Developing Dynamic Daylighting Metric for Dynamic Facades in Office Buildings in Dubai

تطوير مقياس لتقييم الاضاءة الطبيعية للواجهات المتحركة في المباني المكتبية في دبي

by

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ABSTRACT

Designing a proper daylight is very crucial when it comes to engineering and architecture. Such considerations provide various benefits in terms of increasing visual comfort and decreasing energy demands.

The purpose of this study is to develop a new daylight performance metric that is suitable for dynamic facades.

To fulfill this purpose, a modified daylight metric has been developed which consists of Dynamic Useful Daylight (DUD) to measure the work plane area that receives a desired daylight illuminance and Dynamic Sunlight Exposure (DSE) to measure the work plane area that receives excessive direct sunlight.

The design configurations involved in this study are; the base case scenario (without any louver), fixed shading louvers and dynamic shading louvers. Moreover, the study manipulates different parameters such as the tilt angles of the louvers, the width of the louvers and the spacing between two louvers to determine the best configuration that provides the ultimate daylight in three different days of the year.

Through this study, it has been obtained that the maximum Dynamic Useful Daylight (DUD) can be achieved by using dynamic shading louvers as opposed to not using shading louver at all or using the traditional fixed shading louvers. Specifically, it has been obtained that using dynamic shading louvers achieves an annual average Dynamic Useful Daylight (DUD%) of 35%, 29%, 33%, and 31% on the southern, northern, eastern, and western orientations, respectively.

Keywords: Daylight, Dynamic Shading Louvers, Fixed Shading Louvers, Dynamic Facade, Daylight Metric, Dynamic Useful Daylight, Dynamic Sunlight Exposure, Glare

نبذة مختصرة

إن تصميم الإضاءة في المباني أمر بالغ الأهمية في علوم الهندسة المختلفة ولاسيما في الهندسة المعمارية على وجه الخصوص حيث أن التصميم الجيد للإضاءة له فوائد عديدة و متنوعة من حيث توفير الراحة البصرية لمستخدمي المباني وتقليل متطلبات الطاقة مما يؤدي بدوره لتخفيض استهلاك الطاقة وبالتالي تقليل اجمالي التكلفة المالية الناتجة عن هذا الاستهلاك.

الغرض من هذا البحث هو تطوير مقياس أداء جديد لتقييم الإضاءة الطبيعية للواجهات المتحركة في المباني المكتبية في دبي. لتحقيق هذا الهدف ، تم استحداث مقياس أداء جديد والذي يشمل على عنصرين اساسيين وهما:

1. (DUD) وهو اختصار لـ Dynamic Useful Daylight والذي يقوم بحساب المساحة (من منطقة مستوى عمل معين) التي تتلقى كمية اضاءة طبيعية ومرغوبة خلال وقت معين من اليوم.

2. (DSE) وهو اختصار لـ Dynamic Sunlight Exposure والذي يقوم بحساب المساحة (من منطقة مستوى عمل معين) التي تتلقى ضوء شمس مباشر وغير مرغوب خلال وقت معين من اليوم.

لإتمام هذه الدراسة، تم اختيار عدد (3) حالات مختلفة لتقييم مدى كفاءة اداة القياس المستحدثة حيث شملت الحالة الأولى والأساسية مكتب بواجهة زجاجية وبدون استخدام اي نظام تظليل لحجب اشعة الشمس. فيما شملت الحالة الثانية استخدام نفس المكتب مع اضافة واجهة عبارة عن ألواح تظليل رفيعة وثابته لحجب اشعة الشمس المباشرة. وأخيراً، شملت الحالة الثالثة استخدام نفس المكتب بألواح تظليل رفيعة ومتحركة تتغير اتجاهاتها بحسب الوقت واليوم بما يتناسب مع حالة الشمس.

في كل حالة من الحالات الخاضعة للدراسة، تم التلاعب بعوامل ومعطيات مختلفة مثل زوايا الميل لألواح التظليل، وعرض الألواح، والمسافة بين الألواح وغيرها من المتغيرات لتحديد أفضل حالة أو "سيناريو" يوفر افضل اضاءة طبيعية داخل المكتب مع حجب اكبر قدر ممكن من أشعة الشمس المباشرة وتم اختبار كل حالة في ثلاثة أيام مختلفة من السنة وفي أوقات مختلفة.

من خلال هذه الدراسة ، تم الاستنتاج أن افضل طريقة لتوفير اضاءة طبيعية جيدة في المكاتب عن طريق استخدام ألواح تظليل ديناميكية حيث تم تحقيق أعلى نسب اضاءة جيدة (DUD%) وأقل نسب اضاءة غير مرغوبة (DSE%) من خلال استخدام الألواح المتحركة مقارنةً باستخدام الألواح الثابته أو بدون اسخدام ألواح نهائياً.

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1. CHAPTER 1: INTRODUCTION

1.1.Background

Nowadays, people are more aware about the built environment and its impacts on nature, ecosystem, wellbeing, earth and different living aspects. Moreover, people are observing the excessive usage of energy resources that the buildings consume in order to achieve different deliverables such as occupants' comfort through using excessive heating and cooling loads, aesthetic through contemporary architecture and products production such as the case in industrial buildings. Therefore, sustainability and smart solutions are being adapted by many designers and investors to minimize the negative environmental impacts of the buildings and reduce their energy demand while maximizing the occupants' comfort and assuring that their needs are fulfilled.

According to U.S. Energy Information Administration (EIA), in 2016, residential and commercial buildings consumed about 40% of the total energy consumption in the country ("How much energy is consumed in U.S. residential and commercial buildings? - FAQ - U.S. Energy Information Administration (EIA)" 2017). This indicates that buildings designs need further improvements to increase the energy efficiency and reduce the buildings' energy consumption thus reducing the overall energy consumption of a certain country which will eventually impact its carbon footprint in a positive way.

Building façade is the building's skin that creates an enclosure and separates the internal environment from the external environment. Different building façades have different influences on the energy performance of the building due to various factors such as the local climate, construction materials used, technologies used and so many other factors.

Furthermore, Building façades have many important purposes such as providing privacy, view to the outside, allow air flow and exchange between the outer and inner surfaces, providing protection against glare, enhancing natural daylight, insuring security, creating noise protection and so many other purposes (Johnsen & Winther 2015).

In office buildings, for instance, using curtain walls as a building facade is common, nowadays, and has different advantages and disadvantages. The main advantages are the fact that curtain walls allow the penetration of natural daylight thus minimize the artificial lighting requirements. Also, they act as a barrier against the outdoor environmental conditions while still providing views to outside (e.g. rainy or windy days). On the other hand, using such material can allow excessive light transmittance which causes excessive heat gain, thus, higher cooling load demand to achieve the desired comfort level (McFarquhar n.d.).

Using smart dynamic facades that can respond to the external and internal environments can be an effective way to enhance the overall energy performance. In addition, an adaptive dynamic facade can have better thermal and visual comfort for the occupants especially when applied for commercial and office buildings.

Static building facade, on the other hand, can provide a good energy performance, thermal comfort and visual comfort only throughout a specific period of the year or a certain time of the day since it does not respond to the changing external conditions (Johnsen & Winther 2015).

This paper will focus on studying the capability of dynamic façade to enhance natural daylight and minimize direct sunlight and glare throughout the year. Well day-lit spaces will ultimately have an impact on the occupants' visual and thermal comfort and eventually a reduction in cooling demands.

1.2.Brief on Sustainability and Global Context

The usage of renewable and non-renewable natural resources has increased dramatically over the years as a result of the change and development of cultures around the world.

In stone-age society, for instance, people were consuming 3kg of resources per day per person. However, in Agrarian society, the consumption increased to 11kg per day per person. Moreover, in industrial societies which were lunched with the beginning of the 18th century, people consumed about 44kg per day per person. This indicates that as the world economy and global population grows, more raw materials and products are being consumed annually which, if not replaced, will be depleted sooner than expected (OVERCONSUMPTION? Our use of the world´s natural resources 2009).

The amount of extraction of resources varies around the world depending on many factors such as the size of the continent, the size of the population, the level of education, the affluence and the availability of the resources.

In 2005, Asia was ranked as the largest continent in terms of resources extraction due to its large size in terms of area and population and had a share of 48% of the total resources extraction around the world. Second was North America (19%), followed by Latin America (13%), Europe (13%), Africa (9%), and Oceana (3%) (OVERCONSUMPTION? Our use of the world´s natural resources 2009).

The phenomenon of climate change is happening due to over consuming the resources and the various human activities that cause several problems such as air pollution which lead to diseases and poor air quality, water pollution which put the natural fresh water reserves in danger, increased acid rain and burning forests as a result of increased temperatures and global warming.

Nowadays, the challenge lies in providing high quality lifestyles for the global population without depleting the natural resources of the planet. For instance, In terms of reducing the non-renewable resources extracted for buildings, reducing the buildings' energy usage and demand will lead to reduce the amount of generated electricity which will eventually reduce the need of burning fossil fuel. This reduction in the buildings' energy demand require adopting new sustainable and smart solutions in the construction industry.

1.3.Importance of the Study

The author believes that focusing on new sustainable technologies, strategies, and approaches that can contribute to a better energy performance is crucial. The adaptive dynamic facade is a unique concept which combines both smart and sustainability to deliver a healthier environment. Implementing such concepts will possibly have various benefit, such as:

1. Reducing toxic emissions such as carbon monoxide, nitrogen dioxide, sulphur dioxide and other harmful pollutants. Thus, reducing global warming and global carbon footprint.
2. Cost saving through reducing the cooling/heating load of mechanical systems as well as lighting systems.
3. Better energy management and consumption.
4. Increasing the occupants' satisfaction through thermal and visual comfort.
5. In office buildings, this concept can improve the staff productivity, lessen absenteeism and improve their health and wellbeing.
6. Promote healthier environments.
7. Promote smarter cities.
8. Reduce extraction of resources

1.4.Research Outline

The research will be structured in several thematic chapters, as follows:

Chapter1: Introduction

The first chapter is the introductory chapter in which a general background about building energy consumption and building facades is provided. Also, the current global situation and context is presented in terms of over consuming energy, climate change and sustainability. Moreover, the chapter demonstrates the importance of this research area and the benefits of studying such concepts.

Chapter2: Literature Review

In this chapter, a background of dynamic facades, advantages, and disadvantages will be. Also, different published papers, conference papers, and dissertations around the same research topic will be reviewed. Furthermore, daylight and glare metrics will be reviewed and explained. Finally, the problem statement and the research questions will be mentioned to clarify the aims and objectives of the research.

Chapter3: Methodology

In this chapter, previous methodologies and approaches adopted by previous researchers on this research area will be elaborated. Afterwards, the preferred methodology and tools for this research topic will be chosen based on clear justifications. Moreover, in this chapter, the variable and fixed parameters will be identified as well as the research's scope of work. Also, the model description, specifications, and all design scenarios will be explained in details.

Finally, the chapter will be concluded by explaining the performance assessment criteria specified by the author to assess the results obtained from the research.

Chapter4: Discussions and Findings

In this chapter, the author will discuss, in depth, all the findings and results that are extracted from the simulation process.

Chapter5: Summary of the Findings and Conclusion

In this chapter, the author will summarize all the findings obtained from the discussion chapter along with the answer to the research question. Lastly, the author will suggest some recommendations and possibilities for future studies around the same topic.

2. CHAPTER 2: LITERATURE REVIEW

In this chapter, the author will be dividing the review of literature thematically referring to several journal articles discussing different subjects around the topic. The information reviewed will build a clear idea about what has been done by previous researchers, what are the gaps, and the possibilities of taking the research a step further. At the end of this section, research questions will be identified and the aim and objectives of this research will be stated.

2.1.Background

Designing the building facade requires a deep understanding and analysis of different factors including the climate to achieve a satisfaction in the indoor environments. Loonen et al. (2013) have defined climate adaptive building shells as “the ability of the building shells to repeatedly and reversibly change some of their functions, features or behavior over time in response to changing performance requirements and variable boundary conditions, and does this with the aim of improving overall building performance”. They added, “building shells are the elements that separate the outdoor environment from the indoor environment such as the façade and the roof”.

Nowadays, building standards require buildings to be energy efficient and zero net energy buildings that use zero annual non-renewable energy. To achieve this, energy demands for cooling, heating and lighting have to be minimized and the remaining energy demand to be supplemented using PV solar cells or other methods to generate renewable energy (Selkowitz, Lee & Aschehoug 2003). To reduce the energy demand in the first place, involving sustainable and smart strategies in early design stages is a must. This practically means that facade and other main building elements need to be adaptive to the changing external environmental conditions in order to adjust the energy demand accordingly.

There are two main types of building facades; static facades and flexible facades. Both facades are adaptive at certain point and to a certain extend. The adaptation in static facades is usually done manually whereas flexible facades usually use computer-based technologies and sensors to automatically adapt to a certain condition.

In this research, the main focus will be on flexible facades which can be introduced to the envelope in different ways and methods.

Selkowitz, Lee & Aschehoug (2003) mentioned in their paper that the static façade has many limitations in terms of providing optimal comfort from every aspect all year round. On the other hand, the authors believe that dynamic facades are advanced facades which have the potential to adapt to the changing external conditions. Dynamic facades require several factors to be practical such as integration with buildings systems, dynamic operation, and changing life cycle performance issues. The authors pointed several challenges and opportunities related to dynamic façade systems. First, the authors stated that these advanced facades will have high initial cost compared to traditional static facades due to the integrated technology. However, the additional cost can be offset in another area of the design. For instance, using smart windows will minimize or eliminate the need to install air conditioning units or conventional blinds for shading. Also, advanced facades such as dynamic facades can have operation cost savings such as the savings in energy usage that can reduce the annual energy cost which can return the additional initial cost after a certain period of time. Additionally, the second challenge is that dynamic facades require sensors, automated solutions, and system integration which require skilled designer, especially for large buildings. Third, using advanced facades require designing more powerful simulation design tools that will be capable to simulate different types of facades of different forms and at any circumstances. Finally, the authors emphasized the importance of mock-ups and field experimentation as they help validate the results attained from simulation tools before proceeding to construction phase.

2.2.How dynamic facades were studied by others

Many researchers have studied dynamic facades previously in different ways and aspects. They have been studied in terms of energy performance, occupants comfort, and natural daylight. The methodologies used also vary from experimental approach, simulation approach and many other approaches. In this part of the literature review, many papers will be summarized to have an idea of what people have done before to study topics in this research area.

Hammad & Abu-Hijleh (2010) have published a paper that aimed to evaluate the potential of using dynamic external louvers for office buildings in Abu Dhabi, UAE. Their main focus was to predict and estimate the energy consumption (HVAC and lighting) when using dynamic external louvers.

The research was based on computer simulation approach using commercial package for IES-VE simulation software. The authors started by defining the fixed and variable parameters to carry on their research. Moreover, the variable parameters were; the position of the light sensors, glass shading coefficient, louvers tilt angle, and orientation. However, the fixed parameters were; the location of the building, the building model and the 4 preselected days for simulation purposes (20 December, 20 June, 20 September and 21 March).

The base model was a rectangular office of 4m (Width) by 8m (Length) by 2.7m (Height) with a window flushed with the external façade of 3m (Width) by 2.7m (Height). Additionally, nine louvers of 3.5m (Length)*0.3m (Width)*0.03m (Thickness) were placed for this case and distanced 0.1m away from the window. Also, all material finishes was assumed and defined. Moreover, HVAC and lighting assumptions were specified based on medium density occupancy as the office was made to accommodate two adults with two desks and two computers. In addition, the internal temperature of the space was set to be constant (24º C).

Furthermore, two sensor positions were proposed to evaluate the optimal position. They were assumed to be at 2m and 4m away from the external wall. Also, the optimal daylight illuminance of the office was assumed to be 500 lux. This means that the sensor will switch the artificial lighting off whenever the daylight illuminance exceeds 500 lux and it will switch them on ,if the daylight illuminance is less than 500 lux.

The authors proposed four scenarios to conduct the simulation analysis. The first scenario was the base case scenario where no shading louvers and light control were used. The second scenario was using light control through sensor and dimming control with no shading louvers. Additionally, the third scenario was using fixed louver and the fourth and final scenario was using dynamic shading louvers. All scenarios were simulated in 4 preselected days and the simulations were done for 3 orientations (south, east, and west). The results showed that for most orientations, using dimming light controls achieves a good energy savings and sometimes even better than using external louvers. Moreover, it was found that for south facing facade, the fixed external louvers at a tilt angle of -20º was able to achieve energy savings similar to the ones achieved by dynamic shading louvers. Also, for west and east facing facades, using external louvers did not provide extra energy savings compared to using light dimming technology by itself.

This concludes that using dynamic external louvers as a replacement for static external louvers do not worth the investment since similar energy savings were obtained for both configurations with or without light dimming sensor technology.

Hammad & Abu-Hijleh (2010) evaluated the daylight from energy saving perspective in which light dimming sensor technology was used to determine the sufficient daylight availability within the space in order to control the operation of electrical lights. Moreover, the daylight sufficiency was measured using 500 lux as the reference illuminance level to control the operation of the electrical light. The paper, however, did not evaluate the excessive direct sunlight within the office, as it was not included within the objectives of the study.

Turning off the electrical lights when the available illuminance level is above 500 lux will probably lead to a reduction in lighting load. However, having too much sunlight penetration inside the office can lead to overheating which results in increased cooling load.

Winther, Heiselberg & Lund Jensen (2010) conducted a comparison study between static and dynamic glazed facades used for office building in Denmark. The aim of the study was to determine the facade design solutions that can fulfill the energy regulations of future buildings in Denmark.

The focus of the paper was to reduce the annual energy demand of the building using different strategies without using any type of renewable energy technologies.

Denmark has a vision to reduce the energy demand of their buildings by 25% (71kWh/m^2 per year) in 2010, 50% (48kWh/m^2 per year) in 2015, and 75% (24kWh/m^2 per year) in 2020. To achieve this vision, different design solutions have to be adopted.

The authors focused their paper in studying the possibilities of optimizing static façade components and their contribution in energy demand reduction. Also, the paper tested several adaptive technologies used in dynamic facades and their impact on the total energy demand of the buildings in Denmark.

The authors used computer simulation approach to carry on this research and the software used were BSim [SBi-BSim] and Be06 [SBi-Be06] which are the main energy simulation programs used in Denmark.

The selected reference building is a typical office building in Denmark with glazed façade and a total energy demand of 96kWh/m^2 per year (base case). It was assumed that the glazing area of the building and the façade layout are the same for both the static and dynamic façade configurations.

The static façade was altered using different scenarios such as multiple glazing layers, changing the glazing type ,thus, changing the g-value, and improving the insulation components.

The first solution was to change the thermal conductance of the glazing. By reducing the total U-value of the glazing to 0.7 W/m^2, the total energy demand was reduced from 96kWh/m^2 to 85kWh/m^2. Moreover, the second solution was to change the type of the glazing from clear glazing to solar reflective glazing. This change caused a change in the g-value and the light transmittance of the glazing which led to an increase in the total energy demand from 85kWh/m^2 per year to 92kWh/m^2 per year.

Finally, the last solution for the static façade was to change the light control system of the building from manual light control system to an automatic system. This change led to a reduction in lighting and cooling energy demand. Thus, the total energy demand of the building decreased from 92kWh/m^2 per year to 73kWh/m^2 per year.

The authors observed that although static façade solutions have proved to be beneficial in terms of reducing the total annual energy demand, this reduction is not significant enough to achieve future energy regulations in Denmark. Therefore, to achieve further reduction in energy demand, dynamic façade solutions were studied.

The first tested solution was the dynamic heat transfer control that was implemented through the usage of dynamic window shutters. By using such technology, the total energy demand decreased from 96kWh/m^{2}per year to 76kWh/m^2 per year. Moreover, the second solution was manipulating the g-value of the glazing. This was achieved by installing external solar shading devices with high solar reflectance that allowed the g-value to drop. This drop contributed to a reduction in the total energy demand of the building from 67kWh/m^2 per year to 70kWh/m^2 per year. The third solution was through combining natural and mechanical ventilation. This combination led to a reduction in SPF (Specific fan power) which reduced the energy demand for ventilation. Additionally, this solution decreased the total energy demand of the building from 70kWh/m^2 per year to 51kWh/m^2 per year. As observed, the reduction in the total energy demand is dramatic compared to the base case scenario and it is very close to the energy regulations of BR2015.

Additional energy demand reduction was achieved by adding the automatic light control system that was used as one of the static façade solutions. Adding such technology led to a further decrease in the total energy demand from 51kWh/m^2 per year to 40kWh/m^2 per year. Moreover, increasing the thermal mass in the interior construction parts led to a decrease in the energy demand of the building from 49kWh/m^2 per year to 37kWh/m^2 per year. Finally, reducing the infiltration from0.3/hr to 0.15/hr led to even a further decrease in energy demand from

37kWh/m^2 per year to 23kWh/m^2 per year which can fulfill the future energy regulations in Denmark.

It is concluded that through combining static and dynamic solutions, buildings can fulfill the energy regulations for 2020, in Denmark (Vildbrad, Kvols & Lund, 2010).

Konstantoglou, Kontadakis & Tsangrassoulis (2013) published a conference paper that aimed to examine external dynamic facade systems and the impact of their transparency and automatic movement on the overall performance of the façade. They have used (EnergyPlus) simulation software to evaluate the energy performance of different individual facade components especially their impact on the primary energy consumption (heating, cooling and lighting).

A typical office space was selected to perform the analysis and 4 different scenarios of wall to window ratio (WWR) were assumed to test the various dynamic facade components. The study was performed based on Athens climatic data on an hourly basis for a complete year.

The authors selected a south facing office space as a base model (5.4m long * 3.4m wide).

Four different scenarios were created in which one scenario (base case) had a window to floor ratio WFR10% and the remaining three scenarios had window to wall ratio of WWR40%, WWR60% and WWR80%. Each of the four scenarios uses multiple shading components such as blinds, light shelves, and overhand shading.

The model properties and shading specifications are shown in Table 2.1.

Table 2.1: Model Properties (Konstantoglou, Kontadakis & Tsangrassoulis, 2013)

Office space properties	Floor Reflectance	0.2
	Walls Reflectance	0.5
	Ceiling Reflectance	0.8
Window properties	Area	3.9 m^2, 5.5 m^2, 7.3 m^2
	U-Factor	2.314 W/m^2K
	Visible Transmittance	0.74
	SHGC	0.615
Light-shelf properties	Width	0.5 m, 1.0 m
Overhang properties	Width	0.5 m, 1.0 m
Blinds properties	Width	0.1 m
	Reflectance	0.5
	Material	Aluminum

The room occupancy was defined as 0.1person/m^2 and the simulation time frame was set to be from 8:00 to 19:00 during weekdays. Also, the lighting power and the electric power were fixed at 16 W/m^2 and 15 W/m^2, respectively.

To test the shading components, 6 control strategies were defined besides the base case scenario (S1), as shown in Table 2.2.

Table 2.2: Blinds Control Strategies (Konstantoglou, Kontadakis & Tsangrassoulis, 2013)

Table 2: Blinds Control Strategies

S1	No Shading (Base Case)
S2	Static Blinds (0°, 10°, 20°, 30°, 40°,50°, 60°, 70°, 80°, 90°)
S3	Sunblocking Control Strategy (blocks direct solar radiation)
S4	Glare Control Strategy (minimizes glare)
S5	View Out Control Strategy (ensures visual contact)
S6	Dynamic Control Strategy based on Illuminance levels (500 lux)
S7	Combined Control Strategy (combines S5 and S6)

As obtained from simulation, the usage of overhangs led to the lowest primary energy consumption for WWR40% and WWR60% compared to any other type of shading or control strategy. Moreover, for the base case scenario (WFR 10%), light shelves were able to achieve the lowest primary energy consumption compared to any other shading component.

Additionally, for static blinds (horizontal blinds at 90º), a reduction in primary energy consumption was achieved for WWR60% and WWR80% by 15.4% and 32.8%, respectively, compared to the base case scenario. On the other hand, using static blinds for WWR10% and WWR40% led to an increase in energy consumption by 59.4% and 4.2%, respectively.

Moreover, for dynamic control strategies, the best energy savings were obtained for WWR80% compared to all cases.

In general, automated and dynamic control strategies contributed to the lowest primary energy consumption as opposed to static blinds with slate angle of 40º and above for all scenarios.

To be more specific, in WWR40%, WWR60%, and WWR80, the dynamic control strategy (S6) was able to achieve the lowest energy consumption. However, for WWR10%, glare control (S4) was able to achieve the lowest energy consumption.

In conclusion, it was observed that the presence of any type of shading element or strategy contributes to lower energy consumption compared to non-shading scenarios. Also, the higher the window to wall ratio (WWR), the more beneficial shading devices become due to the larger glazing surfaces. Also, Automated blinds have shown their effectiveness in energy savings when used for higher WWR whereas overhangs and light shelves perform better with smaller window to wall ratio (WWR) (Konstantoglou, Kontadakis & Tsangrassoulis 2013).

This study evaluates the impact of different window to wall ratios combined with different control strategies on the primary energy consumption as a whole. However, the study lacks the demonstration of the relationship between WWR% and daylight design and whether the daylight quality can be improved by manipulating different WWR%.

Developing a relationship between WWR% and daylight can dramatically improve the daylight design for many buildings through obtaining the best WWR% that can provide the maximum useful illuminance required for a certain space and minimize the direct sunlight with the assistance of shading louvers.

A dissertation written by Al Thobaiti (2014) aimed to study the effect of using intelligent façade systems to enhance the energy performance and efficiency of buildings. Moreover, the scope of his dissertation was restricted on HVAC energy consumption only and not the total energy consumption. However, Hammad & Abu-Hijleh (2010) analyzed the impact of such systems on both the HVAC energy and the daylight performance.

Al Thobaiti (2014) used two methodologies to come up with his results which are the simulation method using (Autodesk Ecotect) software and validated the results using experimental physical model approach. The idea of the research was to evaluate the performance of intelligent façade systems as a secondary skin of the building.

The author started by constructing a model in simulation software to determine the operational energy used by the model and three scenarios were created and compared with each other. The first scenario was to simulate the cooling energy demand of the model without any type of shading. The second scenario was to simulate the cooling energy demand of the model with static shading louvers. Finally, The third scenario was to evaluate the cooling energy demand of the model using dynamic shading louvers.

The design specifications used for the simulation model were identified. A 4ft x 4ft x 4ft unit was constructed in the software with a south facing window of 26ft x 36ft.The results were all restricted to one orientation (south) as opposed to Hammad & Abu-Hijleh (2010) who studied three orientations (south, east, and west). Moreover, Al Thobaiti (2014) have specified fixed parameters such as the location (Miami, United States), the color of the louvers (white), the materials used as well as the time frame which was from 10:00am to 4:00pm. The model had R-13 Fiberglas insulation in the internal surfaces and the window was a single glazed window with 85% visual transmittance. Also, the external louvers on the outer skin had reflectance of 85% and were distanced 4in from each other and 10in from the glazing.

Furthermore, other important parameters were specified such as the width of the louver blade (a), the distance between two blades (b), the tilt angle of the louver (β) which ranges between 0º and 90º and the solar altitude angle (α), as shown in Figure 2.1.

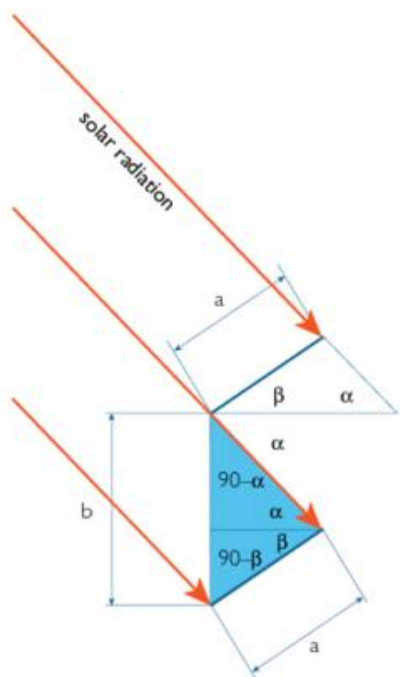

Figure 2.1: Shading Design Parameters (Al Thobaiti, 2014)

Also, The tilt angles of the louvers were calculated using the following formula:

$$\frac{a}{sin(90-\alpha)} = \frac{b}{sin(\alpha+\beta)}$$

Al Thobaiti (2014) have proposed three external louvers arrangements for his research which were horizontal louvers, vertical louvers and a combination of both to determine the optimal configuration for energy demand reduction.

Due to the infinite ways and possibilities for louver movement, the researcher manually calculated the best tilt angles for each hour in the time frame between 10am to 4pm, plugged in the calculated angles in the simulation software and end up with 7 different results. The approach of manually adjusting the louvers is accurate; however, it is time consuming since the louvers angles have to be changed on an hourly basis.

The results of the simulation have shown that the first scenario, where no shading was used, consumed high HVAC energy compared to the other two scenarios. In this scenario, it showed that the minimum energy demand for HVAC was obtained in the morning at 10:00 where 0.205 KWh was required and the maximum energy demand for HVAC was obtained at 12:00 where 0.284 KWh was required. In the second scenario where horizontal louvers were used, Al Thobaiti (2014) changed the tilt angle of the louvers according to the movement of the sun where the angles ranged between 36º at 10:00 and 54º at 4pm. Basically, the louvers adapts to the solar altitude as it closes from 10pm up to 2pm and starts to open up afterwards. It was observed that the horizontal louvers were able to save 24% of the HVAC energy demand compared to the non-shading scenario.

In the third scenario, vertical louvers were used instead of the horizontal louvers with a varying tilt angles as the time changes. The model was able to save about 6% of the HVAC energy demand compared to the non-shading scenario. Lastly, the author simulated the model using a combination configuration which involves both horizontal and vertical louvers. The results have shown that the combination configuration is the most optimal configuration among all scenarios as it was able to save up to 36% of HVAC energy demand compared to the non-shading scenario.

Moreover, by conducting a physical/experimental approach, Al Thobaiti (2014) was able to validate the simulation results and was able to get close results regardless of the minor increase or decrease in the energy consumption.

In conclusion, it was observed that introducing dynamic external louvers in building facades as a second skin can contribute in minimizing solar heat gains, thus, reducing the energy demand for cooling purposes.

Mr. Al Thobaiti studied the different configurations of dynamic shading louvers on reducing the HVAC energy demand of a small unit and the study was restricted to the southern orientation. However, future researches shall investigate the impact of using these configurations on the eastern and western orientations in terms of energy savings and to what extent can energy consumption be reduced compared to the case of the southern orientation.

Bakker et al. (2014) conducted an experimental study to test the relation between automated dynamic facades and occupants satisfaction. The aim of the study was to determine whether automated dynamic facades, as a form of internal roller shades, cause distractions and discomfort for the end users in terms of the transition movement speed and frequency.

The experiment was taking place in April and May in a daylight laboratory at Eindhoven University of Technology, in Netherlands. The test room size was 5.4m*5.4m*2.7m with a fully glazed west façade. Moreover, from the internal side, the room was equipped with two movable and automated roller shades (upper and lower) that are non-transparent and can be operated separately. In addition, the room was equipped with a desk and a computer with fixed position relative to the façade.

Furthermore, horizontal and vertical illuminance sensors were installed at various positions within the room to monitor the daylight conditions and different roller shades positions were recorded over time. Also, user override for upper and lower shades was available by providing hand held user interface to allow more or less transparency.

In this experiment, 26 test subjects participated for a period of 4.5h and were sitting behind the desk at 1.5m distance from the façade. All participants were subjected to several test scenarios (with and without manual override) to evaluate the different control strategies. Also, all experiments and scenarios were taking place during the afternoon period to ensure the availability of direct sunlight.

In the first scenario, the roller shades (upper and lower) move automatically every 10 minutes over a distance of 20cm. however, in the second scenario, the roller shades move automatically every 2minutes over a distance of 5cm. In the third scenario, the roller shades operate automatically by responding to the daylight conditions. In this scenario, the lower roller shade is fixed whereas the upper roller shade moves continuously based on the vertical window luminance to avoid glare and to maintain a workplace luminance between 500 and 2000lux. The forth scenario is similar to the first scenario , however, in this case only the upper roller shade moves every 10 minutes over a distance of 20cm. In addition to these scenarios, another four scenarios were carried out by using manual override.

At the end of the experiments, Bakker et al. (2014) distributed a web-based questionnaire to the test subjects to evaluate the occupants' satisfaction in terms of visual comfort, thermal comfort, freshness, noise, draught, view to outside and the changing façade. In general, 69% of the participants responded positively to the experiment environment.

The study have shown various participants' responds with regards to comfort. In summary, it was observed that there wasn't any link between automated dynamic facades and discomfort or disturbance. Most test subjects have responded moderately positive regarding the usage of the system and none of them was very pleasant about it. Also, most participants preferred less frequent and discrete transition in the facade over a smooth transition with higher frequency. In addition, including manual override option to the system led to higher user satisfaction with regards to the light levels and the overall working environment.

Johnsen & Winther (2015) conducted a study for dynamic facades to help meet the future energy requirements in Denmark. They developed a smart dynamic façade system called (Energy Frames) which is able to provide heating, cooling, daylighting, and ventilation using the minimum energy demand possible, as stated in their research. The easy application of the system is what makes it special as it can be snapped into an existing building or new buildings' envelopes.

The authors have investigated several dynamic elements for reducing the energy demand. The main elements were; changing the glazing properties and using the movable insulating shutters that could help reduce the heating demands during the winter season, as Winther, Heiselberg & Lund Jensen (2010) did in their study.

Johnsen & Winther (2015) have compared the U-value property for four different types of glazing which are; double glazing with low emissivity, triple glazing with low emissivity, triple solar protective glazing and finally the energy frame system which consisted of double glazing with low emissivity and movable insulating shutters.

Johnsen & Winther (2015) agree with Winther, Heiselberg & Lund Jensen (2010) that using two glazing layers with low emissivity and movable insulating shutters have a U-value of 0.5 W/m^2k compared to 1.0 W/m^2k when using two glazing layers with low emissivity only. This means that the transmission heat loss can be reduced into half. Moreover, the study revealed that using double glazing with low emissivity and dynamic shutters provided 22% more solar heat gain and 13% more daylight when the shutters are open compared to the triple glazing with low emissivity. In addition, the energy frame system provided 85% more solar heat gain and 34% more daylight compared to the triple solar protective glazing. This increase in the solar heat gain reduces the energy for heating purposes in winter seasons and the increase in the natural daylight enhances the visual comfort of the occupants. However, in order to reduce solar heat gain in summer season, using movable shading louvers are recommended by the authors to reduce the glare and bright light while providing view to the outside. Furthermore, the authors discussed the integration of smart controls into the façade to create a dynamic façade that is responsive to the surrounding environment and the occupants' need.

The study lacks technical details, however, the authors have specified two main modes for the system which are (comfort mode) and (energy mode) in which the comfort mode will turn on whenever the occupants are in the building and the energy mode will take over when the building is empty. This classification is applicable throughout the year and it will ensure that the system is performing at its best prioritizing the users' needs when it's on comfort mode and prioritizing the energy efficiency when it's on energy mode. The concept of categorizing seems good, however, further investigation need to be made to determine the control mechanism with regards to the season and the transition between one season to another.

Internal dynamic facades were also studied from different perspectives and using different approaches. Badawieh (2017) studied internal dynamic facades from energy saving perspective as opposed to Bakker et al. (2014) who studied internal dynamic facades from occupant satisfaction perspective. Also, Badawieh (2017) used simulation tool approach rather than experimental approach which were used earlier by Bakker et al. (2014).

Badawieh (2017) carried out her research on a glazed south facing office space in the Housing Bank in Amman, Jordan. The office space measurements were as follows: 3m width, 4.7m length and 4.8m height. All construction materials for the base case were clearly specified and fixed throughout the research, as seen in Table 2.3

Table 2.3: Construction materials used for base case (Badawieh, 2017)

	Material Used	Thickness(m)	Density(kg/m^2)	Conductivity(W/mK)	Category	U value (W/m^2K)
Internal Partitions	Gypsum Plasterboard	150	950	0.1600	Plaster	0.7129
	Cavity	13	-	-	-	
	Timber Board	19	650	0.1650	Timber	
Internal Ceiling/Flooring	Cast Concrete	200	2100	1.4000	Concrete	1.6429
	Lightweight Concrete	60	1200	2.3076	Concrete	
	Screed	30	1200	0.4100	Screeds and Renders	
	Synthetic Carpet	10	160	0.0600	Carpets	
	Material	Thickness(m)	Transmittance	Visible Light Normal Transmittance	Inside Reflectance	U-Value
Glazing	Clear Float	4	0.820	0.44	0.070	5.7546

Badawieh (2017) used IES-VE as a simulation tool and specified the time frame which was from 8:30am to 4:30pm on 4 specific preselected days which were 21st March, 21st June, 21st September, and 21st December.

Four scenarios were tested and evaluated which were top down automatic shading, bottom up automatic shading, manual shading and tinted glazing with visual transmittances of 0.7 at bottom and 0.7 at top. For manual shading, it was assumed that the shades stay completely up from 8:30am to 11:30am and then close completely from 11:30am to 4:30pm. Also, light sensors were used in some of the scenarios. The aim of this research was to analyze different elements such as the illumination levels, solar heat gain, cooling loads, heating loads and electricity consumption.

Badawieh (2017) conducted a simulation for each element and came up with multiple results. By taking the average for the four preselected days, it was observed that for lighting levels, manual shading was able to save the greatest amount of energy among all types. However, because the manual shading was set to be either fully opened or fully closed, at the periods where the shading was fully closed, the office space illuminance fell below 500 lux, which is below the optimal illuminance for the office space. For this reason, manual shading was excluded.

Tinted glass with 0.7 visual transmittances at bottom happens to be the second greatest contributor to energy savings regarding lighting loads. On the other hand, automatic shading top to bottom was able to save the least amount of energy among all types in terms of illumination. Moreover, for solar heat gain, automatic shading bottom up seems to have the greatest contribution to energy savings as opposed to tinted glazing which had the least energy savings regarding solar heat gain. Furthermore, for electricity consumption, manual shading with sensors had the highest energy savings while automatic shadings (bottom up and top bottom) had the least energy savings with regard to electrical loads. In addition, for cooling loads, manual shading was able to save the greatest amount of energy while tinted glass saved the least. Finally, for heating loads, automatic shading (top bottom) saved the largest amount of energy while tinted glass saved the least.

In addition to the energy analysis, Badawieh (2017) conducted an economical analysis to determine the cost and the payback period of each system. The author concluded that manual shading is the preferred shading type as automatic shading and tinted shading do not worth the investment. It was observed that manual shading contributed in the largest energy savings in all scenarios on average. Also, the payback periods of manual shading, tinted glass and automatic shading were estimated to be 5years, 15 years, and 17 years, respectively.

2.3.Case Study: Bahar Towers Responsive Facade

a. Building description:

Al Bahar towers are two high-rise buildings next to each other located in Abu Dhabi, UAE. This building was the first building that was awarded with LEED silver in the gulf region. The towers are for office use and consist of 25 floors with responsive facades that are self-automated and adapt to the sun movement.

The facade takes an Islamic ornament shape called “Mashrabiya” which was used during the old days in the region to provide privacy as well as reduce glare and solar gain. The shape of the facade reflects the traditional aspects of the city in a contemporary and sustainable way (Al Bahar Tower - External Automated Shading System 2013).

The single unit of the moving part consists of several main components and each tower consists of over 1,000 units that are controlled by BMS (Building Management System) of the towers. The system consists of several sensors to allow the units to open in case of overcast sky or partially close in case of sunny days. Moreover, each unit is pre-programmed to perform at a certain level to provide the optimal amount of daylight while reducing glare and excessive solar gain, thus, minimizing the energy consumption. This makes the facade very intelligent in terms of adapting itself to the changing outdoor environment while providing visual and thermal comfort for the occupants.

The reduction in solar gain that this facade has to offer has additional benefits in terms of reducing the load on the air conditioning which reduces the annual amount of harmful emissions. It is claimed that the facade can reduce up to 50% of the solar gain, thus, reduce around 1,750 tons of CO_2 yearly. This reduction is incredible as it has a positive impact on the city’s carbon footprint (Al Bahar Tower - External Automated Shading System 2013).

b. Facade Mechanism

The automated facade is placed about two meters away from the actual exterior facades of the towers which makes it perform as a double skin facade. Each triangle within the Mashrbiya is coated with fiberglass and preprogrammed to adjust itself. At night, all units are usually folded due to the absence of the sun which makes most of the actual building's skin exposed. As the sun rises, the units start to open starting from the eastern sides and moving along the sun path during the day ("Al Bahar Towers’ Responsive Sun Shades" 2015).

2.4.Daylight Metrics and Glare

Proper daylight design and strategies can have a great contribution to sustainability and energy efficient buildings which are the core of LEED, BREEAM, ESTIDAMA and other green building rating systems.

Daylight is the total illumination of a certain space resulted from the combination of sun and sky which are the main natural sources of light. Additionally, daylight metrics are a mathematical combination of measurements, dimensions, and conditions.

The purpose of defining and understanding daylight metrics is to combine several factors that determine and predict the daylight performance in a specific space(Mardaljevic, Heschong & S. Lee 2009).

There are many benefits of employing daylight metrics to any design including:

- Determining the availability of sufficient daylight

  A space would qualify as "daylit" if a sufficient amount of illumination is available. The sufficient amount of illumination varies depending on several factors such as occupancy, tasks performed in the space and minimum requirements provided by local codes. Daylight metrics will predict if the available daylight would be the primary light source in the space or an artificial lighting is required.

- Determining the quality of visual environment

  Visual comfort is a very important aspect when designing a space. Since different tasks require different illumination levels, using proper combination of daylight metrics could asses in determining the lighting quality of a certain space. The main issues associated with light quality are glare and veiling reflections.

- Determining the impact of daylight performance on energy

  Daylight design is considered successful and effective if it contributes in a reduction in both energy use and energy demand by reducing the annual usage of artificial lighting (DAYLIGHTING METRICS—Defining Successful Daylighting 2008).

Below is a brief explanation of four main daylight metrics:

2.4.1. Daylight Factor (DF)

As defined by Lechner (2015), “The daylight factor is the ratio of the illumination indoors to outdoors on an overcast day, which is an indication of the effectiveness of a design in bringing daylight indoors”. Different spaces with different functions require unique daylight factors (e.g. offices and classrooms require DF of 2%).

Unlike illuminance (lux), Daylight factor is a constant measurement for any particular design for overcast skies which means that as the outdoor illumination changes the indoor illumination changes proportionally (Lechner 2015).

2.4.2. Useful Daylight Illuminance (UDI)

Useful Daylight Illuminance is another important metrics used by some designers to evaluate the daylight performance. It basically measures how often a certain space achieves a daylight illuminance within a specific range during a period of a full year. Useful Daylight Illuminance follows a climate-based approach where values of the hourly sun and sky conditions are derived from annual climate databases.

By using UDI as a daylight metrics, designers can obtain the illuminance levels that fall in the useful range (e.g. 100 lux to 2000 lux), the illuminance levels that exceed the useful range and the illuminance levels fall below the useful range (Nabil & Mardaljevic 2006).

2.4.3. Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)

Recently, LEEDv4 adopted sDA and ASE as a daylight metrics that can impact the daylighting credits ("Spatial Daylight Autonomy - How the Metric Informs Design Decisions | U.S. Green Building Council" 2017).

Spatial Daylight Autonomy (sDA) is a new climate-based metric that improves the predictive abilities of the previous daylight metrics as it aims to assess the quality of daylit spaces. Moreover, Spatial Daylight Autonomy (sDA) determines the percentage of floor area that receives a certain amount of illuminance yearly. For instance, the percentage of floor area that receives at least 300 lux for at least 50% of the yearly occupied hours (Sterner 2014).

Figure 2.2 illustrates the concept of sDA on a classroom provided with external overhangs and light shelves. In this case, the figure shows that 54.3% of the floor area receives at least 300 lux for at least 50% of the yearly occupied hours. On the other hand, Figure 2.3 shows the same classroom without external overhangs and light shelves. The figure shows a poor daylight where only 28.1% of the floor area receives at least 300 lux for at least 50% of the yearly occupied hours (Wymelenberg & Mahić 2016).

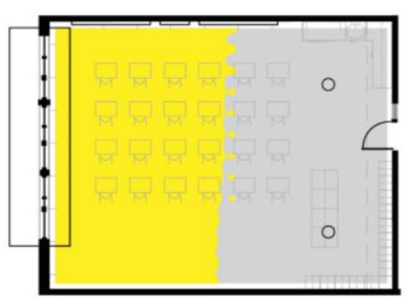

Figure 2.2: sDA analysis of a classroom with external shading and light shelves (Wymelenberg & Mahić 2016)

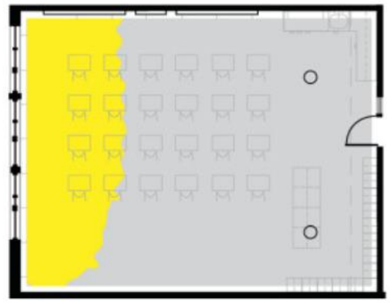

Figure 2.3: sDA analysis of a classroom without external shading and light shelves (Wymelenberg & Mahić 2016)

ASE, however, measures the percentage of floor area that receives too much direct sunlight to the extent that causes glare or increased cooling load. For instance, the percentage of floor area that receives at least 1000 lux for at least 250 hours yearly (Sterner 2014).

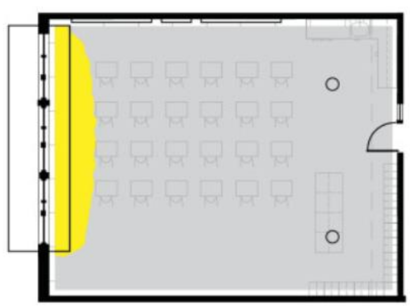

Figure 2.4: ASE analysis of a classroom with external shading and light shelves (Wymelenberg & Mahić 2016)

Figure 2.4 shows ASE of a classroom with using external overhangs and light shelves. It clearly shows that the space receives less direct sunlight yearly compared to the scenario in Figure 2.5. As shown in Figure 2.4, only 10.1% of the floor area receives at least 1000 lux for at least 250 yearly occupied hours. However, in Figure 2.5, 31.3% of the floor area receives at least 1000 lux for at least 250 yearly occupied hours. The scenario in Figure 2.5 will more likely cause overheating and visual discomfort such as glare.

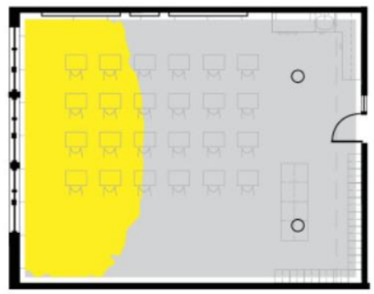

Figure 2.5: ASE analysis of a classroom without external shading and light shelves (Wymelenberg & Mahić 2016)

2.4.4. LEED Requirements for Daylight

LEED pays special attention to daylight due to its various benefits such as ensuring occupant's visual and thermal comfort. The main aim of including daylight is to create a connection between the occupants and the outdoor environment as well as reducing the electrical consumption through minimizing the usage of artificial lighting.

LEEDv4 points for daylight are 1-3 points and the requirements to attain these points are as follows:

1- Provide glare-control devices (manual or automatic) for regularly occupied spaces.

2- Select one of the options below:

   a. Simulation using Spatial Daylight Autonomy and Annual Sunlight Exposure

      This can be demonstrated using computer simulation tool (e.g. IES-VE). Each building type has different requirements in terms of sDA, as shown in Table 2.4.

