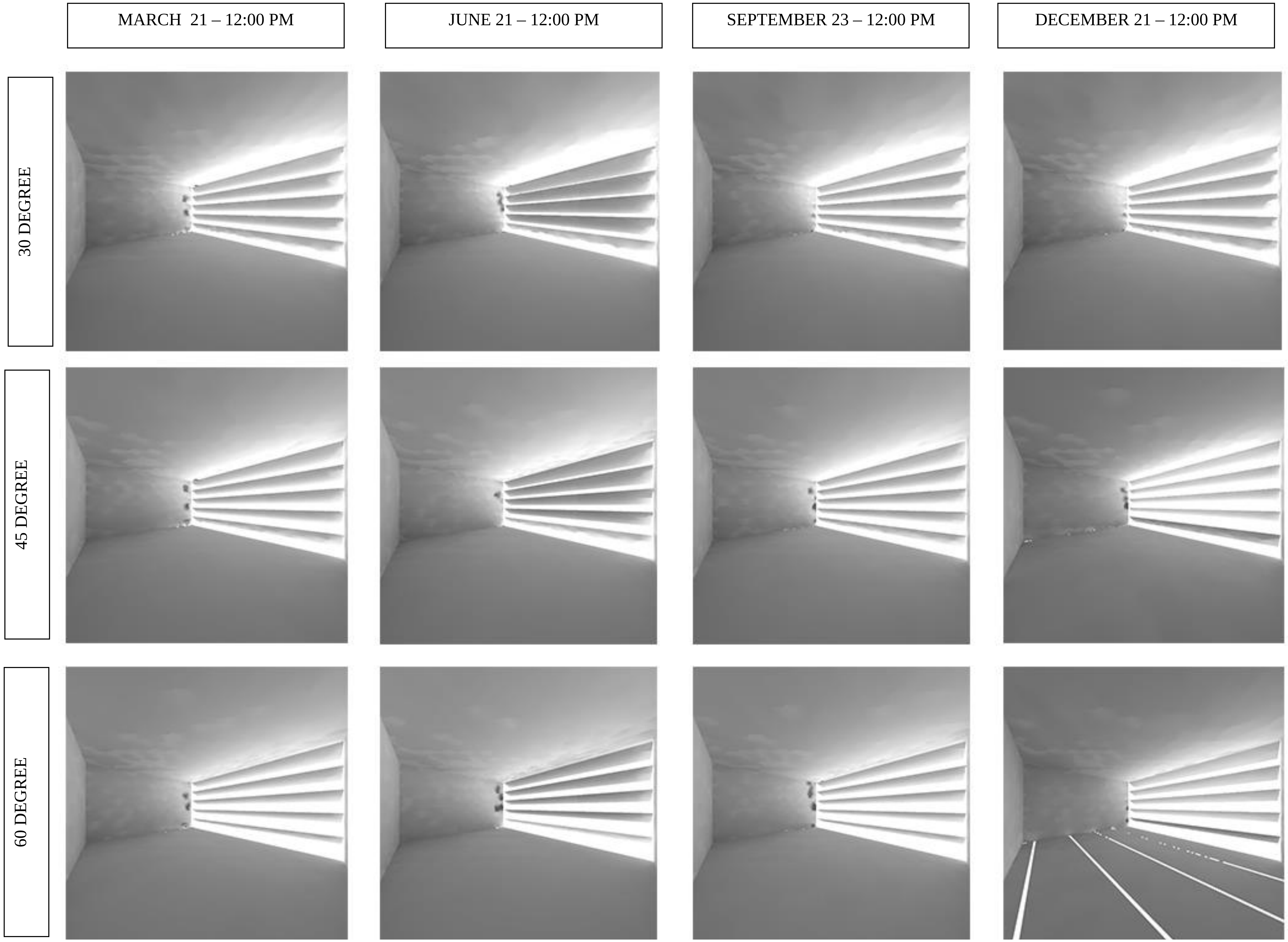


Figure 4. 13. Renders on equinox and solstice days at 12:00 pm of Shading Model 1

All in all, while shading model 1 positioned 30° creates some unacceptable low illuminance values in year, 45° and 60° are successful to shade classroom with the range of 300 lux – 2000 lux of illuminance values. So shading model 1 can be adopted to the façade of the field to get more daylight performance. This solution is also supported by the values of sDA and ASE of each options of rotation angles. It is seen from the Table 4.19, sDA values is unqualified in 30° than the others with the value of 3.6%. As mentioned before, the percentage of sDA must be more than 50%. While, model 1 with 45° is more getting close than 30° with the percent of 27.9, the 60° gives full response because all areas have more values than 300 lux in year. According to results of ASE, the percentage of areas, which have more than 1000 lux in year, are 3.6%, 27,9% and 24.3, respectively. This value is really low in 30° because of low illuminance values. It increased to 24.3% in 60°. Also, the renders of the spaces on each equinox and solsticee days at 12:00 pm are shown in Figure 4.13 to understand the comparisons.

Table 4.19. The percentage of sDA and ASE daylight metrics of shading model 1.

	30 DEGREE	45 DEGREE	60 DEGREE
sDA (%)	3.6	27.9	100
ASE (%)	7.1	8.6	24.3

4.2.3. Simulation Results of Shading Model 2

After evaluating the daylight performance of the shading Model 1, the shading model 2 was designed with the method explained in Section 3.3. The main differences of these two shading devices is that model 1 has single orientation while model 2 has double or multi orientation. Other than that, the areas they cover and their material are assigned same as deatiled in Section 3.2. As in shading model 1, this shading model has 3 different orientation angle which are 30°, 45° and 60°. The daylight performance of shading model 2 is evaluated with illuminance value, UDI, DA sDA and ASE in equinox and solstice days at 12:00 pm as mentioned before. Then, these two different shadings were compared to each other

4.2.3.1. Results of Shading Model 2 Positioned 30 Degree

In March 21, the half of the room has 440 lux- 1400 lux range of illuminance value as seen in Table 4.20. But at the other half, this value become the range around 3000 lux. This situation creates unbalanced areas in terms of daylighting. Also, the same situations happen in September and December. The values changed between 456 lux – 39284 lux and 716 lux – 26920 lux shown in Table 4.22 and 4.23, respectively. At each date, the half of the room has valuable range of illuminance spaces, but it increased dramatically at near of the windows. Nevertheless, in June 21 shown in Table 4.21, all spaces have the range between 144 lux and 1856 lux. With these values, some areas remain under 300 lux. Although it may be dark for occupants, the general values are useful values because their ranges are between 300 lux and 2000 lux.

According to the results of UDI, the first 2 lines located at near to the window, which corresponding to numbers of 9 and 10 in tables, the percentage of occupied times range changed between 38% and 70%. The reason of this is having values that are more than 2000 lux in these lines. This range changes between 74% and 93% because illuminance values were getting more desired values. In terms of the results of other climate-based daylight metric of DA, the first 3 line has more than 1000 lux value in year with the range of 83% and 95%. Other areas have 33% and 81%. The results of UDI and DA are shown in Figure 4.14 and 4.15, respectively.

All in all, shading model 2 positioned 30° has not create sufficient daylight distribution in field. Although it has a god daylight performance in June, in other specific months of the year the values higher than required. So, this model does not do shading to field.

Table 4.20. The raytracing illuminance values in March 21 at 12:00 pm of Shading Model 2 (30°)

Shading Model 2 (30°) March 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	440	520	588	596	588	632	640	628	608	524	556	524	504	364
2	512	588	732	608	720	672	672	692	680	712	592	548	532	412
3	752	616	652	712	752	800	744	840	848	744	740	580	596	632
4	804	800	856	904	992	1008	896	860	832	836	776	720	656	656
5	944	1044	924	1024	980	928	1096	1056	1052	1056	920	872	812	756
6	1200	1240	1396	1364	1148	1452	1388	1432	1284	1360	1120	1052	1048	892
7	1836	30988	1804	2000	31344	1704	1656	30944	1544	1948	1624	1448	1344	1096
8	2208	2000	2376	2296	2356	2296	31564	2168	2212	31332	31188	1984	31168	1276
9	3248	2984	2640	2732	2976	3056	2764	2608	2348	2604	2776	2656	2208	1812
10	4320	3820	32392	3472	3492	33232	3408	3224	3376	3372	3260	2804	3280	32208

Table 4.21. The raytracing illuminance values in June 21 at 12:00 pm of Shading Model 2 (30°)

Shading Model 2 (30°) June 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	156	200	212	212	216	240	224	224	212	188	216	200	208	144
2	180	200	248	200	248	236	240	236	240	248	212	200	188	152
3	240	196	228	228	240	268	236	272	308	268	256	204	208	232
4	260	256	272	304	316	340	292	284	272	284	264	248	244	232
5	292	340	308	316	344	312	368	372	376	364	344	316	288	268
6	384	396	492	488	400	516	504	520	464	484	396	400	392	328
7	548	484	624	736	748	640	624	564	584	728	628	524	508	460
8	616	648	800	860	920	920	848	912	888	800	680	772	720	520
9	972	1168	1160	1148	1452	1332	1136	1208	1104	1136	1320	1120	928	888
10	1908	1796	1484	1656	1856	1916	1632	1596	1584	1500	1644	1456	1524	1488

Table 4.22. The raytracing illuminance values in September 23 at 12:00 pm of Shading Model 2 (30°)

Shading Model 2 (30°) September 23, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	536	632	700	736	736	772	784	772	744	676	688	636	600	456
2	628	720	840	784	872	844	848	856	848	856	752	688	648	536
3	848	780	832	896	940	984	940	1000	992	908	888	752	736	736
4	952	952	1028	1072	1156	1176	1088	1060	1020	1016	948	892	828	796
5	1116	1176	1128	1204	1184	1152	1280	1236	1208	1212	1096	1044	976	924
6	1424	1396	1508	1484	1324	1536	1520	1516	1400	1452	1252	1200	1168	1064
7	2168	38568	1780	2172	38760	1724	1948	38440	1592	2092	1856	1472	1676	1508
8	2428	2064	2256	2136	2212	2112	38660	2024	2000	38428	38312	1824	38316	1404
9	3268	3048	2360	2436	2592	2520	2472	2316	2092	2296	2352	2220	2216	1792
10	4004	5932	39184	3132	3156	39588	3080	2916	2656	2976	2896	2264	2648	39284

Table 4.23. The raytracing illuminance values in December 21 at 12:00 pm of Shading Model 2 (30°)

Shading Model 2 (30°) December 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	844	944	10272	964	912	992	964	944	924	800	832	10036	740	600
2	10328	10232	1072	10180	26112	928	10188	26020	920	10232	25896	752	10004	9904
3	1332	940	992	944	1032	992	920	1036	1064	912	896	716	776	888
4	1352	1128	1120	1096	1152	1164	1032	980	916	968	916	16672	788	828
5	1364	10544	16936	1120	1020	1032	1104	1104	1080	1072	948	908	10176	848
6	1584	17224	10616	1448	1152	1332	1356	1344	1200	1296	1008	10312	1068	908
7	26920	10720	17312	10880	10788	17280	10596	10428	17096	10704	10520	17012	10460	10268
8	1776	1640	1656	1660	1720	1440	1712	1592	1476	1308	1288	1416	1216	1004
9	1752	17728	17520	2032	1924	17488	1848	1864	17308	1760	1792	17336	7472	1260
10	18264	11464	1732	18192	1924	1888	18164	2052	1764	18172	1868	1560	27396	1624