Table 2.4: Points for daylit floor area: Spatial daylight autonomy (U.S. Green Building Council 2016)

New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality		Healthcare	
sDA (for regularly occupied floor area)	Points	sDA (for perimeter floor area)	Points
55%	2	75%	1
75%	3	90%	2

In addition to sDA, Annual Sunlight Exposure $ASE_{(1000\ lux, 250\ hours)}$ must not exceed 10% and the work plane height must be at 30inches from finished floor level of the regularly occupied floor. Also, in the process of simulation, permanent elements have to be included and movable furniture or partitions can be excluded.

b. Simulation using illuminance calculations

This can be demonstrated by also using computer simulation tool. Illuminance levels must be between 300 lux and 3000 lux for the timeframe between 9:00am to 3:00pm.

To achieve (1) point in daylight, 75% of the regularly occupied floor area has to achieve the mentioned illuminance range. Moreover, to attaining (2) points, 90% of the regularly occupied floor has to achieve the mentioned illuminance range(U.S. Green Building Council 2016).

c. Measurements

The third option is the field measurement option which is applicable for buildings that are already constructed. LEEDv4 requires measuring the illuminance levels of the regularly occupied floor with furniture, equipment, and fixtures in place. Moreover, measurement shall be done at an appropriate work plane height between 9:00am to 3:00pm.

In addition, LEED requires the measured illuminance range to be between 300 to 3000 lux. If this illuminance range is at least 75% of the regularly occupied floor area, the building attains 2 points in daylight and if the illuminance range is at least 90% of the regularly occupied floor area, the building attains 3 points (U.S. Green Building Council 2016).

2.4.5. Glare

Glare is the excessive brightness or the high contrast that interferes with the visual comfort and performance within a space. There are two main types of glare which are direct glare and indirect glare. The direct glare is caused directly by a source of light within the field of vision. This source can be either natural such as sunlight or skylight or it can be artificial light source such as ceiling or table lamp. On the other hand, indirect glare is usually caused by a reflection of the light on other surfaces such as glossy floor finishes or furniture (Lechner, 2015).

Achieving a certain illuminance within a space is not enough as analyzing glare along with daylight analysis give the designer a better understanding about the performance of a certain space in terms of daylight sufficiency and occupants probability of discomfort due to the glare. Accordingly, the design can be adjusted to ensure a high performance for both factors.

2.5.Climate and Solar Altitude in Dubai

In this section, the author will refer to the climate database built within Integrated Environmental Solutions (IES-VE) software to determine the climate and the solar altitude of Abu Dhabi. Although the research is intended to be for office buildings in Dubai, unfortunately, IES only has the climatic data of Abu Dhabi which is the capital of United Arab Emirates and it is about 150km away from Dubai. Since Dubai and Abu Dhabi are close in terms of locations, both cities have almost similar climate and weather conditions throughout the year. Thus, the author will refer to Abu Dhabi's climate as Dubai's climate.

After demonstrating the climate data of Dubai throughout the year, the author will demonstrate in-depth weather analysis for the three different days which will be selected for this research paper that are; 21st March, 21st June and 21st December.

- Temperature

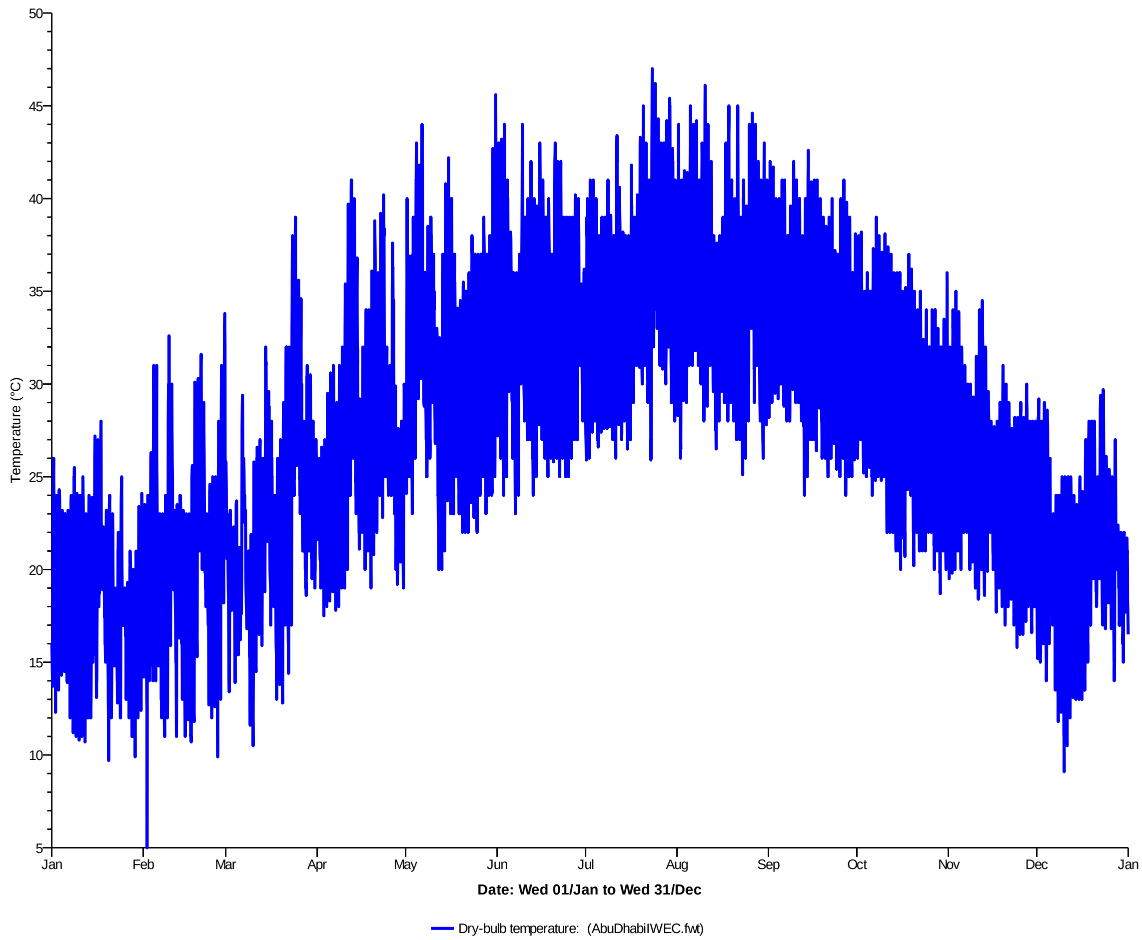

Figure 2.6: Dry-bulb temperature throughout the year in Dubai (IES-VE Database)

Figure 2.6 shows that the temperatures in Dubai are the highest between mid July and mid August. On the other hand, the temperatures are the lowest in the period between December and January.

- Relative Humidity (RH%)

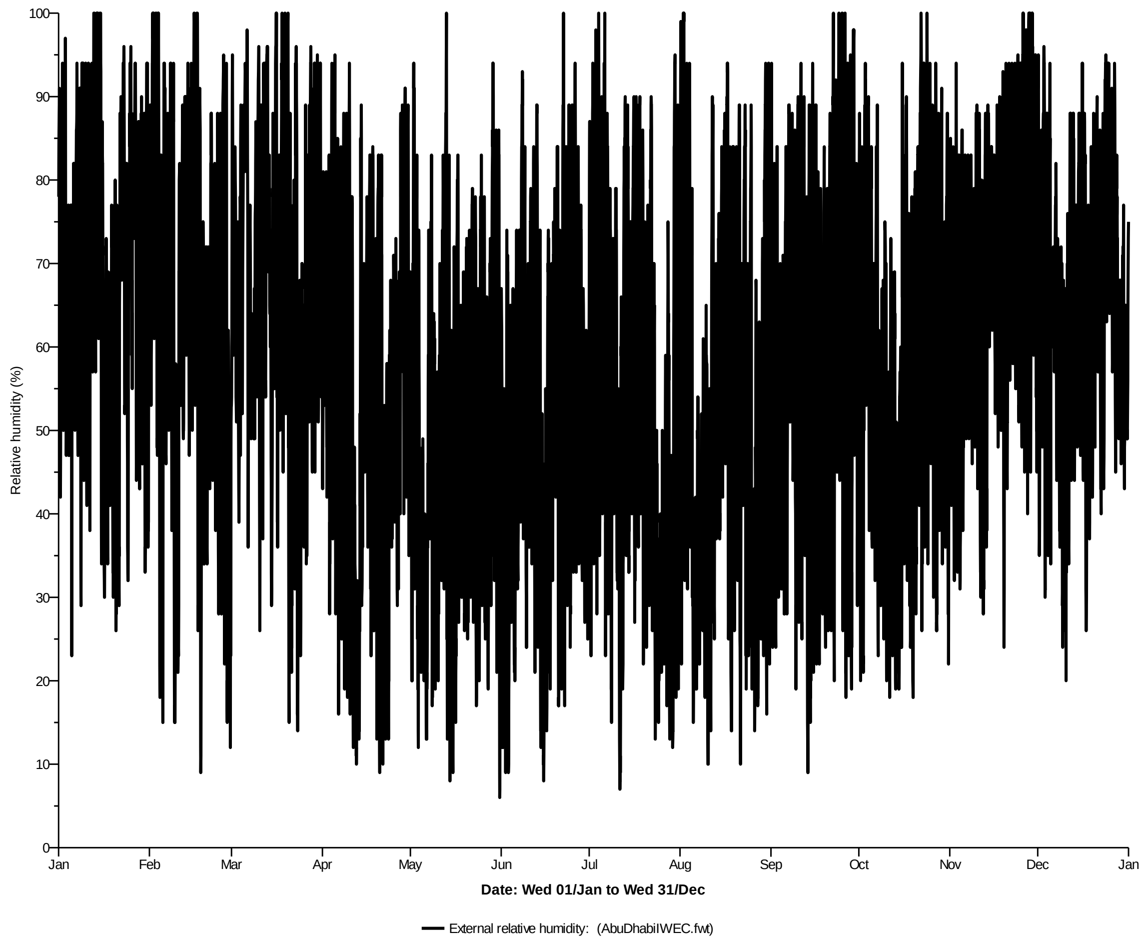

Figure 2.7: Relative humidity throughout the year in Dubai (IES-VE Database)

Figure 2.7 indicates that the relative humidity in Dubai is high in the period between November and early February. On the other hand, the relative humidity is low in the period between March and mid October.

- Precipitation

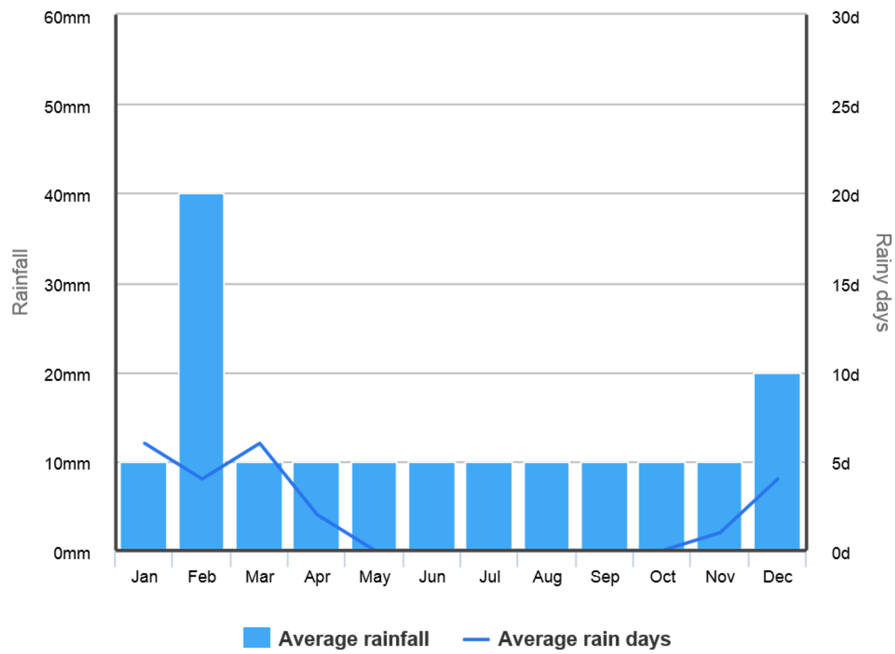

Figure 2.8: Average Rainfall in Dubai ("Weather and temperature averages for Dubai, Dubai" 2017)

In general, Figure 2.8 shows that rainfall in Dubai is rare. It also shows that the maximum rainfall throughout the year occur in February where the average rainy days is 20days followed by December where the average rainy days is 10 days only.

- Solar Altitude

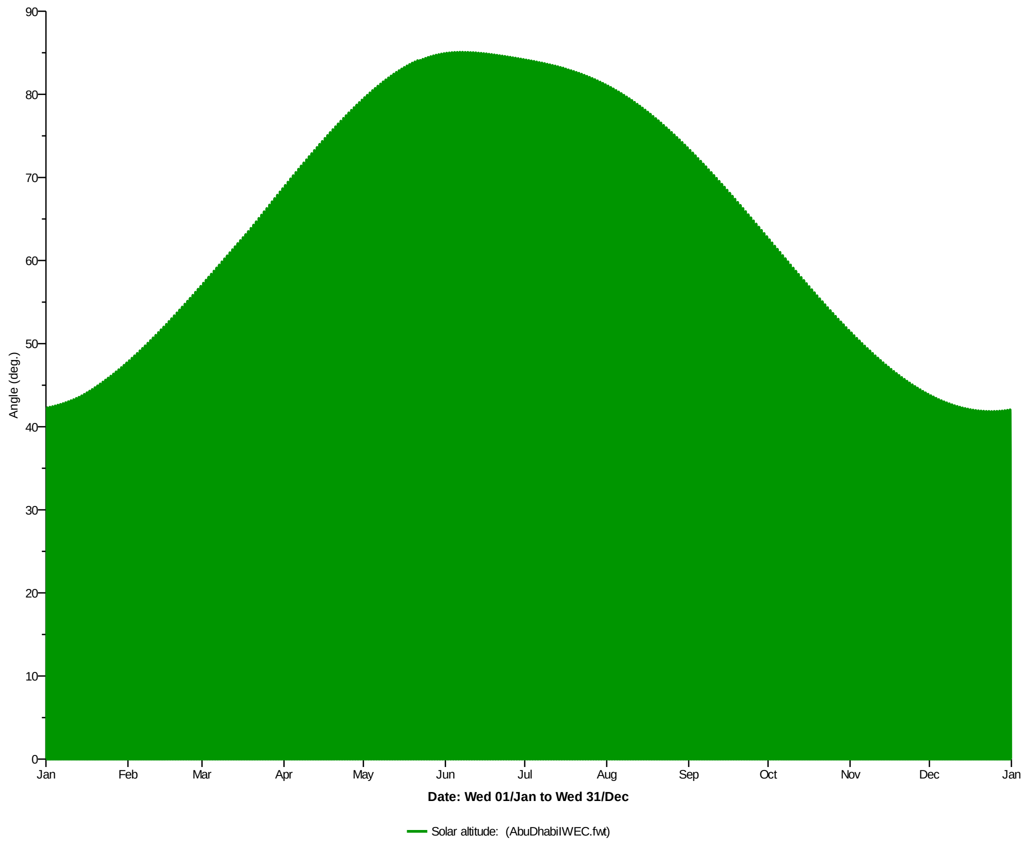

Figure 2.9: Solar altitude throughout the year in Dubai (IES-VE Database)

Figure 2.9 shows the solar altitude over a full year in Dubai. It shows that the sun is at its lowest altitude between December and February. The sun then starts to get higher altitude starting from March and peaking in June and July.

Here, the author demonstrates the weather in three different days, as follows:

- March 21st:

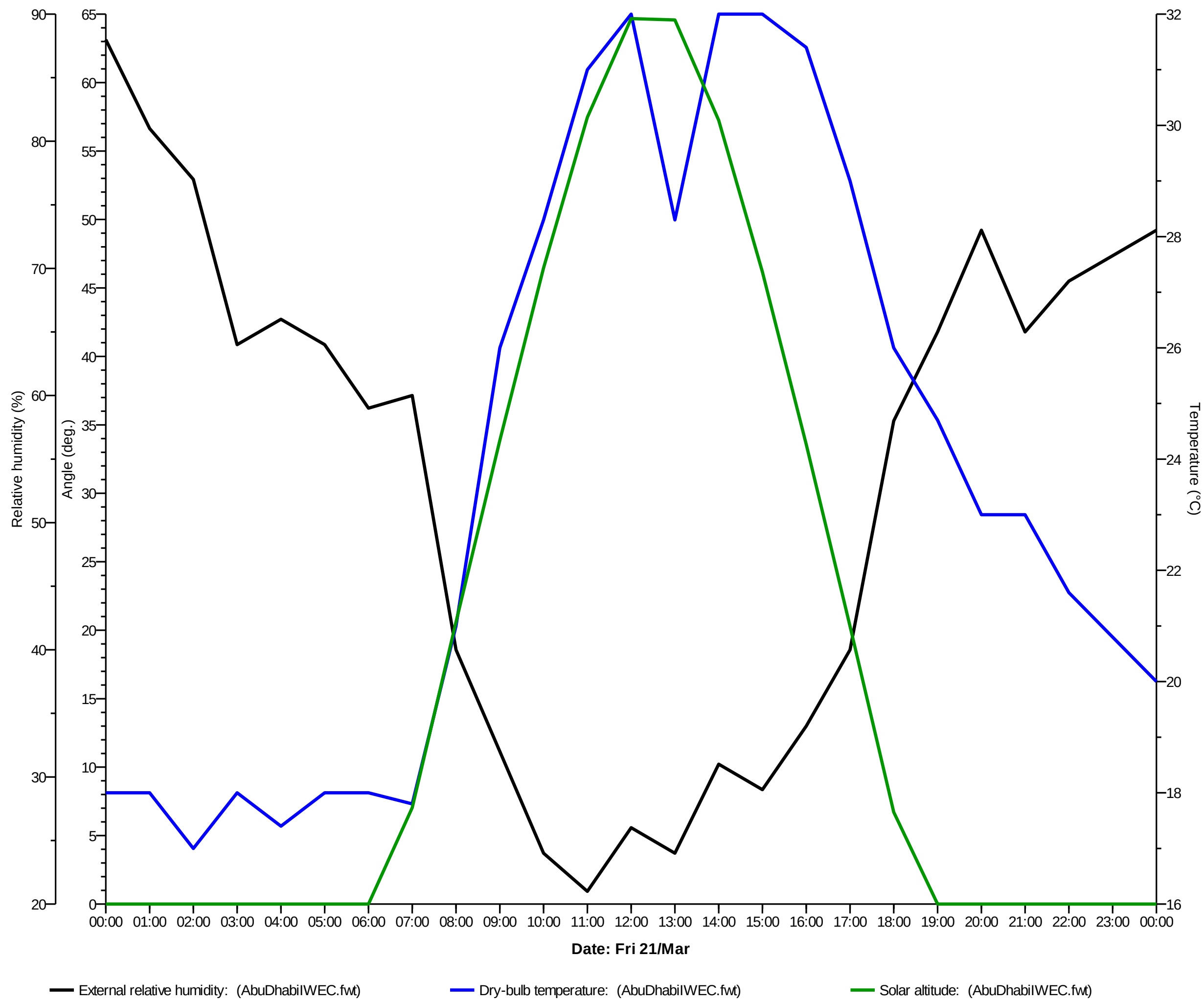

Figure 2.10: Relative Humidity, Temperature and Solar Altitude of Dubai in Mar 21(IES-VE Database)

Figure 2.10 shows that the dry-bulb temperature is very low around 12am and 7am where it starts to increase throughout the day and peaks at 12pm and 2pm where it reaches as high as (32°C). After 2pm, the temperature starts to decrease again as the sun sets.

Moreover, Figure 2.10 shows that the relative humidity (RH%)is maximum at 12am where it reaches about (88%) and starts to decrease as the time passes to reach the lowest relative humidity (21%) at 11am. After 11am, the relative humidity increases again throughout the day. Finally, the highest solar altitude at this time of the year is between 12pm to 1pm where it is at 65°.

- June 21st

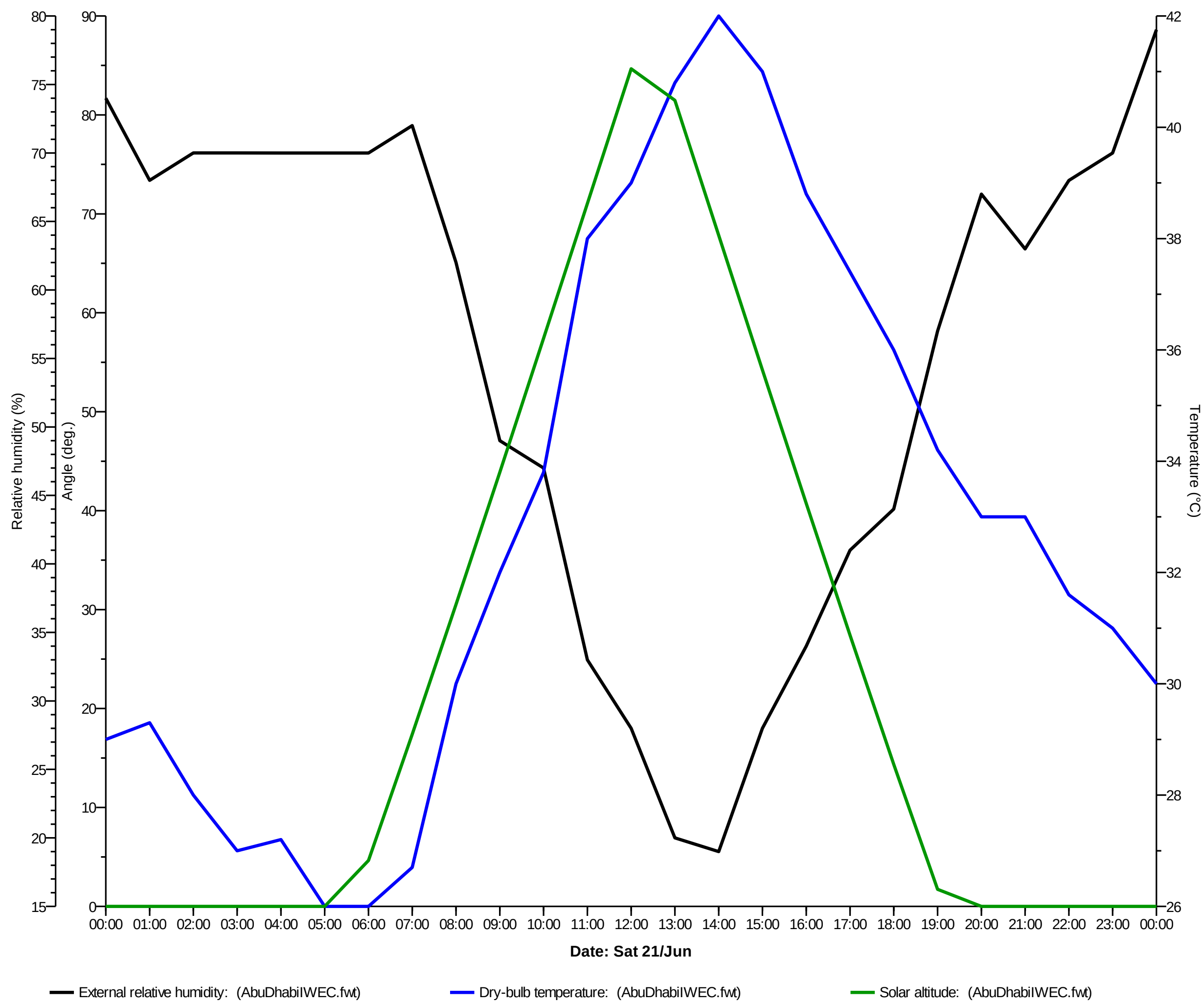

Figure 2.11: Relative Humidity, Temperature and Solar Altitude of Dubai in Jun 21 (IES-VE Database)

Day (June 21) is considered as the hottest day among the 3 chosen days for this study. Figure 2.11 indicates that at this time of the year, the temperature peaks at 2pm where it reaches (42°C) which is too high, compared to March 21 and December 21. On the other hand, the temperature is at its lowest at the time between 5am to 6am where it reaches as low as 26°C. Moreover, regarding the relative humidity (RH%), the maximum humidity at this time of the year happens to be at 12am where it reaches 74% and the minimum RH% is at 2pm where it is around 19%. Additionally, the highest solar altitude at this time is at12pm where it is at 85°.

- December 21st

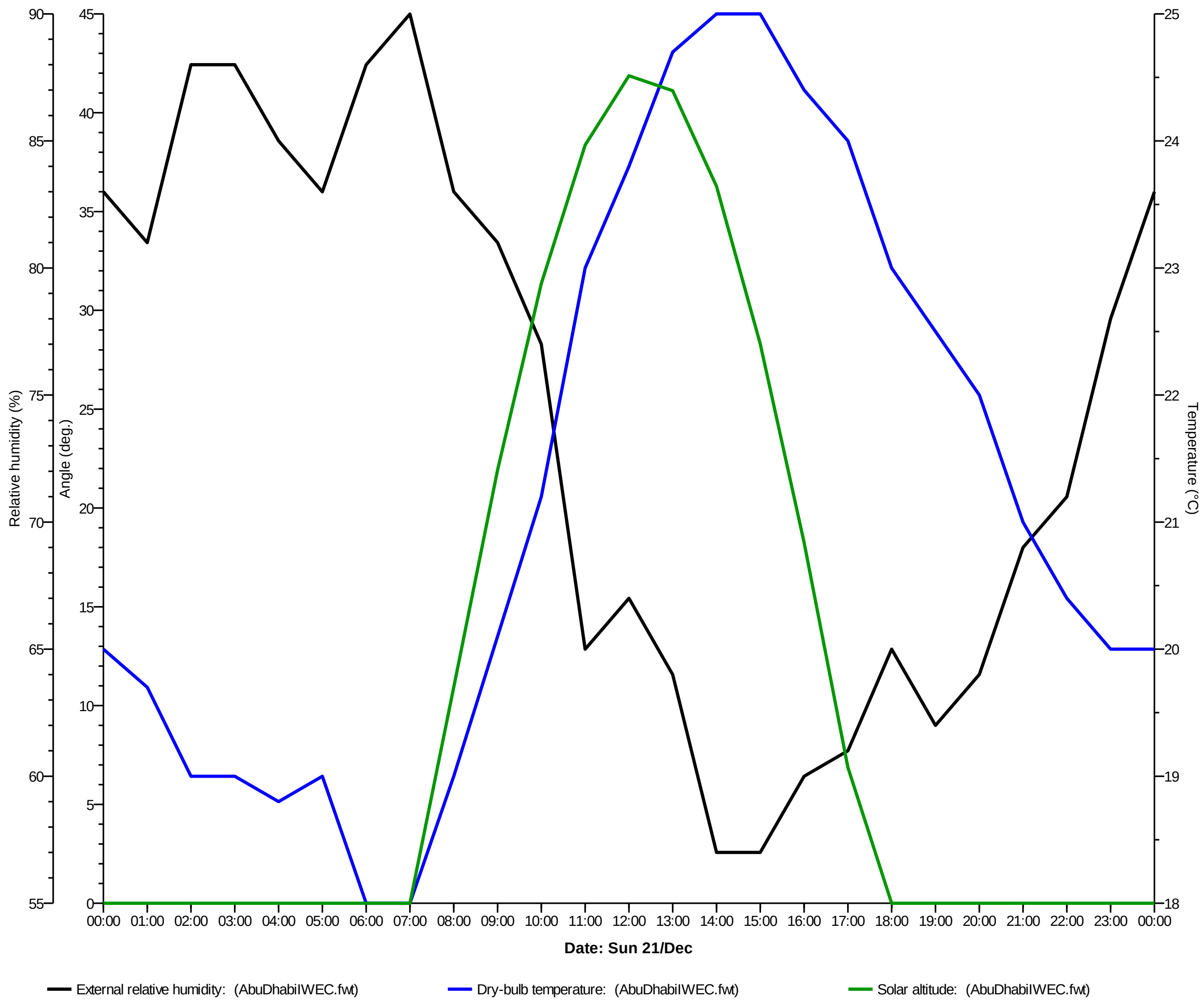

Figure 2.12: Relative Humidity,Temperature and Solar Altitude of Dubai in Dec 21 (IES-VE Database)

December 21 is considered the coolest day among the other two day. Figure 2.12 shows that the highest temperature is between 2pm to 3pm where it reaches 25°C. On the other hand, the temperature is at its lowest in this day between 6am to 7am where it reaches as low as 18°C.

Regarding the relative humidity (RH%), at this time of the year, the maximum relative humidity occurs at 7am where it reaches about 90% whereas the lowest relative humidity is between 2pm and 3pm and it equals 3% only. In addition, the highest solar altitude is at12pm where it is 41°.

As observed from Figure 2.10, Figure 2.11 and Figure 2.12, the relative humidity is always inversely proportional to the dry-bulb temperature. Moreover, the solar altitude (85°) in June 21 is the highest among all days, whereas, in December21, the solar altitude (41°) is the lowest. In addition, it is observed that the solar altitude is always directly proportional to the dry bulb temperature.

2.6.Problem Statement and Research Questions

Most of the previously reviewed papers were studying the impact of static versus dynamic shading louvers from energy consumption point of view or occupants satisfaction perspective. Even the papers that were covering a daylight performance, were studying the energy savings that are associated with minimizing the usage of electrical lighting by using automatic shading or light dimming sensors. Moreover, not many papers were found regarding studying the possibility of maximizing the daylight in terms of performance and quality while focusing in minimizing the direct sunlight exposure and the glare severity, all at the same time.

Referring to section 2.4, most of the daylight metrics such as sDA, ASE, and UDI are used for annual analysis (performed over a period of 12 months). The problem with these metrics is that they are not applicable for dynamic shading louvers or systems. The reason being that dynamic shading louvers change usually in hourly, daily or monthly basis which require a metric that allow analysis to be performed on an hourly, daily or a monthly basis.

Although these newly developed metrics are useful for some designs and have been widely used nowadays specially by international rating systems such as LEED, more enhancement and additional versions of these metrics shall be developed to benefit a wider range of design options.

Moreover, the author has two main question that would like to investigate through this study which are as below:

1- Is using dynamic facade in the form of (dynamic shading louvers) effective in terms of providing quality daylight, minimizing direct sunlight exposure and glare, all at the same time?

2- To what extent can dynamic shading louvers improve the daylight performance of an office space and how significant are the improvements, if any, compared to using no louvers at all or using the traditional fixed shading louvers?

2.7.Aims and Objectives

The aim of this paper is to investigate and develop a modified daylight performance metric for dynamic shading louvers that allow designers to identify the percentages of useful daylight and direct sunlight exposure that are associated with every angle of movement and at any time and at any day of the year. Additionally, the objective of the study is to determine the best design configuration at every time of the day that will achieve the maximum useful daylight while minimize the direct sunlight exposure using the developed daylight metric.

3. CHAPTER 3: METHODOLOGY

Through this section, the author will point out different methodologies and approaches adopted by previous researchers based on the reviewed literature in Chapter2. Also, the preferred approach/methodology will be demonstrated with proper justifications. Lastly, both fixed and variable parameters, assumed in this study, will be clarified in depth along with the different design scenarios.

3.1.Different research approaches that were used to study dynamic facades

Below are the methodologies adopted by previous researchers that studied similar research area.

3.1.1. Computer simulation approach

Hammad & Abu-Hijleh (2010) adopted computer simulation approach to evaluate the energy performance of external dynamic shading louvers in (Abu Dhabi, UAE) in terms of HVAC consumption and lighting loads. Beside the dynamic shading louvers, the research aimed to determine the contribution of using light sensors at two different locations in energy consumption.

The authors used IES-VE (commercial package) to determine the optimal slat angle that offers the maximum reduction in HVAC and lighting loads for 4 preselected days on 3 orientations (south, east and west).

For lighting load analysis, they used the light control strategy (light sensors) to determine the energy consumption due to the usage of electrical lights during these days. The concept was to measure the available illuminance in the office space where the light sensors are connected to the fluorescent lights which allow them to switch on and off according to a reference illuminance level which is 500 lux. Specifically, when indoor illuminance falls below 500 lux, the electrical lights turn on and when it exceeds 500 lux, they remain off due to sufficient daylight availability.

Afterwards, the authors simulated the energy savings associated with controlling the usage of electrical lights.

For HVAC loads, the authors manipulated the slat angle of the louvers to determine the optimal angle that can contribute to the maximum saving in energy consumption. They tested both the fixed shading louvers and the dynamic shading louvers through changing the slat angle on an hourly basis within a specific timeframe and compare the obtained results with the base case scenario. Then, the overall lighting and HVAC energy consumptions at each hour and each slat angle were obtained for the pre-selected days. Finally, a comparison of the total energy conceptions for all scenarios was made through comparing the total (kW) at every hour with the base case scenario.

Also, Winther, Heiselberg & Lund Jensen (2010) used computer simulation approach to carry on their research and the software used were BSim [SBi-BSim] and Be06 [SBi-Be06]. They tested several design scenarios and solutions for static and dynamic facades to figure out the solutions that can contribute to lowering the total annual energy demand of buildings in Denmark. The authors manipulated different façade components and compared the results against a chosen reference building which was a typical office building with glazed façade. Some of the proposed solutions were; changing the U-value of the glazing, changing the glazing type, changing the light control system, using reflective external solar shading, and many other solutions. Each solution was simulated in terms of lighting, cooling and heating demand and summed up to come up the total annual energy demand using that specific solution. Then, each solution was combined with the previous solution and the total annual energy demand by using both solutions was determined. The software was able to simulate most of the solutions and the objective of the research was achieved.

In addition, Badawieh (2017) used computer simulation method for her research paper. The author used IES-VE software (student version) to determine the impact of internal dynamic shading louvers on heating load, cooling load, lighting load, and solar heat gain. She was able to examine several scenarios in 4 pre-selected days and obtained numerical data which assessed her in evaluating the effectiveness of using dynamic internal louvers.

For lighting, Badawieh (2017) simulated the illumination for the base case scenario which is without using any type of shading. Then, the illumination for each shading configuration (automatic, manual and tinted glass) was simulated and compared to the base case scenario. The comparison was made in terms of the illuminance level (lux) difference with and without the shading and the corresponding savings in energy, if any.

Furthermore, the author simulated the solar heat gain for the base case scenario and compared it to the multiple scenarios in terms of kW. Any reduction in energy consumption due to the various shading control strategies were presented and explained. Moreover, electrical consumption was simulated using dimming light control.

Similar to Hammad & Abu-Hijleh (2010), Badawieh (2017) used 500 lux as a reference illuminance level for the dimming light control strategy. The same concept was applied where the electrical lights turn on when the illuminance equals or falls below 500 lux and turn off when it exceeds 500 lux. The electrical consumption was then compared between the base case and all scenarios with and without the dimming light control and the energy savings, if any, were determined.

Finally, for the cooling and heating loads, the author simulated the sensible load (summation of external and internal conduction gain) for the base case scenario at every hour within the timeframe. Then, the sensible load for each scenario was also simulated at every hour and compared with the sensible load for base case. In most cases, a reduction in cooling and heating loads was obtained compared to the base case scenario, thus, the energy savings with regard to the base case were positive.

Similarly, Konstantoglou, Kontadakis & Tsangrassoulis (2013) used computer simulation approach for their research. EnergyPlus was the simulation tool that was used to assess the energy performance of several shading devices such as blinds, light shelves, and overhang shadings. Their approach was different as they manipulated a design parameter called window to wall ratio (WWR). They examined different scenarios with different window to wall ratio and determined that shading system that performs better in each scenario in terms of energy consumption.

3.1.2. Mixed-methodology approach

Al Thobaiti, (2014) used mixed-methodology to carry on his research which are computer simulation approach and physical model approach. He used Autodesk (Ecotect) to run various simulations to determine the best louvers configuration that consumes the lowest energy. Although the process was time consuming since he had to change the position of the slat angle frequently, Al Thobaiti, (2014) was able to come up with results that answered his research question. Moreover, he validated his results by building a physical model and conducting an actual experiment to verify whether the results obtained from simulation are accurate.

Bakker et al. (2014) also used a mixed-methodology to determine the occupants' satisfaction and reaction to automated dynamic façade. They used a mock-up (field experiment) of the system and allowed participants to experience the system in real life. The mock-up contained actual internal roller shades and several scenarios were tested in the presence of the participants. The second methodology used was the survey-based methodology in which participants were asked to fill out an online survey to determine their honest feedback regarding automated dynamic façade.

3.2.Preferred approach for this research with justification

The author will be adopting computer simulation approach for this research paper. Below are several reasons why choosing such approach will be advantageous for this research area:

1- Using a computer simulation tool will allow variety of design options and scenarios to be tested due to its flexibility in changing and alternating the parameters. Specifically, it will be easier to alternate the tilt angles and shading geometry of louvers and test their performance during different times of the day. Also, distant locations can be easily simulated by referring to the built-in climate databases as opposed to experimental method which might require travelling to the location of interest to test the experiment under realistic conditions.

2- Using simulation tool is cost efficient as opposed to using any other methods such as experimental/field approach which usually requires purchasing expensive tools and/or equipments. Specifically, this method will mainly cost the price of purchasing the software and probably external hard drives for storage and backup purposes.

3- Computer simulation is a time efficient method as opposed to other methods such as field measurement approach which can require several site visits to analyze several scenarios under different conditions or timings.

Although this method has various advantages, it also have its limitations such as:

1- Simulation of complex designs may require a heavy duty CPU with a large memory capacity and a high processor, which may be quite expensive.
2- Results obtained from simulation might be inaccurate and may require validation using other methods since there are inherent assumptions by the mathematical models used within the simulation software in addition to the assumption that are used by the researcher to simplify the problem.

3.3.Preferred simulation software

The author has chosen Integrated Environmental Solutions (IES-VE) (student version) to carry on this research. IES-VE is a powerful simulation tool that enables designers and engineers to test various options and designs to come up with the best design options in terms of natural daylight.

The U.S. department of Energy considers IES-VE as qualified computer software that determines energy and power cost savings that meet federal tax incentive requirements for commercial buildings. Moreover, they have listed other capabilities that the software can achieve such as:

- Simulate natural ventilation
- Simulate mixed mode (natural and mechanical ventilation)
- Simulate daylight
- Determine water use by occupants for domestic uses
- Determine water use by heating, cooling and landscape
- Determine on-site energy systems (e.g. PV cells)

And so many other uses (Tax Deduction Qualified Software for buildings 2016).

Moreover, the software has several modules for various simulation purposes, the main component are as follows (<VE> MODULE TUTORIAL n.d.):

- ModelIT:

This module is responsible for modeling geometries. Users can model various designs ranging from simple to detailed geometries. Moreover, geometries created by other modeling software (e.g. CAD, Revit or Sketchup) can be easily imported into IES-VE.

- SunCast:

This module is responsible for analyzing the solar gain impact on the building according to the simulation location chosen. Moreover, it can help the user to visualize the solar radiation impact on the facade and internal surfaces of the building.

- ApachiSim:

This module is responsible for analyzing various thermal simulations. It enables dynamic interactions between the building internal loads, external climates, mechanical system and many other aspects. Through this engine, the user can simulate factors like cooling load, heating load, people gain, solar gain, lighting gain and so many other things. In addition, this engine is able to integrate different information from other modules such as the solar analysis obtained from the SunCast Module.

- FlucsDL:

This module is responsible for daylight analysis. In this module, the user can analyze illuminance or daylight factor on any surface of the model and at any work plane height. The results obtained are presented in either graphical or numerical data.

- Radiance:

Like FlucsDL, this module is responsible for daylight analysis. However, using Radiance will allow the user to obtain rendered and photorealistic results of the simulated object. Moreover, illuminance and luminance can be presented on the rendered results, if further numerical details is required. In addition, glare analysis can be done using this module to predict the probability of glare occurrence.

- MicroFlow:

This module is responsible for analyzing the air movement within the model. The outputs are presented in computational fluid dynamics (CFD), which is powerful in assessing different air patterns and distributions.

3.4.Research Scope of Work and Limitations

In this paper, the author will be using the computer software (IES-VE) to analyze different tilt angles of dynamic shading louvers in terms of daylight and glare performance for a personal office in Dubai through using (FlucsDL) engine in IES-VE.

The obtained performance of daylight and glare will then be compared to the daylight and glare performance when using no louvers at all and when using fixed shading louvers. Specifically, in this paper, the author will be focusing on maximizing the penetration of useful daylight and minimizing the penetration of direct sunlight into the office.

This study is not intended to examine and alternate glazing properties and construction materials as they are out of the scope of this research. Additionally, the research is not intended to study the fixing details and structural supports of the louvers as well as the mechanism of the moving louvers. Moreover, occupants, furniture, equipment, and other accessories will be excluded from the simulation process. Lastly, determining energy loads and demands associated with each tilt angle is out of the scope of this study.

3.4.1. Daylight and Glare Metrics Used in this Study

In this section, the author will specify the glare and the daylight metric that will be used for this study.

- Daylight Metric

For daylight analysis, the author will be using a developed method which is a modified version of UDI (Useful Daylight Illuminance) that was explained earlier, in chapter2.

The author named this modified metric as (DUD) and (DSE) which stand for Dynamic Useful Daylight and Dynamic Sunlight Exposure, respectively. The main reason behind the modification of the original metric is because UDI is an annual-basis metrics and the aim of this study is to determine the best configurations for daylight performance and glare on a daily basis rather than annual basis. Therefore, DUD and DSE will be adopted as daylight metrics in this paper.

Dynamic Useful Daylight (DUD) is the percentage of the regularly occupied floor area that receives daily illuminance between 500-1000 lux. Any value that falls between this range will be considered as useful, therefore, the higher the percentage of DUD, the better.

Dynamic Sunlight Exposure (DSE), however, is the percentage of the regularly occupied floor area that receives daily illuminance of more than 1000 lux. This range will be considered as undesired daylight due to the probability of glare occurrence, visual discomfort and high energy consumption. Therefore, the lower the percentage of DSE, the better.

The author will be implementing DUD and DSE by the following steps:

1- The office will be modeled in the modeling component of the software (ModelIT), followed by solar analysis using (SunCast).
2- The area of the floor will be divided automatically into smaller equal areas ($0.25m^2$ each) in IES-VE by using (FlucsDL) and by specifying the grid size to be 0.5m. As a result, each small area will have a unique lux level.
3- The obtained lux levels will be projected into Microsoft Excel to determine the percentage of area in which a specific range of illuminance occur (e.g. the percentage of area that has a lux level range between 500 to 1000 lux, which is DUD percentage and the percentage of area that has a lux level of over 1000 lux, which is DSE percentage)
4- The author will assess each scenario in terms of daylight (percentages of DUD and DSE)

- Glare

After obtaining the optimal tilt angles or design configuration for each time in terms of the best daylight performance (DUD% and DSE%), the author will be evaluating the glare performance for the obtained daylight optimal angles or design configuration. The glare performance for the optimal configuration at each time will then be compared to the glare performance in the base case scenario at each time (without any louvers).

The author will be using (Radiance engine) built within IES-VE for the glare analysis. Moreover, the glare analysis will be presented as luminance levels (cd/m^2).

Luminance levels will be compared in each scenario to figure out whether adding shading louvers is effective in terms of eliminating glare occurrence or reducing the severity of it.

3.5.Introducing Parameters

This section describes both fixed and variable parameters, as explained below:

- Location and climate:

This is a **fixed parameter** in which the researcher will choose a hot-humid climate (Dubai, United Arab Emirates) for this study. The reason of fixing this parameter is to restrict the analysis of the daylight performance of the system to a specific climatic conditions.

- Time frame/days:

This is a **fixed parameter** in which the researcher will conduct the simulation in the time frame between 8:00am to 4:00pm which is the typical working hours for most offices in Dubai.

The author will evaluate the performance of each louver configuration at a time increment of 2hrs which are 08:00, 10:00, 12:00, 14:00, and 16:00. Moreover, 3 different days with different solar altitudes will be chosen which are 21^{st} March, 21^{st} June and 21^{st} December.

- Floor area and dimensions

This is a **fixed parameter**. A small personal office will be simulated in the mentioned location (Dubai) to assess the daylight and glare performance.

The office has an area of $20m^2$ (5m Length * 4m width * 3.7m height) and it consists of three walls and one fully glazed wall with movable shading louvers, as shown in Figure 3.1, Figure 3.2 and Figure 3.3.

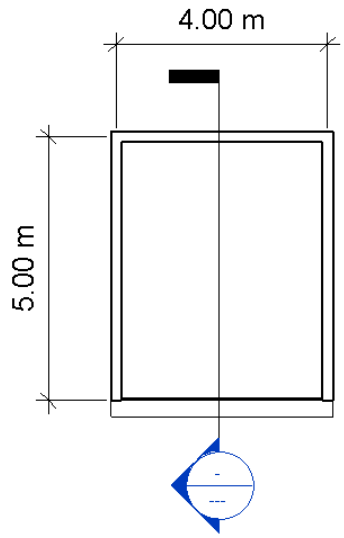

Figure 3.1: Model Plan

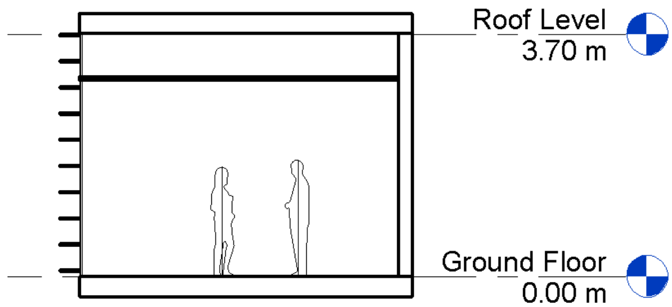

Figure 3.2: Section

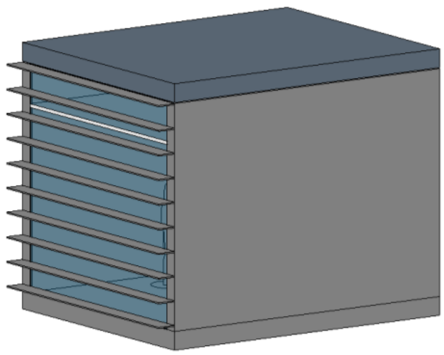

Figure 3.3: 3D model

- Orientation

The glazed wall with the louvers will be facing different orientations to determine the effectiveness of using dynamic shading louvers to enhance daylight performance. Thus, the model will be rotated towards North, South, East and West to form 4 main scenarios which will be explained in further details in, Section 3.8.

- Work plane height

The work plane height is another **fixed parameter**. As per LEED v4 requirements, the work plane height must be 30 inches above the finished floor level which is equivalent to 0.76m. Thus, the author will be using 0.76m as a work plane height.

- Shading Louver Geometry:

This is a **variable parameter**. This includes the width of the shading louvers (W), the tilt angle (α°), number of shading louvers (N) and the spacing between them (S). Note that some of these parameters are dependent on each other. For instant, the spacing between shading louvers is inversely proportional to the number of louvers which means that the more distant the spacing is, the less number of louvers will be required for a given glazing size. Also, the spacing between louvers is directly proportional to the width of the louver which means that as the spacing between louvers get closer, the width of the louver gets smaller.

The shading louvers will be placed along the 4m glazed wall of the model in all scenarios. However, in the case where the model will be facing south, the author will be using horizontal louvers as shown in Figure 3.4. However, for East, West, and North orientations, vertical louvers will be used as shown in Figure 3.5.