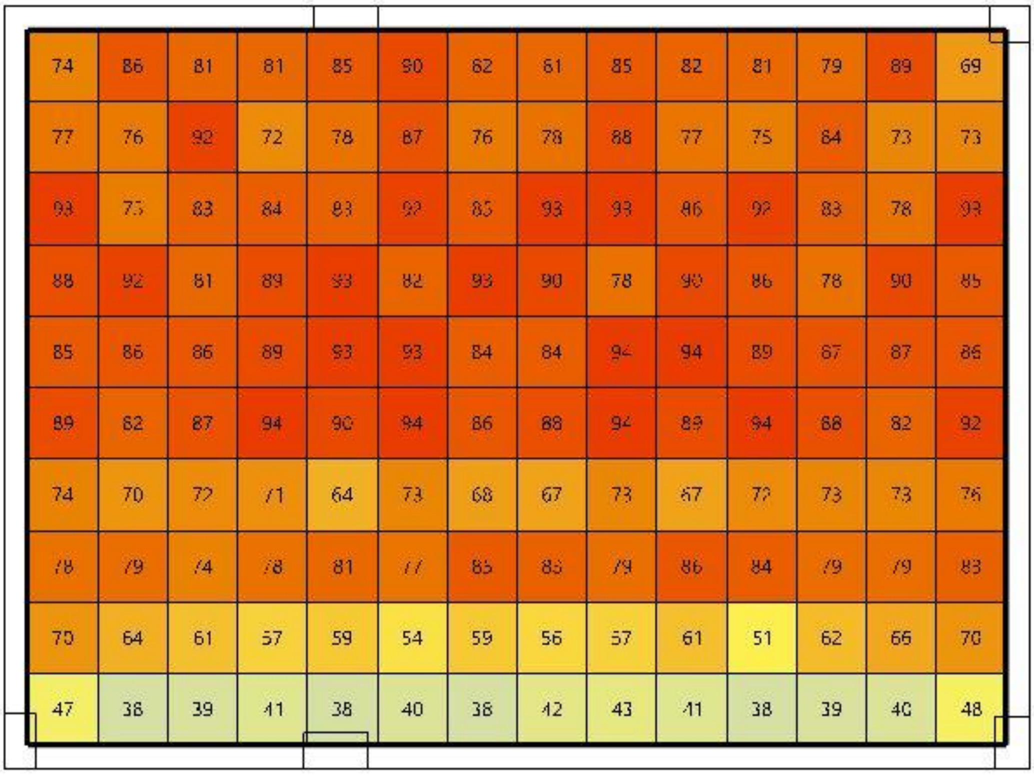


Figure 4.14. Distribution of daylight illuminance range of spaces (UDI) in year of shading model 2 (30°).

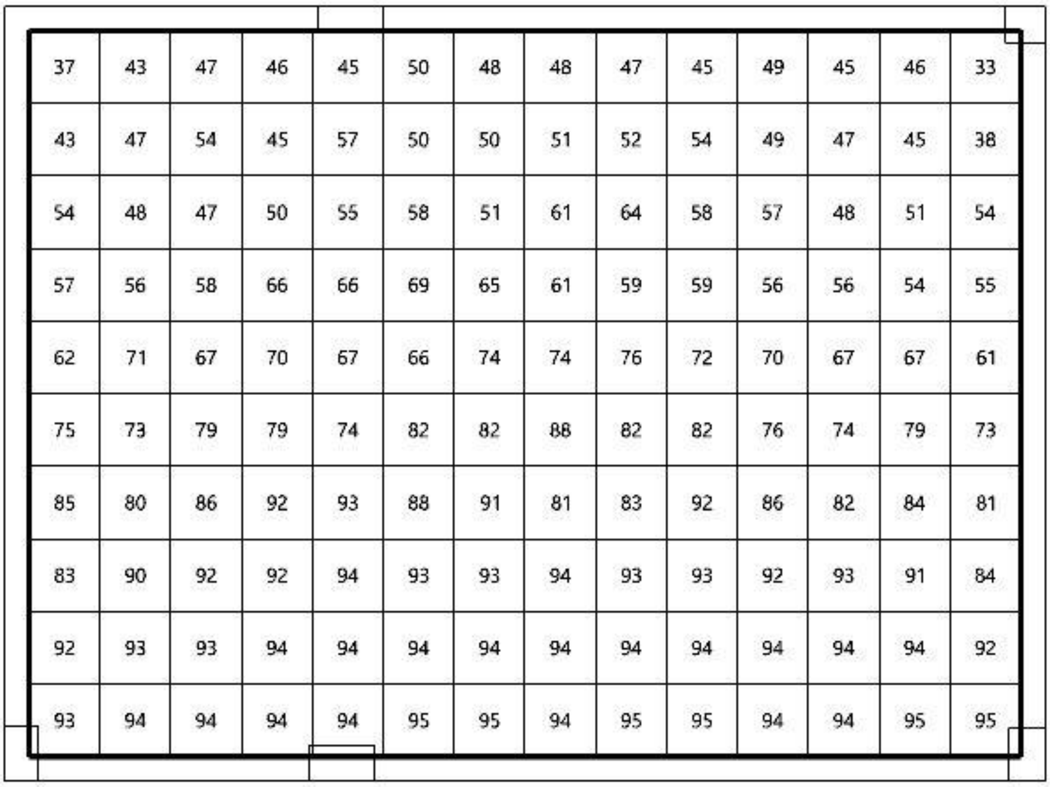


Figure 4.15. Distribution of annual daylight hours of spaces (DA) in year of case model shading model 2 (30°).

4.2.3.2. Results of Shading Model 2 Positioned 45 Degree

The second comparison group of shading models 2 is positioned with 45 degree. This model performed worse than shading model 2 positioned 30° in terms of illuminance values. In general, the values change between 328 lux- and 40592 lux in specific days and time. If we look in detail, in March 21, the first 4 rows, which corresponding to numbers from 1 to 4 in Table 4.24, has range of illuminance between 848 lux and 1944 lux as desired. But the values of other 6 rows rise above 2000 lux and creates unsatisfied spaces which have 2092 – 34756 lux range of illuminance values. Opposite to this as seen in Table 4.25, in June, almost whole areas has good daylighting with the illuminance value between 328 lux and 2464 lux. Like the result of March, in September, the first 4 rows have enough illuminance values between 1012 lux and 2160 lux, but it increased in other rows to 40592 lux shown in Table 4.26. So, more than half of the space become unfits for occupants. İn December seen in Table 4.27, almost all areas have more than 2000 lux of illuminance values and creates sun patch.

The percentage of occupied times changed between 19% and 86%. The areas which located near the windows have low percentage because these areas get lots of daylight in year, which have higher value than 2000 lux, as seen in Figure 4.16 which explains UDI values. While looking to results of DA, the areas, which have more than 1000 lux, reach 96 percent in year and it decreased up to 74% at the back side of the classroom shown in Figure 4.17.

As a result, shading model 2 positioned 45° has not ability to shade area in equinox and solstice days at 12:00 pm, except June. The general illuminance values are too high than 2000 lux and creates unsatisfied spaces to occupants.

Table 4.24. The raytracing illuminance values in March 21 at 12:00 pm of Shading Model 2 (45°)

Shading Model 2 (45°) March 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	1040	1044	1232	1388	1352	1360	1416	1312	1324	1224	1188	1096	1072	848
2	1076	1368	1316	1280	1504	1468	143	1444	1444	1216	1340	1220	1112	980
3	1368	1296	1720	1636	1580	1696	1888	1648	1648	1680	1456	1272	1240	1108
4	1728	1864	1944	1804	1924	1832	1912	1944	1944	1840	1760	1640	1340	1208
5	2080	2280	2308	2200	2084	2464	2400	2784	2784	1856	1748	2052	1760	1664
6	2464	832	3124	2960	3048	3008	2672	3192	3192	2140	2536	2504	2092	1844
7	3592	33020	3876	3804	33392	3408	3200	3672	3672	3364	3908	2804	2792	2588
8	4620	34148	4564	4672	33696	4552	33492	33632	33632	33720	33300	4088	32776	3104
9	6104	34756	4800	5268	4776	4864	4680	4880	4880	4732	4400	4244	3976	3744
10	6152	5964	34712	5716	5244	5876	5000	4976	5136	4932	5372	5096	4636	4564

Table 4.25. The raytracing illuminance values in June 21 at 12:00 pm of Shading Model 2 (45°)

Shading Model 2 (45°) June 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	368	360	428	472	448	444	464	424	464	424	416	400	404	328
2	348	456	404	400	460	460	432	452	488	376	440	408	368	328
3	424	376	532	488	484	508	608	496	552	540	448	400	408	360
4	504	568	604	520	580	536	560	580	588	584	564	524	440	384
5	588	676	708	632	676	752	716	864	732	600	532	652	588	540
6	672	832	972	888	980	1004	920	1044	920	672	836	828	680	600
7	1008	1092	1172	125	1316	1120	1028	1152	1188	1124	1304	1004	980	896
8	1276	1480	1476	1632	1480	1636	1396	1484	1772	1548	1364	1496	1192	1144
9	1908	1892	1780	2032	1856	1784	1772	1968	1732	1808	1772	1772	1488	1544
10	2200	2404	2148	2272	2184	2464	2040	2016	2220	2088	2392	2208	2060	1932

Table 4.26. The raytracing illuminance values in September 23 at 12:00 pm of Shading Model 2 (45°)

Shading Model 2 (45°) September 23, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	1168	1240	1416	1576	1576	1604	1636	1556	1560	1460	1404	1296	1236	1012
2	1260	1548	1544	1560	1736	1752	1716	1704	1724	1496	1572	1436	1316	1176
3	1544	1556	1904	1844	1876	1964	2104	1912	1940	1904	1700	1536	1480	1320
4	1884	2032	2120	2060	2160	2112	2160	2168	2112	2064	1976	1856	1608	1456
5	2256	2404	2460	2384	2352	2624	2528	2844	2496	2120	2048	2216	1988	1884
6	2944	5484	5744	3260	5952	5684	3080	6008	5532	2648	5480	2556	2524	2336
7	6524	40416	3640	3832	40592	3320	3440	6324	3396	3468	6456	2864	3092	2972
8	4636	41056	4176	4160	40504	4112	40420	40428	4324	40440	40156	3652	39836	3128
9	8740	41808	6964	7480	4520	6872	7036	4512	6532	6972	4064	6336	6448	3832
10	6088	7896	41264	5152	7460	4772	4584	7184	6920	4444	7304	6784	3944	4256

Table 4.27. The raytracing illuminance values in December 21 at 12:00 pm of Shading Model 2 (45°)

Shading Model 2 (45°) December 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	2104	2004	27284	2344	2304	2252	2352	2180	2200	1984	1936	11052	1716	1432
2	11520	27476	2148	2708	27404	2188	27236	27252	2184	26960	27128	1824	10980	10864
3	2372	11520	2536	2392	11524	2352	11892	11556	2348	11584	2072	1772	11020	1692
4	2916	2880	2788	2356	2540	2368	2544	2472	18156	2416	2248	17980	1760	1708
5	12624	1239	18676	11896	27692	18632	11960	28040	18468	11444	27180	18232	11416	11248
6	3440	19108	12624	3160	3308	3108	2768	3168	2836	2380	2552	11792	2284	2020
7	28968	13032	19228	28552	12664	18800	28000	12200	18932	28136	12416	18348	27568	11568
8	4304	13220	3712	3440	12724	19384	3444	3120	19604	12492	2948	3296	12108	2636
9	4444	19924	19328	3960	19512	19312	3316	19272	18976	3360	3056	18608	3032	3016
10	29776	13556	3564	29584	3480	3480	29184	12812	3196	29012	12920	3216	28624	12556