For horizontal louvers, the length of the louvers (L_h) will be the same as the length of the glazed wall which is 4m. On the other hand, the length of the vertical louvers (L_v) will have the same length as the height of the office which is 3.7m. Thus, length of the louvers (L) can be considered as a **fixed parameter** with respect to the type of louver (horizontal or vertical).

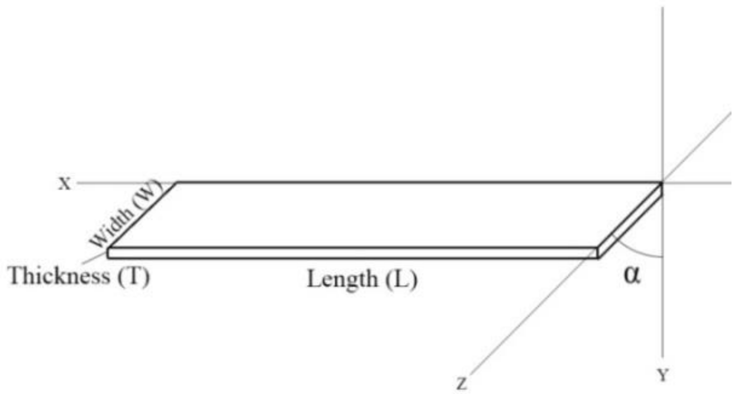

Figure 3.4: Horizontal Louvers

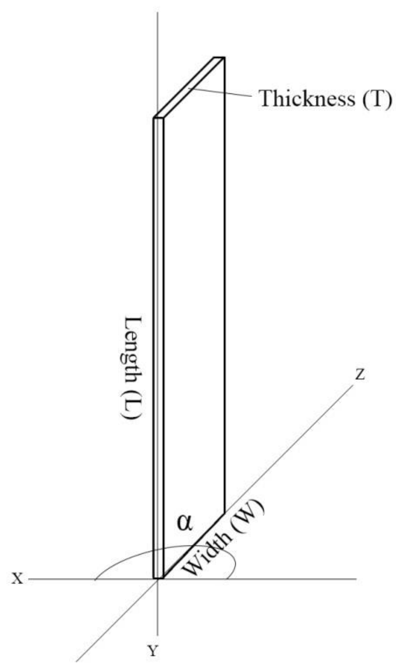

Figure 3.5: Vertical Louvers

- The relationship between (W) and (S)

The author introduced a parameter called (W/S) to express the relation between W (width of the louver) and S (spacing between two louvers). The main reasons of using this relationship is to cut down the simulation process as well as include as much W and S as possible by conducting a simulation for a certain W/S and assume the same results will be obtained for any other cases that corresponds to the same W/S. Table 3.1 shows examples of W/S:

Table 3.1: Examples of W/S

W (m)	S (m)	W/S
0.2	0.4	**0.5**
0.3	0.6	
0.4	0.8	
0.2	0.2	**1.0**
0.3	0.3	
0.4	0.4	
0.3	0.2	**1.5**
0.6	0.4	
0.9	0.6	
0.2	0.1	**2.0**
0.4	0.2	
0.6	0.3	

However, due to the time constrains, the author selected two values for W/S to conduct this study which are W/S=0.5 and W/S=1.0, as shown in Table 3.2

Table 3.2: Selected (W/S) for the study model

W (m)	S (m)	W/S
0.2	0.4	**0.5**
0.2	0.2	**1.0**

- Louver tilt angles

This is **a variable parameter** as the author will be using different tilt angles for the louvers(α) which are-60°, -40°, -20°, 0°, 20°, 40°, and 60°.

Figure 3.6shows the top view of the vertical louvers showing the positions of negative and positive tilt angles that are used for the simulation, as assumed in this study. Similarly, Figure 3.7 shows the side view of the horizontal louvers showing the positions of negative and positive tilt angles of the louvers.

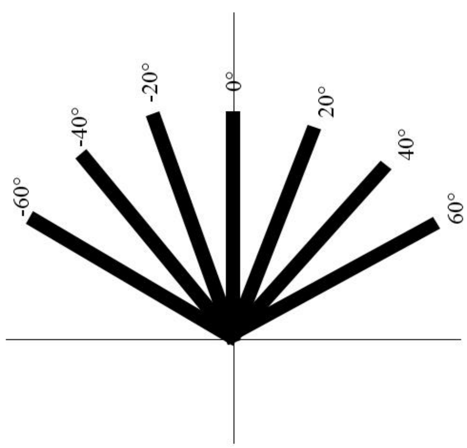

Figure 3.6: top view of the vertical louvers

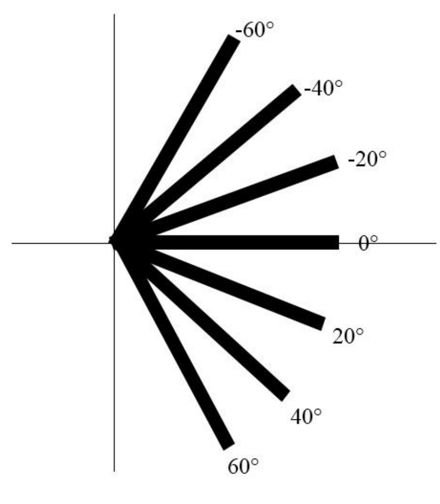

Figure 3.7: Side view of the horizontal louvers

- Detailed Model Construction Materials

The author used fixed building materials for all simulation scenarios based on the common practice in Dubai. Table 3.3 shows a detailed description of the materials used for walls, ceiling, floor, and glazing.

Table 3.3: Used construction materials

Building component	Construction Details (Layers)	Internal Reflectance (%)
External Walls	20mm Plaster 100mm Reinforced Concrete 50mm insulation 100mm Reinforced Concrete 20mm Plaster **Total U-Value = 0.4086 W/m^{2}k**	50%
Floor	150mm Reinforced Concrete 60mm Low Weight Concrete 30mm Screed 10mm Timber Flooring **Total U-Value = 1.7310 W/m^{2}k**	20%
Ceiling	150mm insulation 0.1mm membrane 100mm Concrete Deck 50mm Cavity 12mm Plasterboard **Total U-Value = 1.7310 W/m^{2}k**	80%
Glazing	6mm Outer Pane	Glazing Transmittance = 0.71

	12mm Cavity 6mm Inner Pane **Total U-Value = 0.1849 W/m²k**	

Table 3.4 summarizes all the parameters used in this research paper which include both the fixed and the variable parameters.

Table 3.4: Summary of the research parameters

Parameter		(Fixed / Variable)	Specifications	Remarks
1	**Location of the study**	Fixed	Dubai, U.A.E	The climate database of IES-VE has only the climatic data for Abu Dhabi city. However, the author will assume the same climate is applicable for Dubai since they are close in terms of location, thus, have almost similar climate
2	**Floor Area**	Fixed	$20m^2$	-
3	**Orientation**	Fixed	South, North, East and West	-
4	**Type of louvers**	Fixed	-Horizontal louvers for Southern side -Vertical louvers for Eastern, Western and Northern sides	-
5	**Length of the louvers (L)**	Fixed	Horizontal louvers: 4m Vertical louvers: 3.7m	-
7	**Tilt angle of the louver (α)**	Variable	-60°, -40°, -20°, 0°, 20°, 40°, 60°	-
8	**Thickness of the louver (T)**	Fixed	0.02m	Typical louver depth
9	**W/S**	Fixed	W/S= 0.5 (W=0.2m, S=0.4m)	Each W/S will be examined for all 4 orientations and all 3

			W/S= 1.0 (W=0.2m, S=0.2m)	selected days with alternating the angles between -60 and 60 to determine which W/S and angle provide the maximum useful daylight with minimum glare
10	**Used construction materials**	Fixed	Refer to Table 3.3	Construction materials are selected based on the common practice in Dubai
11	**Simulations days and times**	Fixed	Days: 21st March / 21st June / 21st December Times: 8:00 / 10:00 / 12:00 / 14:00 / 16:00 (Increment of 2hrs)	Days are chosen due to the different solar altitude Timings are chosen between 8am-4pm based on the typical working hours
12	**Work plane height (WP)**	Fixed	30" or 0.76m	As per LEED v4 requirements for daylight analysis
13	**Sky conditions**	Fixed	Clear sky	Clear sky is chosen to evaluate the actual performance of the system without any clouds

3.6.Dynamic Shading Louvers Concept:

The dynamic shading louvers concept that will be adopted in this study is based on louvers that move in X, Y, and Z directions. Meaning, the louver will be able to move the tilt angle, change the spacing between two louvers (vertically and horizontally) and hide the louvers completely.

The conceptual illustrations in Figure 3.8show examples of the louvers' movement options. It shows that in March 21, the vertical louvers at t=12:00 have a tilt angle of 20° and a spacing of 0.2m which represent the optimal configuration for this time and day in terms of daylight and glare. However, at t=14:00, the best configuration is using a tilt angle of -40° and a wider spacing (0.4m) instead of 0.2m. On the other hand, at t=16:00, the best design configuration is to use no louvers at all to obtain optimal daylight and glare performance.

Since louvers cannot just disappear at t=16:00, they will hide at the ends of the glazing (in a louver house) to allow full exposure of the glazing and to give a sense of having no louvers to optimize the useful daylight.

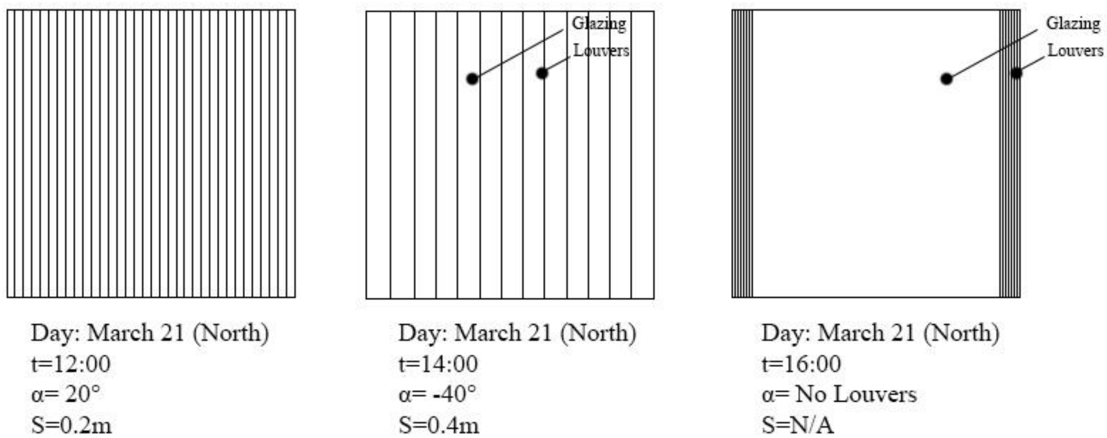

Figure 3.8: Conceptual Illustration of the Dynamic Shading Louvers movement Options

3.7.Sun Path

The author selected three different days to represent the entire year. The selection was based on the sun path as the three days fall into different periods of the year, thus, the sun penetration into the model is different which will have an impact on the daylight performance.

This selection will allow the author to determine the best shading configuration for each day which will be applicable for the entire corresponding month as well.

- March 21st

Figure 3.9shows the sun path around the model on 21st of March. As noticed, the sun moves at medium solar altitude compared to the other two days that are shown in Figure 3.10 and Figure 3.11.

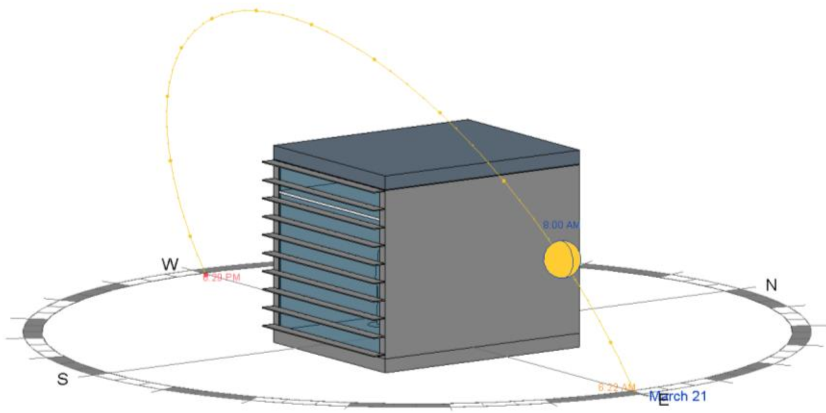

Figure 3.9: Sun path around the model (March 21)

- June 21st

Figure 3.10 shows the sun path in 21st of June. The sun, in this case, is at the highest solar altitude among the three selected days. As seen, the sun at noon time is almost perpendicular to the roof of the model.

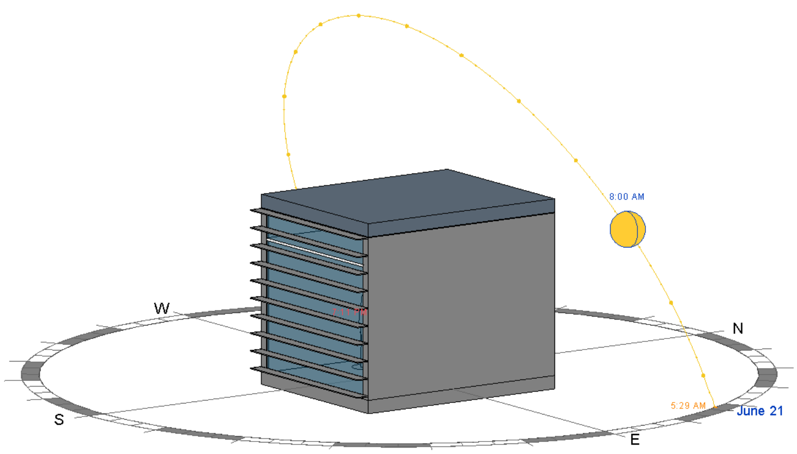

Figure 3.10: Sun path around the model (June 21)

- December 21st

Figure 3.11 shows the sun movement around the model on 21st of December. In this case, the sun is at its lowest position compared to the cases in March and June. As noticed. at noon time, the sun is at an angular altitude and seems to penetrate through the southern facade quite well.

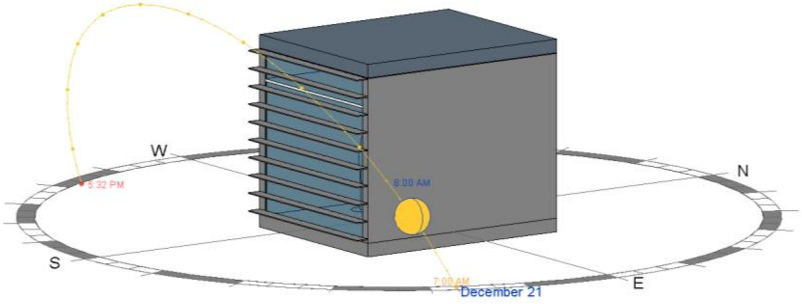

Figure 3.11: Sun path around the model (December 21)

3.8.Simulation Scenarios

In this section of the chapter, the author will explain the various design scenarios that the research will undertake.

3.8.1. Base Case Scenario

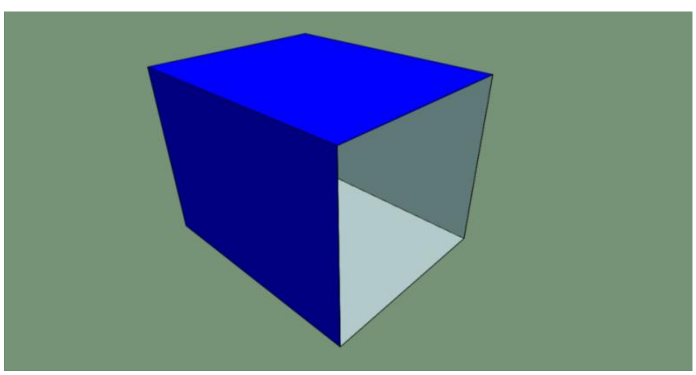

Figure 3.12: Base Case Scenario

The first scenario is the base case scenario where no louvers are used. The author will analyze the office in terms of daylight and glare for the three days (21st March, 21st June and 21st December) facing all four orientations.

The results of this scenario are very important as they will be the reference base for the following scenarios. The aim of simulating the model without any shading louvers is to compare the daylight and glare performance with and without the dynamic shading louvers under the same time and conditions. This will enable the author to decide the best options among all cases and will allow the author to know to what extent can dynamic shading louvers optimize the daylight performance.

3.8.2. Scenario1: South Orientation

A. W/S=0.5

In this scenario, the author will be using W=0.2 and S=0.4 to represent W/S=0.5, as shown conceptually in Figure 3.13. The glazed wall of the model will be facing South and horizontal louvers will be used, as shown in Figure 3.14.

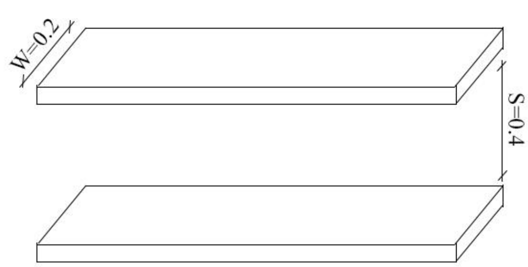

Figure 3.13: Conceptual illustration of W/S=0.5

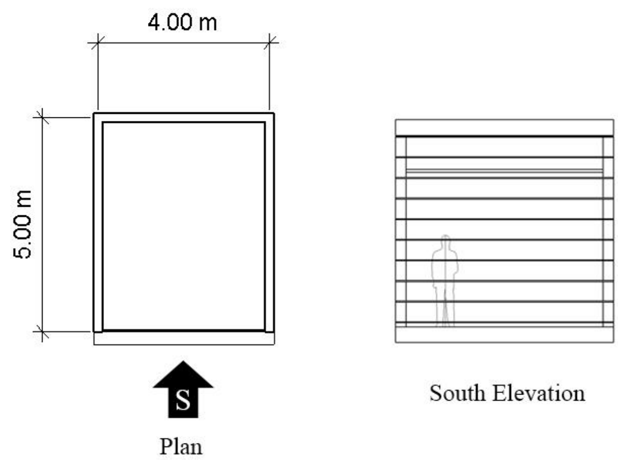

Figure 3.14: Plan and Elevation of South Orientation

The model will be analyzed first on 21st of March in terms of daylight (DUD% and DSE%). The simulations will take place 7 times for a certain given time. For instance, at time t=08:00, the author will simulate angles -60°, -40°, -20°, 0°, 20°, 40°, and 60° to determine the optimal angle among them in terms. Similarly, the optimal angles will be determined for the other specified times (10:00, 12:00, 14:00, 16:00) within day 21st of March.

After obtaining the optimal daylight angles for each time of the day, the author will perform a glare analysis to compare Glare levels between the base case scenario where no louvers are used and the optimal scenario obtained from daylight analysis.

The same process will be repeated for both 21st of June and 21st of December and by the end of the simulation process, the author will generate a table showing the best configuration for the southern facade using W/S=0.5.

b. W/S=1.0

The same process mentioned in point (a) will be repeated but using W/S=1.0, that is W=0.2, and S=0.2, as shown in Figure 3.15.

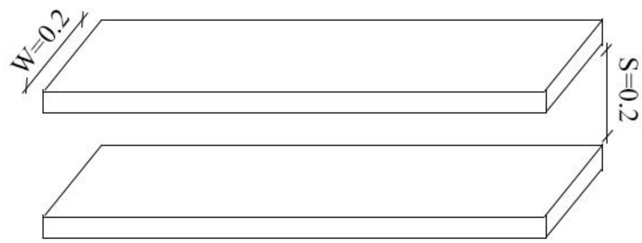

Figure 3.15: Conceptual illustration of W/S=1.0

3.8.3. Scenario 2: North Orientation

For North orientation, the author will be using the same W/S which are 0.5 and 1.0. However, due to the less sunlight penetration in this orientation compared to the other orientations, the author will be evaluating the daylight and glare performance in 21st of June only. The reason of doing so is because on 21st of March and 21st of December the sun path leans towards the south. Additionally, vertical louvers will be used for this scenario, as shown in Figure 3.16

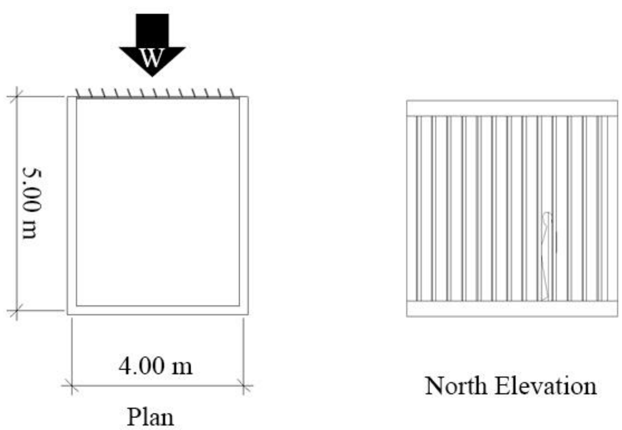

Figure 3.16: Plan and Elevation of North Orientation

3.8.4. Scenario 3: East Orientation

In this scenario, the author will be repeating the same process explained for South orientation to conduct the daylight and glare analysis. However, in this case the building will be facing East and vertical louvers will be used, as shown in Figure 3.17.

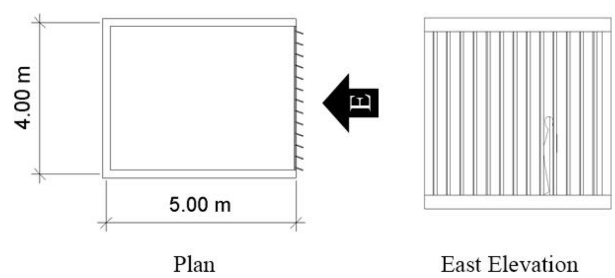

Figure 3.17: Plan and Elevation of East Orientation

3.8.5. Scenario 4: West Orientation

In the last scenario, the author will be evaluating the daylight and glare performance in the western side of the office, as shown in Figure 3.18

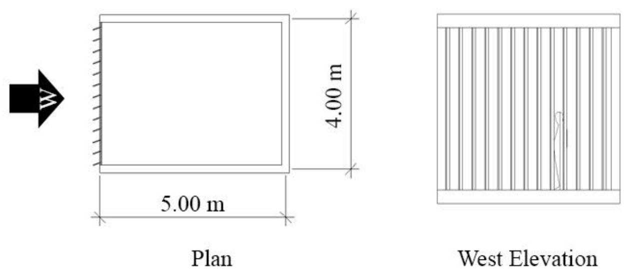

Figure 3.18: Plan and Elevation of West Orientation

3.8.6. Fixed shading louvers

At the end of each scenario, the author will conduct a comparison in daylight analysis (DUD% and DSE%) for the base case scenario, the dynamic shading louvers, and the fixed shading louvers. The average DUD% for each configuration will be calculated and the ultimate configuration that provides the maximum average DUD% and the minimum average DS% will be selected as the best configuration among all three configurations for that specific time and date

3.8.7. Performance Assessment Criteria

- Daylight Assessment

As mentioned earlier, the author will be assessing the results based on Dynamic Useful Daylight (DUD), Dynamic Sunlight Exposure (DSE). The best tilt angles for each day and time will be the ones that achieve the maximum DUD (lux range 500-1000 lux) and the minimum DSE (over 1000 lux) taking into account the glare occurrence probability that may lead to occupants' discomfort. That means that the main concern is assessing DUD% available in a certain scenario and complementing that with achieving the minimum DSE and glare.

It is important to specify a performance assessment criteria to assess the author while evaluating the results in terms of optimal and non-optimal scenarios.

In this regards, it is important to note that the author has specified 5% of the work plane area as an acceptable limit for DSE. Meaning, 0% DSE is an optimal dynamic sunlight exposure which means that 0% of the work plane area receives over 1000 lux under specific conditions. Furthermore, DSE of up to 5% will be considered as acceptable in this study since it allows minimal penetration of direct sunlight. Moreover, DSE percentages that fall between 5% to 10%will be considered as high and any DSE that is above 10% will be considered as excessive DSE, thus, not acceptable, as explained in Table 3.5.

However, this developed criteria will only act as a general guideline but will not necessarily be applied for every single scenario. Some scenarios might not follow the developed guideline for special reasons that will be justified, if such cases occur.

Table 3.5: DSE Assessment Criteria

DSE (% of work plane area)	DSE Assessment
0%	**Optimal DSE**
1%-5%	**Acceptable DSE**
5%-10%	**High DSE (can be acceptable sometimes, depending on the case)**
>10%	**Excessive DSE (Not Acceptable)**

Although both analysis (daylight and glare) are important in providing better indoor environments in terms of visual comfort, unfortunately, it is not always possible to achieve the optimal solutions for both analysis under the same circumstances. Thus, clear assessment criteria has to be defined to choose the most suitable solution.

- Glare Assessment

Since the glazing part of the office is expected to have the highest glare occurrence compared to the internal surfaces, the author will be comparing basically the luminance levels on the glazing in the base case scenario with the luminance levels on the glazing in the optimal design configuration that is obtained from the daylight analysis.

The used engine for glare analysis will be (Radiance) in which luminance levels will be compared and presented in photorealistic images. The lower the luminance level occurring on the glazing the better since it will create less contrast between the glazing and the internal surfaces, thus, minimize the glare.

4. CHAPTER 4: DISCUSSIONS AND FINDINGS

In this chapter, the findings and results of the simulation will be analyzed and discussed.

4.1.South Orientation

In this section, the author will include the daylight and glare analysis results for the southern orientation for the three preselected days with fixed shading louvers, dynamic shading louvers and without any shading louvers.

4.1.1. Daylight and Glare Analysis for March 21, W/S=0.5

- **Daylight Analysis:**

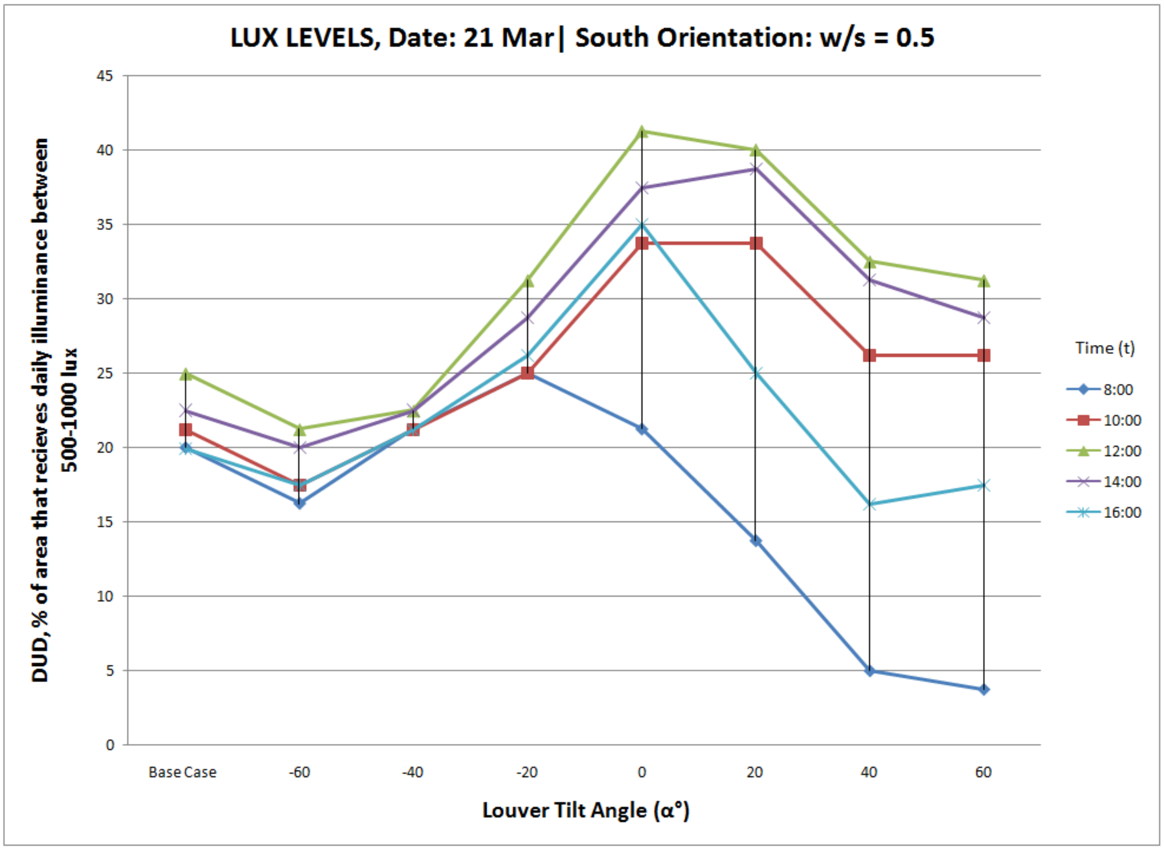

Figure 4.1: DUD analysis, 21 Mar, w/s=0.5 (South)

[RS1]

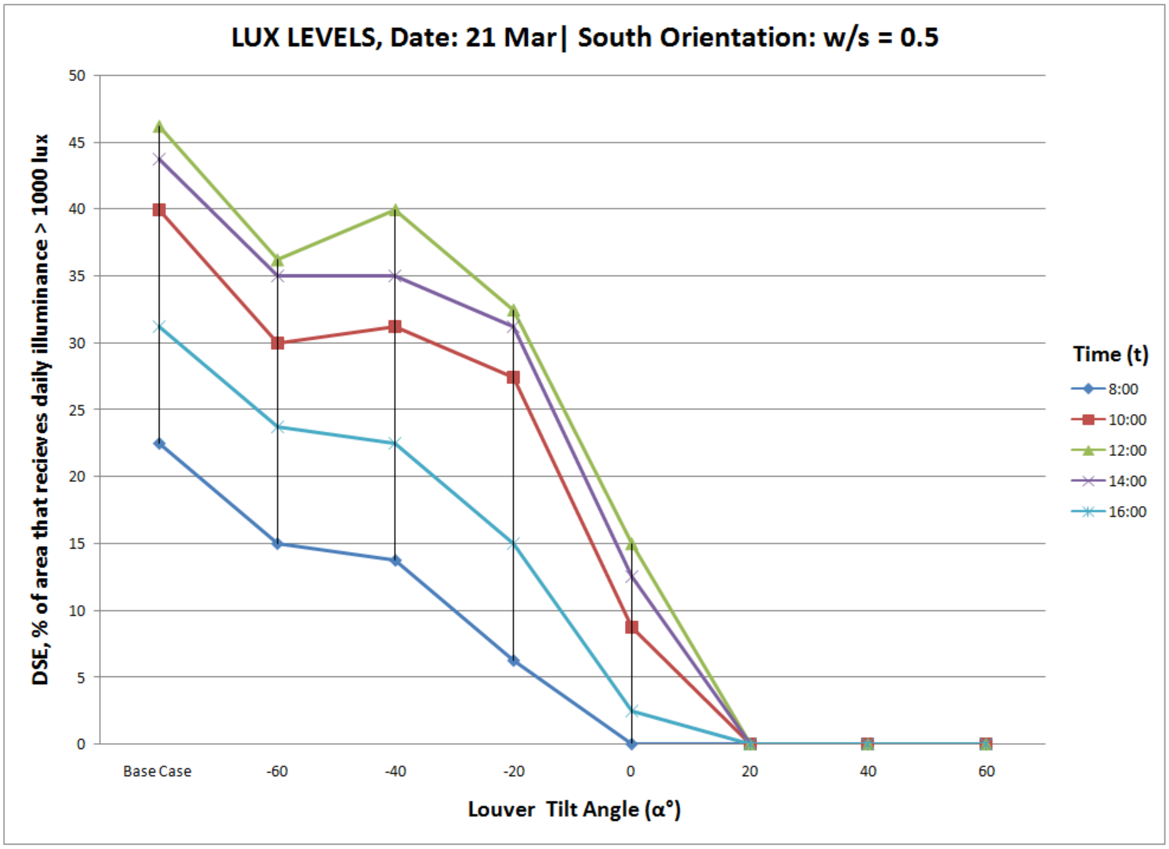

Figure 4.2: DSE analysis, 21 Mar, w/s=0.5 (South)

Figure 4.1 and Figure 4.2 show the daylight results for 21 March using w/s=0.5 for the south orientation. In the discussion below, the author will demonstrate the base case scenario versus the optimal angle for each time of the day (Dynamic shading louvers).

Discussion:

As seen, at t=08:00, the maximum percentage of the work plane area that receives illuminance levels between 500-1000 lux (DUD%) is 25% and it occurs at α=-20° compared to DUD% of 20% only, in the base case scenario. Moreover, at the same time and angle, the percentage of the work plane area that receives more than 1000 lux (DSE%) is 6% compared to 22.5%, in the base case scenario.

As noticed, 6% does not represent the optimal DSE percentage, however, the author will still be considering α=-20° to be the optimal angle since DSE of 6%is slightly above the acceptable limit, as per the pre-defined assessment criteria.

Although DSE percentages at α=0°, α=20°, α=40° and α=60° are 0%, the DUD percentages at these angles are not the maximum and the author, in this case, is prioritizing the maximum DUD%. Figure 4.3and Figure 4.4 show the 3D illustration of the optimal angle (α= -20°) using W/S=0.5 and the illuminance levels for t=08:00 at the optimal angle, respectively.

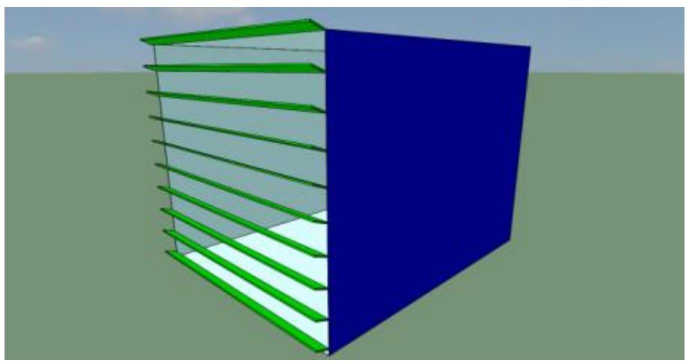

Figure 4.3: 3D Model of the optimal angle (α=-20°) at t=08:00 on 21 Mar (W/S=0.5, South)

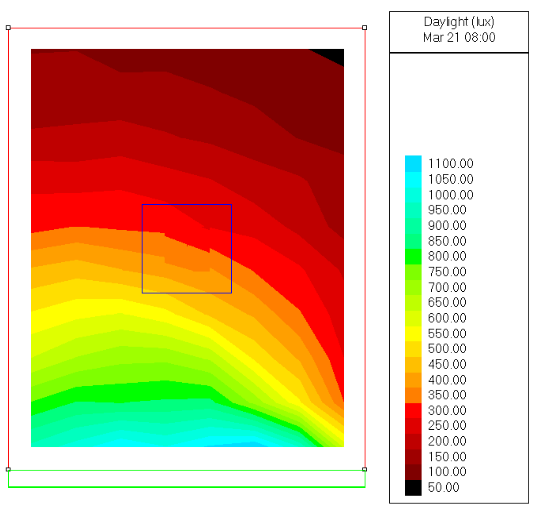

Figure 4.4: Illuminance levels for t=08:00, α=-20, Mar 21, W/S=0.5, South

Additionally, at t=10:00, angles α=0° and α=20° achieve the same percentage of DUD , that is 34%, which represents the maximum dynamic useful daylight (DUD%) among all angles and the base case scenario. However, the percentage of the dynamic sunlight exposure (DSE%) differ for each angle as it is 9% at α=0° and 0% at α=20° which makes α=20° the optimal angle for t=10:00 since it achieves the lowest DSE%.

When compared to the base case scenario at t=10:00, DUD% equals to 21% which is less than DUD% at α=20° and DSE% equals to 40% which is too high and can cause excessive sunlight exposure. Figure 4.5and Figure 4.6 show the 3D model of the optimal angle (α=20°) using W/S=0.5 and the Illuminance levels for t=10:00 at angle 20, respectively.

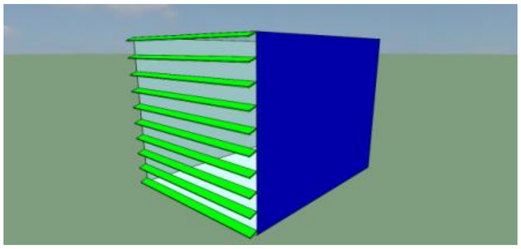

Figure 4.5: 3D Model of the optimal angle (α=20°) at t=10:00 on 21 Mar (W/S=0.5, South)

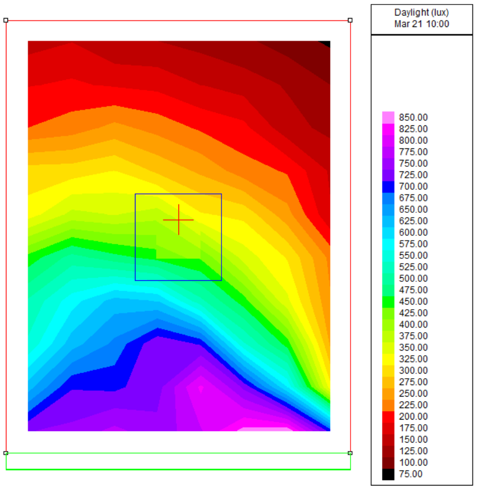

Figure 4.6: Illuminance levels for t=10:00, α=20, Mar 21, W/S=0.5, South

Also, at t=12:00, the maximum percentage of DUD is 41% and occur at α=0° but the percentage of DSE at α=0° is 15%, which is too high and can lead to increased energy demand for cooling. Thus, the author is choosing α=20° to be the optimal angle instead of α=0° since it has slightly lower DUD percentage which equals to 40% but DSE% of 0%. However, when comparing the results of α=20° to the base case scenario, DUD% without louvers equals to 25% only which is less than DUD% at α=20° and DSE% equals to 46%, which is too high compared to the optimal angle. Figure 4.7 shows the Illuminance levels for t=12:00 at α=20°.

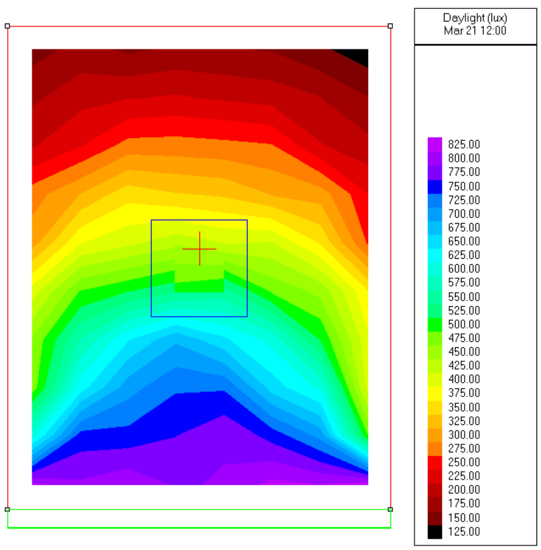

Figure 4.7: Illuminance levels for t=12:00, α=20, Mar 21, W/S=0.5, South

Furthermore, at t=14:00, the maximum percentage of DUD happens to be at α=20° which is 39% and the minimum percentage of DSE is (0%) at the same angle which makes it the optimal angle for this particular time of the day. When compared to the base case scenario, DUD% equals to 22.5% and DSE% equals to 44% which are far from being optimal. Figure 4.8 shows the illuminance levels at t=14:00 and α=20°.

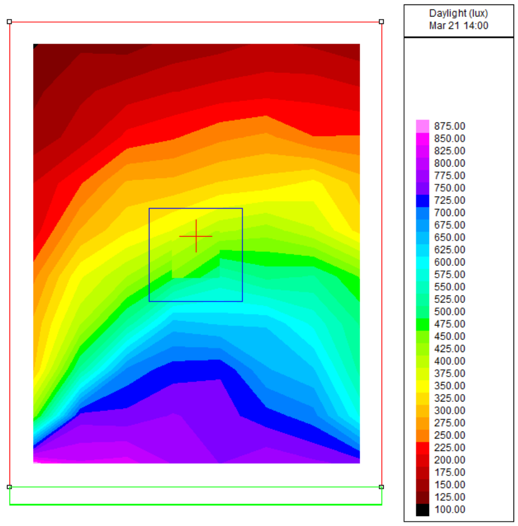

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Figure 4.8: Illuminance levels for t=14:00, α=20, Mar 21, W/S=0.5, South

Finally, at t=16:00, the maximum DUD percentage occurs at α=0° which is 35% compared to the base case scenario where the DUD percentage is 20% only. On the other hand, the percentage of DSE% at α=0° is 2.5% which is within the acceptable range, compared to DSE% in the base case scenario which is 31%. Figure 4.9and Figure 4.10show 3D model and illuminance levels at t=16:00 and α=0°, respectively.

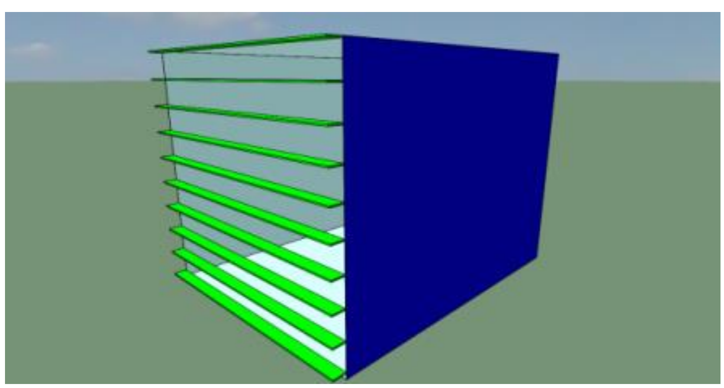


Figure 4.9: 3D Model of the optimal angle (α= 0°) at t=16:00 on 21 Mar (W/S=0.5, South)

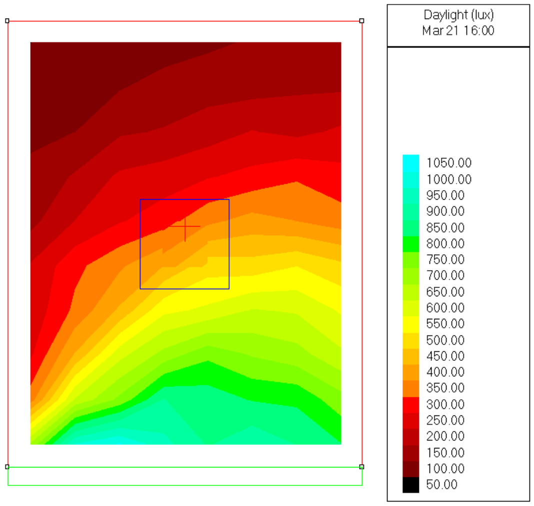


Figure 4.10: Illuminance levels for t=16:00, angle 0, Mar 21, W/S=0.5, South

As observed, in the base case scenario, dynamic sunlight exposure (DSE) percentages at all times hit the maximum among all other cases where shading louvers are used. The reason is because the office is more exposed to direct sunlight as opposed to having shading louvers which minimize the penetration of direct sunlight ,thus, minimize DSE percentages.

So far, the scenarios where dynamic shading louvers are used are much better in terms of daylight performance than the case where no louvers are used since the presence of shading louvers block most of the direct sunlight while allowing useful daylight penetration. Fixed shading louvers, however, have different daylight results as will be shown in the comparison tables in Table 4.1 and Table 4.2.

Findings:

Table 4.1: Daylight analysis (Average DUD%) - March 21, South (W/S=0.5)

Dynamic Useful Daylight Analysis (DUD%) - March 21, South (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	20%	16%	21%	25%	21%	14%	5%	4%
10:00	21%	17.5%	21%	25%	34%	34 %	26%	26%
12:00	25%	21%	22.5%	31%	41%	40%	32.5%	31%
14:00	22.5%	20%	22.5%	29%	37.5%	38%	31%	29%
16:00	20%	17.5%	21%	26%	35%	25%	16%	17.5%
Avg. DUD%	**22%**	**18%**	**22%**	**27%**	**34%**	**30%**	**22%**	**22%**
Time (t)	Same as Above	Dynamic shading louvers at the Optimal Angles(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00				25%				
10:00						34%		
12:00						40%		
14:00						39%		
16:00					35%			
Avg. DUD%		**35%**						

Table 4.2: Daylight analysis (Average DSE%) - March 21, South (W/S=0.5)

Dynamic Sunlight Exposure Analysis (DSE%) - March 21, South (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	22.5%	15%	14%	6%	0%	0%	0%	0%
10:00	40%	30%	31%	27.5%	9%	0%	0%	0%
12:00	46%	36%	40%	32.5%	15%	0%	0%	0%
14:00	44%	35%	35%	31%	12.5%	0%	0%	0%
16:00	31%	24%	22.5%	15%	2.5%	0%	0%	0%
Avg. DSE%	**37%**	**28%**	**29%**	**22%**	**8%**	**0%**	**0%**	**0%**
Time (t)	Same as Above	Dynamic shading louvers at the Optimal Angles (α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00				6%				
10:00						0%		
12:00						0%		
14:00						0%		
16:00					2.5%			
Avg. DSE%		**2%**						

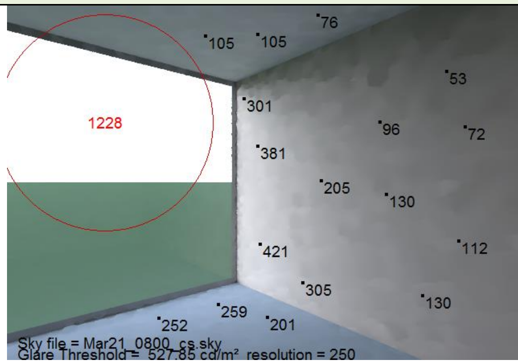
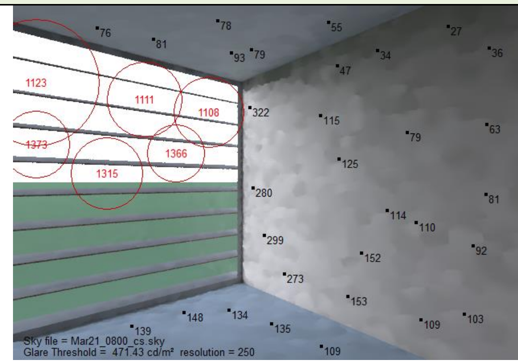
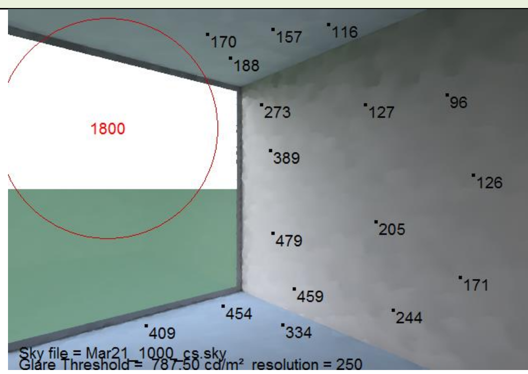
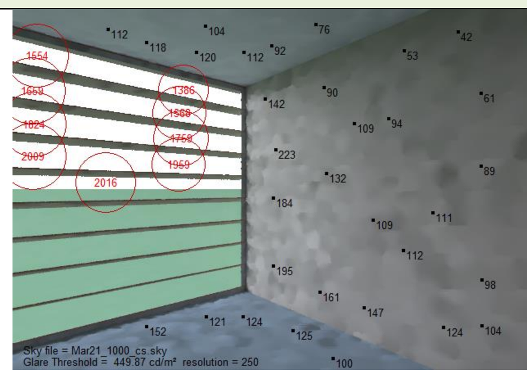
Table 4.1 shows that the average Dynamic Useful Daylight (DUD%) in the base case scenario is 22% only compared to 35% when using dynamic shading louvers. Moreover, when using fixed shading louvers at α=0°, the average DUD% is 34% which is very close to the average DUD% when using dynamic shading louvers. However, the average DSE% in Table 4.2 shows that the average DSE% using dynamic shading louvers is 2% compared to 8% when using fixed shading louvers at α= 0°.

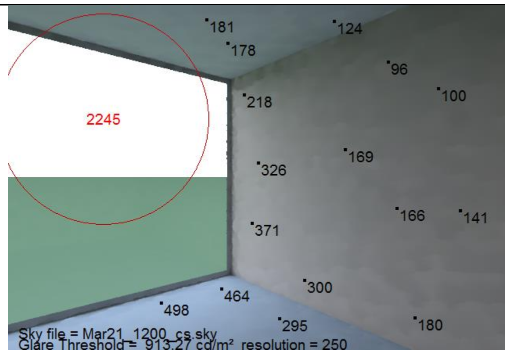
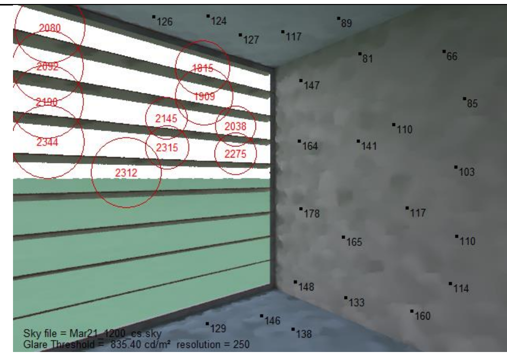
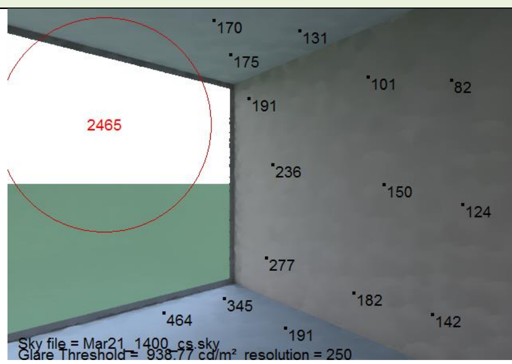
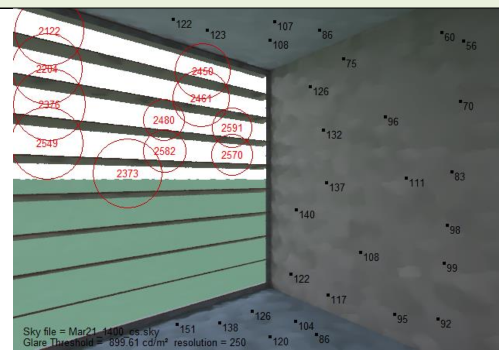
Also, although the average DSE% at α=20°, α=40° and at α=60° is 0%, the average DUD% at these angles do not represent the maximum average DUD%. Thus, using dynamic shading louvers of W/S=0.5 in 21st March (south) is the best option among all other options in terms of daylight performance.

- Glare Analysis

Since using dynamic shading louvers is the best option for this specific scenario, as concluded from the daylight analysis section. In this section, the author will be comparing the glare analysis of the dynamic shading louvers at the optimal angles against the glare analysis in the base case scenario to emphasis the effectiveness of the system, as shown in Table 4.3.

Table 4.3: Summary of the Glare Analysis - Mar 21, South (W/S=0.5)

Glare Analysis for March 21, South (W/S=0.5)		
t=08:00	**Base Case**	**Dynamic Shading Louvers (α=-20°)**
		
t=10:00	**Base Case**	**Dynamic Shading Louvers (α=20°)**
		
t=12:00	**Base Case**	**Dynamic Shading Louvers (α=20°)**

<table>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers (α=20°)</td></tr>
<tr><td></td><td>
</td><td>
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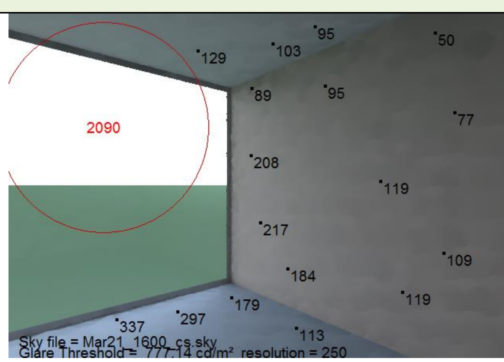
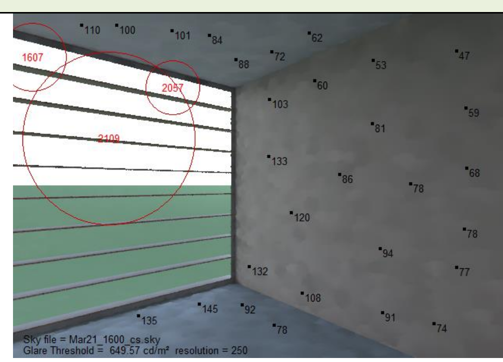
<tr><td>t=16:00</td><td>Base Case</td><td>Dynamic Shading Louvers (α=0°)</td></tr>
<tr><td></td><td>
</td><td>
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Discussion:

The red circles shown in the figures in Table 4.3 represent the glare spots. As noticed, the glare is always present on the glazing in both the base case scenario and the dynamic shading louvers scenario due to the high luminance resulted from the sky and sun lights. Also, it can be noticed that the luminance on the glazing start to increase from the early morning until t=14:00 where it starts to decrease afterwards due to the position of the sun at this time of the day. However, the luminance levels on the internal surfaces drop in all cases where dynamic shading louvers are used as opposed to the base case scenario where higher luminance levels are shown.

At t=08:00, uniform luminance of 1228 cd/m2is shown on the glazing in the base case scenario compared to the dynamic shading louvers where the luminance levels vary and can reach as minimum as 1108 cd/m2.

Similarly, at t=10:00, uniform luminance of 1800 cd/$m^2$is shown on the glazing in the base case scenario. On the other hand, when using dynamic shading louvers, the luminance levels vary and can reach as low as 1386 cd/m2.

Moreover, at t=12:00, the luminance level on the glazing in the base case scenario is 2245 cd/m2 compared to various luminance levels at the optimal tilt angle at this time where the luminance can drop to as low as 1815 cd/m2.

Furthermore, at t=14:00, the glare on the glazing in the base case scenario is resulted due to the high luminance of 2465 cd/m2. However, when using dynamic shading louvers at α=20° the luminance levels on the glazing vary to reach as low as 2122 cd/m2.

Finally, at t=16:00, the luminance level on the glazing is 2090 cd/m2, in the base case scenario, compared to different luminance levels that can reach as low as 1607 cd/m2 when using dynamic shading louvers.

Findings:

Table 4.4: Glare analysis Summary - March 21, South (W/S=0.5)

	Luminance Levels on the glazing (cd/m²)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	1228	1800	2245	2465	2090	**1966**
Optimal Case	1373	2016	2344	2582	2109	**2085**

Table 4.4 shows the summary of the glare analysis for March 21 using W/S=0.5 on the southern orientation. The glare analysis shown is for the glazing part of the room only. Since the luminance levels varies with the presence of the shading louvers, in the optimal cases, the maximum luminance level is taken into consideration for comparison purposes.

Table 4.4 shows that the average luminance level in the base case scenarios is 1966 cd/m2 compared to 2085 cd/m2 in the optimal cases, in Day March 21.

Although the average luminance level on the glazing is higher in the optimal cases, the author will still be considering the optimal cases as the best shading configurations since they provide the maximum daylight performance which is more important, in this study. Moreover, it is important to note that the glare is a subjective measure which varies in terms of satisfaction from a person to another.

4.1.2. Daylight and Glare Analysis for June 21, W/S=0.5

- **Daylight Analysis:**

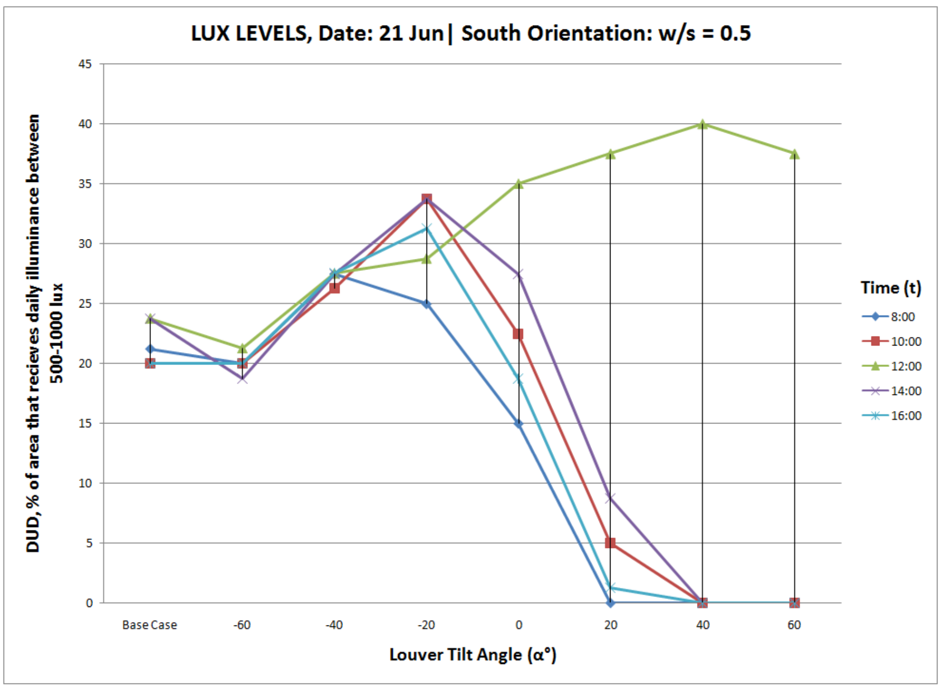


Figure 4.11: DUD analysis, 21 Jun, w/s=0.5 (South)

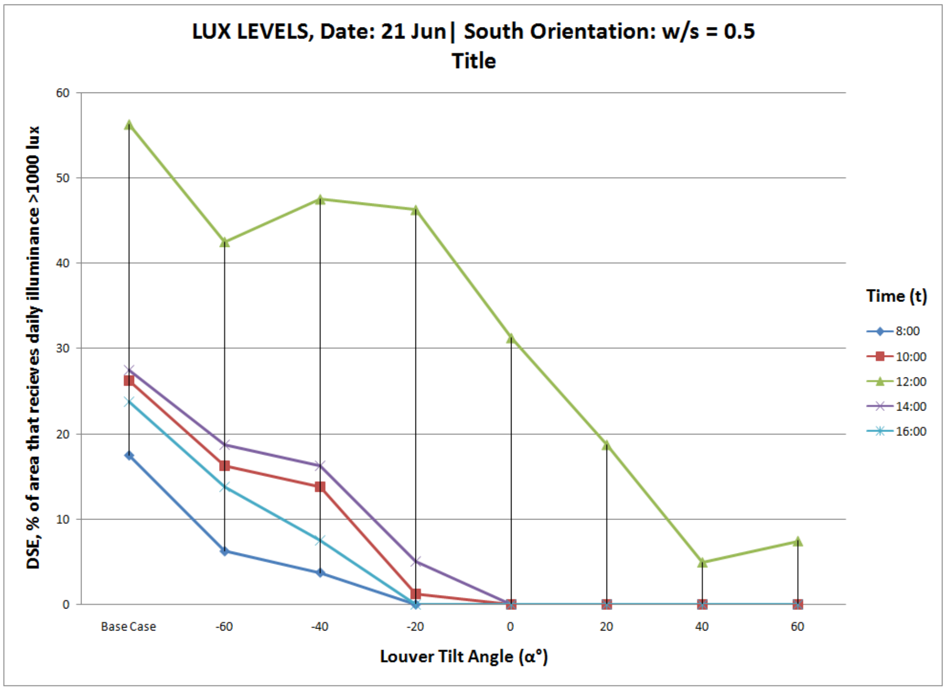


Figure 4.12: DSE analysis, 21 Jun, w/s=0.5 (South)

Figure 4.11 and Figure 4.12 show the daylight analysis for the southern orientation using W/S=0.5 on 21st of Jun.

Discussion:

At t=08:00 and α=-40°,Figure 4.11 shows that the dynamic useful daylight percentage (DUD%) is 27.5% which is the maximum DUD among all angles compared to the base case scenario where DUD% is 21%. Moreover, at the same angle and time, DSE percentage is 4% which is within the acceptable range compared to the base case scenario which has DSE% of 17.5%. Thus, the optimal angle for t=08:00 is α=-40°. Figure 4.13 and Figure 4.14 show the 3D model of the optimal angle (-40°) and the illuminance levels at t=08:00 and α=-40°, respectively.

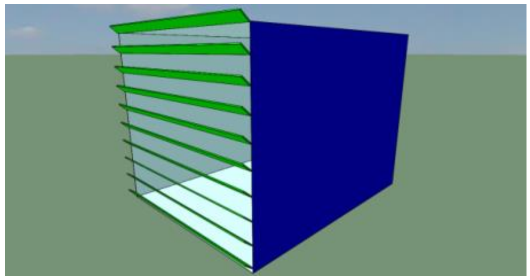


Figure 4.13: 3D Model of the optimal angle (α=-40°) at t=08:00 on 21 Jun (W/S=0.5, South)

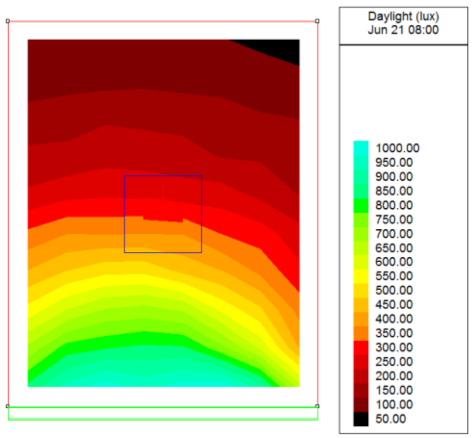


Figure 4.14: Illuminance levels for t=08:00, α=-40, Jun 21, W/S=0.5, South

At t=10:00, the maximum percentage of DUD occurs at α=-20° and it equals to 34% of the work plane area compared to the base case scenario where DUD% equals to 20% only. Moreover, at the same time and angle, DSE percentage equals to 1% which is very close to the optimal value of DSE (0%) compared to the base case scenario which has DSE% of 26%.

Thus, α=-20° is the optimal angle for t=10:00 using W/S=0.5 in June 21. Figure 4.15and Figure 4.16 show the 3D illustration of the optimal angle and the illuminance levels, respectively.

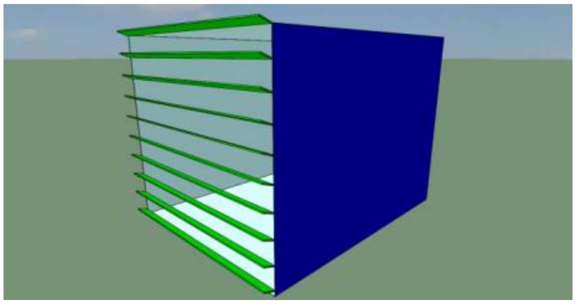


Figure 4.15: 3D Model of the optimal angle (α= -20°) at t=10:00 on 21 Jun (W/S=0.5, South)

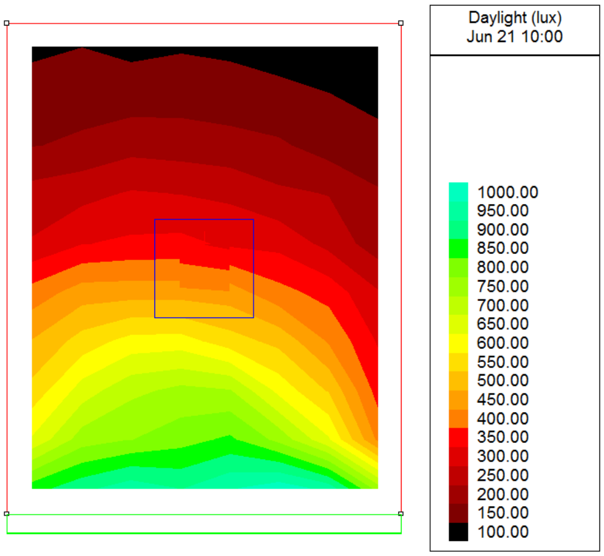


Figure 4.16: Illuminance levels for t=10:00, α=-20, Jun 21, W/S=0.5, South

Additionally, at t=12:00, the maximum DUD percentage occurs at α=40° and it equals to 40% of the work plane area compared to DUD of 24% that occurs in the base case scenario. On the other hand, DSE percentage equals to 5% only at the same time and angle which is within the acceptable range as opposed to DSE of 56% that occurs in the base case scenario.

Thus, α=40° is the optimal angle for t=12:00.Figure 4.17and Figure 4.18 show the 3D model of the optimal angle and the illuminance levels, respectively.

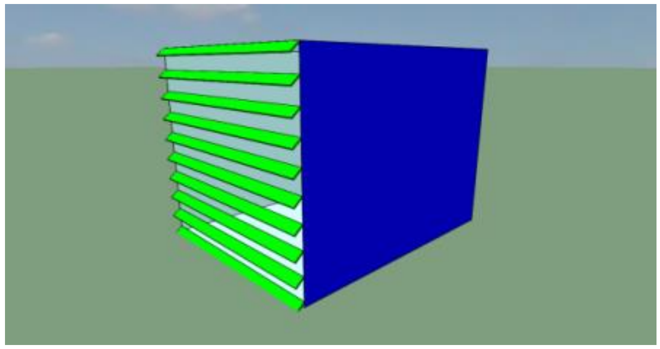


Figure 4.17: 3D Model of the optimal angle (α=40°) at t=12:00 on 21 Jun (W/S=0.5, South)

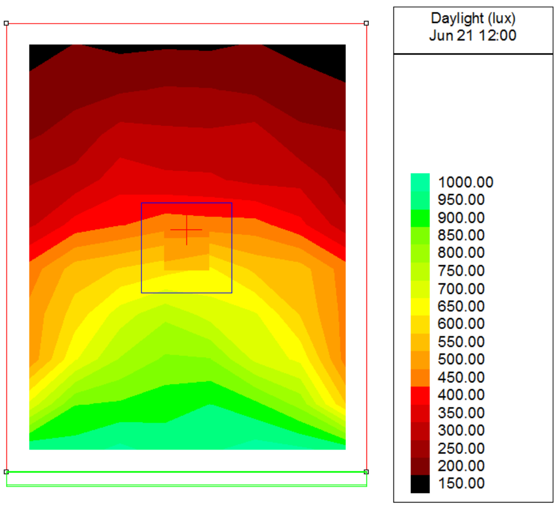


Figure 4.18: Lux levels for t=12:00, α=40, Jun 21, W/S=0.5, South

Similar to t=10:00, at t=14:00, the maximum DUD% occurs at α=-20° and it equals to 34% compared to DUD% of 24% in the base case scenario. However, the percentage of DSE is slightly higher than DSE% at t=10:00 since it equals to 5% compared to DSE% of 27.5% in the base case scenario for the same time. Since DSE% of 5% falls within the acceptable range, α=-20° can be recommended to be the optimal angle at t=14:00. Figure 4.19shows the illuminance levels at t=14:00 and at the optimal angle (α=-20).

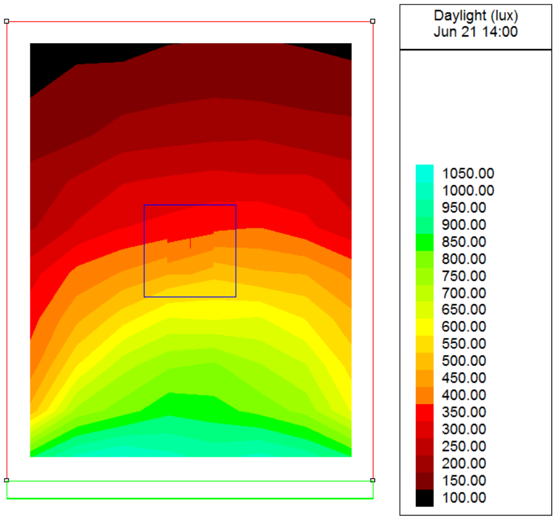


Figure 4.19: Illuminance levels for t=14:00, α=-20, Jun 21, W/S=0.5, South

Finally, at t=16:00, the maximum DUD% occurs at α=-20° and it equals to 31% compared to DUD% of 20% only in the base case scenario. Moreover, the Dynamic Sunlight Exposure (DSE%) at α=-20° equals to 0%, which is the optimal DSE value, compared to DSE% of 24% in the base case scenario which is too high.

Thus, α=-20° is the optimal angle for t=16:00 and Figure 4.20 shows the illuminance levels for the same.

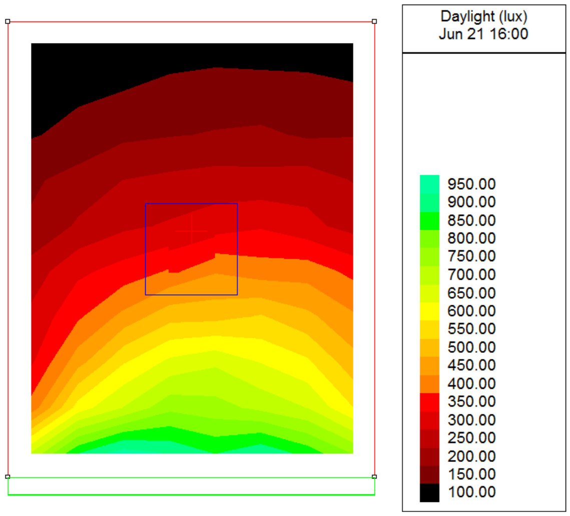


Figure 4.20: Illuminance levels for t=16:00, α=-20, Jun 21, W/S=0.5, South

As mentioned before, the horizontal louvers facing upwards are the ones with negative angles (-60,-40 and -20) whereas the horizontal louvers facing downwards are the ones with positive angles (60, 40 and 20). Thus, the results shown in Figure 4.12 are reasonable since the DSE values decreases as the louvers angles tilt downwards because since are indirectly exposed to sunlight as opposed to the ones facing upwards which have a direct exposure to sunlight.

Findings:

Table 4.5: Daylight analysis (Average DUD%) - June 21, South (W/S=0.5)

Dynamic Useful Daylight Analysis (DUD%) - June 21, South (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	21%	20%	27.5%	25%	15%	0%	0%	0%
10:00	20%	20%	26%	34%	22.5%	5%	0%	0%
12:00	24%	21%	27.5%	29%	35%	37.5%	40%	37.5%
14:00	24%	19%	27.5%	34%	27.5%	9%	0%	0%
16:00	20%	20%	27.5%	31%	19%	1%	0%	0%
Avg. DUD%	**22%**	**20%**	**27%**	**31%**	**24%**	**11%**	**8%**	**7.5%**
Time (t)	Same as Above	Dynamic shading louvers at the Optimal Angles (α°)						
		-60	-40	-20	0	20	40	60
8:00			27.5%					
10:00				34%				
12:00							40%	
14:00				34%				
16:00				31%				
Avg. DUD%		**33%**						

Table 4.6: Daylight analysis (Average DSE%) - June 21, South (W/S=0.5)

Dynamic Sunlight Exposure Analysis (DSE%) - June 21, South (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	17.5%	6%	4%	0%	0%	0%	0%	0%
10:00	26%	16%	14%	1%	0%	0%	0%	0%
12:00	56%	42.5%	47.5%	46%	31%	19%	5%	7.5%
14:00	27.5%	19%	16%	5%	0%	0%	0%	0%
16:00	24%	14%	7.5%	0%	0%	0%	0%	0%
Avg. DSE%	**30%**	**20%**	**18%**	**10%**	**6%**	**4%**	**1%**	**1.5%**
Time (t)	Same as Above	Dynamic shading louvers at the Optimal Angles (α°)						
		-60	-40	-20	0	20	40	60
8:00			4%					
10:00				1%				
12:00							5%	
14:00				5%				
16:00				0%				
Avg. DSE%		**3%**						

Table 4.5 shows that the average DUD% when using dynamic shading louvers is 33% compared to the average DUD% in the base case scenario where it is 22% only. Moreover, using dynamic shading louvers for this scenario proved that the system can achieve the maximum DUD% among all the cases where fixed shading louvers are used at different angles.

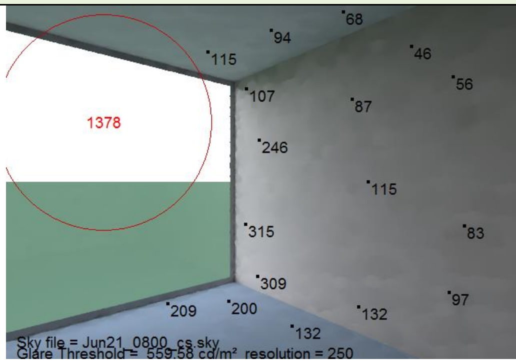
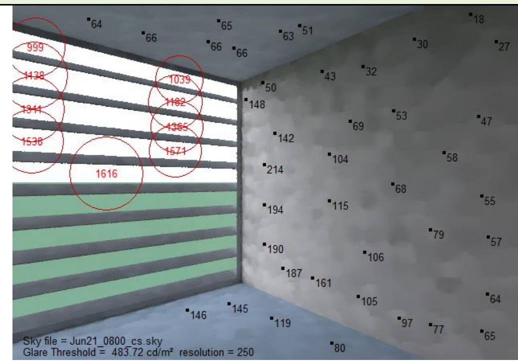
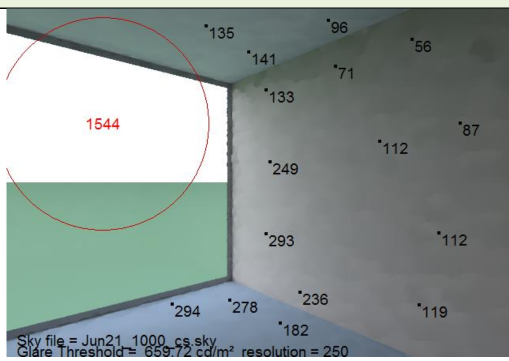
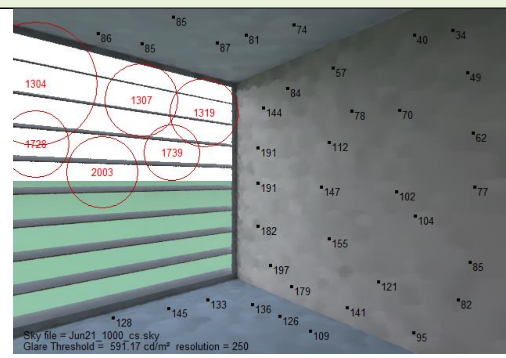
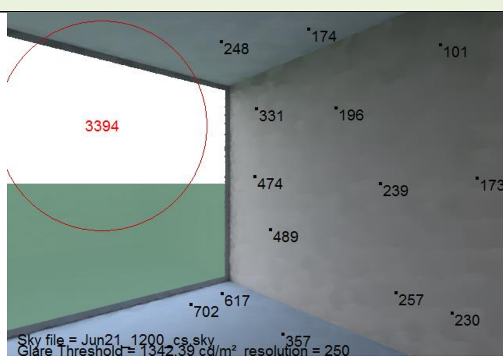
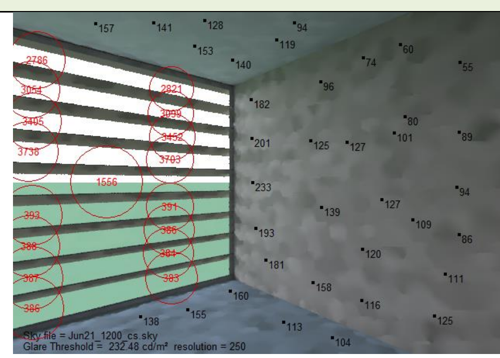
Additionally, the average DSE% when using dynamic shading louvers equals to 3% compared to DSE% of 30%in the base case scenario, as shown in Table 4.6. Although using fixed shading louvers at α=40° and α=60° have lower DSE% which are1% and 1.5%, respectively, DUD% at these angles are 8% and 7.5%, respectively. Thus, using fixed shading louvers at α=40° and α=60° cannot be accepted since they allow little useful daylight.

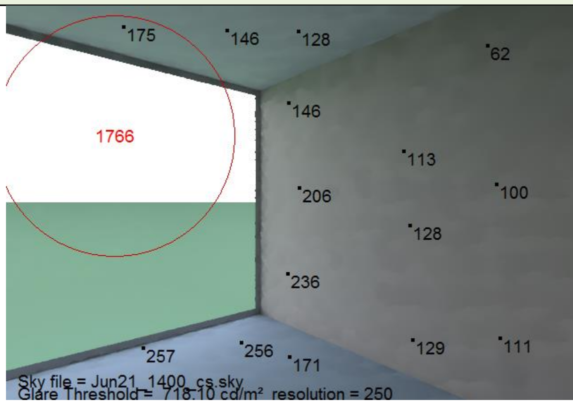
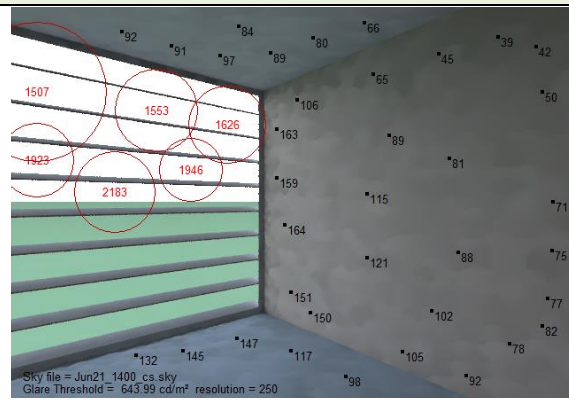
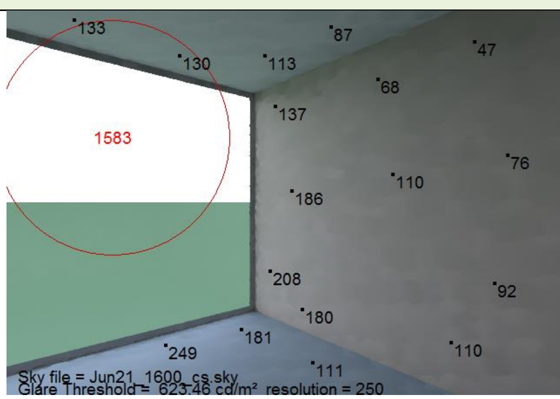
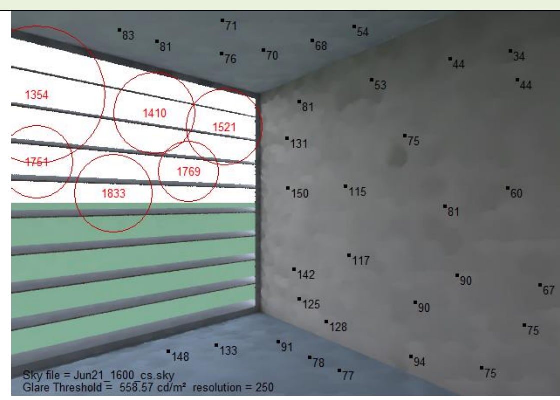
In conclusion, using dynamic shading louvers of W/S=0.5 in 21st June (south) is the best option among all other options in terms of daylight performance.

- **Glare Analysis**

As obtained from the daylight analysis for [21 June (W/S=0.5) south], the dynamic shading louvers are the best option among all other options. In this section, the author will be comparing the glare performance in the base case scenario with the glare performance using dynamic shading louvers at the optimal angles obtained from the daylight analysis.

Table 4.7: Summary of the Glare Analysis - Jun 21, South (W/S=0.5)

<table>
<tr><th colspan="3">Glare Analysis for June 21, South (W/S=0.5)</th></tr>
<tr><td>t=08:00</td><td>Base Case</td><td>Dynamic Shading Louvers (α=-40°)</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=10:00</td><td>Base Case</td><td>Dynamic Shading Louvers (α=-20°)</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers (α=40°)</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
</table>

t=14:00	**Base Case**	**Dynamic Shading Louvers (α=-20°)**
		
t=16:00	**Base Case**	**Dynamic Shading Louvers (α=-20°)**
		

Discussion:

As shown in Table 4.7, the internal surfaces when using dynamic shading louvers at the optimal angle (α=-40°) show that they receive lower luminance range when compared to the luminance range in the base case scenario. Moreover, the luminance on the glazing in the base case scenario is more uniform and it equals to 1378 cd/m2 compared to the various luminance levels shown on the glazing when using dynamic shading louvers where the luminance can reach as low as 999 cd/m2.

In addition, at t=10:00, the table shows that the glazing, in base case scenario, has a luminance level of 1544 cd/m2 compared to luminance level range of 1304-2003 cd/m2 when using dynamic shading louvers at α=-20°, at this particular time of the day.

Moreover, at t=12:00, the table shows that the glare on the glazed wall is the highest among all the previous base case scenarios. The luminance level on the glazing, in this case, is 3394 cd/m2 compared to the various luminance levels shown in the case where dynamic shading louvers are used. The luminance levels at the optimal angle(α=40°) can reach as low as 2786 cd/m2 at the top of the glazing.

Furthermore, the glare on the glazing at t=14:00 starts to decrease as the time passes throughout the day where 1766 cd/m2 is shown on the surface compared to using dynamic shading louvers at α=-20° where the luminance levels range between 1507-2183 cd/m2.

Finally, at t=16:00, the glare on the glazing, in the base case scenario, is resulted due to the high luminance of 1583 cd/m2 compared to the luminance range of 1354-1833 cd/m2 shown in the case where dynamic shading louvers are used.

Findings:

Table 4.8: Glare analysis Summary - June 21, South (W/S=0.5)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	1378	1544	3394	1766	1583	**1933**
Optimal Case	1616	2003	3738	2183	1833	**2275**

Table 4.8 shows the luminance levels on the glazing in June 21 using W/S=0.5 on the southern orientation. The table shows that the average luminance level in the base case scenarios is 1933 cd/m2 compared to an average luminance level of 2275 cd/m2, in the optimal cases. Although the optimal cases are showing higher luminance levels, the author will be featuring daylight performance over glare performance. Thus, the optimal cases will be chosen to be the best design configuration for this particular scenario.

4.1.3. Daylight and Glare Analysis for December 21, W/S=0.5

- **Daylight Analysis**

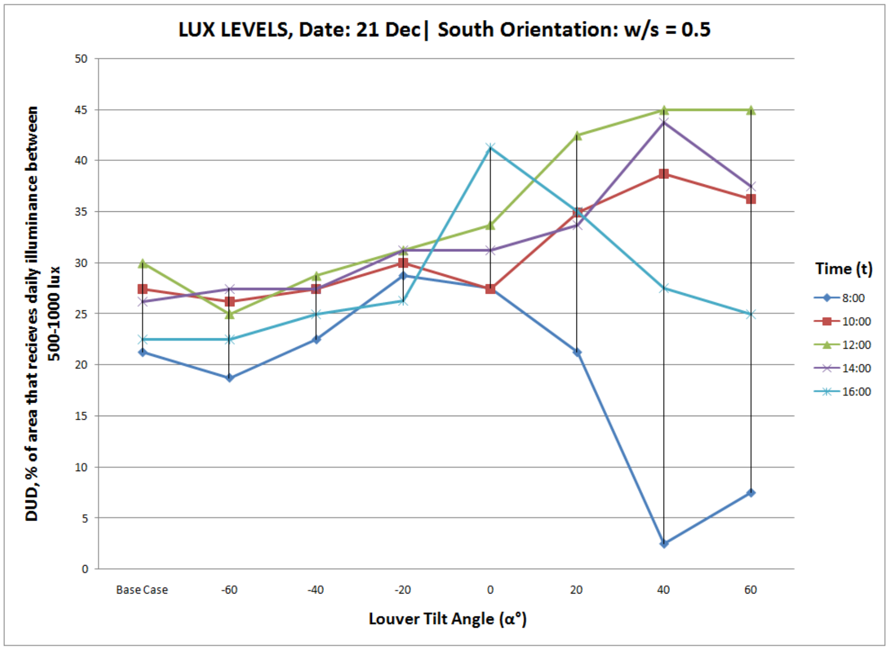


Figure 4.21: DUD analysis, 21 Dec, w/s=0.5 (South)

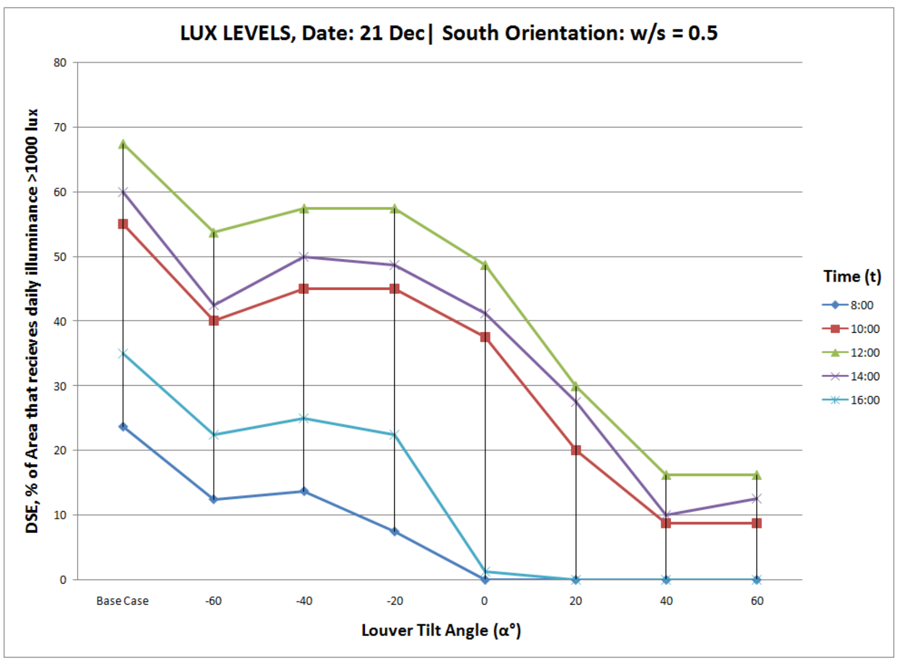


Figure 4.22: DSE analysis, 21 Dec, w/s=0.5 (South)

Figure 4.21 and Figure 4.22 show the daylight analysis in Dec 21 for W/S=0.5 in the southern orientation.

Discussion:

Due to the low sun altitude in this time of the year and due to the sun path leaning towards south, it is expected to notice more direct sunlight penetration between 10am to 2pm and minimum to no direct sunlight between 8am to 10am and 2pm to 4pm.

As shown in the figures, at t=08:00, the angle that achieves the maximum percentage of Dynamic Useful Daylight (DUD%) is α=-20° where DUD% equals to 29%. Also, at the same angle and time, the Dynamic Sunlight Exposure (DSE) percentage equals to 7.5%. However, at α=0°, DUD% equals to 27.5% and DSE% equals 0% which equals to the optimal DSE value.

Since the difference in DUD values for α=-20° and α=0° is minimal (1.5%) and the DSE value is optimal in the case of α=0°, the author is selecting α=0° to be the optimal angle for this time instead of α=-20°.Additionally, when comparing α=0° to the base case scenario, DUD% in the base case scenario equals to 21% which is less than DUD% at α=0°. Moreover, DSE% in the base case scenario equals to 24% which is much higher than DSE% at α=0°.Figure 4.23and Figure 4.24 show the 3D model for the optimal angle and the illuminance levels at t=08:00 and α=0°, respectively.

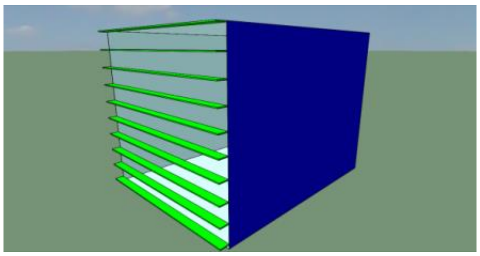


Figure 4.23: 3D Model of the optimal angle (α=0°) at t=08:00 on 21 Dec (W/S=0.5, South)

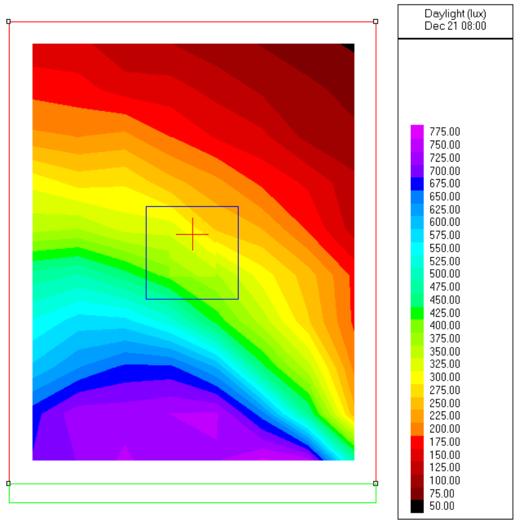


Figure 4.24: Illuminance levels for t=08:00, α=0, Dec 21, W/S=0.5, South

Moreover, at t=10:00, the maximum DUD percentage occurs at α=40° where 39% of the work plane area receives illuminance between 500-1000 lux. However, only 27.5% of the work plane area receives illuminance between 500-1000 lux, in the base case scenario. Also, at the same time and at α=40°, DSE% equals to 9% which is within the acceptable range, as per the pre-defined assessment criteria, compared to DSE% of 55% in the base case scenario.

Thus, the optimal angle for t=10:00 is α=40° which is shown in Figure 4.25. Also, Figure 4.26 shows the illuminance levels at t=10:00 using the optimal angle.

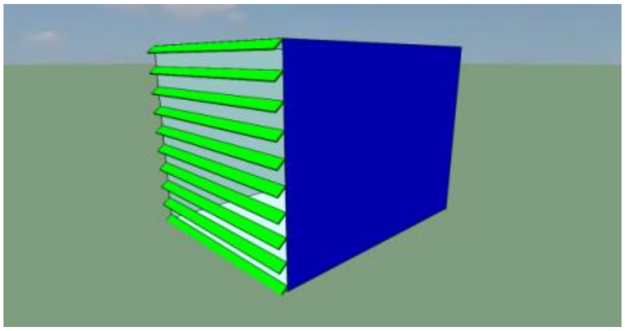


Figure 4.25: 3D Model of the optimal angle (α= 40°) at t=10:00 on 21 Dec (W/S=0.5, South)

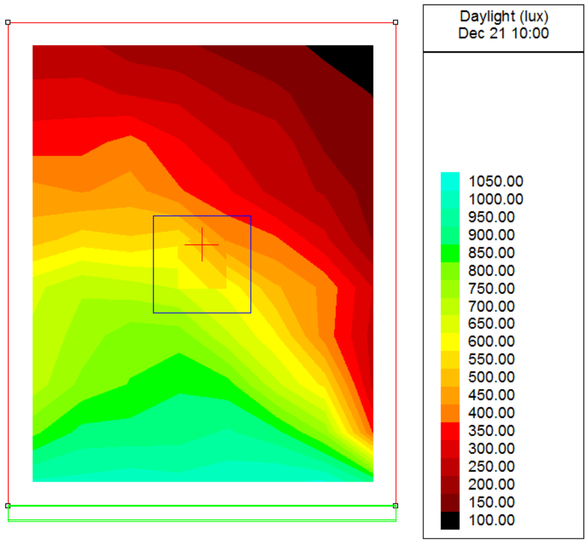


Figure 4.26: Illuminance levels for t=10:00, α=40, Dec 21, W/S=0.5, South

Similarly, at t=12:00 and t=14:00, the maximum percentages of dynamic useful daylight (DUD%) occurs at the same angle which is α=40°. However, at t=12:00, the maximum DUD% value is 45% and the maximum DUD% value for t=14:00 is 44%. Additionally, the DSE% values for this angle at t=12:00 and t=14:00 are 16% and 10%, respectively.

Although the DSE% at t=12:00 is considered excessive since it is more than 10%, it is the minimum DSE% for this time when comparing the DSE percentages for the other angles which makes 16%an acceptable DSE value, in this case.

Similarly, for t=14:00, the DSE value (10%) is considered high but will be considered acceptable in this case since it is the minimum DSE percentage among all the other angles at this time. Also, when compared to the base case scenario, the percentages of DSE% at t=12:00 and t=14:00 are 67.5% and 60%, respectively. These percentages of DSE indicate a very high sun exposure that could lead to higher energy consumption and occupants' discomfort.

Figure 4.27 shows the illuminance levels at t=12:00 and at α=40° and Figure 4.28 shows the illuminance levels for t=14:00 and at α=40°.

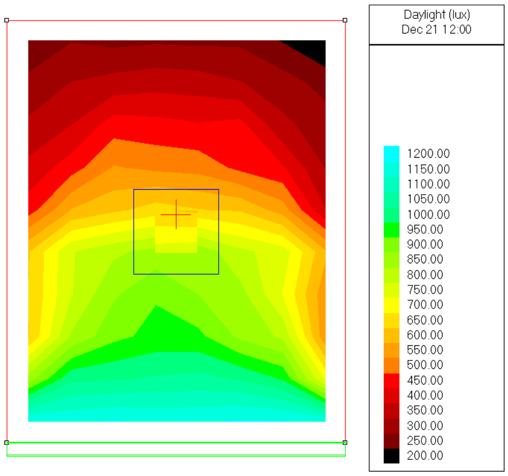


Figure 4.27: Illuminance levels for t=12:00, α=40, Dec 21, W/S=0.5, South

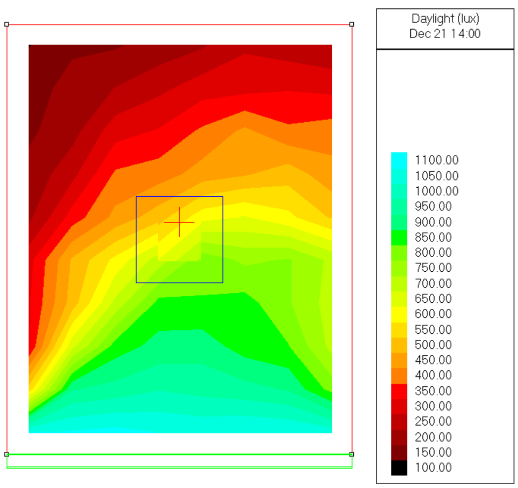


Figure 4.28: Illuminance levels for t=14:00, α=40, Dec 21, W/S=0.5, South

Finally, at t=16:00, the maximum DUD percentage occurs at α=0° and equals to 41%, whereas, the obtained DUD value for the base case scenario at the same time is 22.5% only. Also, at the same time and at α=0°, the DSE percentage is 1% which falls within the acceptable range compared to DSE percentage of 35% in the base case scenario. Figure 4.29 shows the illuminance levels for t=16:00 and at α=0°.