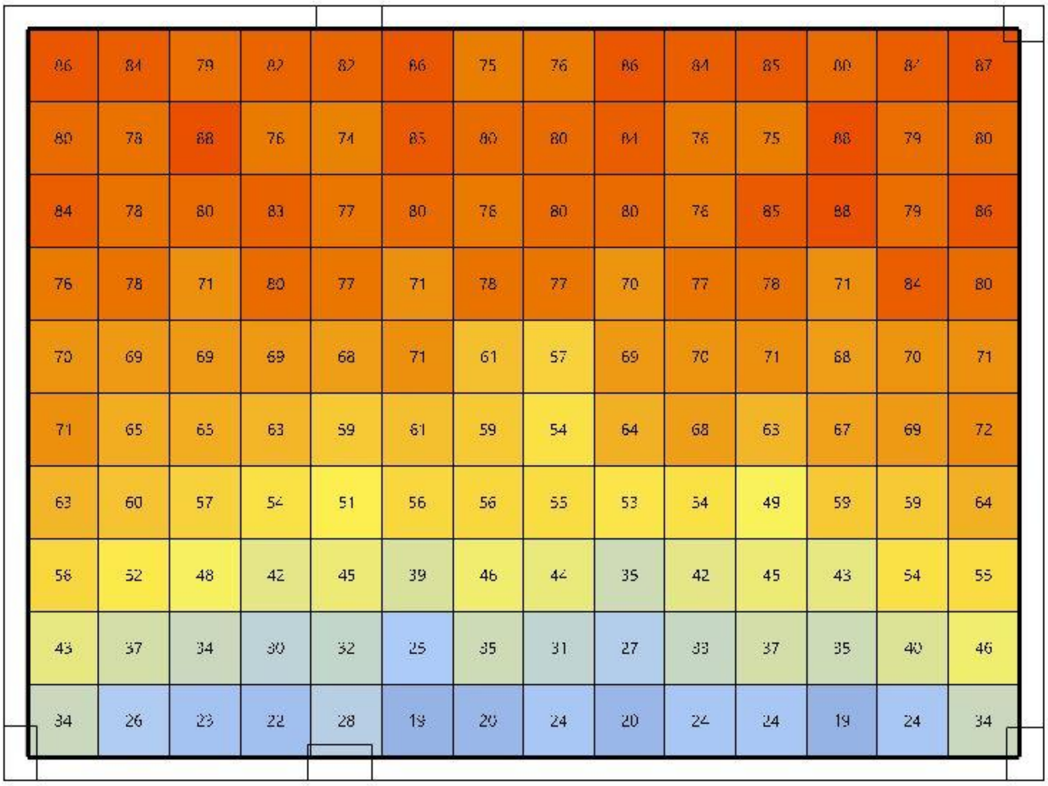


Figure 4.16. Distribution of daylight illuminance range of spaces (UDI) in year of shading model 2 (45°).

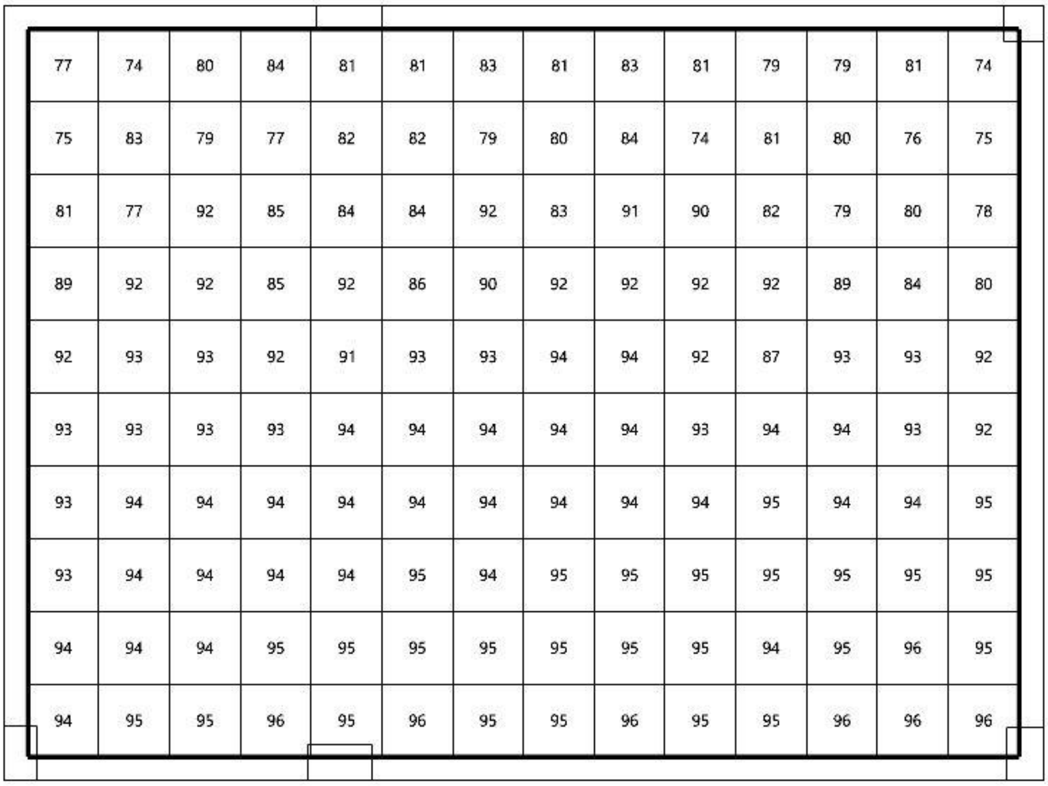


Figure 4.17. Distribution of annual daylight hours of spaces (DA) in year of case model shading model 2 (45°).

4.2.3.3. Results of Shading Model 2 Positioned 60 Degree

Daylight performance of the shading model 2 positioned 60 degree are also evaluated to compare with other situations. If we look at the results in detail, In the equinox day of March, almost all areas have more than 2000 lux illuminance. The minimum and maximum values are 1512 lux and 36356 lux, respectively. The illuminance between these two values have high numbers like around 34000 lux especially on seventh rows in Table 4.28. In June, when the values in the first 8 rows vary between 604 and 2000 lux, these values reach 3004 lux in the past two rows seen in Table 4.29. In September, only first 2 rows provide the required values with the range of 1680 lux- 2500 lux. The other areas have more than 3000 lux illuminance and reached to 44468 lux, which the highest value the shading element has, as shown in Table 4.30. At last, the illuminance changes between 2828 and 31940 lux in December seen in Table 4.31. And all values have been greater than the maximum required value of 2000 lux.

Because of these high illuminances in classroom, the percent of occupied times in year change between 14% and 76% in shading model 2 positioned 60°.While, the first five rows in table have more than fifty percent, other rows have less percentage than fifty as seen in Figure 4.18. Because they have mostly more than 1000 lux in year according to result of DA shown in Figure 4.19. In total, all areas have more than 1000 lux in year with the range of 93%-96%.

All in all, according to results, the shading model 2 is not suitable to shade the classroom in any positions because of high illuminance values than required. Generally, most of values have more than 2000 lux illuminance on field and this situation creates sun patch. On the other hand, the distribution of illuminance is not homogeneous in the spaces and it creates unsatisfied areas. It is seen in the renders, which shown in Figure 4.20, to understand the comparison of the spaces on each equinox and solstice days at 12:00 pm.