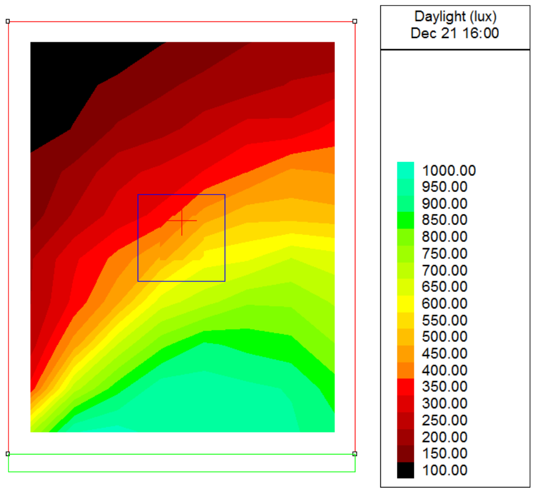


Figure 4.29: Illuminance levels for t=16:00, α=0, Dec 21, W/S=0.5, South

Findings:

Table 4.9: Daylight analysis (Average DUD%) - December 21, South (W/S=0.5)

Dynamic Useful Daylight Analysis (DUD%) - December 21, South (W/S=0.5)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	21%	19%	22.5%	29%	27.5%	21%	2.5%	7.5%
10:00	27.5%	26%	27.5%	30%	27.5%	35%	39%	36%
12:00	30%	25%	29%	31%	34%	42.5%	45%	45%
14:00	26%	27.5%	27.5%	31%	31%	34%	44%	37.5%
16:00	22.5%	22.5%	25%	26%	41%	35%	27.5%	25%
Avg. DUD%	**25%**	**24%**	**26%**	**29%**	**32%**	**34%**	**32%**	**30%**
Time (t)		**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	Same as Above				27.5%			
10:00							39%	
12:00							45%	
14:00							44%	
16:00					41%			

Avg. DUD%		**31%**

Table 4.10: Daylight analysis (Average DSE%) - December 21, South (W/S=0.5)

Dynamic Sunlight Exposure Analysis (DSE%) - December 21, South (W/S=0.5)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	24%	12.5%	14%	7.5%	0%	0%	0%	0%
10:00	55%	40%	45%	45%	37.5%	20%	9%	9%
12:00	67.5%	54%	57.5%	57.5%	49%	30%	16%	16%
14:00	60%	42.5%	50%	49%	41%	27.5%	10%	12.5%
16:00	35%	22.5%	25%	22.5%	1%	0%	0%	0%
Avg. DSE%	**48%**	**34%**	**38%**	**36%**	**26%**	**16%**	**7%**	**8%**
Time (t)	Same as Above	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00					0%			
10:00							9%	
12:00							16%	
14:00							10%	
16:00					1%			
Avg. DSE%		**7%**						

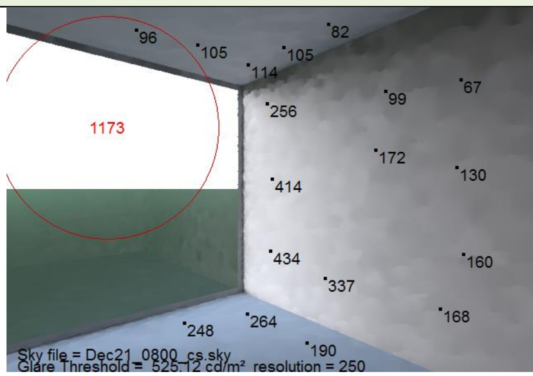
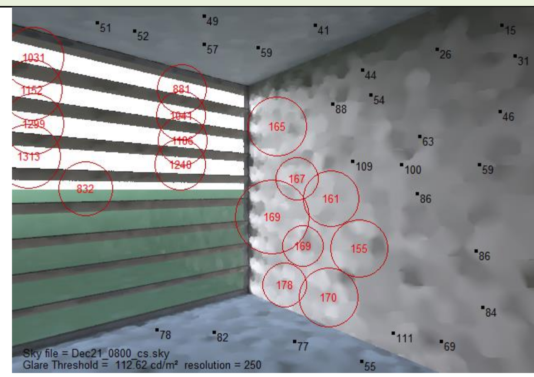
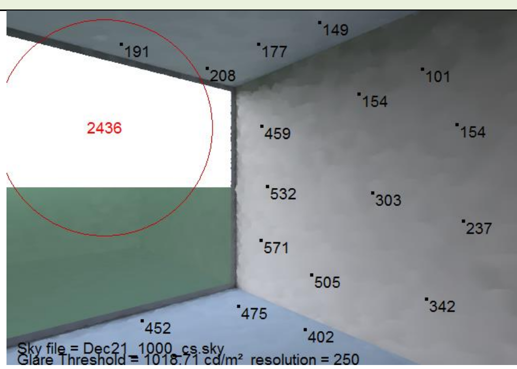
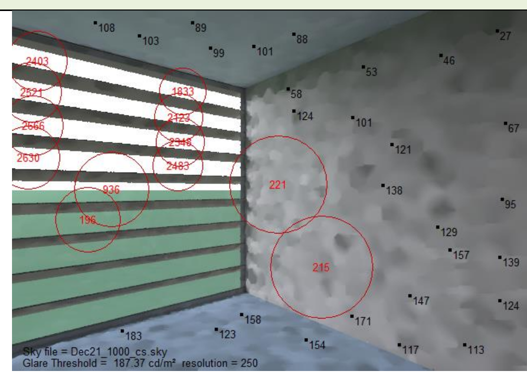
Table 4.9 shows that the average DUD% when using dynamic shading louvers is 31% compared to the average DUD% in the base case scenario which is 25% only. Moreover, when using fixed shading louvers at α=0°, α=20° and α=40°, the average DUD% are 32%, 34% and 32%, respectively, which are higher than the average DUD% when using dynamic shading louvers. However, looking at the average DSE% for α=0°, α=20° and α=40° in Table 4.10, the values are 26%, 16% and 7%, respectively. On the other hand, when using the dynamic shading louvers, the average DSE% is 7% which is identical to the average DSE% at α=40°.

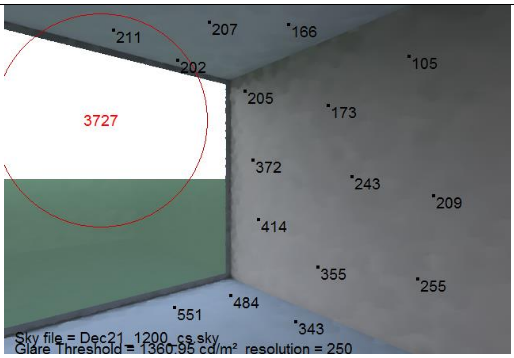
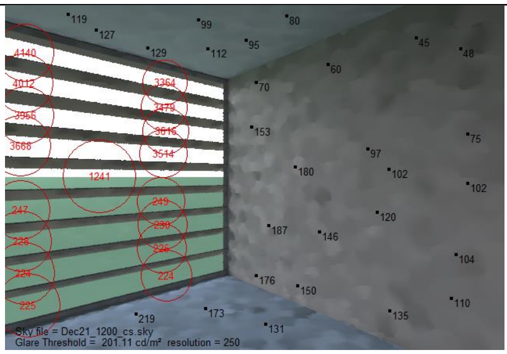
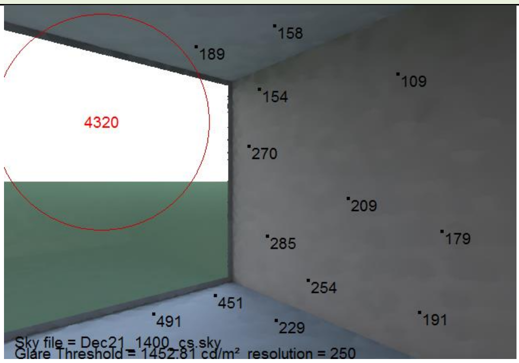
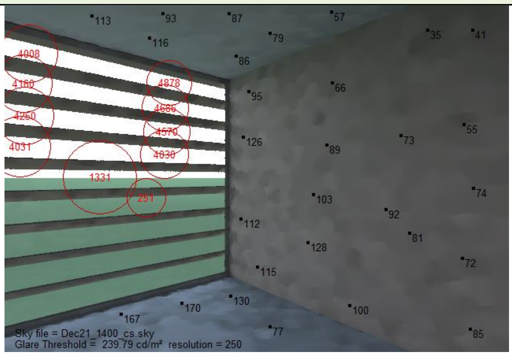
Since using fixed shading louvers at α=40° and using dynamic shading louvers result in almost the same performance with regards to the daylight, the author will choose fixed shading louvers at α=40° to be the optimal daylight configuration for this specific scenario.

- **Glare Analysis**

As obtained from the daylight analysis, the optimal configuration for this scenario is the fixed shading louvers. Therefore, this section, the author will conduct a comparison between the base case scenario and the fixed shading louvers at α=40° scenario in terms of glare performance.

Table 4.11: Summary of the Glare Analysis - Dec 21, South (W/S=0.5)

Glare Analysis for Dec 21, South (W/S=0.5)		
t=08:00	**Base Case**	**Fixed Shading Louvers (α=40°)**
		
t=10:00	**Base Case**	**Fixed Shading Louvers (α=40°)**
		
t=12:00	**Base Case**	**Fixed Shading Louvers (α=40°)**

<table>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Fixed Shading Louvers (α=40°)</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=16:00</td><td>Base Case</td><td>Fixed Shading Louvers (α=40°)</td></tr>
</table>

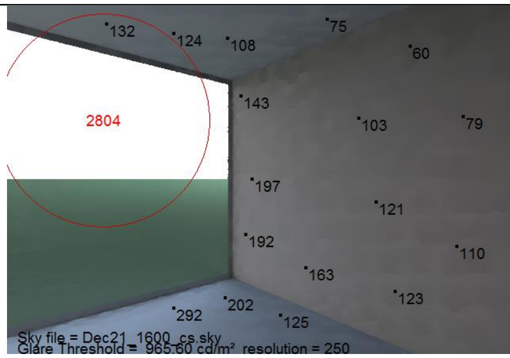
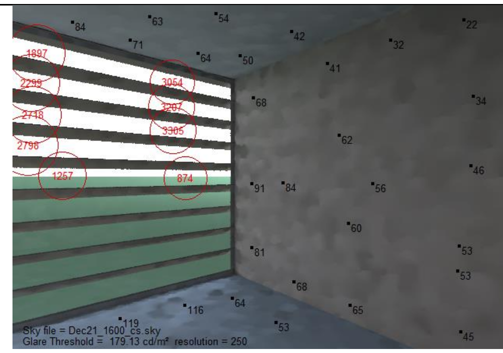
		

Table 4.11 shows the summary of the glare analysis results on 21 December using W/S=0.5 on the southern orientation.

Discussion:

As shown in Table 4.11, the base case scenario at t=8:00 experiences high glare on the glazing as a result of the high luminance which equals to 1173 cd/m2. Moreover, the luminance levels on the internal surfaces (wall, ceiling and floor) seem to have higher luminance level range as opposed to the case when fixed shading louvers are used. As noticed, when using fixed shading louvers at α=40°, the glare start to vary across the glazing where it can reach as low as 881 cd/m2. However, the sun at this time is still in the eastern side which explains the glary spot on the wall reflected from the sun. Although the fixed shading louver scenario experiences little glare on the walls, the luminance level is not significant compared to the luminance levels on the glazing. Therefore, the slight glare occurrence can be neglected.

Moreover, at t=10:00, the base case scenario shows high luminance level on the surface of the glazing which is 2436 cd/m2 compared to the luminance levels that occur when using fixed shading louvers at α=40° which range between 2666-1833 cd/m2. Also, in the fixed shading louvers scenario, slight glare occurs on the end of the wall due to the sun position within the sky at this particular time which reflects a higher luminance on the wall. The glare in this case is considered very slight, so, it will be neglected.

Furthermore, at t=12:00, the base case scenario shows that the luminance on the glazing is 3727 cd/m2 as opposed to the luminance levels on the glazing using fixed shading louvers which range between 4140-3364 cd/m2. Moreover, the luminance level range on the internal surfaces are lower in the fixed shading louvers scenario as opposed to the luminance levels occur on the surfaces in the base case scenario.

Additionally, at t=14:00, the base case scenario experiences uniform glare on the glazing due to the high luminance which equals to 4320 cd/m2. Similarly, the glazing in the case where fixed shading louvers are used experiences glare, however, in this case the glare varies across the glazing due to the presence of louvers and the luminance levels on the surface range between 4878-4008 cd/m2.

Finally, at t=16:00, the glazing in the base case scenario shows a luminance level of 2804 cd/m2 compared to the luminance level range of 3305-1897 cd/m2 in the fixed shading louvers scenario. Moreover, the internal surfaces experience lower luminance range when using fixed shading louvers as opposed to the base case scenario.

In general, the glare on the glazing in the early morning (e.g. t=08:00) experiences high luminance levels across the surface and specially on the eastern side of the glazing due to the sunrise time and the sun position in the sky which is quite low. On the other hand, the glare on the glazing towards the end of the day (e.g. t=16:00) experiences high luminance levels specially on the western side of the glazing due to the sunset time and the sun position in the sky. Additionally, it can be noticed that at t=12:00, the luminance levels on the eastern and western sides of the glazing are very close due to the almost middle position of the sun at this particular time of the day.

Findings:

Table 4.12: Glare analysis Summary - Dec 21, South (W/S=0.5)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	1173	2436	3727	4320	2804	**2892**
Optimal Case	1313	2630	3666	4031	2798	**2888**

Table 4.14 shows the luminance levels on the glazing in December 21 using W/S=0.5 on the southern orientation. The table shows that the average luminance level on the glazing when using no louvers is 2892 cd/m2 which is very similar to the average luminance level when using fixed shading louvers at the optimal tilt angle (α=40°) which is 2888 cd/m2. However, significant differences were obtained for daylight performance when using the two scenarios where fixed shading louvers were performing better. Thus, the optimal cases (using fixed shading louvers) will be considered as the best design configuration for both daylight and glare.

4.1.4. Daylight and Glare Analysis for March 21, W/S=1.0

- **Daylight Analysis**

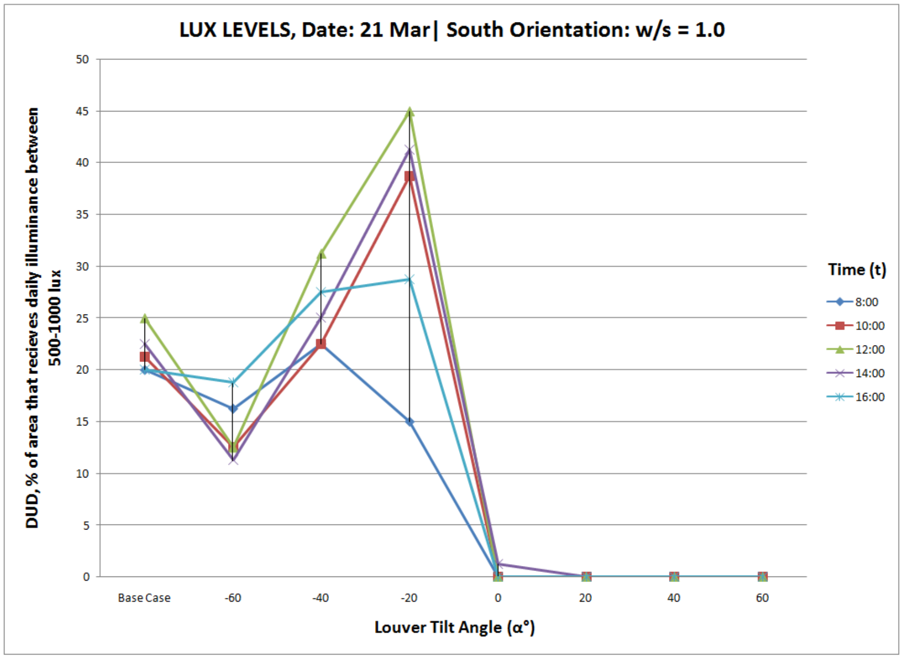


Figure 4.30: DUD analysis, 21 Mar, w/s=1.0 (South)

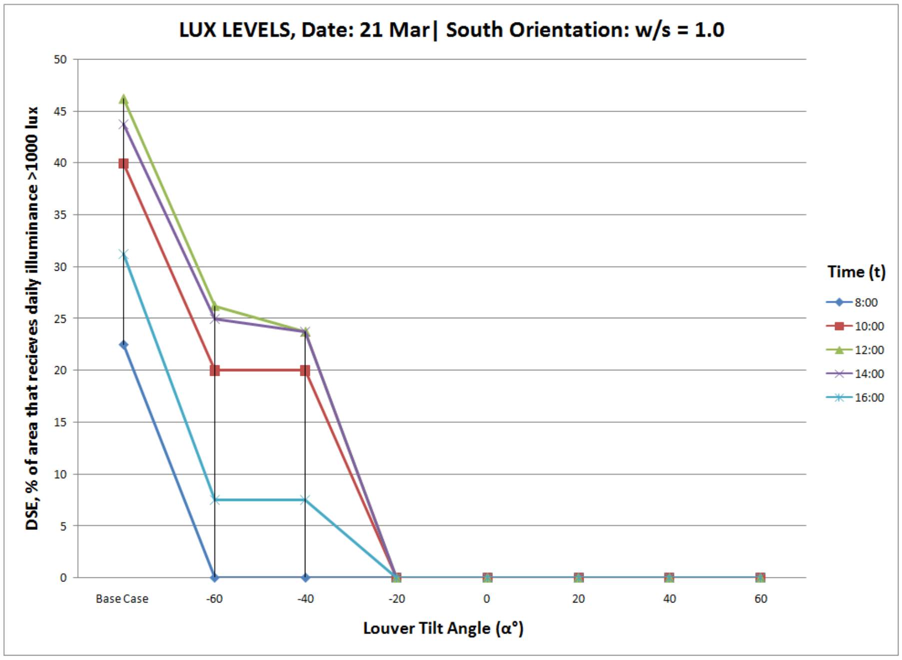


Figure 4.31: DSE analysis, 21 Mar, w/s=1.0 (South)

Figure 4.30 and Figure 4.31 show the daylight analysis (DUD% and DSE%) for 21 March using W/S=1.0 and for the southern orientation.

Discussion:

As shown in the figures, at t=08:00, the maximum Dynamic Useful Daylight (DUD%) occurs at α=-40° and it equals to 22.5%, whereas, in the base case scenario, DUD% is only 20% of the work plane area. On the other hand, the Dynamic Sunlight Exposure (DSE%) at the same time and at α=-40° equals to 0% which is the optimal percentage for DSE compared to the base case scenario where DSE% is 22.5%.

Thus, α=-40° is the optimal angle among all simulated configurations. Figure 4.32and Figure 4.33 show the 3D illustration of the model at α=-40° and the illuminance levels at the same angle at t=08:00, respectively.

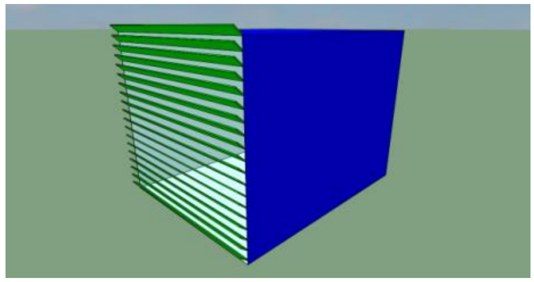


Figure 4.32: 3D Model of the optimal angle (α= -40°) at t=08:00 on 21 Mar (W/S=1.0, South)

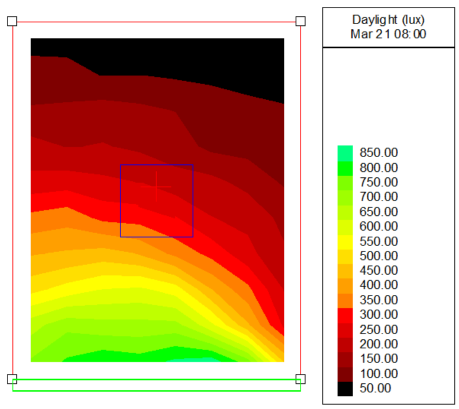


Figure 4.33: Illuminance levels for t=08:00, α=-40, Mar 21, W/S=1.0, South

Moreover, at t=10:00, the maximum DUD% occurs at α=-20° and it equals to 39%, whereas, the DUD% at the same time but in the base case scenario equals to 21%. Moreover, at t=10:00 and α=-20°, the percentage of DSE is 0% which makes α=-20° the optimal angle for this particular time. On the other hand, at t=10:00 and in the base case scenario, the percentage of DSE is 40% which is too high and cannot be accepted. Figure 4.34and Figure 4.35 show the 3D illustration of the model at α=-20° and the illuminance levels at the same angle, respectively.

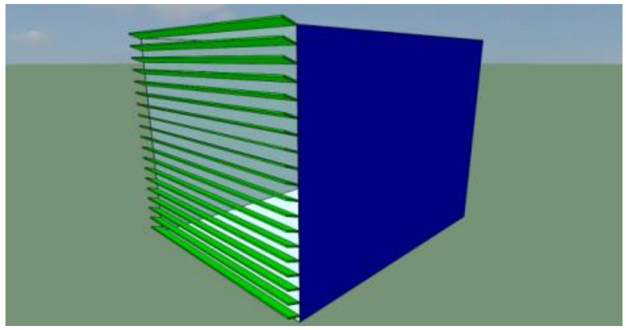


Figure 4.34: 3D Model of the optimal angle (α=-20°) at t=10:00 on 21 Mar (W/S=1.0, South)

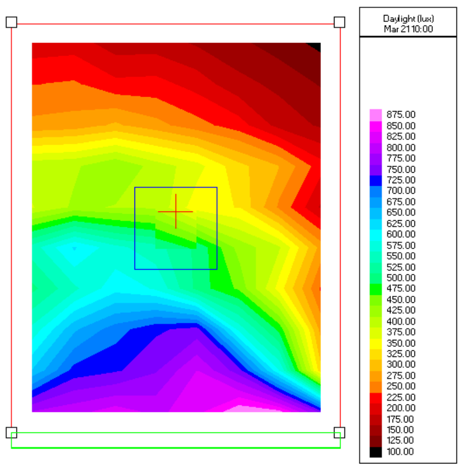


Figure 4.35: Illuminance levels for t=10:00, α=-20, Mar 21, W/S=1.0, South

Furthermore, at t=12:00, DUD% is the maximum at α=-20° where 45% of the work plane area receives illuminance between 500-1000 lux. On the other hand, in the base case scenario, only 25% of the work plane area receives illuminance between 500-1000 lux. Additionally, at t=12:00 and α=-20°, DSE percentage is at its optimal value which is 0% compared to the base case scenario at the same time which has a DSE% of 46%.Therefore, the optimal angle for t=12:00 is α=-20°.Figure 4.36 shows the illuminance levels at α=-20° and t=12:00.

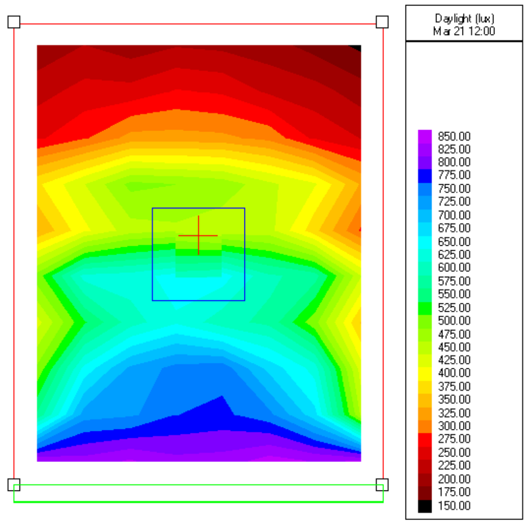


Figure 4.36: Illuminance levels for t=12:00, α=-20, Mar 21, W/S=1.0, South

Moreover, at t=14:00, the maximum DUD% occurs also at α=-20° where it achieves41% of the work plan area. Whereas, in the base case scenario and at t=14:00, the DUD% is only 22.5%. Also, the DSE percentage at α=-20° is 0% and in the base case scenario is as high as 44%.Therefore, α=-20° will be considered as the best angle for this time of the day. Figure 4.37 shows the illuminance levels at α=-20° and t=14:00.

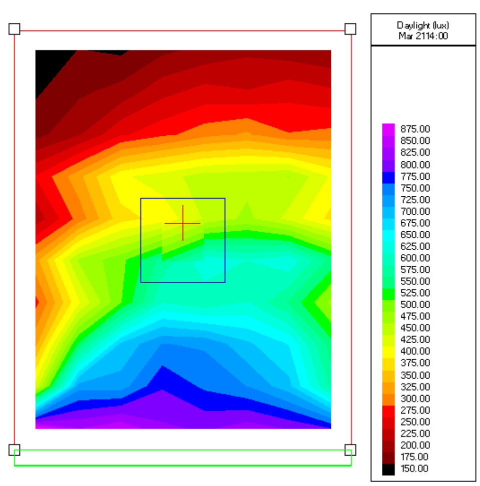


Figure 4.37: Illuminance levels for t=14:00, α=-20, Mar 21, W/S=1.0, South

Lastly, at t=16:00, the optimal angle in which the maximum DUD percentage occur is α=-20° where DUD% reaches up to 29% compared to DUD% of 20% only in the base case scenario.

As for DSE%, the minimum percentage occurs at α=-20° where it hits the optimal percentage for DSE which is 0%. However, in the base case scenario, DSE% is 31% which is too high and cannot be accepted. This concludes that α=-20° is the optimal angle for t=16:00. Figure 4.38 shows the illuminance levels at α=-20° and t=16:00.

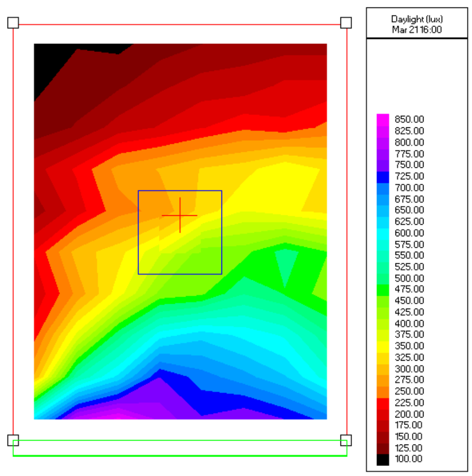


Figure 4.38: Illuminance levels for t=16:00, α=-20, Mar 21, W/S=1.0, South

Findings:

Table 4.13: Daylight analysis (Average DUD%) - March 21, South (W/S=1.0)

Dynamic Useful Daylight Analysis (DUD%) - March 21, South (W/S=1.0)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	20%	16%	22.5%	15%	0%	0%	0%	0%
10:00	21%	12.5%	22.5%	39%	0%	0%	0%	0%
12:00	25%	12.5%	31%	45%	0%	0%	0%	0%
14:00	22.5%	11%	25%	41%	1%	0%	0%	0%
16:00	20%	19%	27.5%	29%	0%	0%	0%	0%
Avg. DUD%	**22%**	**14%**	**26%**	**34%**	**0%**	**0%**	**0%**	**0%**
Time (t)	Same as Above	**Dynamic shading louvers at the Optimal Angles (α°)**						

		-60	-40	-20	0	20	40	60
8:00			22.5%					
10:00				39%				
12:00				45%				
14:00				41%				
16:00				29%				
Avg. DUD%		**35%**						

Table 4.14: Daylight analysis (Average DSE%) - March 21, South (W/S=1.0)

Dynamic Useful Daylight Analysis (DSE%) - March 21, South (W/S=1.0)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	22.5%	0%	0%	0%	0%	0%	0%	0%
10:00	40%	20%	20%	0%	0%	0%	0%	0%
12:00	46%	26%	24%	0%	0%	0%	0%	0%
14:00	44%	25%	24%	0%	0%	0%	0%	0%
16:00	31%	7.5%	7.5%	0%	0%	0%	0%	0%
Avg. DSE%	**37%**	**16%**	**15%**	**0%**	**0%**	**0%**	**0%**	**0%**
Time (t)	Same as Above	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00			0%					
10:00				0%				
12:00				0%				
14:00				0%				
16:00				0%				
Avg. DSE%		**0%**						

Table 4.13 shows that the maximum average DUD% is 35% and occurs when using dynamic shading louvers as opposed to 22% only, in the base case scenario. Additionally, the average DUD% when using fixed shading louvers at α=-20° is 34% which is very close to the average DUD% when using dynamic shading louvers.

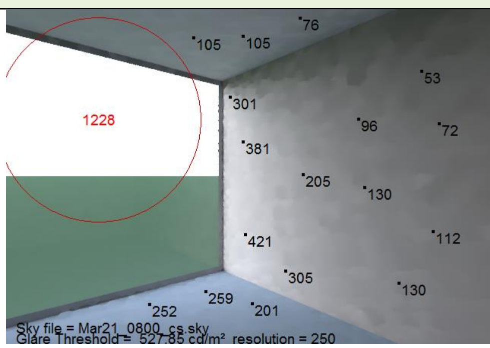
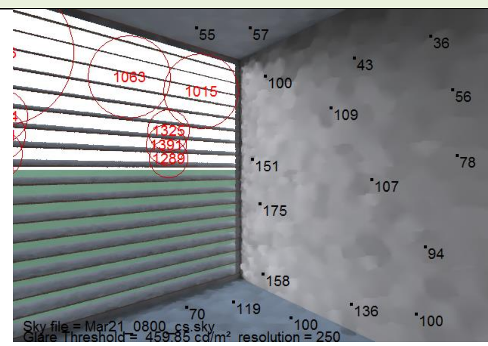
As for the average DSE%, Table 4.14 shows that the average DSE% when using dynamic shading louvers is equal to the average DSE% when using fixed shading louvers at α=-20° which equals to 0% compared to average DSE% of 37% in the base case scenario.

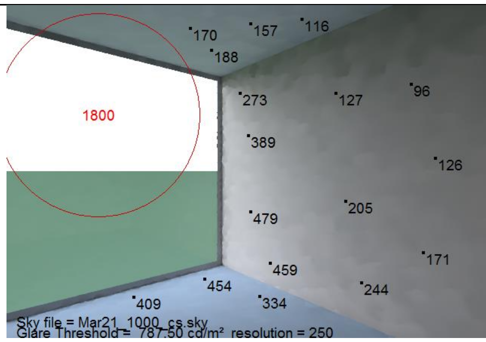
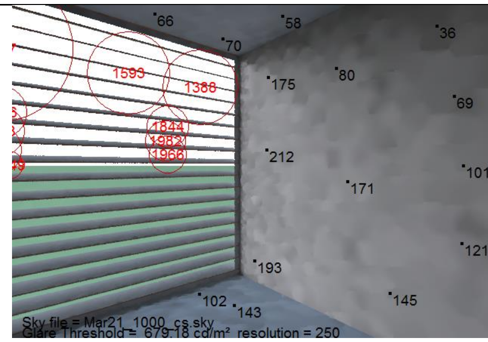
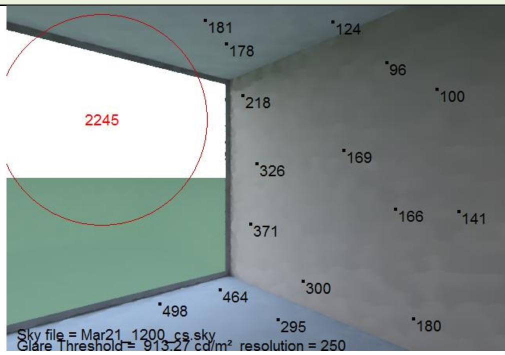
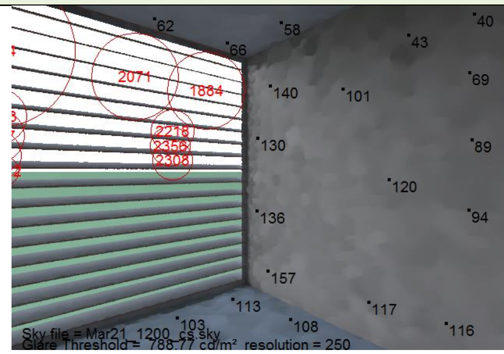
This means that choosing any configuration (dynamic or fixed at α=-20°) will have almost the same daylight performance for this scenario. Therefore, the author will simply choose fixed shading louvers since tilting the angles in this case will have no additional value.

- **Glare Analysis**

In this section, the author will be comparing the glare analysis results of the base case scenario against the glare results of fixed shading louvers at α=-20°.

Table 4.15: Summary of the Glare Analysis - Mar 21, South (W/S=1.0)

Glare Analysis for March 21, South (W/S=1.0)		
t=08:00	**Base Case**	**Fixed Shading Louvers (α=-20°)**
		
t=10:00	**Base Case**	**Fixed Shading Louvers(α=-20°)**

<table>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Fixed Shading Louvers(α=-20°)</td></tr>
<tr><td></td><td>
</td><td>
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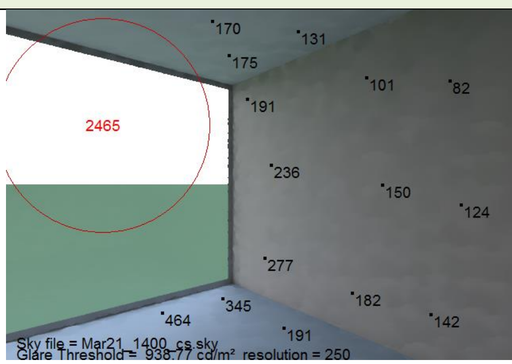
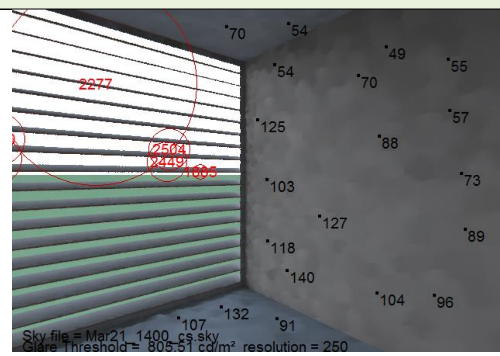
<tr><td>t=14:00</td><td>Base Case</td><td>Fixed Shading Louvers (α=-20°)</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
</table>

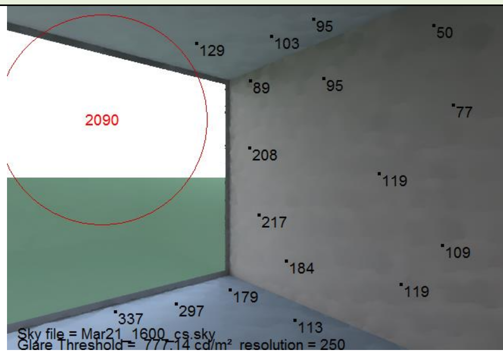
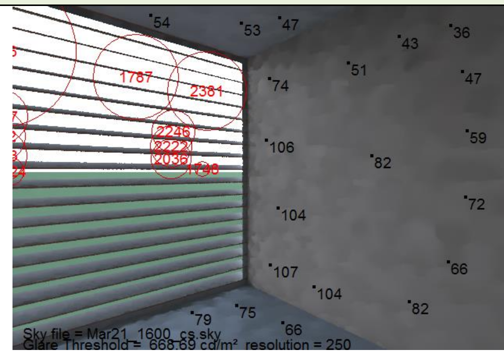
t=16:00	**Base Case**	**Fixed Shading Louvers (α=-20°)**
		

Table 4.15 shows the summary of the glare analysis for March 21 using W/S=1.0 on the southern orientation.

Discussion:

Table 4.15 shows thin the base case scenario at t=08:00 experiences a glare on the glazing due to the high luminance of 1228 cd/m2. Additionally, the part of the wall that is close to the glazing receives higher luminance values compared to the rest of the wall due to the sun position within the sky at this particular time. However, when using fixed shading louvers at α=-20°,the luminance level values on the glazing reduce to as low as 1015 cd/m2.

In addition, at t=10:00, the glazing in the base case scenario receives luminance of 1800 cd/m2 compared to different luminance values when using fixed shading louvers which can drop as low as 1388 cd/m2. Also, the luminance level range along the internal surfaces are less when using fixed shading louvers as opposed to the base case scenario.

Similarly, at noon, the glazing receives less luminance , thus, less glare on the glazing when using fixed shading louvers. specifically, the glazing in the base case scenario shows that it receives a luminance of 2245 cd/m2, whereas the luminance values can drop to as low as 1884 cd/m2 at some parts of the glazing when using fixed shading louvers.

Lastly, at t=16:00, the glazing in the base case scenario receives luminance of 2090 cd/m2 which is less than the luminance on the glazing in the base case scenario at t=14:00. Adding fixed shading louvers at α=-20° reduced the glare even further by reducing the luminance range values on the surface to as low as 1787 cd/m2.

Findings:

Table 4.16: Glare analysis Summary - Mar 21, South (W/S=1.0)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	1228	1800	2245	2465	2090	**1966**
Optimal Case	1391	1982	2356	2504	2222	**2091**

Table 4.19 shows that the average luminance level in the base case scenarios is 1966 cd/m2 compared to an average luminance level of 2091 cd/m2 in the optimal cases. The difference is considered minimal compared to the significant difference shown in the daylight results for the

two scenarios. Thus, the optimal cases (fixed shading louvers at =-20°) will still be the best design options to provide the maximum daylight and acceptable glare occurrence.

4.1.5. Daylight and Glare Analysis for June 21, W/S=1.0

- **Daylight Analysis**

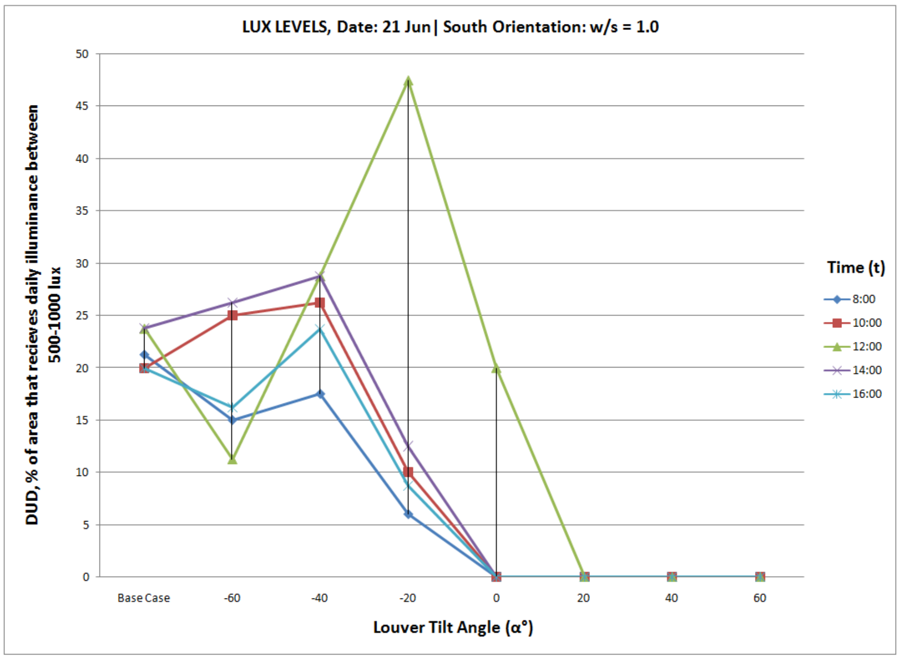


Figure 4.39: DUD analysis, 21 Jun, w/s=1.0 (South)

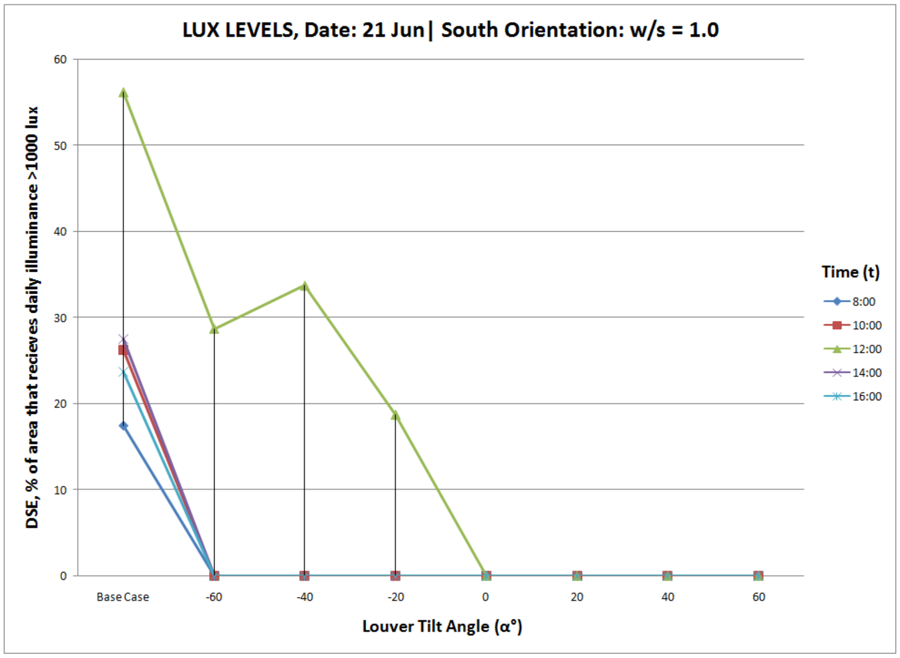


Figure 4.40: DSE analysis, 21 Jun, w/s=1.0 (South)

Figure 4.39 and Figure 4.40 show the daylight analysis (DUD% and DSE%) for the southern orientation on 21 June using W/S=1.0.

Discussion:

As shown in Figure 4.39, at t=08:00, the maximum Dynamic Useful Daylight (DUD%) occurs in the base case scenario where it reaches as high as 21%. However, Figure 4.40 shows that the Dynamic Sunlight Exposure (DSE%) at the base case is17.5% of the work plane area which excessive and not acceptable, as per the pre-defined assessment criteria specified earlier. Thus, the author will select the second best angle that provides a high DUD% which is at α=-40° where DUD% is 17.5% and DSE% is 0%.Thus, α=-40° will be considered as the optimal angle for t=08:00, in this case. Figure 4.41and Figure 4.42 show the 3D model at α=-40° and the illuminance levels at α=-40° at t=08:00, respectively.

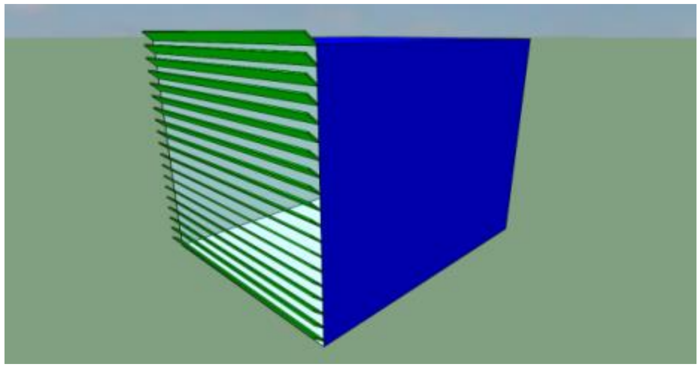


Figure 4.41: 3D Model of the optimal angle (α= -40°) at t=08:00 on 21 Jun (W/S=1.0, South)

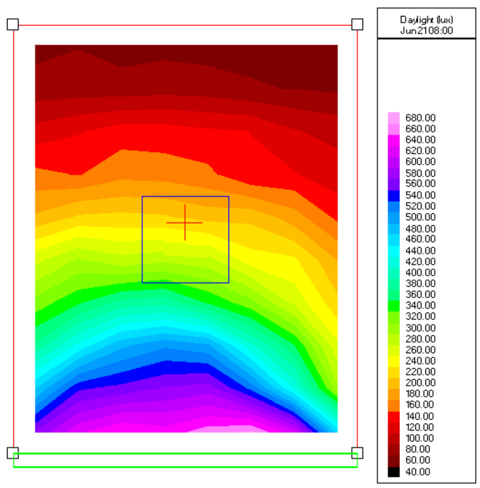


Figure 4.42: Illuminance levels for t=08:00, α=-40, Jun 21, W/S=1.0, South

Moreover, at t=10:00, Figure 4.39 shows that the optimal angle that achieves the highest DUD% value is α=-40° where DUD% equals to 26% compared to 20% in the base case scenario. On the other hand, Figure 4.40 shows that at α=-40°, the optimal angle for DSE% is also achieved which is 0% compared to DSE% of 26.25% in the base case scenario. Thus, α=-40° is the best tilt angle for t=10:00.Figure 4.43 shows the illuminance levels at t=10:00 using α=-40°.

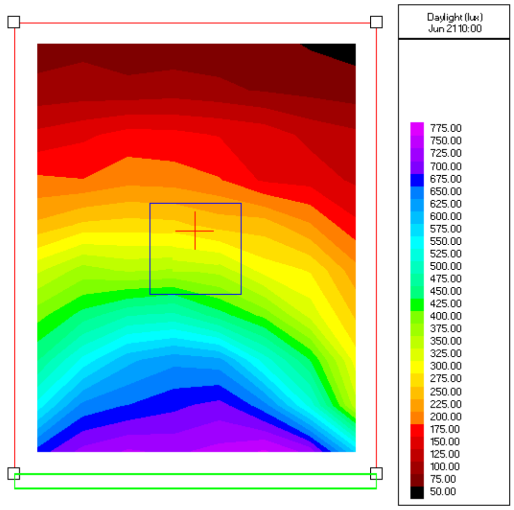


Figure 4.43: Illuminance levels for t=10:00, α=-40, Jun 21, W/S=1.0, South

Furthermore, at t=12:00, DUD% increases dramatically at α=-20° where it reaches as high as 47.5% which represents a great amount of useful daylight penetration compared to 24% only in the base case scenario. However, the dynamic sunlight exposure percentages (DSE%) are too high at both α=-20° and the base case scenario where they reach as high as 19% and 56%, respectively, which is not acceptable. Having such high dynamic sunlight exposure could lead not only to increased cooling load but also could disturb the work tasks and could cause visual and thermal discomfort for the occupants. Thus, the author is selecting the second best angle that provides a high DUD% at t=12:00 which is α=0° where DUD% is 20% and DSE% is 0%. Figure 4.44 shows the 3D model at α=0° using W/S=1.0 and Figure 4.45 show the illuminance levels at t=12:00 and α=0°.

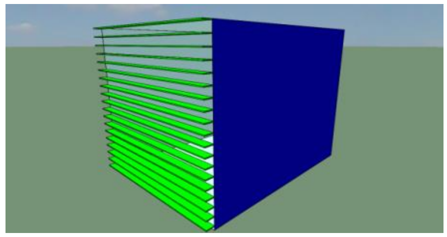


Figure 4.44: 3D Model of the optimal angle (α=0°) at t=12:00 on 21 Jun (W/S=1.0, South)

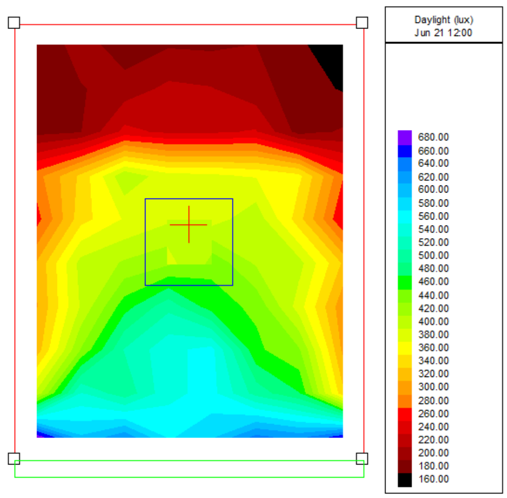


Figure 4.45: Illuminance levels for t=12:00, α=0, Jun 21, W/S=1.0, South

In addition, Figure 4.39 shows that at t=14:00 and α=-40°, the maximum DUD% occurs which equals to 29% compared to 24% in the base case scenario. Moreover, DSE% at α=-40° is 0% which is the optimal DSE% value whereas DSE% in the base case scenario reaches as high as 27.5%. Thus, the author is selecting α=-40° as the optimal tilt angle for t=14:00.Figure 4.46 shows the illuminance levels at the optimal angle at t=14:00.

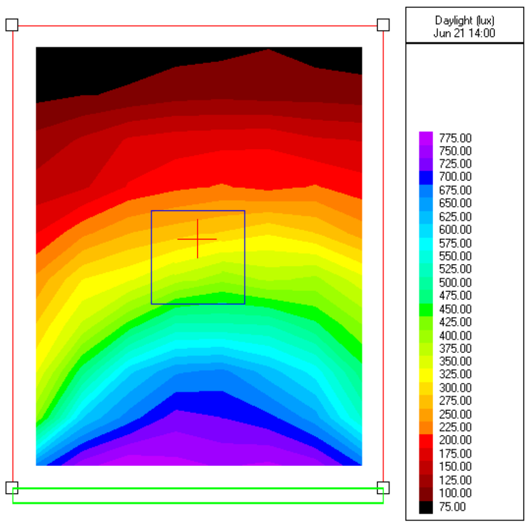


Figure 4.46: Illuminance levels for t=14:00, α=-40, Jun 21, W/S=1.0, South

Lastly, at t=16:00, the optimal angle in which the maximum DUD% occurs is α=-40° where it reaches as high as 24% compared to 20% only in the base case scenario. Also, DSE% at α=-40° equals to 0% which is the optimal value compared to DSE% of 24% in the base case scenario. Thus, α=-40° is the most suitable angle for t=16:00.Figure 4.47 shows the illuminance levels at the optimal angle at t=16:00.

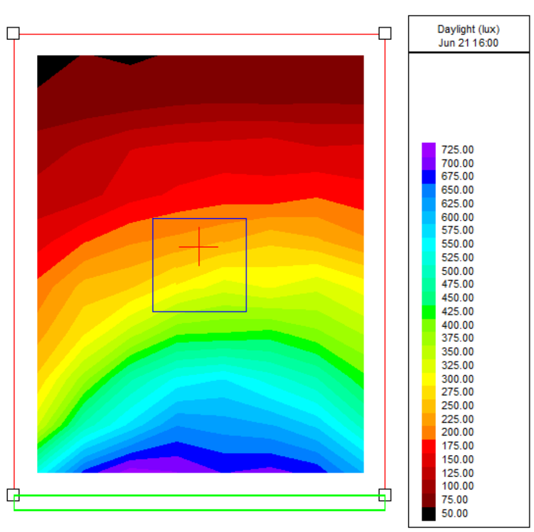


Figure 4.47: Illuminance levels for t=16:00, α=-40, Jun 21, W/S=1.0, South

Findings:

Table 4.17: Daylight analysis (Average DUD%) - June 21, South (W/S=1.0)

Dynamic Useful Daylight Analysis (DUD%) - June 21, South (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	21%	15%	17.5%	6%	0%	0%	0%	0%
10:00	20%	25%	26%	10%	0%	0%	0%	0%
12:00	24%	11%	29%	47.5%	20%	0%	0%	0%
14:00	24%	26%	29%	12.5%	0%	0%	0%	0%
16:00	20%	16%	24%	9%	0%	0%	0%	0%
Avg. DUD%	**22%**	**19%**	**25%**	**17%**	**4%**	**0%**	**0%**	**0%**
Time (t)		Dynamic shading louvers at the Optimal Angles (α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	Same as Above		17.5%					
10:00			26%					
12:00					20%			
14:00			29%					
16:00			24%					
Avg. DUD%	**23%**							

Table 4.18: : Daylight analysis (Average DSE%) - June 21, South (W/S=1.0)

Dynamic Sunlight Exposure Analysis (DSE%) - June 21, South (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	17.5%	0%	0%	0%	0%	0%	0%	0%
10:00	26%	0%	0%	0%	0%	0%	0%	0%
12:00	56%	29%	34%	19%	0%	0%	0%	0%
14:00	27.5%	0%	0%	0%	0%	0%	0%	0%
16:00	24%	0%	0%	0%	0%	0%	0%	0%
Avg. DSE%	**30%**	**6%**	**7%**	**4%**	**0%**	**0%**	**0%**	**0%**
Time (t)		Dynamic shading louvers at the Optimal Angles (α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	Same as Above		0%					
10:00			0%					
12:00					0%			
14:00			0%					

16:00			0%					
Avg. DSE%	**0%**							

Table 4.17 shows that the average DUD% when using dynamic shading louvers happens to be 23% compared to 22% in the base case scenario. In addition, the average DUD% at the fixed shading louvers (α=-40°)is the highest average DUD% in this scenario which equals to 25%. However, looking at the average DSE% shown in Table 4.18, the fixed shading louvers at α=-40° achieve an average DSE% of 7% compared to an average DSE% of 0% when using dynamic shading louvers. Additionally, the average DSE% in the base case scenario is as high as 30%, which is not recommended.

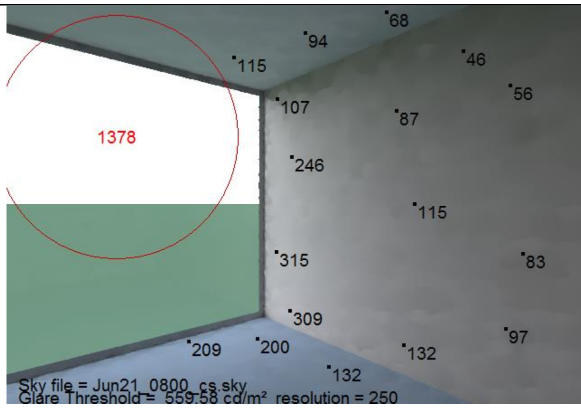
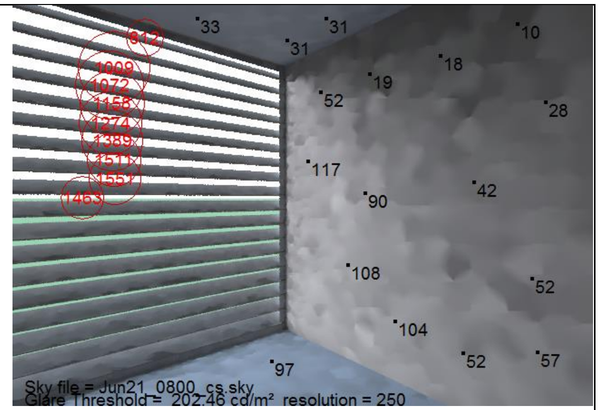
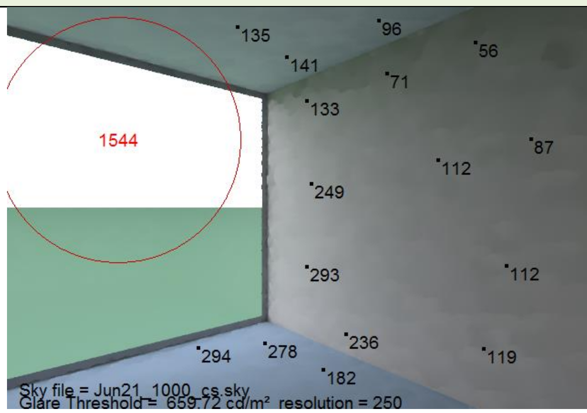
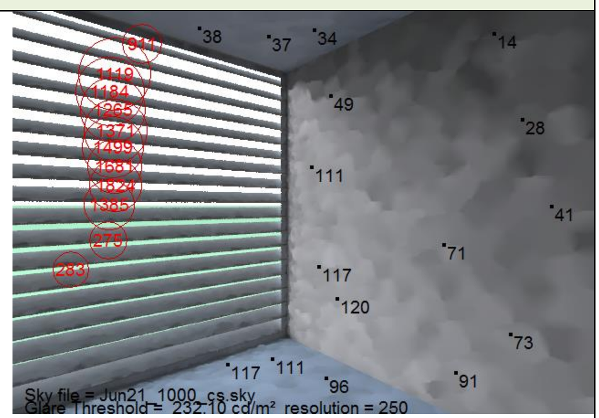
Therefore, since using dynamic shading louvers achieve high DUD% and no direct sunlight exposure, the author is considering choosing it as the optimal configuration for this particular scenario.

- **Glare Analysis**

In this section, the author will be analyzing the comparison in glare performance between the base case scenario and the dynamic shading louvers at α=-40° to figure out if the glare results agree with the results obtained from the daylight analysis.

Table 4.19: Summary of the Glare Analysis - Jun 21, South (W/S=1.0)

Glare Analysis for June 21, South (W/S=1.0)		
t=08:00	**Base Case**	**Dynamic Shading Louvers(α=-40°)**

<table>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=10:00</td><td>Base Case</td><td>Dynamic Shading Louvers (α=-40°)</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers (α=0°)</td></tr>
</table>

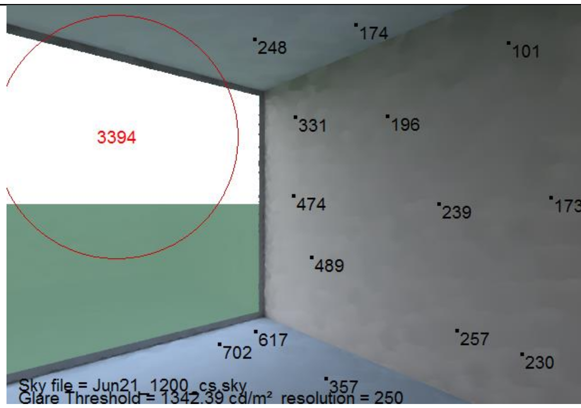
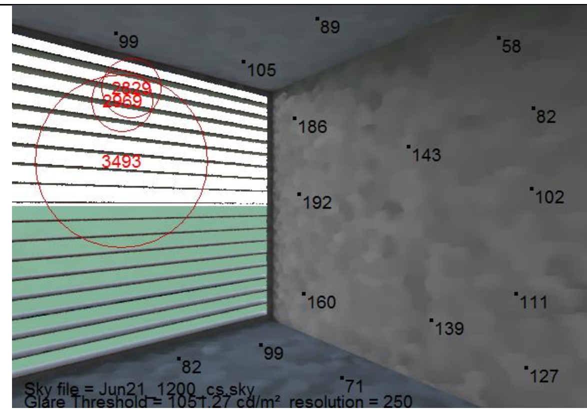
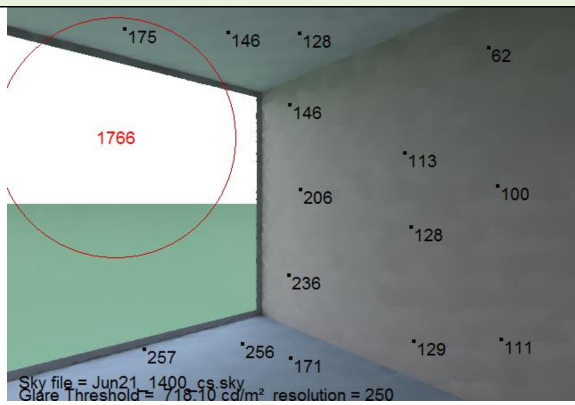
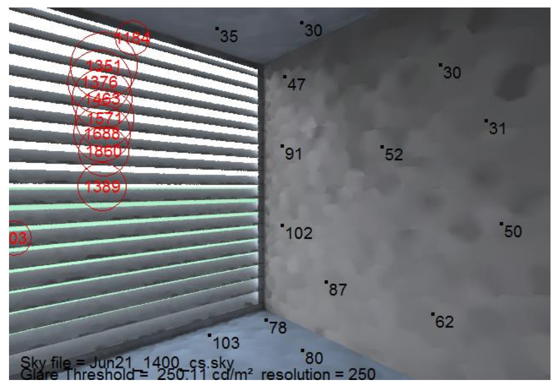
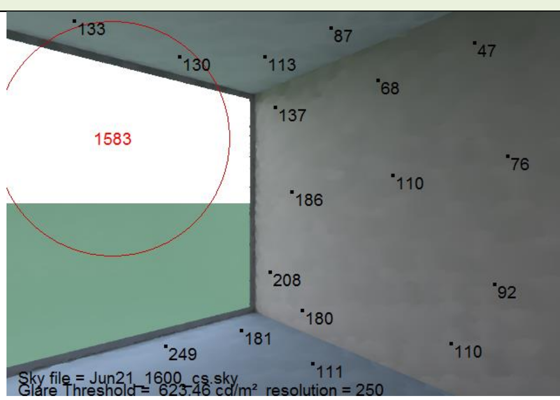
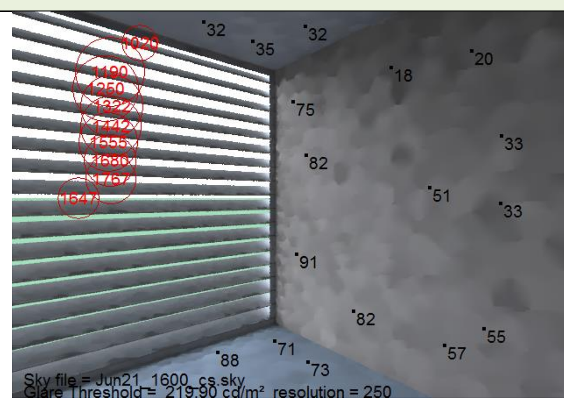
<table>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers (α=-40°)</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=16:00</td><td>Base Case</td><td>Dynamic Shading Louvers (α=-40°)</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
</table>

Table 4.19 shows the summary of the glare analysis for June 21 using W/S=1.0 on the southern orientation.

Discussion:

At t=08:00 and as seen in Table 4.19, the glazing in the base case scenario shows a glare occurrence due to the high luminance level on the surface which equals to 1378 dc/m2 compared to the dynamic shading louvers scenario where the luminance levels vary. As noticed, when using dynamic shading louvers, the luminance levels range on the glazing can decrease to as low as 1000 cd/m2. In addition, using dynamic shading louvers reduces the overall luminance levels range in the internal surfaces of the office compared to the base case scenario.

Furthermore, at t=10:00, the table shows that in the base case scenario the glare on the glazing is high due to the luminance level on the surface which is 1544 cd/m2. However, just by adding dynamic shading louvers instead, the luminance levels range across the glazing decreases and can reach to as low as 1119 cd/m2 at some parts of the glass.

Moreover, at t=12:00, the base case scenario shows a luminance of 3394 cd/m2 on the glazing which is the highest glare occurrence among all the base case scenarios. On the other hand, adding dynamic shading louvers reduces the glare to about 2800 cd/m2 at some parts of the glazing.

Additionally, at t=14:00, the glazing in the base case scenario has a luminance of 1766 cd/m2 compared to the various luminance levels on the glazing when using dynamic shading louvers which can reach to as low as 1184 cd/m2.

Finally, at t=16:00, the base case scenario shows that 1583 cd/m2 of luminance appears on the glazed wall which causes glare. However, adding dynamic shading louvers contributed in reducing the glare through reducing the luminance levels range across the glazing to vary between 1020-1767 cd/m2.

Findings:

Table 4.20: Glare analysis Summary - Jun 21, South (W/S=1.0)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	1378	1544	3394	1766	1583	**1933**
Optimal Case	1551	1824	3493	1860	1680	**2082**

Table 4.20 shows that the average luminance level when using no louvers at all times is 1933 cd/m2 compared to an average luminance level of 2082 cd/m2 in the optimal cases. The increase in luminance levels in optimal cases is minimal compared to the significant increase in daylight. Thus, using dynamic shading louvers for this scenario will be considered as the optimal design configuration.

4.1.6. Daylight and Glare Analysis for December 21, W/S=1.0

- **Daylight Analysis**

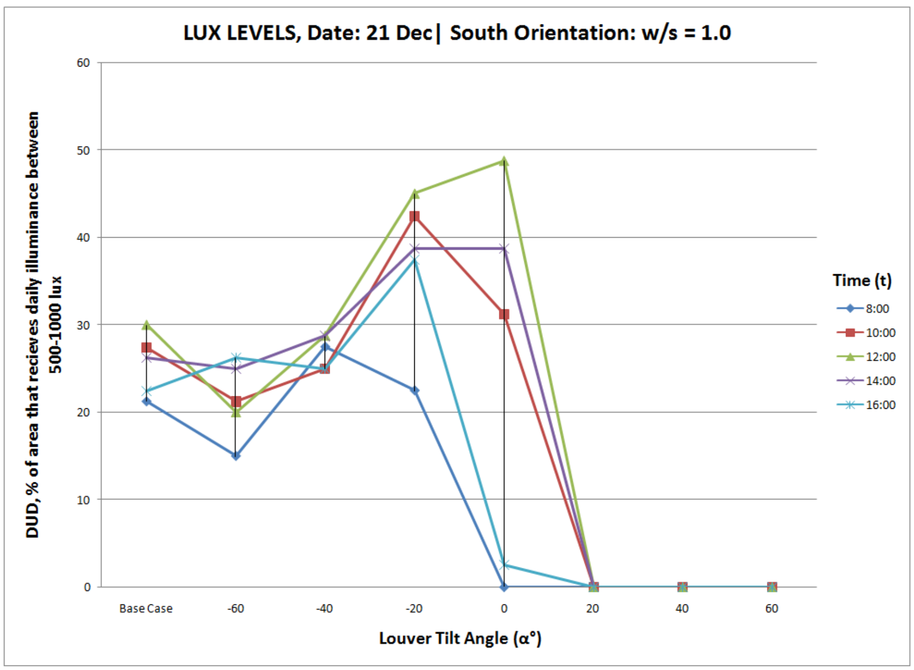


Figure 4.48: DUD analysis, 21 Dec, w/s=1.0 (South)

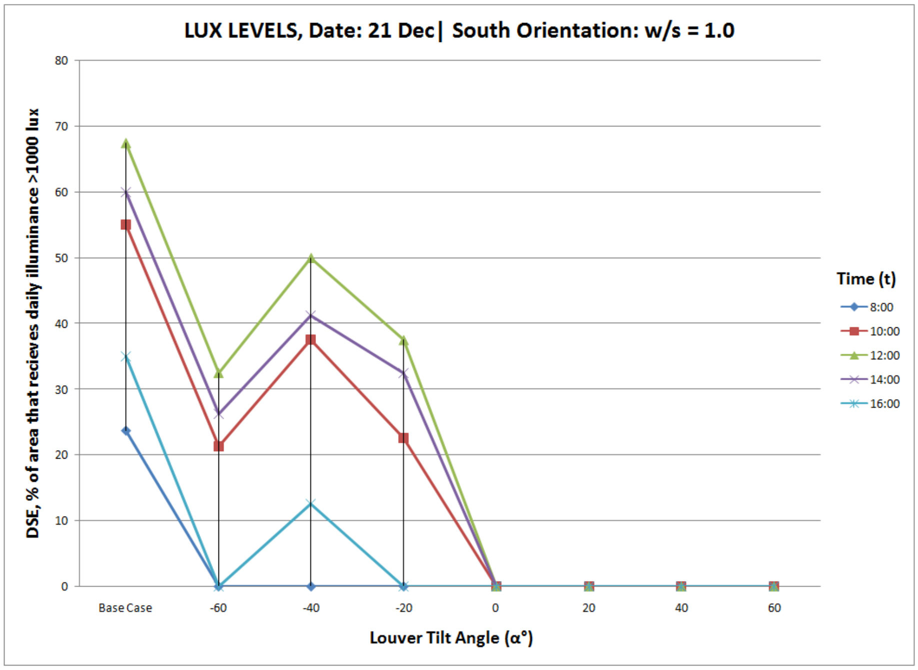


Figure 4.49: DSE analysis, 21 Dec, w/s=1.0 (South)

Figure 4.48 and Figure 4.49 show the dynamic useful daylight (DUD%) and the dynamic sunlight exposure (DSE%) for the southern orientation in December using W/S=1.0

Discussion:

At t=08:00, Figure 4.48 shows that the maximum DUD% occurs at α=-40° where the percentage of the work plane area that receives illuminance between 500-1000lux is 27.5%. On the other hand, DUD% in the base case scenario is only 21%.

Moreover, at α=-40°, DSE% is 0% which is the optimal DSE percent compared to the base case scenario where DSE is 24% which is considered excessive, as per the pre-defined assessment criteria. Thus, the author is selecting α=-40° as the optimal angle for t=08:00.Figure 4.50 shows the 3D illustration of the optimal angle and Figure 4.51 shows the illuminance levels at the same angle.

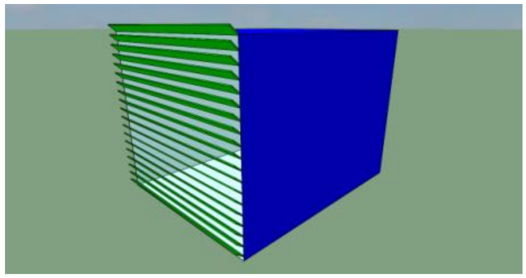


Figure 4.50: 3D Model of the optimal angle (α= -40°) at t=08:00 on 21 Dec (W/S=1.0, South)

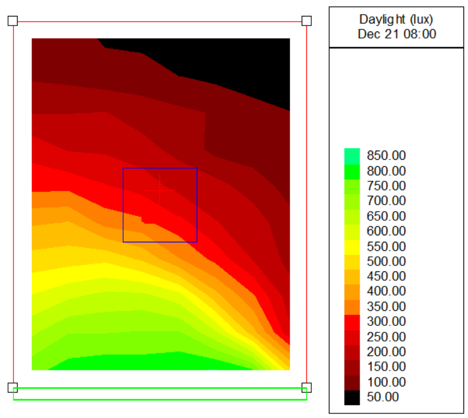


Figure 4.51: Illuminance levels for t=08:00, α=-40, Dec 21, W/S=1.0, South

Furthermore, at t=10:00, the optimal angle that provides the maximum DUD% at this time is α=-20° where DUD% equals to 42.5% compared to 27.5% only, in the base case scenario. However, at α=-20°, DSE% is excessive as it equals to 22.5% and the DSE% in the base case scenario is 55%. Since the DSE% at α=-20° falls within the excessive range, it cannot be accepted. Thus, the author is selecting the second best optimal angle that achieves high DUD% and low DSE% at t=10:00 which is α=0° where DUD% is 31.25% and DSE% is 0%. Figure 4.52 shows 3D illustration of the optimal angle and Figure 4.53 shows the illuminance levels at the same angle.

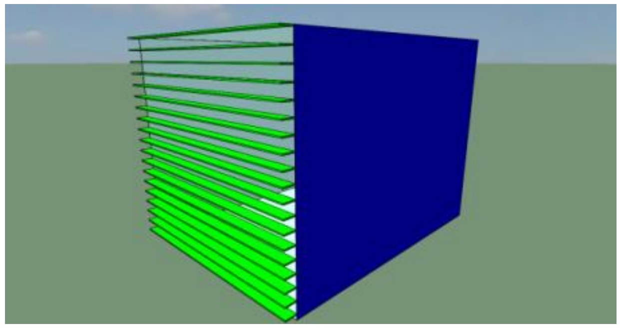


Figure 4.52: 3D Model of the optimal angle (α= 0°) at t=10:00 on 21 Dec (W/S=1.0, South)

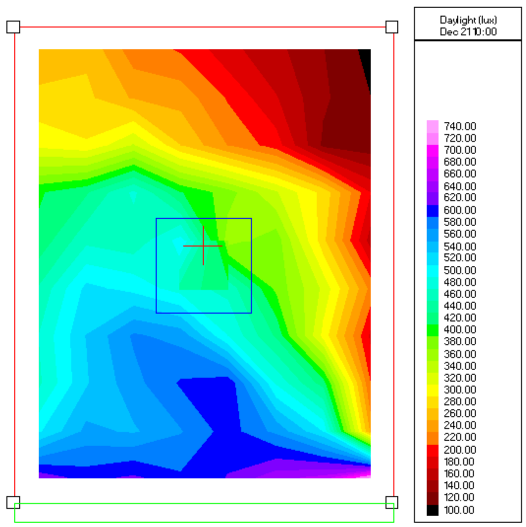


Figure 4.53: Illuminance levels for t=10:00, α=0, Dec 21, W/S=1.0, South

Additionally, at t=12:00, the maximum DUD% occurs at α=0° where it is 49% compared to 30% only, in the base case scenario. Moreover, at α=0°, the minimum DSE% is achieved, which is 0%compared to 67.5% in the base case scenario which is very significant. Thus, the author is selecting α=0° as the optimal angle for t=12:00.Figure 4.54 shows the illuminance levels at the optimal angle.

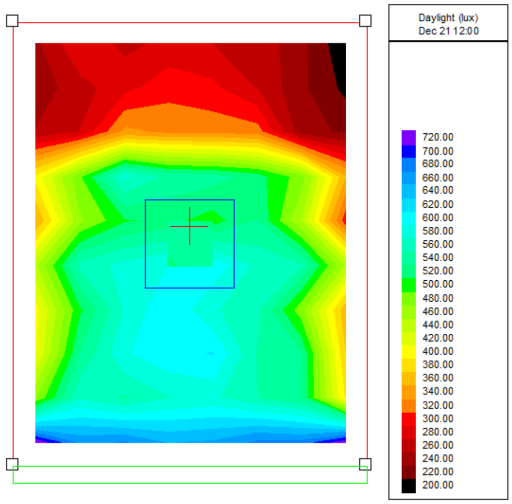


Figure 4.54: Illuminance levels for t=12:00, α=0, Dec 21, W/S=1.0, South

Moreover, at t=14:00, the maximum DUD% is occurring at α=0° where the value reaches as high as 39% compared to 26% only, in the base case scenario. Also, DSE% at α=0° equals to 0% compared to 60%, in the base case scenario. Thus, the author is selecting α=0° to be the optimal angle for t=14:00.Figure 4.55 shows the illuminance levels at the optimal angle.

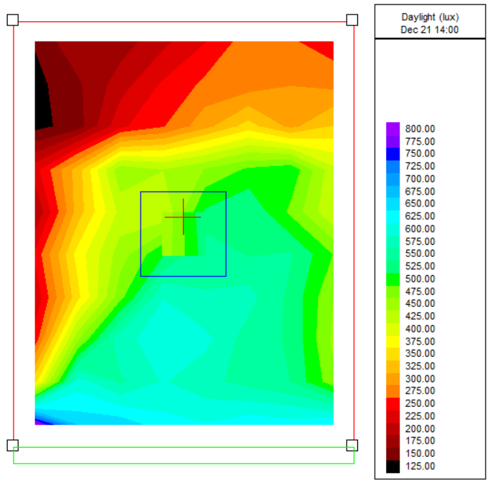


Figure 4.55: Illuminance levels for t=14:00, α=0, Dec 21, W/S=1.0, South

Lastly, at t=16:00, the optimal angle in which the optimal DUD% occur is α=-20° where DUD% is 37.5% compared to 22.5% only, in the base case scenario. On the other hand, DSE% at α=-20° is the minimum DSE% which is 0% compared to 35%, in the base case scenario. Thus, the author is selecting α=-20° to be the optimal angle at t=16:00.Figure 4.56 and Figure 4.57 show the 3D model of the optimal angle and the illuminance levels at the same angle, respectively.

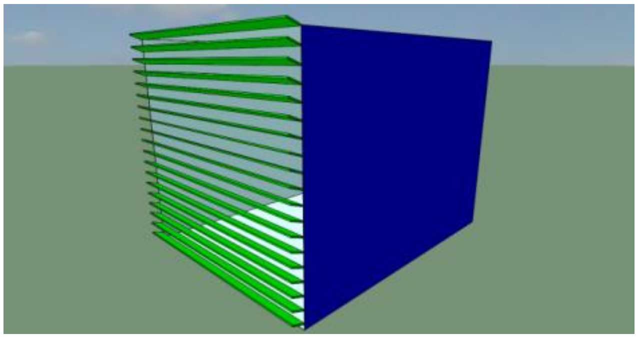


Figure 4.56: 3D Model of the optimal angle (α= -20°) at t=16:00 on 21 Dec (W/S=1.0, South)

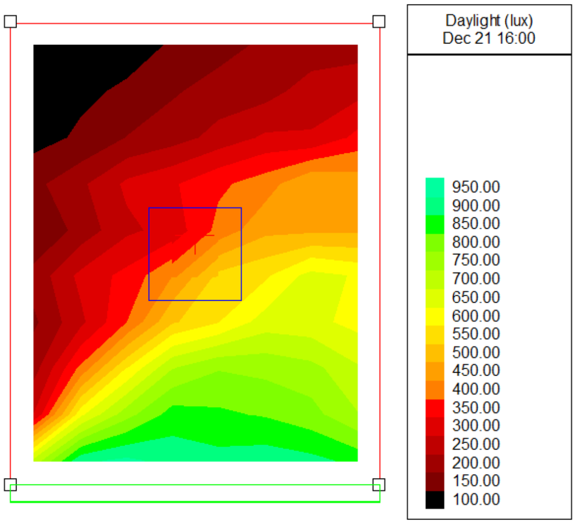


Figure 4.57: Illuminance levels for t=16:00, α=-20, Dec 21, W/S=1.0, South

Findings:

Table 4.21: Daylight analysis (Average DUD%) - December 21, South (W/S=1.0)

Dynamic Useful Daylight Analysis (DUD%) - December 21, South (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	21%	15%	27.5%	22.5%	0%	0%	0%	0%
10:00	27.5%	21%	25%	42.5%	31%	0%	0%	0%
12:00	30%	20%	29%	45%	49%	0%	0%	0%
14:00	26%	25%	29%	39%	39%	0%	0%	0%
16:00	22.5%	26%	25%	37.5%	2.5%	0%	0%	0%
Avg. DUD%	**25%**	**21%**	**27%**	**37%**	**24%**	**0%**	**0%**	**0%**
Time (t)	Same as Above	Dynamic shading louvers at the Optimal Angles (α°)						
		-60	-40	-20	0	20	40	60
8:00			27.5%					
10:00					31%			
12:00					49%			
14:00					39%			
16:00				37.5%				
Avg. DUD%		**37%**						

Table 4.22: Daylight analysis (Average DSE%) - December 21, South (W/S=1.0)

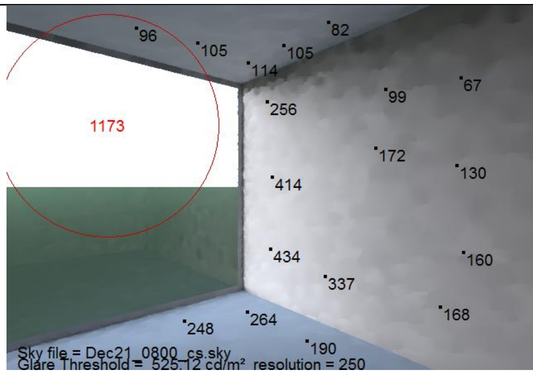
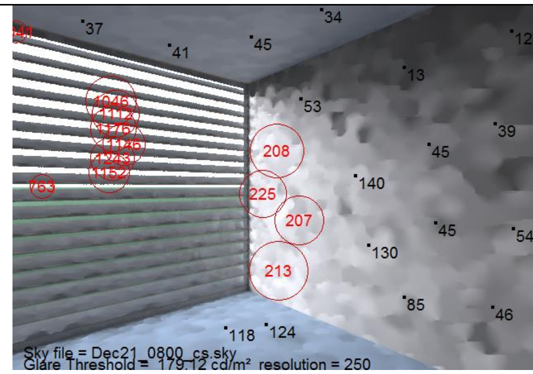
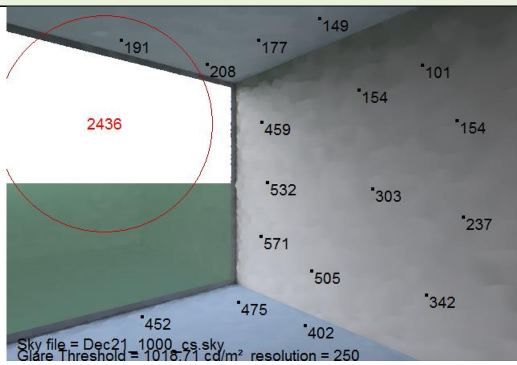
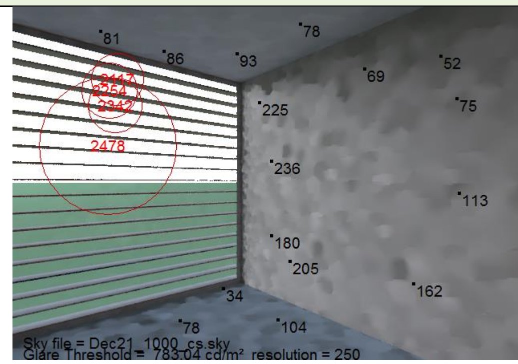
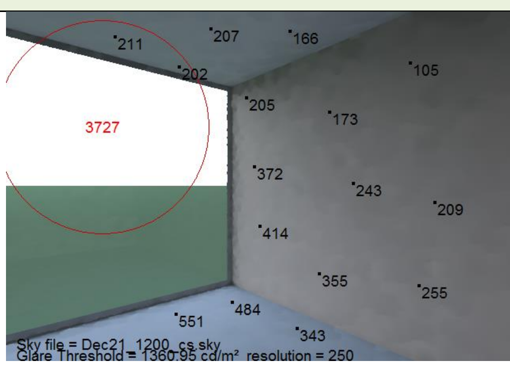
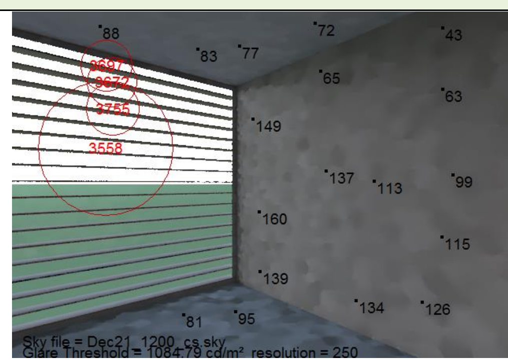
Dynamic Sunlight Exposure Analysis (DSE%) - December 21, South (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	24%	0%	0%	0%	0%	0%	0%	0%
10:00	55%	21%	37.5%	22.5%	0%	0%	0%	0%
12:00	67.5%	32.5%	50%	37.5%	0%	0%	0%	0%
14:00	60%	26%	41%	32.5%	0%	0%	0%	0%
16:00	35%	0%	12.5%	0%	0%	0%	0%	0%
Avg. DSE%	**48%**	**16%**	**28%**	**19%**	**0%**	**0%**	**0%**	**0%**
Time (t)	Same as Above	Dynamic shading louvers at the Optimal Angles (α°)						
		-60	-40	-20	0	20	40	60
8:00			0%					
10:00					0%			
12:00					0%			
14:00					0%			
16:00				0%				
Avg. DSE%		**0%**						

Table 4.21 shows that the average DUD% when using dynamic shading louvers for this scenario is 37% compared to 25% only, in the base case scenario. Moreover, when using fixed shading louvers at α=-20°, the average DUD% is 37% which is similar to the average DUD% when using dynamic shading louvers. However, looking at the data shown in Table 4.22, the average DSE% when using dynamic shading louvers is 0% compared to 19% when using fixed shading louvers at α=-20° which is very high. Thus, using dynamic shading louvers for this scenario is the most suitable configuration in terms of providing the maximum useful daylight and the minimum sunlight exposure.

- **Glare Analysis**

Table 4.23: Summary of the Glare Analysis - Dec 21, South (W/S=1.0)

Glare Analysis for December 21, South (W/S=1.0)		
t=08:00	**Base Case**	**Dynamic Shading Louvers α=-40°**

<table>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=10:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=0°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=0°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=0°</td></tr>
</table>

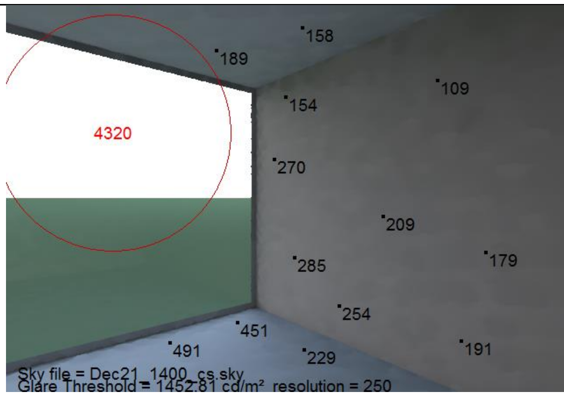
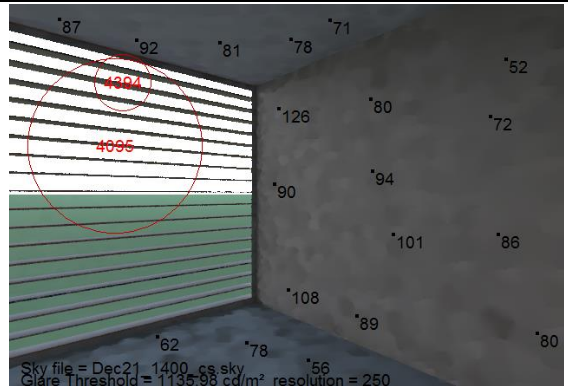
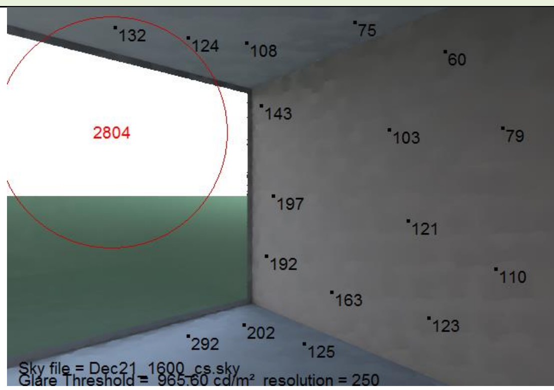
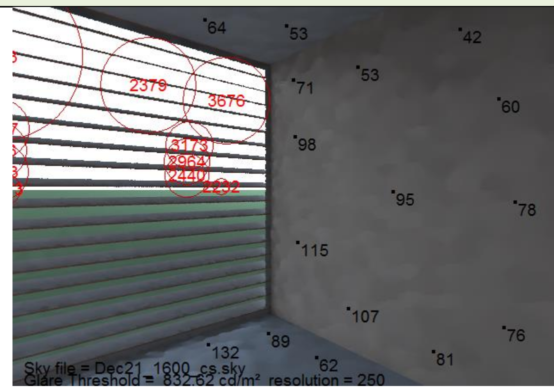
		
t=16:00	**Base Case**	**Dynamic Shading Louvers α=-20°**
		

Table 4.23 shows the summary of the glare analysis for December 21 using W/S=1.0 on the southern orientation.

Discussion:

At t=08:00, the glazing in the base case scenario shows high luminance which corresponds to glare occurrence. As shown in Table 4.23, the luminance level on the glazing is 1173 cd/m2 compared to the various luminance range when using dynamic shading louvers at α=-40° where the luminance can drop to as low as 1046 cd/m2. In addition, higher luminance levels are shown in some parts of the wall , when using shading dynamic shading louvers, due to the sun position within the sky in the early morning. However, this slight glare will be neglected since using dynamic shading louvers at this particular angle provides an average DUD% of 27.5% which compensate for the very slight occurrence of glare.

In Addition, at t=10:00, the glare on the glazing, in the base case scenario, starts to increase as the time passes throughout the day. Specifically, 2436 cd/m2 luminance is shown on the glazing which causes high glare on the surface. However, using dynamic shading louvers at α=0° causes the luminance level on the glazing to vary across the surface where it can decrease to as low as 2117 cd/m2. Moreover, using dynamic shading louvers reduce the luminance range across all the internal surfaces when compared to the base case scenario.

Furthermore, at noon, the luminance on the glazing, in the base case scenario, continue to increase where it equals to 3727 cd/m2. However, using dynamic shading louvers at α=0° vary the luminance level range across the glazing where the luminance can drop to as low as 3558 cd/m2. In addition, at t=14:00, very high luminance occurs on the glazing (4320 cd/m2) which causes glare on the surface. On the other hand, the luminance levels when using dynamic shading louvers at α=0° vary to reach as low as 4095 cd/m2. Lastly, at t=16:00, the luminance on the glazing equals to 2804 cd/m2 compared to the different luminance levels when using dynamic shading louvers at α=-20°where the luminance can drop to as low as 2379 cd/m2.

Findings:

Table 4.24: Glare analysis Summary - Dec 21, South (W/S=1.0)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	1173	2436	3727	4320	2804	**2892**

Optimal Case	1152	2478	3558	4095	3173	**2891**

As observed in Table 4.24, the results for the average luminance level on the glazing for both the base case and the optimal case are almost identical where they equal to 2892 cd/m2 and 2891 cd/m2, respectively. Although the average luminance levels show almost no difference, the daylight results for both cases show a huge difference where the optimal case provided better daylight performance in terms of increasing DUD% and decreasing DSE%, compared to the base case where no louvers are used.

4.2.North Orientation

In this section, the author will discuss the daylight and glare analysis results for the Northern orientation for 21 June only with and without shading louvers. The reason of excluding 21 March and 21 December is due to the low sun altitude in these day which reduces the sun penetration in the office from the Northern side.

The results using dynamic and fixed shading louvers will be presented for W/S=0.5 and W/S=1.0 and a comparison between base case and shading louvers will be demonstrated throughout the section.

Moreover, it is important to note that the author will be using vertical louvers for this orientation, as specified earlier in Chapter 3.

4.2.1. Daylight and Glare Analysis for June 21, W/S=0.5

- **Daylight Analysis**

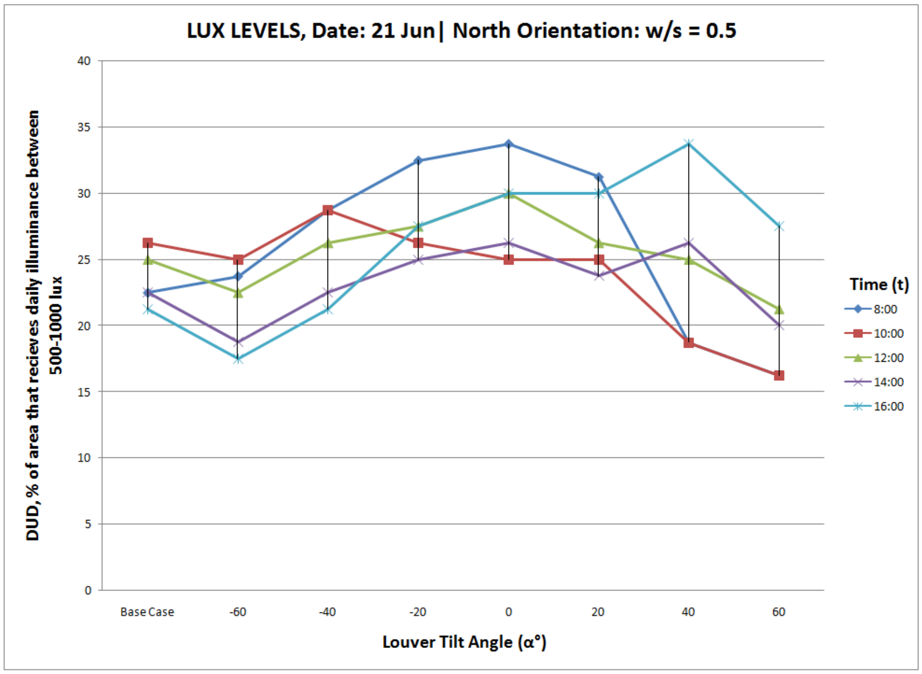


Figure 4.58: DUD analysis, 21 Jun, w/s=0.5 (North)

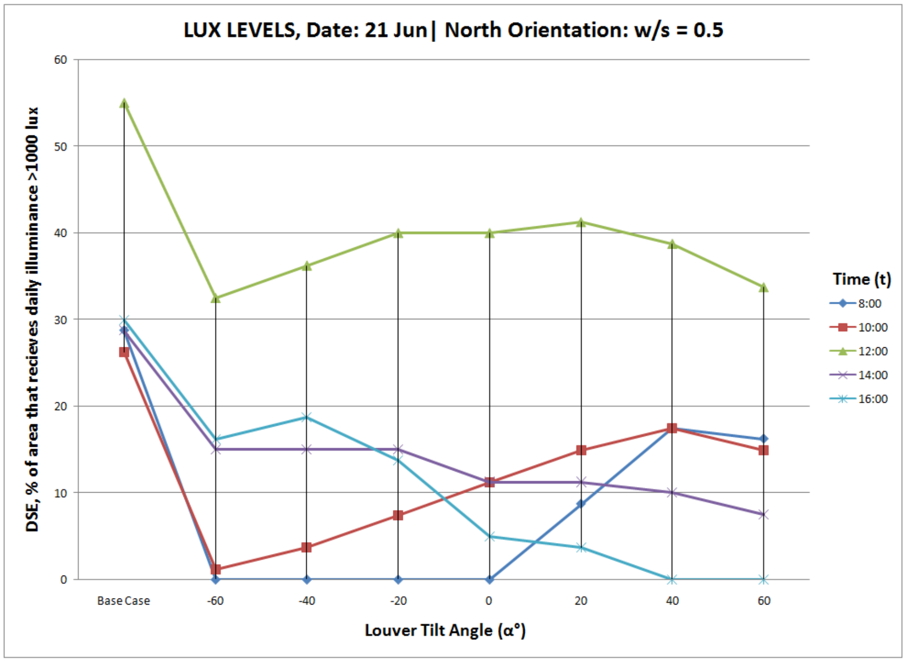


Figure 4.59: DSE analysis, 21 Jun, w/s=0.5 (North)

Figure 4.58 and Figure 4.59 show the daylight analysis results for 21 June using W/S=0.5 on the Northern orientation.

Discussion:

At t=08:00, Figure 4.58 shows that the maximum dynamic useful daylight (DUD%) occurs at α=0° where it equals to 34% compared to 22.5% only, in the base case scenario. On the other hand, the dynamic sunlight exposure (DSE%) at α=0° is 0%compared to DSE% of 29% in the base case scenario. Therefore, the author is selecting α=0° to be the optimal angle for t=08:00, as shown in Figure 4.60.

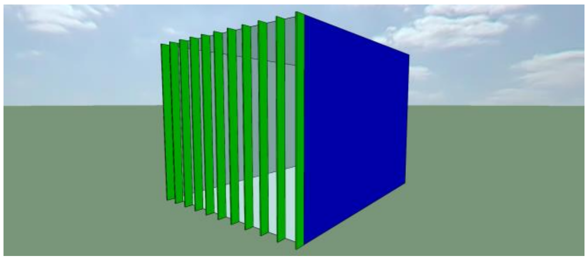


Figure 4.60: 3D Model of the optimal angle α=0° at t=08:00 on 21 Jun(W/S=0.5, North)

Moreover, at t=10:00, the optimal angle in which the maximum DUD% occur is 29% at α=-40° compared to 26% in the base case scenario, as shown in Figure 4.58. On the other hand, Figure 4.59 shows that DSE% at α=-40° is 4% ,which is within the acceptable range compared to DSE% of 26% in the base case scenario. Thus, α=-40° is the optimal angle for t=10:00, as shown in Figure 4.61.