Table 4.28. The raytracing illuminance values in March 21 at 12:00 pm of Shading Model 2 (60°)

Shading Model 2 (60°) March 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	1712	2048	2192	2324	2384	2352	2308	2232	2272	2100	2116	1836	1664	1512
2	1960	2316	2304	2440	2320	2568	2260	2712	2600	2276	2140	2168	1948	1536
3	2036	2272	2404	2664	2836	2660	2568	2720	3084	2644	2604	2192	2068	1820
4	3016	2680	2872	3160	3560	3080	3096	2880	3112	3028	3224	2272	2312	2252
5	3144	3424	3528	3632	4092	3512	3920	4168	3836	3276	3464	3120	2852	2764
6	4032	4308	4496	4176	4944	4400	4516	4672	4412	4216	3900	4272	3272	2988
7	34460	34340	5084	34792	5764	5320	5380	4748	5400	4916	4800	4416	4044	3536
8	6280	6472	6504	6236	35912	6048	6320	34932	5536	35028	35628	5240	34808	4436
9	7276	36772	7100	7248	36356	6388	6952	6212	6064	6112	6120	6424	6048	4856
10	8116	7348	36812	6688	6368	36556	6308	6584	6656	5916	6732	7028	6104	5992

Table 4.29. The raytracing illuminance values in June 21 at 12:00 pm of Shading Model 2 (60°)

Shading Model 2 (60°) June 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	656	792	832	880	892	884	892	880	884	840	912	768	696	676
2	692	936	816	896	804	904	812	988	928	800	796	832	756	604
3	680	736	752	912	968	880	880	920	1092	916	960	768	784	684
4	964	832	896	1024	1132	980	1036	928	1048	1036	1148	800	804	832
5	940	1024	1088	1160	1296	1156	1304	1368	1296	1120	1176	1088	1012	976
6	1204	1292	1452	1360	1648	1408	1500	1524	1460	1384	1376	1456	1136	1052
7	1468	1524	1600	1792	1944	1848	1892	1684	1920	1736	1688	1536	1504	1272
8	1800	1976	2244	2176	2264	2160	2292	1960	2020	2108	2268	1976	1976	1648
9	2180	2592	2592	2720	2668	2432	2768	2404	2272	2424	2472	2576	2424	1944
10	2864	2672	3004	2788	2532	2972	2536	2524	1936	2496	2748	3064	2688	2408

Table 4.30. The raytracing illuminance values in September 23 at 12:00 pm of Shading Model 2 (60°)

Shading Model 2 (60°) September 23, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	1848	2192	2348	2488	2560	2560	2548	2488	2488	2340	2332	2048	1864	1680
2	2076	2444	2496	2656	2588	2784	2584	2916	2788	2512	2388	2360	2140	1768
3	2248	2488	2652	2880	3064	2916	2880	2972	3204	2840	2812	2436	2304	2048
4	3048	2880	3064	3292	3616	3288	3352	3144	3264	3208	3344	2576	2552	2476
5	3264	3544	3624	3720	4068	3700	6584	4112	3888	6100	3536	5912	3028	2928
6	4368	7084	7028	4496	7608	6968	4696	7388	6920	4356	6776	6768	3664	3496
7	44468	44328	4872	44560	8184	5032	7932	7508	7656	7520	7432	6892	4288	3960
8	6216	5960	5896	5688	42412	5488	5624	41672	5104	41748	44640	4808	41552	4400
9	10032	43600	8960	9244	42936	8344	8968	5760	8016	8320	5608	8176	8216	4928
10	8044	9656	45716	6232	8620	45368	5896	8652	8392	5576	8616	8496	5544	8236

Table 4.31. The raytracing illuminance values in December 21 at 12:00 pm of Shading Model 2 (60°)

Shading Model 2 (60°) December 21, 12:00 PM														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	3816	4152	29420	4504	4552	29612	4376	4320	13584	3992	3844	12688	3008	2828
2	29552	29552	4236	29464	29260	4448	29144	29688	4376	29028	28756	3616	12612	12132
3	14136	29404	4248	13800	29696	4484	13536	29568	4788	13504	29184	3628	12600	12440
4	5876	20560	20596	4916	21136	20532	4716	4392	20364	4508	4712	19368	3576	3484
5	14948	30432	20816	14400	30400	20648	14396	30552	20876	13716	29668	20008	13272	13024
6	6168	21680	14912	5420	5796	5092	5248	5396	5228	4916	4704	14128	3984	3816
7	31352	11515	21392	30912	15020	21344	30588	14328	21308	30240	14216	20440	29372	13168
8	31940	15288	21980	31108	14984	21592	30904	14256	20932	30560	14536	20848	29991	13580
9	6724	22240	21840	6008	21816	21288	5740	21044	21188	5328	21032	21136	5032	20292
10	32088	31644	5616	31360	30676	5476	31140	14780	21160	30916	14648	20900	30784	14544

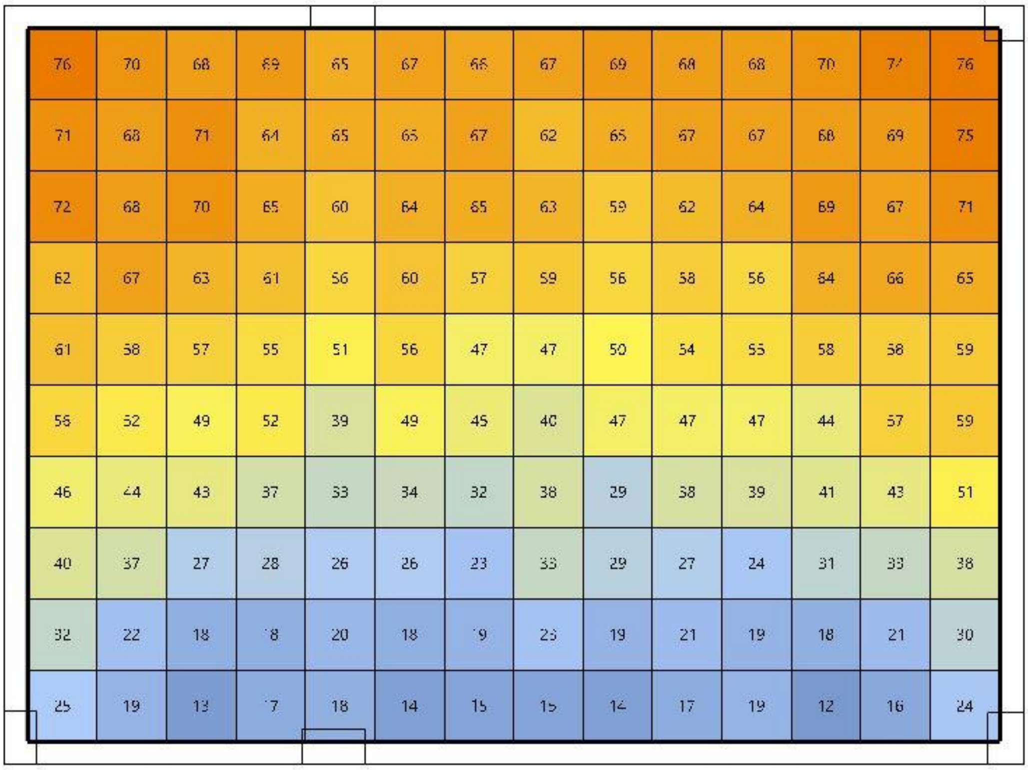


Figure 4.18. Distribution of daylight illuminance range of spaces (UDI) in year of shading model 2 (60°).