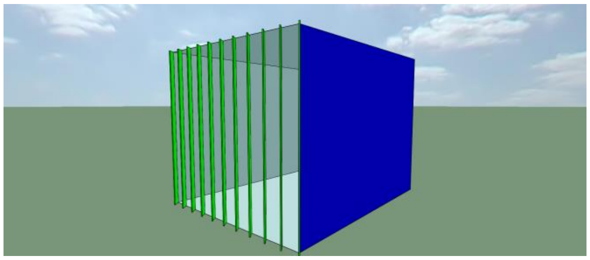


Figure 4.61: 3D Model of the optimal angle α=-40° at t=10:00 on 21 Jun (W/S=0.5, North)

Furthermore, at t=12:00, the maximum DUD% is at α=0° where it equals to 30%, as shown in Figure 4.58. However, Figure 4.59 shows that DSE% at this particular angle is 40%, which is too high and cannot be accepted. Thus, in this case, the author will give the priority to a lower DSE% over the maximum DUD% to minimize the possibilities of glare. Therefore, at α=-60°, the minimum DSE% occur which is 32.5%. Although the DSE% value is still too high, the author will considered it acceptable since it is the minimum DSE% achieved at this time among all other angles including the base case scenario. Moreover, DSE% at α=-60° is lower than DSE% in the base case scenario where it equals to 55%. Therefore, α=-60° will be considered as the optimal angle for t=12:00, as shown in Figure 4.62.

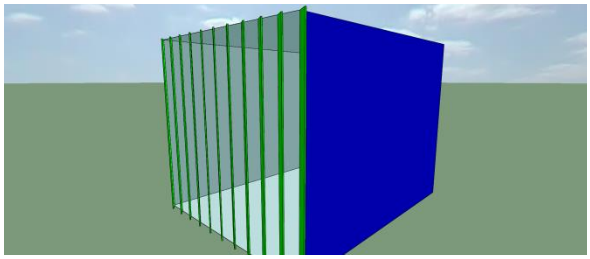


Figure 4.62: 3D Model of the optimal angle α=-60° at t=12:00 on 21 Jun (W/S=0.5, North)

In addition, at t=14:00, the maximum DUD% occurs at α=0° and α=40° which equals to 26%, as shown in Figure 4.58. Since both angles achieve the exact DUD% value, the author will select the angle that provides the lower DSE% which is α=40° where DSE% is 10% compared to 11% at α=0°, as shown in Figure 4.59. Also, in the base case scenario, DUD% is 22.5% only and DSE% is 29% which is too high, compared to the optimal angle obtained for t=14:00 which is α=40°. Figure 4.63 shows the 3D illustration of the optimal angle.

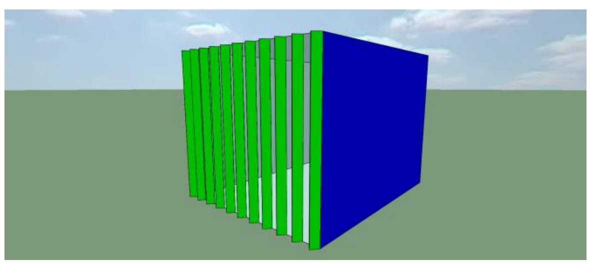


Figure 4.63: 3D Model of the optimal angle α=40° at t=14:00 and t=16:00 on 21 Jun (W/S=0.5, North)

Lastly, at t=16:00, the maximum DUD% is at α=40° where it equals to 34% compared to the base case scenario where DUD% is only 21%, as shown in Figure 4.58. On the other hand, Figure 4.59 shows that the DSE% at α=40°is 0% compared to DSE% of 30% in the base case scenario. Thus, α=40° is the optimal angle at t=16:00, as shown in Figure 4.63.

Appendix A shows the illuminance levels results for the base case and the optimal angles using dynamic shading louvers for all the simulated times.

Findings:

Table 4.25: Daylight analysis (Average DUD%) - June 21, North (W/S=0.5)

Dynamic Useful Daylight Analysis (DUD%) - June 21, North (W/S=0.5)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	22.5%	24%	29%	32.5%	34%	31%	19%	16%
10:00	26%	25%	29%	26%	25%	25%	19%	16%
12:00	25%	22.5%	26%	27.5%	30%	26%	25%	21%
14:00	22.5%	19%	22.5%	25%	26%	24%	26%	20%
16:00	21%	17.5%	21%	27.5%	30%	30%	34%	27.5%
Avg. DUD%	**23%**	**22%**	**26%**	**28%**	**29%**	**27%**	**25%**	**20%**
Time (t)	Same as Above	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00					34%			
10:00			29%					
12:00		22.5%						
14:00							26%	
16:00							34%	
Avg. DUD%		**29%**						

Table 4.26: Daylight analysis (Average DSE%) - June 21, North (W/S=0.5)

Dynamic Sunlight Exposure Analysis (DSE%) - June 21, North (W/S=0.5)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	29%	0%	0%	0%	0%	9%	17.5%	16%
10:00	26%	1%	4%	7.5%	11%	15%	17.5%	15%
12:00	55%	32.5%	36%	40%	40%	41%	39%	34%
14:00	29%	15%	15%	15%	11%	11%	10%	7.5%
16:00	30%	16%	19%	14%	5%	4%	0%	0%
Avg. DSE%	**34%**	**13%**	**15%**	**15%**	**13%**	**16%**	**17%**	**15%**
Time (t)	Same as Above	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00					0%			
10:00			4%					
12:00		32.5%						
14:00							10%	
16:00							0%	
Avg. DSE%		**9%**						

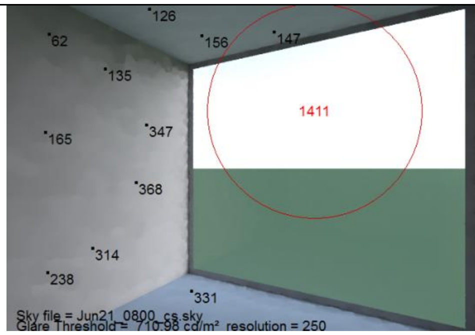
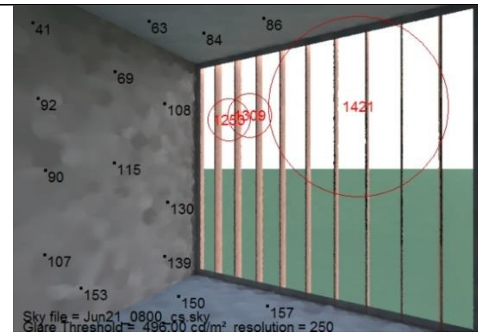
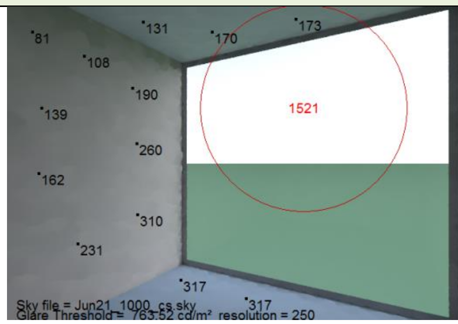
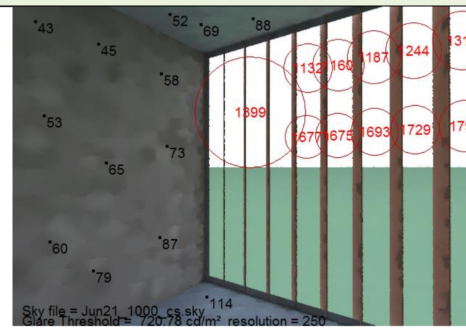
Table 4.25 shows that the average DUD% when using dynamic shading louvers is 29% compared to 23% only, in the base case scenario. Similarly, when using fixed shading louvers at α=0°, the average DUD% happens to be 29% which is identical to the result of dynamic shading louvers. However, looking at the data shown in Table 4.26, the average DSE% equals to 9% when using dynamic shading louvers compared to 34% in the base case scenario which is too high. Moreover, when using fixed shading louvers at α=0°, the average DSE% is 13% which is higher than the average DSE% when using dynamic shading louvers. Thus, the author will select dynamic shading louvers as the most suitable configuration for this specific scenario in terms of daylight performance.

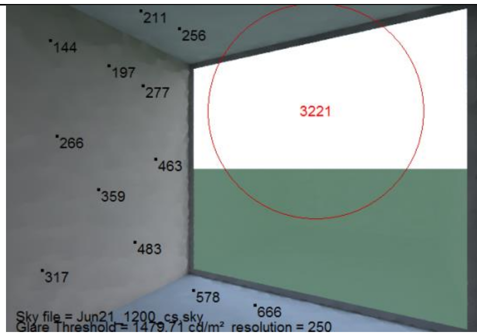
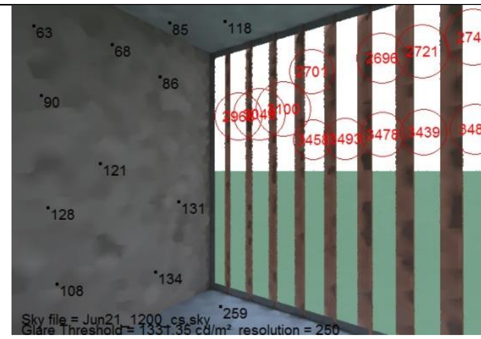
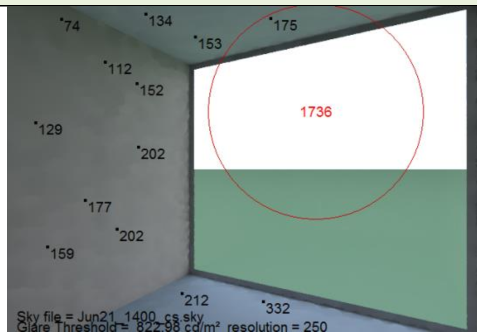
- **Glare Analysis**

In this section, the author will demonstrate the results obtained from glare analysis for the base case scenario and the dynamic shading louvers scenario.

Table 4.27: Summary of the Glare Analysis - June 21, North (W/S=0.5)

Glare Analysis for June 21, North (W/S=0.5)		
t=08:00	**Base Case**	**Dynamic Shading Louvers α=0°**

		
t=10:00	**Base Case**	**Dynamic Shading Louvers α=-40°**
		
t=12:00	**Base Case**	**Dynamic Shading Louvers α=-60°**

<table>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=40°</td></tr>
<tr><td></td><td>
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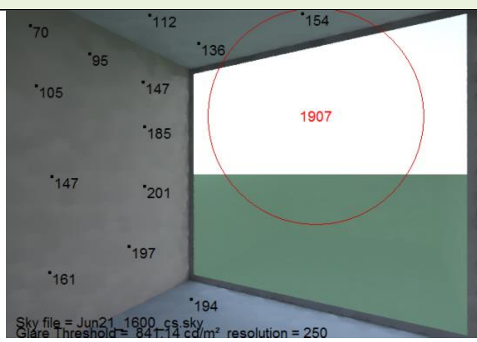
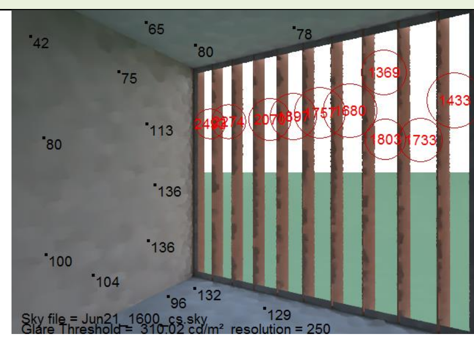
<tr><td>t=16:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=40°</td></tr>
<tr><td></td><td>
</td><td>
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Table 4.27 shows the summary of the glare analysis for June 21 using W/S=0.5 on the northern orientation.

Discussion:

The model in the base case scenario at t=08:00 experiences glare on the glazing, as shown in Table 4.27. This glare is caused due to the high luminance on the surface which equals to 1411 cd/m2. However, when using dynamic shading vertical louvers, the glare appearance vary across the glazed surface to range between 1253 and 1421 cd/m2.

Moreover, at t=10:00, the glazing in the base case scenario experiences glare due to a higher luminance level of 1521 cd/m2. But, the addition of the vertical dynamic shading louvers caused the luminance level across the glazing to drop where it reaches as low as 1244 cd/m2. Also, the luminance level range across the internal surfaces decreased with the addition of the louvers compared to the base case scenario. Furthermore, at t=12:00, the glare on the glazing, in the base case scenario, is caused due to the luminance level of 3221 cd/m2. This luminance changes with the addition of the dynamic shading louvers where it decreases to as low as2701 cd/m2. Also, at t=14:00 and in the base case scenario, the glare is also visible on the glazing due to a luminance of 1736 cd/m2. As observed, adding shading louvers led to a decrease in the luminance level range across the glazed surface to range between 1338 to 1862 cd/m2.

Finally, at t=16:00, the glazing in the base case scenario experiences a luminance value of 1907 cd/m2 compared to the shading louvers scenario where the luminance levels vary across the surface. Besides that, the luminance levels across the internal surfaces (walls, ceiling and floor) decrease with the addition of the vertical dynamic shading louvers.

Findings:

Table 4.28: Glare analysis Summary - Jun 21, North (W/S=0.5)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	t=10:00	t=12:00	t=14:00	t=16:00	Avg. Luminance

						(cd/m2)
Base Case	1411	1521	3221	1736	1907	**1959**
Optimal Case	1421	1729	3489	1873	1803	**2063**

As shown in Table 4.28, the average luminance level when using no louvers at all times is 1959 cd/m2 compared to an average luminance level of 2063 cd/m2 when using dynamic shading louvers at the optimal tilt angles. Although the glazing in the optimal cases seem to experience slightly higher luminance levels than the luminance levels in the base cases, the author will be neglecting this minimal increase since the priority is given to the daylight performance over glare performance throughout this paper. The reason of prioritizing daylight is because daylight has a greater impact on the energy savings than glare and because glare is a subjective factor which does not necessarily provide a solid indication of the comfort or discomfort probability.

4.2.2. Daylight and Glare Analysis for June 21, W/S=1.0

- **Daylight Analysis**

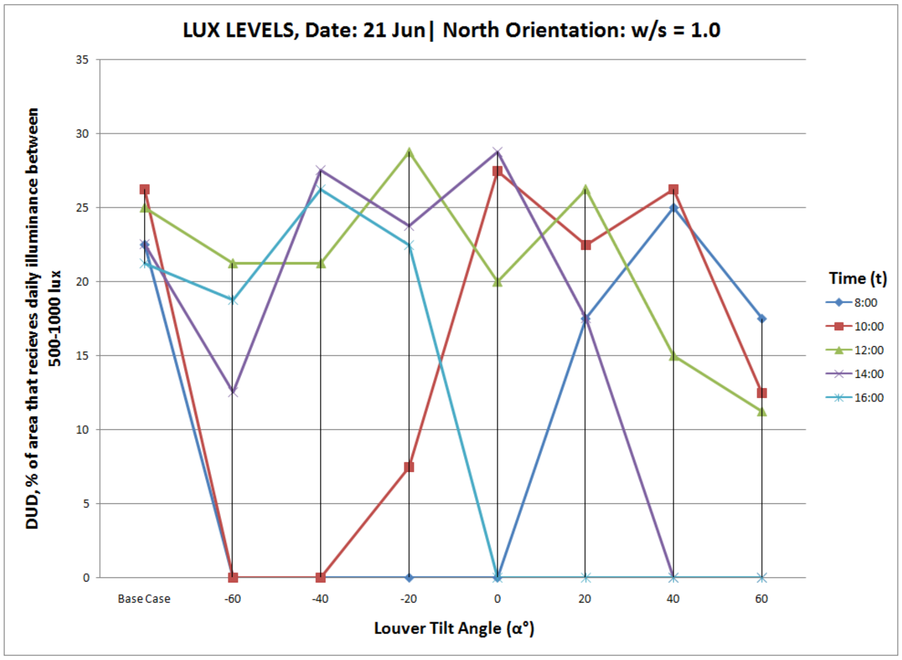


Figure 4.64: DUD analysis, 21 Jun, w/s=1.0 (North)

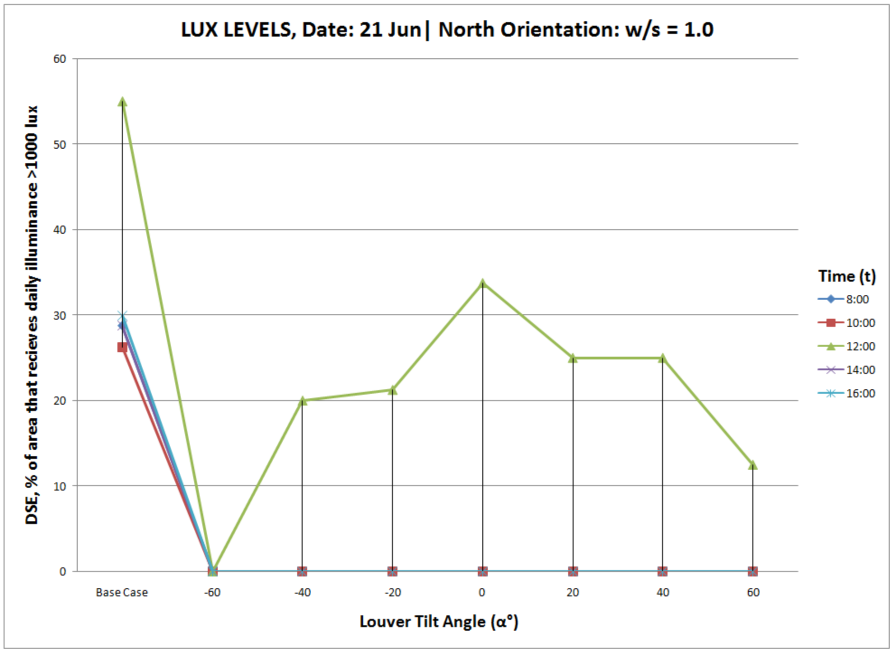


Figure 4.65: DSE analysis, 21 Jun, w/s=1.0 (North)

Figure 4.64 and Figure 4.65 show the daylight analysis for the model on 21 June using W/S=1.0 on the northern orientation.

At t=08:00, Figure 4.64 shows that the maximum DUD% occurs at α=40° which equals to 25% compared 22.5% only, in the base case scenario. Moreover, Figure 4.65 shows that DSE% at α=40° is 0% which is the optimal DSE% compared to DSE% of 29% in the base case scenario. Thus, the author is selecting α=40° to be the optimal daylight angle for t=08:00, as shown in Figure 4.66.

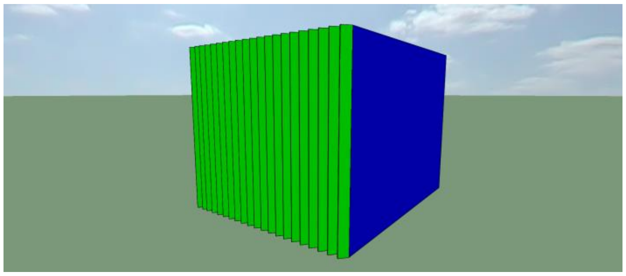


Figure 4.66: 3D Model of the optimal angle α=40° at t=08:00 on 21 Jun (W/S=1.0, North)

Additionally, at t=10:00, Figure 4.64 shows that the maximum DUD% occurs at α=0° where it equals to 27.5% compared to 26% in the base case scenario. However, at the same angle and time, DSE% is 0% whereas DSE% in the base case scenario is 26% which is too high, as shown in Figure 4.65. Therefore, α=0° is the best angle for t=10:00, as shown in Figure 4.67.

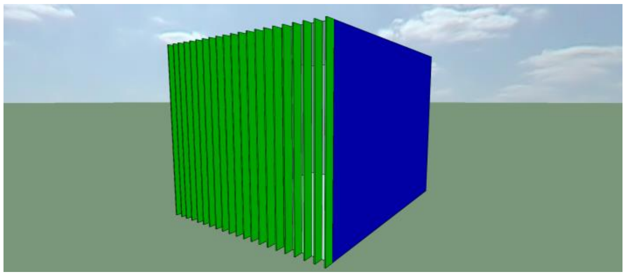


Figure 4.67: 3D Model of the optimal angle α=0° at t=10:00 and t=14:00on 21 Jun (W/S=1.0, North)

Furthermore, Figure 4.64shows that at t=12:00, the maximum DUD% occurs at α=-20° where it equals to 29%. However, Figure 4.65 shows that at the same angle, DSE% is 21% which is too high and cannot be accepted. Therefore, the author is selecting the second best angle that provides high DUD% and low DSE% which is α=-60° where DUD% and DSE% are equal to 21% and 0%, respectively. Comparing these results with the base case scenario, DUD% and DSE% are equal to 25% and 55%, respectively. Although DUD% in the base case scenario is 4% higher than DUD% at α=-60°, the author will still select α=-60° as the optimal since the difference in DUD% is not significant and the reduction in DSE% using the louvers is very dramatic. Figure 4.68 shows the 3D illustration of the optimal angle at this particular time.

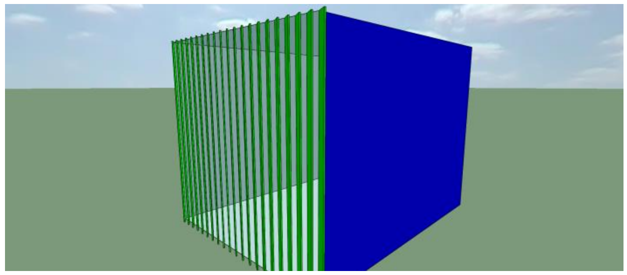


Figure 4.68: 3D Model of the optimal angle α=-60° at t=12:00 on 21 Jun (W/S=1.0, North)

Moreover, at t=14:00, Figure 4.64 shows that 29% is the highest DUD% at this time and occurs while using vertical louvers tilted at α=0°. However, in the base case scenario, DUD% is less and equals to 22.5% only. On the other hand, DSE% analysis in Figure 4.65 shows that DSE of 0% is achieved while using vertical louver at α=0° compared to DSE% of 29% in the base case scenario. Thus, α=0° is the optimal daylight angle for this particular time, as shown in Figure 4.67.

Finally, at t=16:00, the maximum DUD% is 26% and occurs at α=-40°, as shown in Figure 4.64. However, DUD% in the base case scenario shows that only 21% of the work plane area receives illuminance between 500-1000 lux. On the other hand, Figure 4.65 shows that DSE% at α=-40° is 0% which is the optimal value for DSE% compared to DSE% of 30% in the base case scenario. Therefore, α=-40° is considered as the optimal angle at t=16:00, as shown in Figure 4.69.

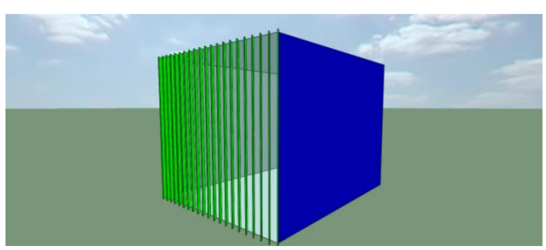


Figure 4.69: 3D Model of the optimal angle α=-40° at t=16:00 on 21 Jun (W/S=1.0, North)

Appendix B shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=1.0.

Findings:

Table 4.29: Daylight analysis (Average DUD%) - June 21, North (W/S=1.0)

Dynamic Useful Daylight Analysis (DUD%) - June 21, North (W/S=1.0)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	22.5%	0%	0%	0%	0%	17.5%	25%	17.5%
10:00	26%	0%	0%	7.5%	27.5%	22.5%	26%	12.5%
12:00	25%	21%	21%	29%	20%	26%	15%	11%
14:00	22.5%	12.5%	27.5%	24%	29%	17.5%	0%	0%
16:00	21%	19%	26%	22.5%	0%	0%	0%	0%
Avg. DUD%	**23%**	**11%**	**15%**	**17%**	**15%**	**17%**	**13%**	**8%**
Time (t)	Same as Above	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00							25%	
10:00					27.5%			
12:00		21%						
14:00					29%			
16:00			26%					
Avg. DUD%		**21%**						

Table 4.30: Daylight analysis (Average DSE%) - June 21, North (W/S=1.0)

Dynamic Sunlight Exposure Analysis (DSE%) - June 21, North (W/S=1.0)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	29%	0%	0%	0%	0%	0%	0%	0%
10:00	26%	0%	0%	0%	0%	0%	0%	0%
12:00	55%	0%	20%	21%	34%	25%	25%	12.5%
14:00	29%	0%	0%	0%	0%	0%	0%	0%
16:00	30%	0%	0%	0%	0%	0%	0%	0%
Avg. DSE%	**34%**	**0%**	**4%**	**4.2%**	**6.8%**	**5%**	**5%**	**2.5%**
Time (t)	Same as Above	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00							0%	
10:00					0%			
12:00		0%						

14:00					0%			
16:00			0%					
Avg. DSE%		**0%**						

Table 4.29 shows that the maximum average DUD% occurs in the base case scenario where no louvers are used. However, looking at the data presented in Table 4.30, the average DSE% in the base case scenario is 34% which is very high and cannot be accepted. On the other hand, the average DUD% when using dynamic shading louvers is 21% which represent the second highest average DUD% after the base case scenario. Moreover, as shown in Table 4.30, the average DSE% when using dynamic shading louvers is 0% which is the optimal DSE% value. Also, as observed, the fixed shading louvers at all angles provide less average DUD% compared to the usage of dynamic shading louvers.

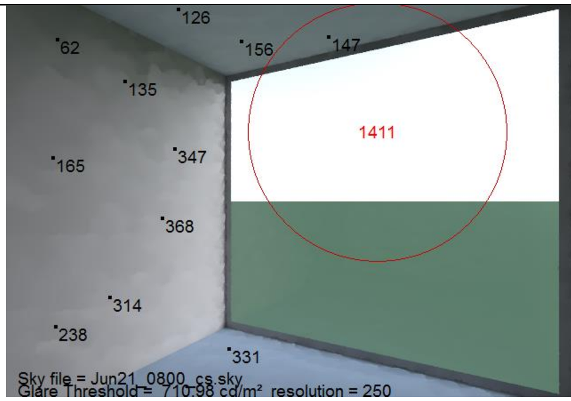
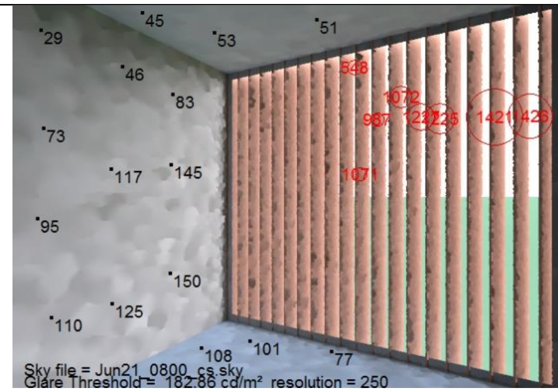
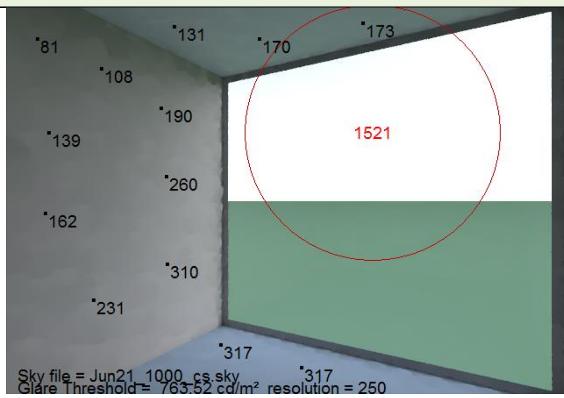
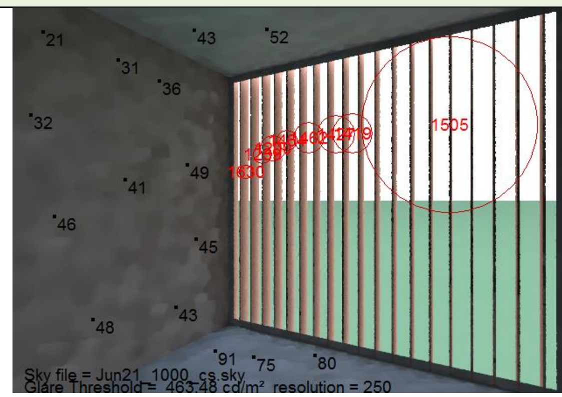
Thus, the author will be considering dynamic shading louvers as the optimal configuration for this scenario in providing the optimal daylight.

- **Glare Analysis**

In this section, the results of glare analysis will be presented for the base case scenario as well as the dynamic shading louvers scenario which was chosen to be the optimal daylight configuration, as per the daylight analysis.

Table 4.31: Summary of the Glare Analysis - June 21, North (W/S=1.0)

Glare Analysis for June 21, North (W/S=1.0)		
t=08:00	**Base Case**	**Dynamic Shading Louvers α=40°**

		
t=10:00	**Base Case**	**Dynamic Shading Louvers α=0°**
		
t=12:00	**Base Case**	**Dynamic Shading Louvers α=-60°**

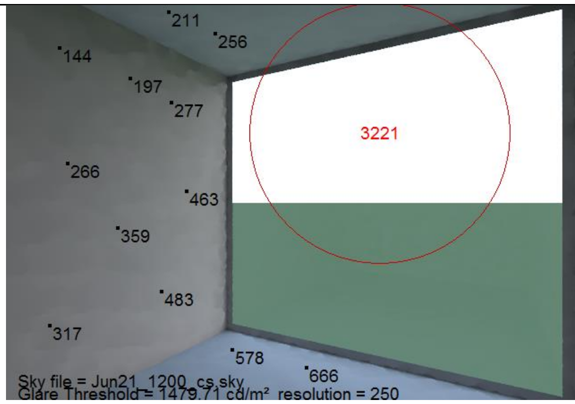
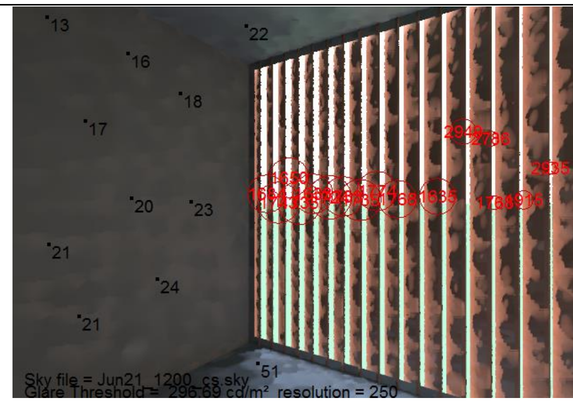
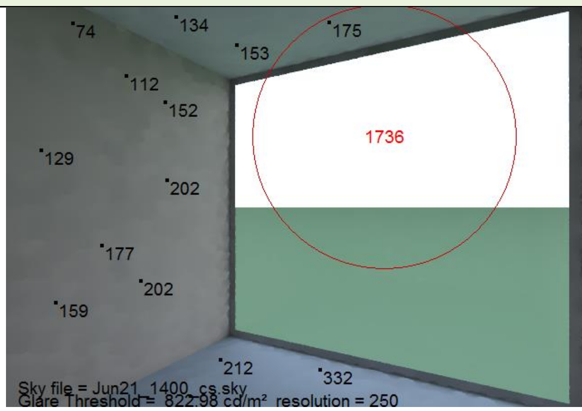
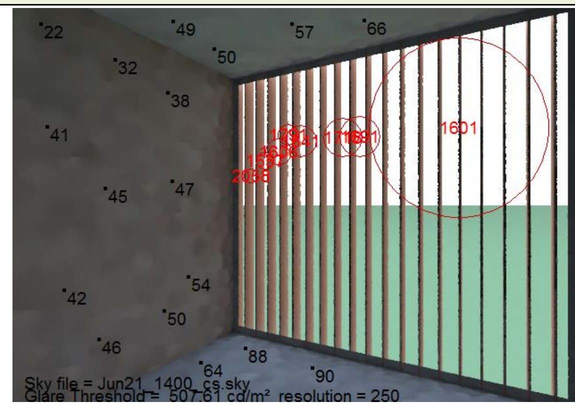
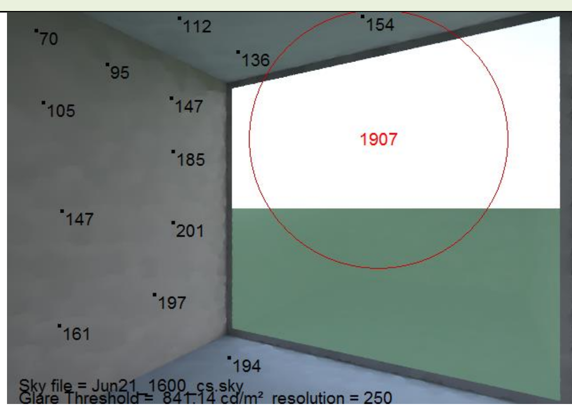
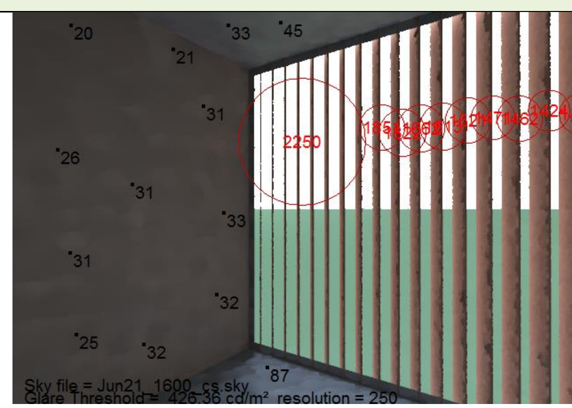
<table>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=0°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=16:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-40°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
</table>

Table 4.31 shows the summary of the glare analysis for June 21 using W/S=1.0 on the northern orientation.

Discussion:

At t=08:00, the base case scenario shows that the room is experiencing glare on the glazing which is due to a luminance of 1411 cd/m2 on the surface. However, adding vertical dynamic shading louvers minimized the glare along the glazed wall through minimizing the penetration of direct sunlight inside the office. Also, the overall luminance levels across the office is reduced when using the dynamic shading louvers compared to the base case scenario.

Moreover, at t=10:00, the glazing experiences glare in the base case scenario due to the luminance level on the surface which equals to 1521 cd/m2. On the other hand, the dynamic shading louvers scenario shows that the glare is minimized along the glazed wall and the internal surfaces of the office (wall, ceiling and floor).

Furthermore, at noon, the luminance level on the glazing is 3221 cd/m2 compared to different lower luminance values when using vertical dynamic shading louvers at the optimal daylight angle α=-60°. However, the luminance levels on the internal surfaces of the room seem to be too low for an office use at this particular time of the day due to the tilt angle (α=-60°) that blocks most of the light penetration.

Additionally, at t=14:00, the glazing in the base case scenario experiences a luminance of 1736 cd/m2 compared to various lower luminance levels when using shading louver at α=0°. Also, the internal surfaces of the room seem to have less intense light compared to the base case scenario,

Lastly, at t=16:00, the glazing in the base case scenario has a luminance value of 1907 cd/m2 compared to less intense glare when using dynamic shading louvers due to the light disturbance cause by the presence on the louvers.

Findings:

Table 4.32: Glare analysis Summary - Jun 21, North (W/S=1.0)

	Luminance Levels on the glazing (cd/m²)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	1411	1521	3221	1736	1907	**1959**
Optimal Case	1426	1505	1650	1601	2250	**1686**

Table 4.41 shows that the average luminance level on the glazing in the optimal cases is 1686 cd/m2 compared to an average luminance level of 1959 cd/m2 in the base cases. The results are aligned with the results obtained from the daylight result where using dynamic shading louvers have proven their effectiveness in increasing DUD%, decreasing g DSE% and decreasing luminance levels which eventually reduces the contrast intensity between the glazing and the internal surfaces, thus, reduce the glare.

4.3.East Orientation

In this section, the author will be studying the potential of dynamic shading louvers in providing the optimal daylight and glare performance in three different days (21 March, 21 June and 21

December). Moreover, the author will be using W/S=0.5 and W/S=1.0 to undertake this aim using vertical shading louvers.

4.3.1. Daylight and Glare Analysis for March 21, W/S=0.5

- **Daylight Analysis**

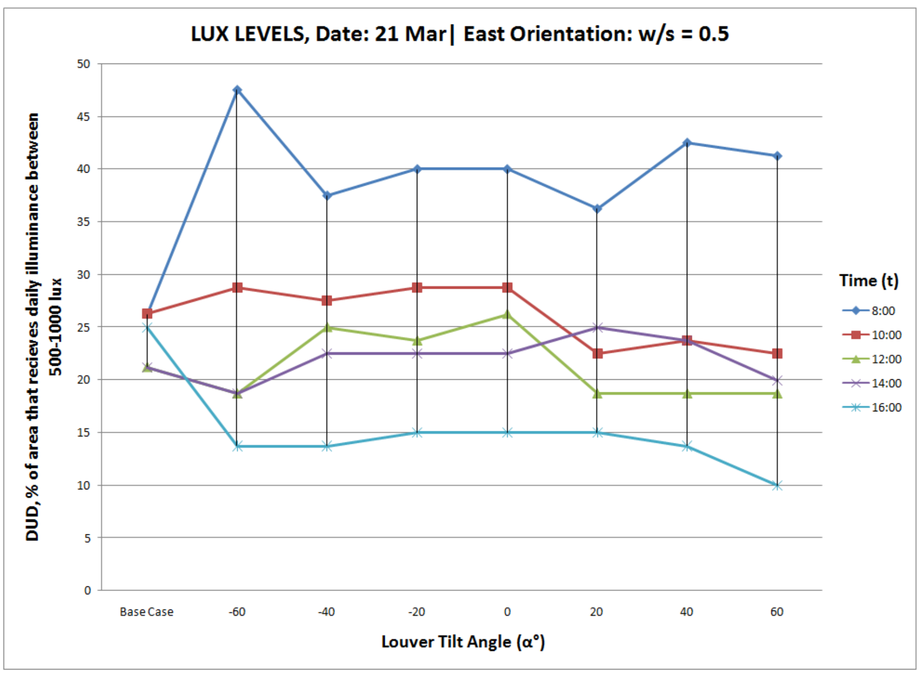


Figure 4.70: DUD analysis, 21 Mar, w/s=0.5 (East)

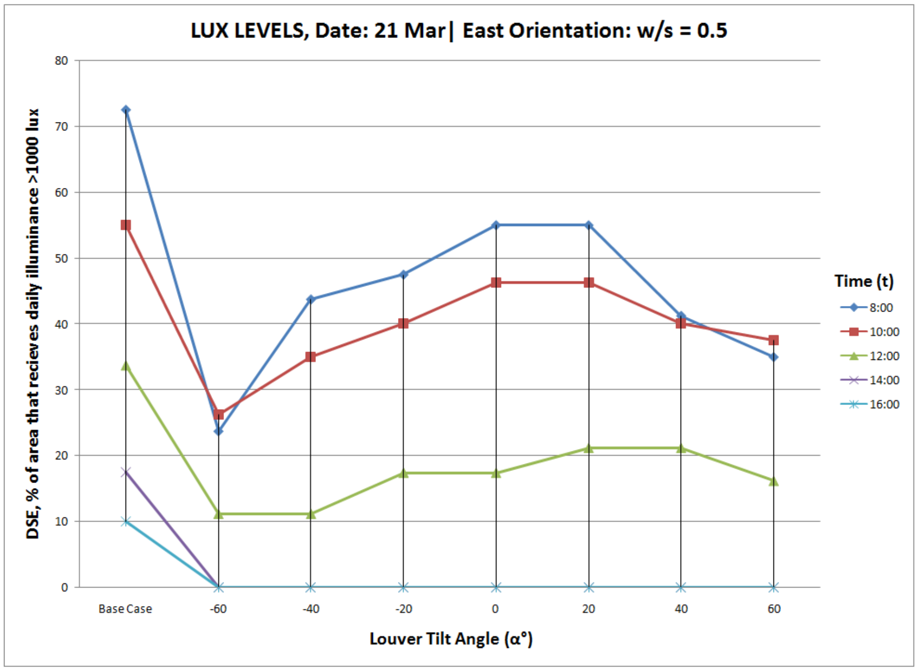


Figure 4.71: DSE analysis, 21 Mar, w/s=0.5 (East)

Figure 4.70 and Figure 4.71 show the daylight analysis for March 21 using W/S=0.5 on the eastern orientation.

Discussion:

As shown in Figure 4.70, the maximum DUD% at t=08:00 occurs at α=-60° where the DUD% is 47.5% compared to 26% only, in the base case scenario. On the other hand, DSE% at α=-60° is 24% compared to 72.5%, in the base case scenario, as shown in Figure 4.71.

Although DSE% at α=-60° is considered too high, it is still the minimum DSE% among all other angles, which makes it acceptable. Thus, the author will consider α=-60° as the optimal angle for this particular time of the day. Figure 4.72 shows the 3D illustration of the optimal angle at t=08:00.

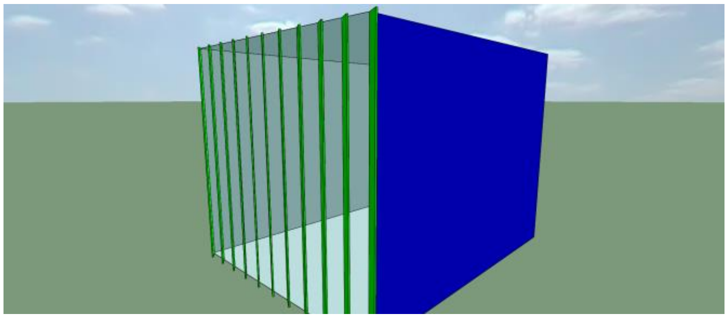


Figure 4.72: 3D Model of the optimal angle α=-60° at t=08:00 and t=10:00 on 21 Mar (W/S=0.5, East)

Moreover, at t=10:00, the maximum DUD% occurs at α=-60° as well where it equals to 29% compared to 26% only, in the base case scenario. The difference in DUD% for both scenarios is not significant, however, Figure 4.71 shows that DSE% at α=-60° is 26% compared to 55%,in the base case scenario which is almost twice as much. Similar to the situation at t=08:00, the author will consider DSE% of 26% at α=-60° is acceptable since it represents the minimum DSE% among all other angles.

In addition, at t=12:00, the maximum DUD% occurs at α=0° where it equals to 26% compared to 21% only, in the base case scenario. However, looking at Figure 4.71, DSE% at α=0° is 17.5% compared to 34%, in the base case scenario. Since DSE% of 17.5% represents the lowest DSE% among all other angles, it will be considered as acceptable. Figure 4.73shows the 3D illustration of the model at the optimal angle α=0° at t=12:00.

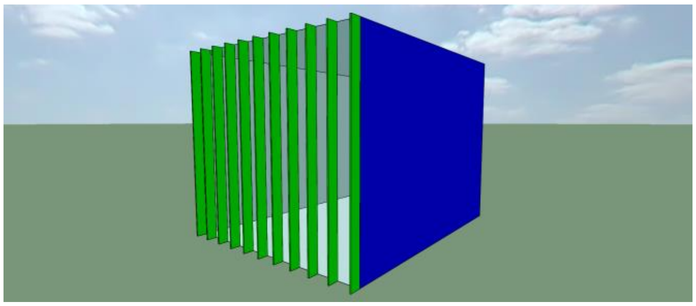


Figure 4.73: 3D Model of the optimal angle α=0° at t=12:00 on 21 Mar (W/S=0.5, East)

Furthermore, at t=14:00, the maximum DUD% occurs at α=20° where it equals to 25% compared to 21% only, in the base case scenario. On the other hand, Figure 4.71 shows that at α=20°, DSE% is 0%, which is the optimal percentage for DSE%, compared to DSE% of 17.5% in the base case scenario. Figure 4.74 shows the 3D model of the office at the optimal angle.

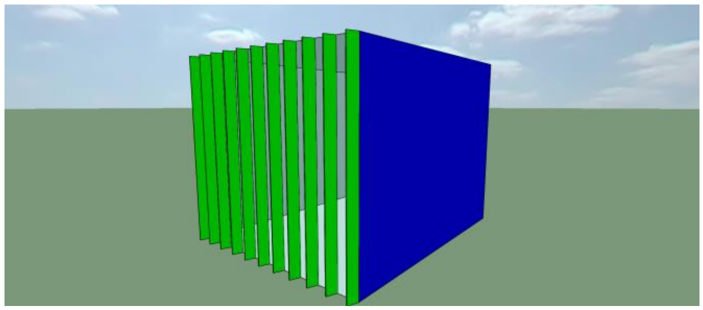


Figure 4.74: 3D Model of the optimal angle α=20° at t=14:00 on 21 Mar (W/S=0.5, East)

Finally, at t=16:00, the maximum DUD% occurs when using no louvers and it equals to 25%. However, DSE% when using no louvers equals to 10% which is considered high, as per the pre-defined assessment criteria. Although the other angles (-60, -40, -20, 0 , 20, 40, and 60) achieve DSE% of 0%, DUD% at these angles are very low compared to DUD% in the base case scenario. Thus, the author will feature the maximum DUD% over the minimum DSE%, in this case. This means that for this particular time of the day, using no louvers at all will be the best configuration to provide a useful daylight.

Since at t=08:00, t=10:00, t=12:00, and t=14:00, the optimal daylight is achieved when using dynamic shading louvers, at t=16:00 the louvers will open up and hide into a "louver house" that can be installed at the sides of the glazing. This will ensure that the glazing surface is fully exposed to the sunlight penetration at this time to ensure better daylight, as shown in Figure 4.75. Such cases will be named as "Hidden Louvers" and they are considered as part of the dynamic shading louvers configuration.

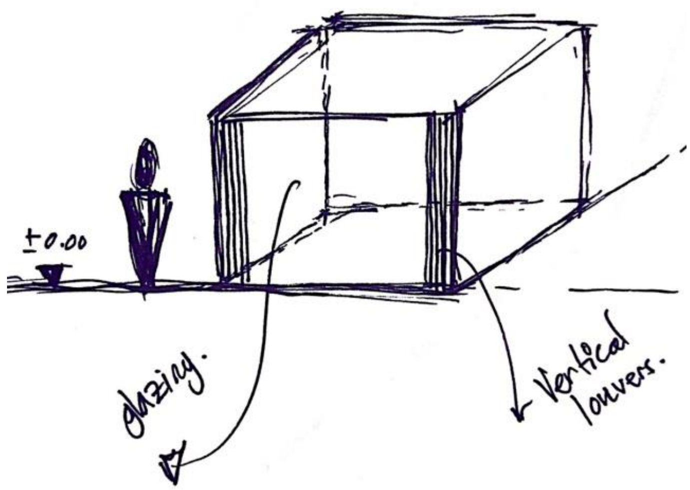


Figure 4.75: Conceptual sketch showing the model with hidden louvers at t=16:00 on 21 Mar (W/S=0.5, East)

Appendix C shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=0.5.