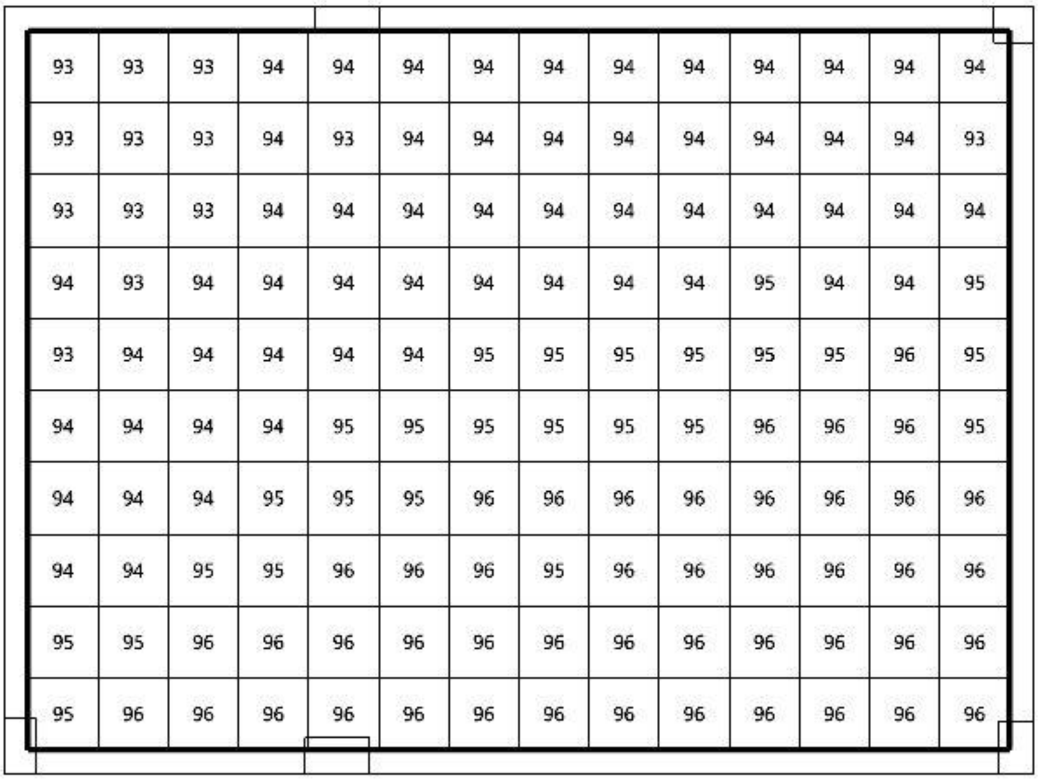


Figure 4.19. Distribution of annual daylight hours of spaces (DA) in year of case model shading model 2 (60°).

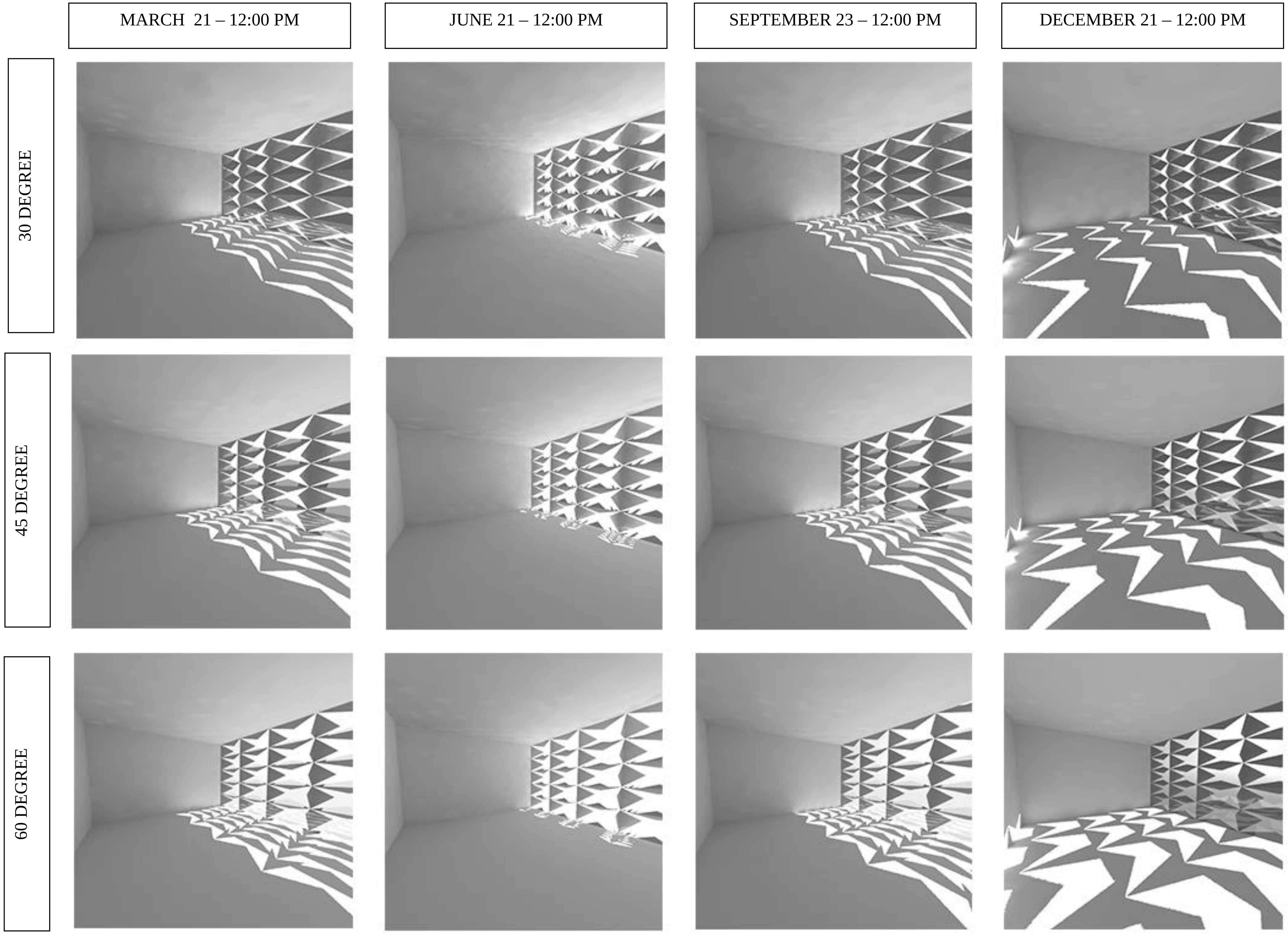


Figure 4. 20. Renders on equinox and solstice days at 12:00 pm of Shading Model 2

As mentioned before, shading model 2 is not successful to shade the classroom. This result is also supported by the values of sDA and ASE of each options of three different rotation angles. Although, the percentage of sDA is required to be more than 50%°, each position gives equal and close value to 100%. It means that shading model 2 cannot shade the area. Because of this reason, although the value of ASE should be around %10, this value is very high as 50%, 75.7% and 87.1% as shown in Table 4.32.

Table 4.32. The percentage of sDA and ASE daylight metrics of shading model 2.

	30 DEGREE	**45 DEGREE**	**60 DEGREE**
sDA	**83.6**	**100**	**100**
ASE	**50**	**75.7**	**87.1**

CHAPTER 5

DISCUSSION AND CONCLUSION

This study represented the performance of different shading models used on the south façade of classroom in terms of daylighting with the use of simulation model. The classroom, which was chosen as the case, is located on Izmir Institute of Technology Campus and have typical three different double-glazed windows on south façade. Especially in climate of Izmir, which has generally sunny sky condition, this classroom cannot perform well in terms of daylight usage. Therefore, different types of shading systems were suggested by taking into consideration the field measurements to create more satisfied spaces to occupants.

Although, there are lots of studies about different types of shading systems in literature; there are two different features that separate this work from others. Firstly, lots of studies which investigated daylight performance of building mostly focuses the office buildings. In this work, we focus to educational buildings. The second objective of this study is to present a shading system that is different from other shading types studied in the literature. While many studies examine the daylight performance of single-oriented shading elements, this study compares single-oriented shading system with multi-oriented system.

The methodology was based on simulating the case model in Rhinoceros/ Grasshopper and to evaluate with two different shading systems. During the designing the simulation models, the geometrical and surface properties were determined as reality and applied in each simulation model. During simulations, in total 140 measurements points are evaluated under clear sky with sun condition. Each model simulated on equinox and solstice days at 12:00 pm. In evaluation process daylight illuminance values and 4 different climate-based daylight metrics were used which are UDI, DA, sDA and ASE. In short, UDI represents annual occurrence of daylight illuminances across the work plane where the illuminances are within the range 300 lux to 2000 lux. DA is an annual metric that presented a percentage of annual daylight hours of specific points in area with the 300-lux threshold. While sDA represents sufficiency of daylight levels, ASE shows the spaces which has 1000 lux illuminance values across the work plane.

Regarding the results of field measurements, shading model 1, which has single-orientated shading panels, was applied to south façade of the field. In terms of daylight illuminance, shading model 1 met expectations and have illuminance values between 44 lux and 16376 lux. If we evaluate the model in itself, shading model 1 positioned 30°has illuminance range between 60 lux and 836 lux and it creates dark spaces to occupants. This ranges increased to 152-2992 lux and 320-2368 lux in position of 45° and 60°, respectively. So, this model achieved its goals of reaching the range of 300- 2000 lux illuminance. In specific days and times, the model can shade the areas and offer better daylighting performance compared with field. It is understood from the result of UDI and DA percentages; 30° rotated shading systems have lower percentage range of 3%-96% compared with other situations because of the low illuminance values. These percentages range increased to 80% - 96% and 84% - 96% on positioned 45° and 60°, respectively. It means that, the illuminance values are suitable to occupants in year. The range of percentages of DA change between 0% and 79% in position of 30° because this model has low risk to have more than 1000 lux illuminance in year. With the increase of illuminances values in 45° and 60°, this range also increased up to 94% and 96%.

According to results of shading model 2, which has multi-oriented shading panels, the illuminances values are greater than shading model 1. In position of 30°, luminance values changed between 140 lux and 39284 lux. The higher value exceeds the required upper threshold of 2000 lux. This situation is the same in other positions. The range changes between 328-40592 lux and 604 - 44468 lux in 45°and 60°, respectively. These very high values do not show proper distribution in field and creates sun patch on ground which can be disturbing for occupants. Regarding the percentage of UDI, the occupied times changed between 38% and 70% in position 30° because lots of spaces have more than 300 lux in year. This percentage changed between 18% and 86% in 45° due to increasing illuminance. These decreased to range of 14% and 76% in 60°. Therefore, the percentage values of DA vary between 74% and %96 with values of more than 1000 lux illuminance.

These two different shading models compared in terms of sDA and ASE. According to result of sDA, while the model 1 reached the desired values of %50 with close percentages in all position, except 30°; shading model 2 have values higher than required. In terms of ASE, model 1 has acceptable values closed to 10% but another model was not successful.

Regarding to all results of the simulations, it is seen that model 1 has a great potential to shade the field in year although it creates some dark spaces in specific positions. Opposite to this shading model 2 cannot able to shade the classroom because of the high illuminance values and sun patches. Therefore, shading model 1 is suitable to affect the daylight performance in positive way and creates satisfied spaces for occupants.

It is expected that this study contributes the literature in terms of evaluate good daylighting performance with using different types of shading systems in educational spaces. During the evaluation process, with the help of the simulations, designers or researches can able to reach optimal daylight performance on field and arrange their designs according to results. Additionally, it is clear that movable shading systems have positive effects on controlling daylight in certain times and helps occupants with the use of spaces in more satisfied ways.

In future, it is expected that this study will provide knowledge about studies on daylight performance in terms of dynamic daylight metrics to designers. As limitation, it was observed that the daylight performance of movable shading systems obtained on equinox and solstice days and specific times gave an average value. In further studies, for more detailed researches, it can be carried out within the range of working hours of spaces for specific days.

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