Findings:

Table 4.33: Daylight analysis (Average DUD%) - Mar 21, East (W/S=0.5)

Dynamic Useful Daylight Analysis (DUD%) - March 21, East (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	26%	47.5%	37.5%	40%	40%	36%	42.5%	41%
10:00	26%	29%	27.5%	29%	29%	22.5%	24%	22.5%
12:00	21%	19%	25%	24%	26%	19%	19%	19%
14:00	21%	19%	22.5%	22.5%	22.5%	25%	24%	20%
16:00	25%	14%	14%	15%	15%	15%	14%	10%
Avg. DUD%	**24%**	**26%**	**25%**	**26%**	**27%**	**24%**	**25%**	**23%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00		47.5%						
10:00		29%						
12:00					26%			
14:00						25%		
16:00	25%							
Avg. DUD%	**30.5%**							

Table 4.34: Daylight analysis (Average DSE%) - Mar 21, East (W/S=0.5)

Dynamic Sunlight Exposure Analysis (DSE%) - March 21, East (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	72.5%	24%	44%	47.5%	55%	55%	41%	35%
10:00	55%	26%	35%	40%	46%	46%	40%	37.5%
12:00	34%	11%	11%	17.5%	17.5%	21%	21%	16%
14:00	17.5%	0%	0%	0%	0%	0%	0%	0%
16:00	10%	0%	0%	0%	0%	0%	0%	0%
Avg. DSE%	**38%**	**12%**	**18%**	**21%**	**24%**	**24%**	**20%**	**18%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00		24%						
10:00		26%						
12:00					17.5%			
14:00						0%		
16:00	10%							
Avg. DSE%	**15.5%**							

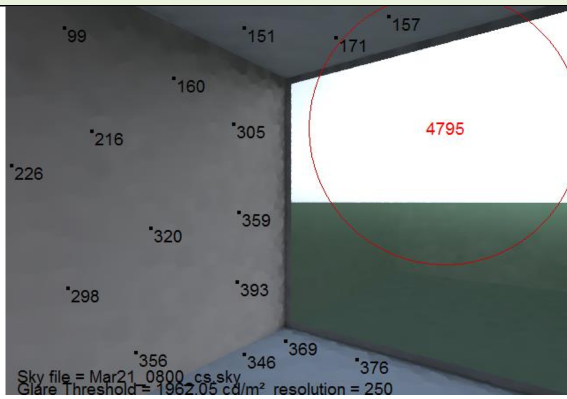
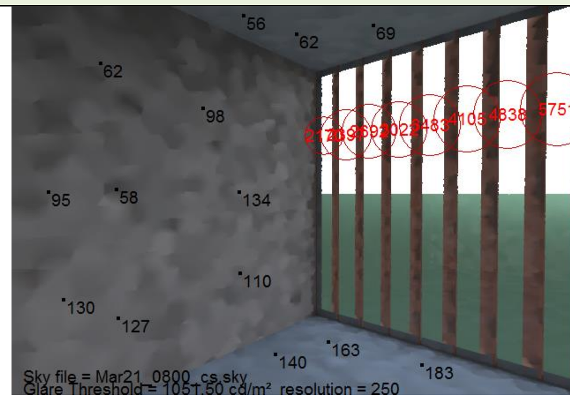
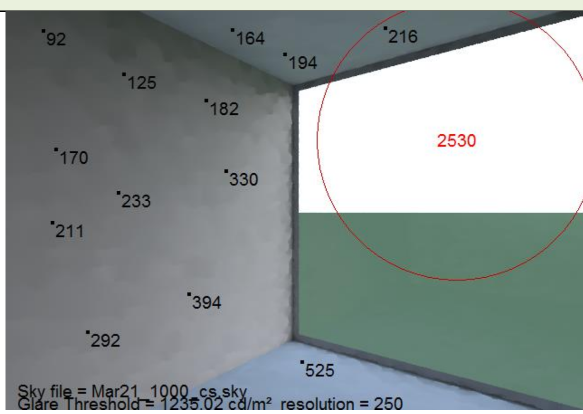
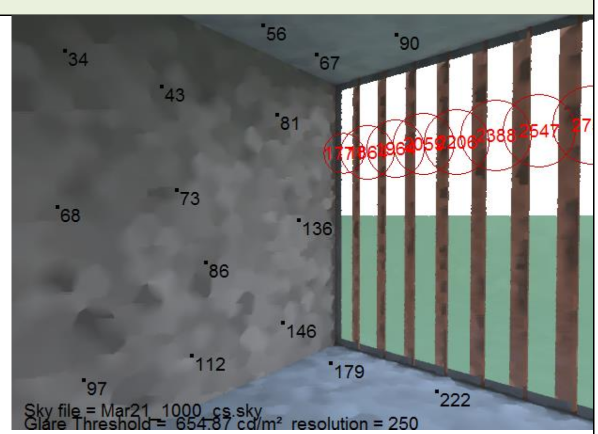
Table 4.33 shows that the maximum average DUD% occurs when using dynamic shading louvers which equals to 30.5% compared to 24% only, in the base case scenario. On the other hand, Table 4.34 shows that the minimum average DSE% occurs when using dynamic shading louvers as well and it equals to 15.5% compared to an average DSE% of 38% in the base case scenario.

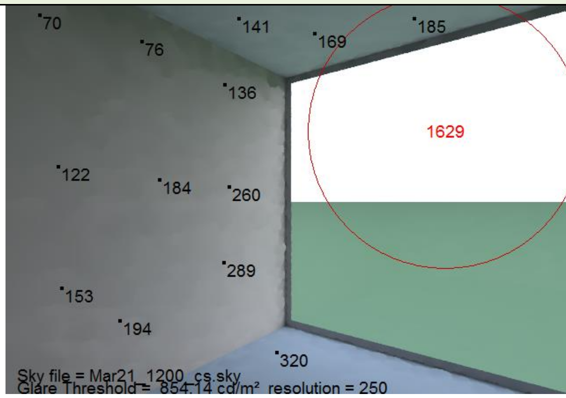
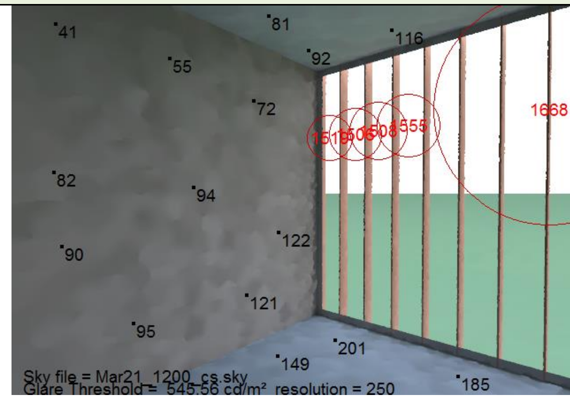
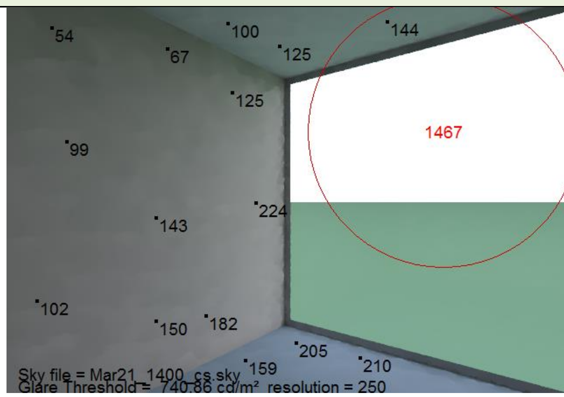
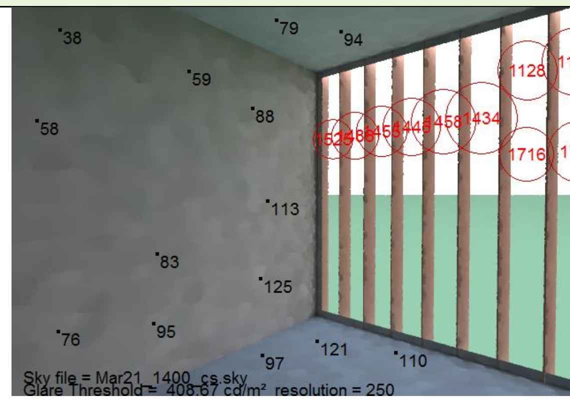
So, in this scenario, the vertical louvers will tilt to α=-60° at t=08:00 and t=10:00, then the louvers will change to α=0° at t=12:00, then the louvers will tilt again to α=20° at t=14:00, and lastly, the louvers will move towards the two ends of the glazing to allow full light penetration.

- **Glare Analysis**

In this section, the results of glare analysis will be presented for the base case scenario as well as the dynamic shading louvers scenario which was chosen to be the optimal configuration, as per the daylight analysis.

Table 4.35: Summary of the Glare Analysis - March 21, East (W/S=0.5)

Glare Analysis for March 21, East (W/S=0.5)		
t=08:00	**Base Case**	**Dynamic Shading Louvers α=-60°**
		
t=10:00	**Base Case**	**Dynamic Shading Louvers α=-60°**
		

<table>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=0°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=16:00</td><td colspan="2">Base Case (The optimal configuration for this time)</td></tr>
</table>

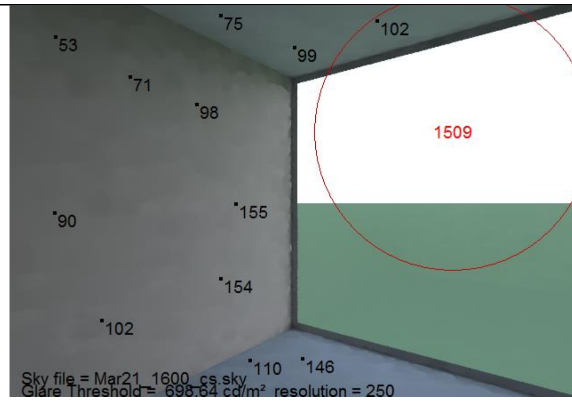
	

Table 4.35 shows the summary of the glare analysis for March 21 using W/S=0.5 on the eastern orientation.

Discussion:

In general, Table 4.35 shows that the maximum luminance value on the glazing occur in the early morning (e.g. t=08:00) since the model is oriented towards east and the sun is sun rising around this time of the day. On the other hand, it can be noticed that the luminance level on the glazing start to decrease as the time passes throughout the day because the sun is heading towards west. Therefore, at t=14:00 and t=16:00, the least luminance level appears on the glazing.

As shown in Table 4.35, at t=08:00, the glazing in the base case scenario experiences glare due to the luminance level of 4795 cd/m2 on the surface but once adding the dynamic shading louvers, the luminance levels along the glazing start to decrease. Also, the luminance levels of the internal surfaces decrease when adding shading louvers compared to the base case scenario.

Moreover, at t=10:00, the base case scenario shows that the glazing receives a luminance of 2530 cd/m2 which causes glare on the surface. However, adding dynamic shading louvers at α=-60° led to a decrease in the overall luminance levels across the glazing and the office space.

Furthermore, at t=12:00, the glazing in the base case scenario shows that the luminance level on the surface equals to 1629 cd/m2 which is less that the luminance level in the base case scenario at t=10:00 and t=08:00. However, adding shading louvers led to a further decrease in the luminance levels on the glazing and the internal surfaces, as shown in Table 4.35.

Additionally, at t=14:00, the glazing in the base case scenario has luminance value of 1476 cd/m2 whereas a decrease in the luminance levels can be noticed once adding the dynamic shading louvers. Finally, at t=16:00, the base case scenario is the optimal scenario for this particular time of the day where the glazing experiences a luminance level of 1509 cd/m2 and a DUD% of 25%, as obtained previously.

Findings:

Table 4.36: Glare analysis Summary - Mar 21, East (W/S=0.5)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	4795	2530	1629	1467	1509	**2386**
Optimal Case	5751	2647	1668	1716	1509	**2658**

Table 4.46 shows that the average luminance level in the base cases is 2386 cd/m2 compared to 2658 cd/m2 in the optimal cases. As noticed, the optimal cases where the daylight is optimal are showing higher luminance levels compared to the base case scenarios. So, the author will prefer higher daylight performance over higher glare performance since glare can vary in acceptance

from person to another and can vary in terms of discomfort from one view to another. This indicates that the optimal case using dynamic shading louvers is the best design configuration for this particular scenario.

4.3.2. Daylight and Glare Analysis for June 21, W/S=0.5

- **Daylight Analysis**

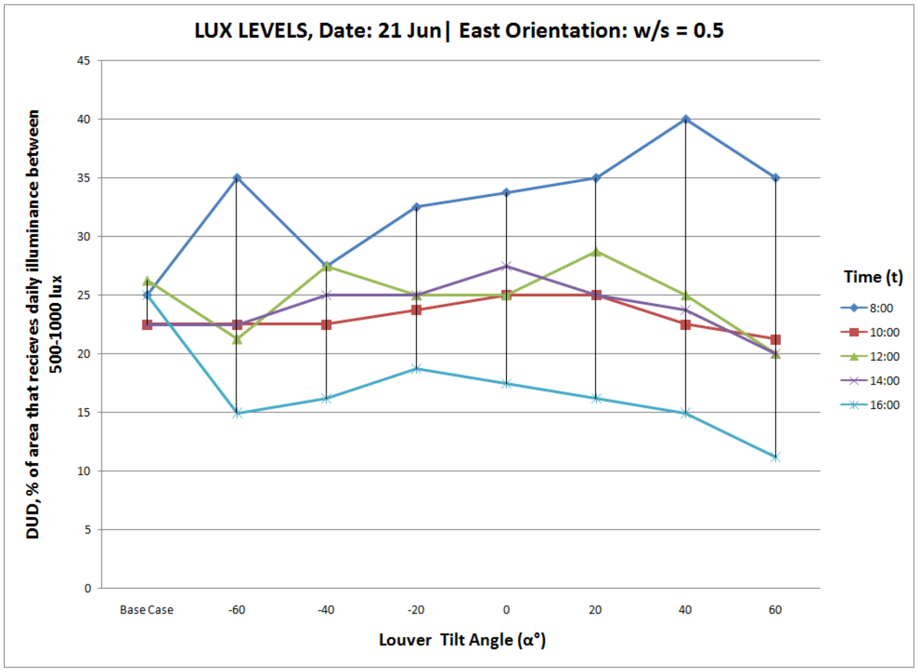


Figure 4.76: DUD analysis, 21 Jun, w/s=0.5 (East)

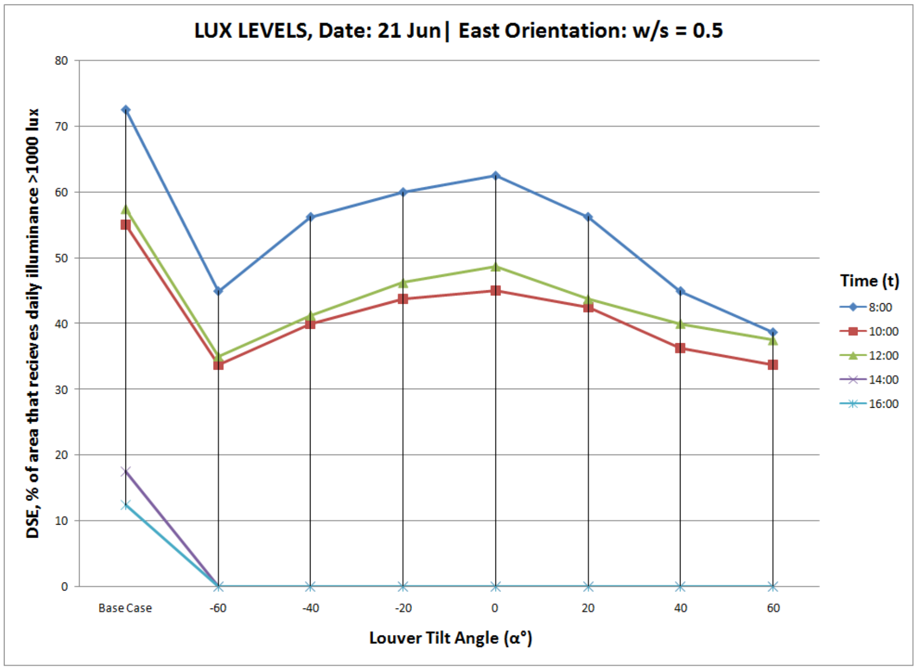


Figure 4.77: DSE analysis, 21 Jun, w/s=0.5 (East)

Figure 4.70Figure 4.76 and Figure 4.77show the daylight analysis for June 21 using W/S=0.5 on the eastern orientation.

Discussion:

Figure 4.76 shows that at t=08:00 the maximum DUD% occurs at α=40° where it equals to 40% compared to 25% only, in the base case scenario. On the other hand, Figure 4.77 shows that at α=40°, DSE% equals to 45% compared to 72.5% in the base case scenario. As observed, DSE% at α=40° is very high, thus, the author will be looking and the angle that provides the minimum DSE% value. At α=60°, the minimum DSE% occur which equals to 39%. Although the difference in DSE% values between α=40° and α=60° is only 6%, the author will still consider selecting the tilt angle that provides the least DSE% which is α=60°. As a result, DUD% reduces to 35% at α=60° compared to 40% at α=40°. Therefore, α=60° is the optimal angle for this time of the day, as shown in Figure 4.78.

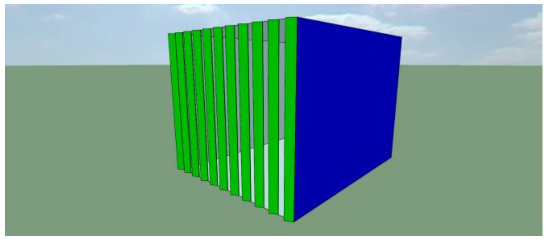


Figure 4.78: 3D Model of the optimal angle α=60° at t=08:00 on 21 Jun (W/S=0.5, East)

Moreover, at t=10:00, the maximum DUD% occurs at α=-20° where it equals to 24% compared to 22.5% in the base case scenario. However, Figure 4.77 shows that DSE% at α=-20° is 44% compared to 55% in the base case scenario. having DSE% of 44% is too high and could lead to overheating. Thus, the author will be selecting the tilt angle that provides the least DSE% among all angles which is α=-60° where DSE% is 34%. As a result, the DUD% value also decreases at α=-60° where it equals to 22.5% instead of 24% when using α=-20°. Since the difference is very slight (1.5%), the author will be selecting α=-60° to be the optimal tilt angle for this particular time of the day, as shown in Figure 4.79.

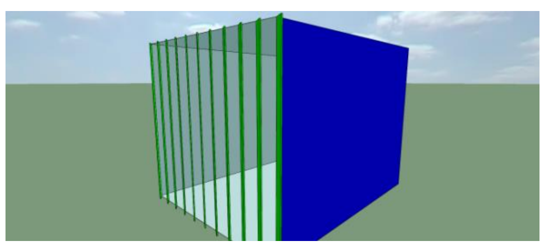


Figure 4.79: 3D Model of the optimal angle α=-60° at t=10:00 on 21 Jun (W/S=0.5, East)

Furthermore, at t=12:00, the maximum DUD% occurs at α=20° where it equals to 29% compared to 26% in the base case scenario. Looking at Figure 4.77, DSE% at α=20° is 44% compared to 57.5% in the base case scenario. DSE% of 44% is excessive and cannot be accepted, thus, the author will consider selecting the tilt angle that provides the minimum DSE% which is α=-60° where DSE% equals to 35%. As a result, DUD% drops to 21% at α=-

60° instead of 29% at α=20°. Nevertheless, the author will consider choosing α=-60° to be the optimal angle for t=12:00 since it provides less sunlight exposure.

Additionally, at t=14:00, Figure 4.76 shows that the maximum DUD% occurs at α=0° where it equals to 27.5% compared to 22.5% only, in the base case scenario. On the other hand, Figure 4.77 shows that DSE% at α=0° is 0% compared to 17.5% in the base case scenario. This makes α=0° the optimal tilt angle for t=14:00.

Lastly, at t=16:00, the maximum DUD% occurs in the base case scenario where it equals to 25% and DSE% equals to 12.5%. As observed using shading louvers at different tilt angles provides DSE% of 0% which is the optimal value for DSE%, however, DUD% when using shading louvers drop to a level where it can cause visual disability for office use. Thus, the author will select the base case scenario (where louvers will be hidden) as the optimal configuration for this time of the day since it provides the maximum DUD%.

Appendix D shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=0.5

Findings:

Table 4.37: Daylight analysis (Average DUD%) - Jun 21, East (W/S=0.5)

Dynamic Useful Daylight Analysis (DUD%) - June 21, East (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	25%	35%	27.5%	32.5%	34%	35%	40%	35%
10:00	22.5%	22.5%	22.5%	24%	25%	25%	22.5%	21%
12:00	26%	21%	27.5%	25%	25%	29%	25%	20%
14:00	22.5%	22.5%	25%	25%	27.5%	25%	24%	20%
16:00	25%	15%	16%	19%	17.5%	16%	15%	11%
Avg. DUD%	**24%**	**23%**	**24%**	**25%**	**26%**	**26%**	**25%**	**21%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00								35%
10:00		22.5%						
12:00		21%						
14:00					27.5%			
16:00	25%							
Avg. DUD%	**26%**							

Table 4.38: Daylight analysis (Average DSE%) - Jun 21, East (W/S=0.5)

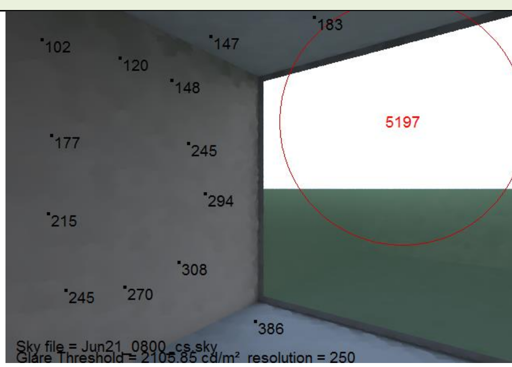
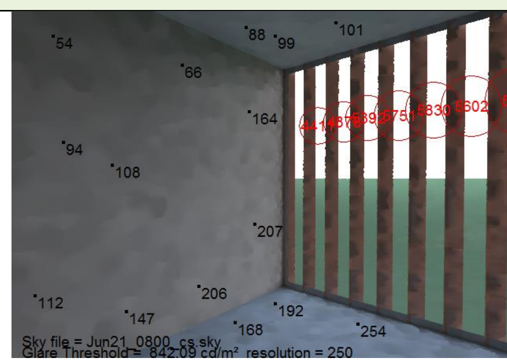
Dynamic Sunlight Exposure Analysis (DSE%) - June 21, East (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	72.5%	45%	56%	60%	62.5%	56%	45%	39%
10:00	55%	34%	40%	44%	45%	42.5%	36%	34%
12:00	57.5%	35%	41%	46%	49%	44%	40%	37.5%
14:00	17.5%	0%	0%	0%	0%	0%	0%	0%
16:00	12.5%	0%	0%	0%	0%	0%	0%	0%
Avg. DSE%	**43%**	**23%**	**27%**	**30%**	**31%**	**29%**	**24%**	**22%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00								39%
10:00		34%						
12:00		35%						
14:00					0%			
16:00	12.5%							
Avg. DSE%	**24%**							

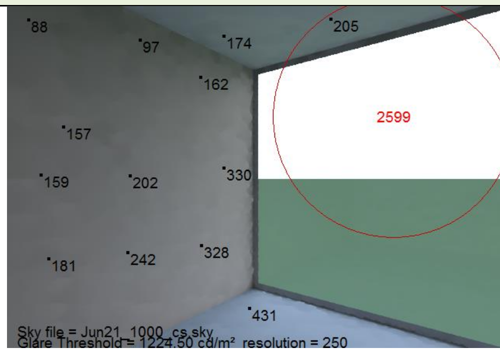
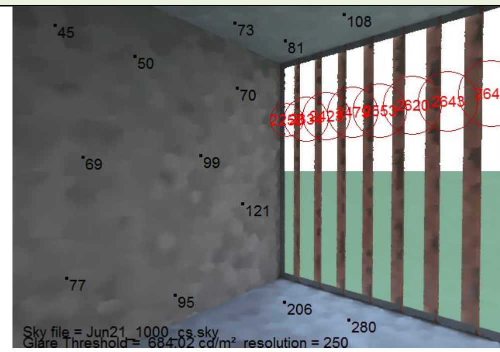
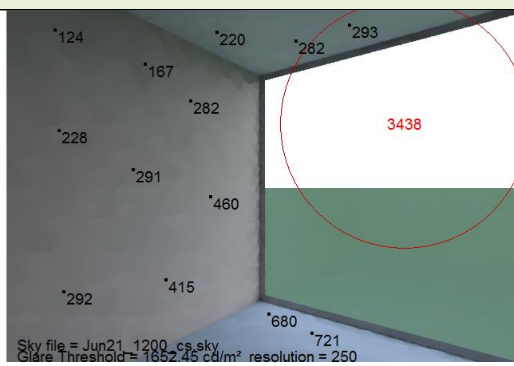
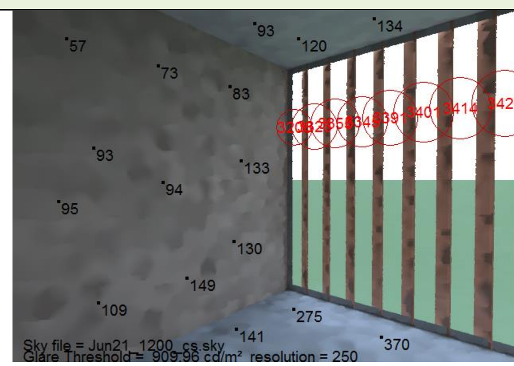
Table 4.37 shows that the maximum average DUD% is 26% and it can be achieved by using dynamic shading louvers and fixed shading louvers at α=0°and α=20°. However, Table 4.38 shows that the average DSE% when using dynamic shading louvers, fixed shading louvers at α=0° and fixed shading louvers at α=20° are 24%, 31%, and 29%, respectively. This means that using dynamic shading louvers is the best option for this specific scenario since it provides the maximum DUD% among all other configurations.

- **Glare Analysis**

In this section, the results of glare analysis will be presented for the base case scenario as well as the dynamic shading louvers scenario which was chosen to be the optimal daylight configuration, as per the daylight analysis.

Table 4.39: Summary of the Glare Analysis - June 21, East (W/S=0.5)

Glare Analysis for June 21, East (W/S=0.5)		
t=08:00	**Base Case**	**Dynamic Shading Louvers α=60°**
		

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>t=10:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-60°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-60°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=0°</td></tr>
</table>

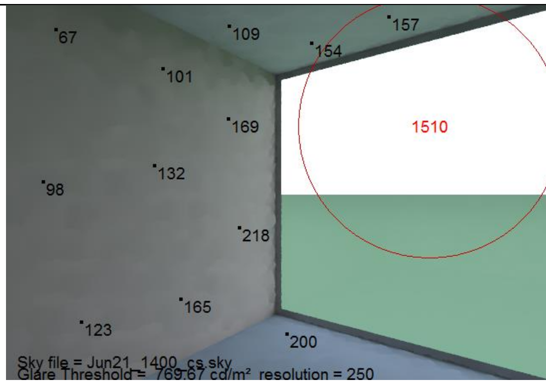
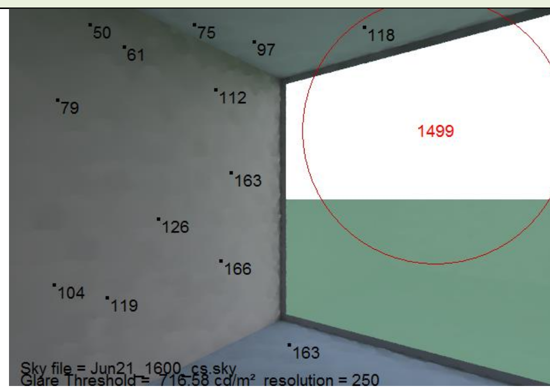
		
t=16:00	**Base Case (The optimal configuration for this time)**	
		

Table 4.39 shows the summary of the glare analysis for June 21 using W/S=0.5 on the eastern orientation.

Discussion:

In general, it can be observed that in the base case scenario at all times, the glare is present on the glazing part of the office due to the high occurrence of luminance values. Moreover, it can be noticed that at the early morning (e.g. t=08:00) the luminance value on the glazing is at its highest value among all other base case scenarios due to the sun position at this of the day where it is low and in the eastern side. On the contrary, the luminance levels across the glazing and the internal surfaces decrease as the time passes throughout the day since the sun is heading towards west.

Using dynamic shading louvers at t=08:00, t=10:00, t=12:00, and t=14:00 have proven to reduce the overall luminance levels in the office. At t=16:00, using no louvers was obtained to be the optimal configuration for this time, as per the daylight analysis. Moreover, the glare analysis have shown a glare occurrence on the glazing at t=16:00 due to the luminance value of 1499 cd/m2. However, the internal surfaces of the office seem to have a homogenous luminance level range across the room.

Findings:

Table 4.40: Glare analysis Summary - Jun 21, East (W/S=0.5)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	5197	2599	3438	1510	1499	**2849**
Optimal Case	5602	2643	3420	1504	1499	**2934**

Table 4.40 shows that the average luminance levels on the glazing in the base cases is 2849 cd/m2 compared to 2934 cd/m2 in the optimal cases where dynamic shading louvers are used. The difference in the average luminance level is very minimal compared to the dramatic difference in daylight performance between the two cases. Therefore, the author will still

consider the dynamic shading louvers as the optimal design for this scenario since it offers better daylight while minimizing direct sunlight, thus, minimizing cooling loads.

4.3.3. Daylight and Glare Analysis for December 21, W/S=0.5

- **Daylight Analysis**

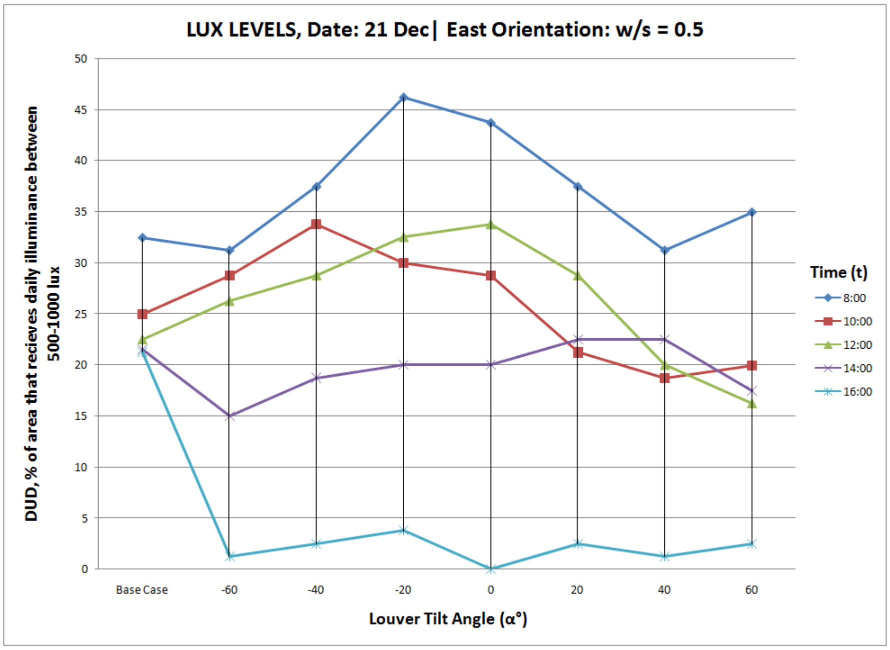


Figure 4.80: DUD analysis, 21 Dec, w/s=0.5 (East)

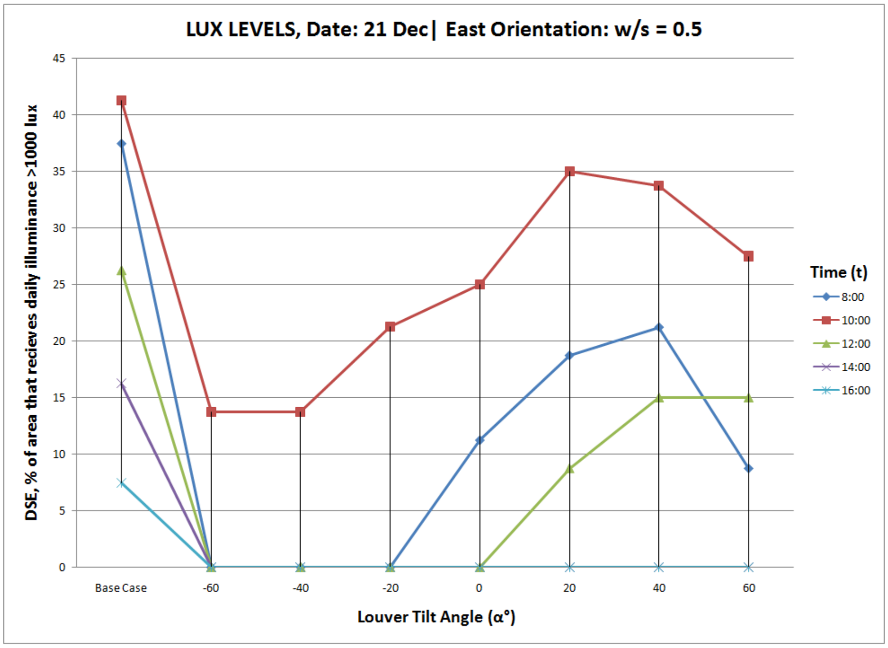


Figure 4.81: DSE analysis, 21 Dec, w/s=0.5 (East)

Figure 4.80 and Figure 4.81 show the daylight analysis for December 21 using W/S=0.5 on the eastern orientation.

Discussion:

As shown in Figure 4.80, the maximum DUD% at t=08:00 occurs at α=-20° where it equals to 46% compared to 32.5% only, in the base case scenario. Also, Figure 4.81 shows that at α=-20°, DSE% is 0% compared to 37.5% in the base case scenario. Thus, the author will select α=-20° to be the optimal tilt angle for t=08:00, as shown in Figure 4.82.

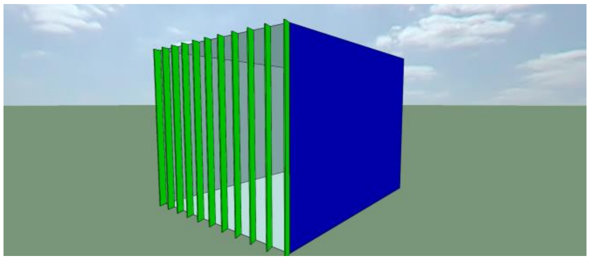


Figure 4.82: 3D Model of the optimal angle α=-20° at t=08:00 on 21 Dec (W/S=0.5, East)

Moreover, at t=10:00, the maximum DUD% occurs at α=-40° where it equals to 34% compared to 25% only, in the base case scenario. However, Figure 4.81 shows that DSE% at α=-40° is 14% compared to 41% in the base case scenario, which is too high. Although DSE% of 14% does not represent the optimal DSE%, the author will still consider it acceptable since it is the minimum DSE% value at this time of the day. Moreover, it is interesting to know that at α=-60°, DSE% of 14% is also achieved which is identical to DSE% at α=-40°, however, DUD% at α=-60° is 29% only compared to DUD% of 34% at α=-40°. Thus, α=-40° is the optimal tilt angle for t=10:00, as shown in Figure 4.83.

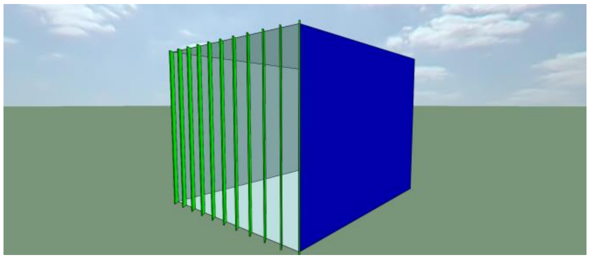


Figure 4.83: 3D Model of the optimal angle α=-40° at t=10:00 on 21 Dec (W/S=0.5, East)

Furthermore, at t=12:00, the maximum DUD% occurs at α=0° where it equals to 34% compared to 22.5% only, in the base case scenario. On the other hand, Figure 4.81 shows that at α=0° DSE% equals to 0%, which is the optimal DSE%, compared to DSE% of 26% in the base case scenario. This indicates that α=0° is the optimal angle for this particular time of the day, as shown in Figure 4.84.

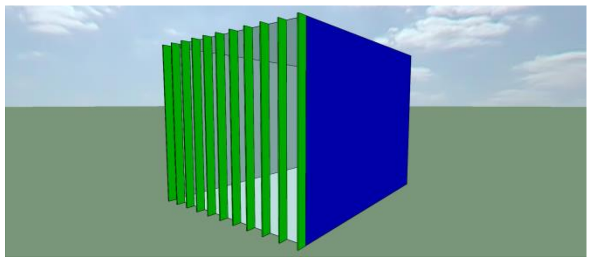


Figure 4.84: 3D Model of the optimal angle α=0° at t=12:00 on 21 Dec (W/S=0.5, East)

Additionally, at t=14:00, the maximum DUD% occurs at α=20° and α=40° where it equals to 22.5% compared to 21.5% in the base case scenario. On the other hand, the minimum DSE% occurs at α=20° and α=40° which equals to 0% compared to 16% in the base case scenario. This indicates that selecting α=20° or α=40° will give us identical results in terms of DUD% and DSE%. However, the author will choose α=20° to be the optimal angle for t=14:00, as shown in Figure 4.85.

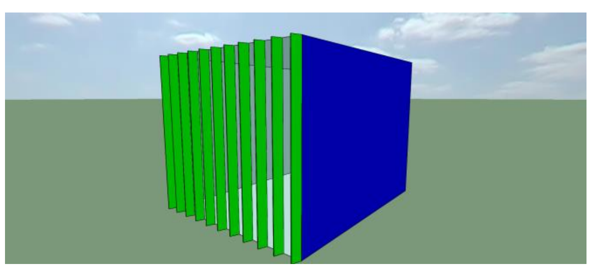


Figure 4.85: 3D Model of the optimal angle α=20° at t=14:00 on 21 Dec (W/S=0.5, East)

Finally, at t=16:00, the maximum DUD% which is 21% occurs in the base case scenario where no louvers are used. Moreover, DSE% in the base case scenario equals to 7.5% which can be acceptable since it provides a good amount of DUD% as opposed to using shading louvers which block most of the useful daylight.

Appendix E shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=0.5

Findings:

Table 4.41: Daylight analysis (Average DUD%) - Dec 21, East (W/S=0.5)

Dynamic Useful Daylight Analysis (DUD%) - December 21, East (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	32.5%	31%	37.5%	46%	44%	37.5%	31%	35%
10:00	25%	29%	34%	30%	29%	21%	19%	20%
12:00	22.5%	26%	29%	32.5%	34%	29%	20%	16%
14:00	21.5%	15%	19%	20%	20%	22.5%	22.5%	17.5%
16:00	21%	1%	2.5%	4%	0%	2.5%	1%	2.5%
Avg. DUD%	**24.5%**	**20%**	**24%**	**26.5%**	**25%**	**22.5%**	**19%**	**18%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00				46%				
10:00			34%					
12:00					34%			
14:00						22.5%		
16:00	21%							
Avg. DUD%	**31.5%**							

Table 4.42: Daylight analysis (Average DSE%) - Dec 21, East (W/S=0.5)

Dynamic Sunlight Exposure Analysis (DSE%) - December 21, East (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	37.5%	0%	0%	0%	11%	19%	21%	9%
10:00	41%	14%	14%	21%	25%	35%	34%	27.5%
12:00	26%	0%	0%	0%	0%	9%	15%	15%
14:00	16%	0%	0%	0%	0%	0%	0%	0%
16:00	7.5%	0%	0%	0%	0%	0%	0%	0%
Avg. DSE%	**26%**	**3%**	**3%**	**4%**	**7%**	**13%**	**14%**	**10%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**

8:00				0%				
10:00			14%					
12:00					0%			
14:00						0%		
16:00	7.5%							
Avg. DSE%	**4%**							

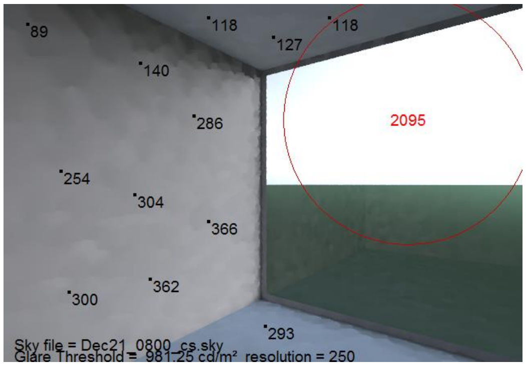
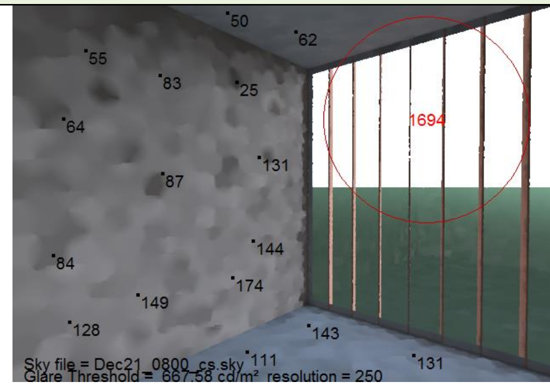
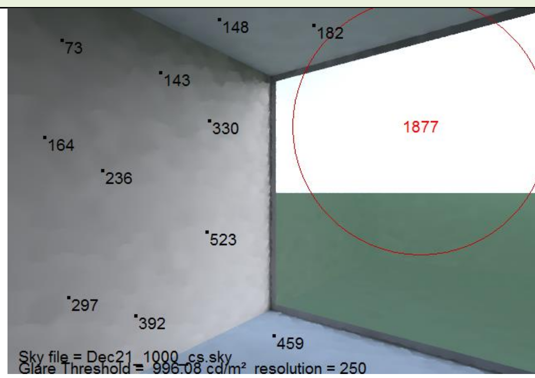
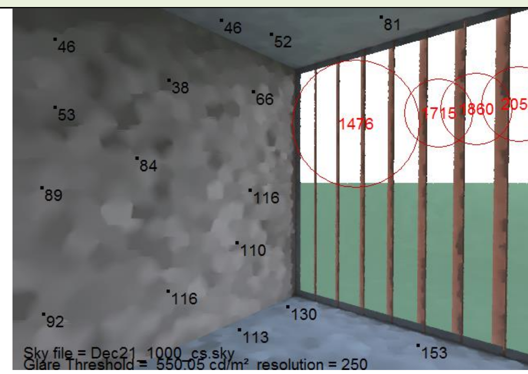
Table 4.41 shows that the maximum average DUD% occurs when using dynamic shading louvers where it equals to 31.5% compared to 24.5% only, in the base case scenario. On the other hand, Table 4.42 shows that the minimum average DSE% occurs when using fixed shading louvers at α=-40° and α=-60° where it equals to 3% only. However, Table 4.41 shows that the average DUD% when using fixed shading louvers at α=-40° and α=-60° are 24% and 20%, respectively. These average DUD% do not represent the maximum DUD%, thus will be excluded from the selection. Moreover, Table 4.42 shows that when using fixed shading louvers at α=-20°, the average DSE% is 4% which is identical to the average DSE% when using dynamic shading louvers. However, looking back to the average DUD%, the dynamic shading louvers and the fixed shading louvers at α=-20° are 31.5% and 26.5%, respectively. This indicates that using dynamic shading louvers is the optimal configuration for this particular scenario.

- **Glare Analysis**

In this section, the results of glare analysis will be presented for the base case scenario as well as the dynamic shading louvers scenario which was chosen to be the optimal daylight configuration, as per the daylight analysis.

Table 4.43: Summary of the Glare Analysis - December 21, East (W/S=0.5)

Glare Analysis for December 21, East (W/S=0.5)

t=08:00	Base Case	Dynamic Shading Louvers α=-20°
		
t=10:00	**Base Case**	**Dynamic Shading Louvers α=-40°**
		
t=12:00	**Base Case**	**Dynamic Shading Louvers α=0°**

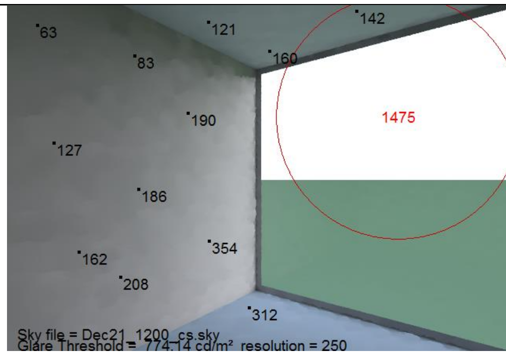
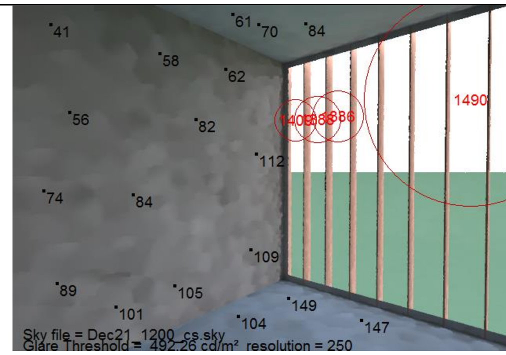
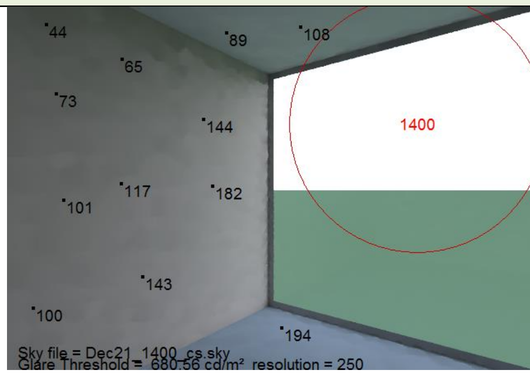
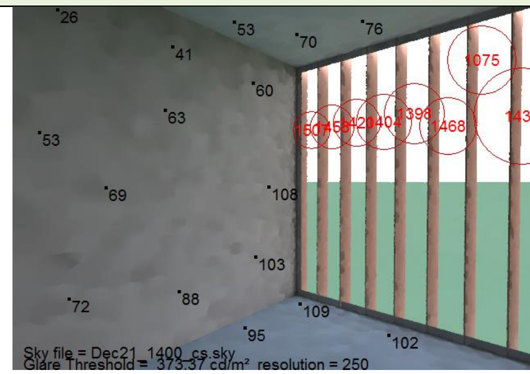
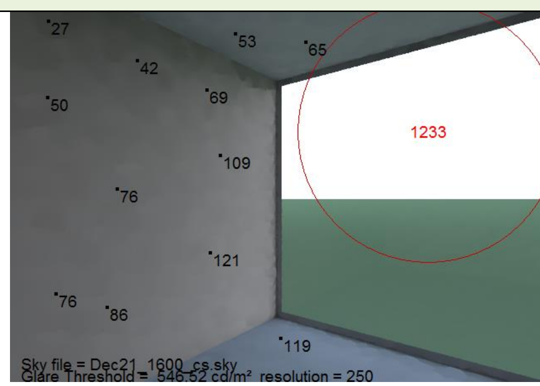
<table>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=16:00</td><td colspan="2">Base Case (The optimal configuration for this time)</td></tr>
<tr><td></td><td colspan="2">
</td></tr>
</table>

Table 4.43 shows the summary of the glare analysis for December 21 using W/S=0.5 on the eastern orientation.

Discussion:

As shown in the figures, the glare on the glazing in the base case scenarios is high compared to the glare when using dynamic shading louvers at t=08:00, 10:00, 12:00, and 14:00. As a result, the overall luminance levels on the internal surfaces of the office reduce when using dynamic shading louvers due to the less direct sunlight penetration.

It can noticed that the overall luminance levels on the glazed surfaces in the base case scenarios are less than the previous cases in March 21 and June 21, due to the different sun altitude in this time of the year. Moreover, as observed, the glare in the early morning seem to be too high compared to the glare towards the end of the day. Furthermore, for t=16:00, the base case scenario experiences lower luminance level on the glazing compared to the base case scenarios at other times of the day.

Findings:

Table 4.44: Glare analysis Summary - Dec 21, East (W/S=0.5)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	2095	1877	1475	1400	1233	**1616**
Optimal Case	1694	2050	1490	1500	1233	**1593**

Table 4.57 shows that the average luminance level in the base cases is 1616 cd/m2 compared to 1593 cd/m2 in the optimal cases. This shows a very slight reduction in luminance levels when using the dynamic shading louvers as opposed to the base case scenarios. This acts as a bonus to

the better daylight performance that is associated with the presence of dynamic shading louvers on the glazing.

4.3.4. Daylight and Glare Analysis for March 21, W/S=1.0

- **Daylight Analysis**

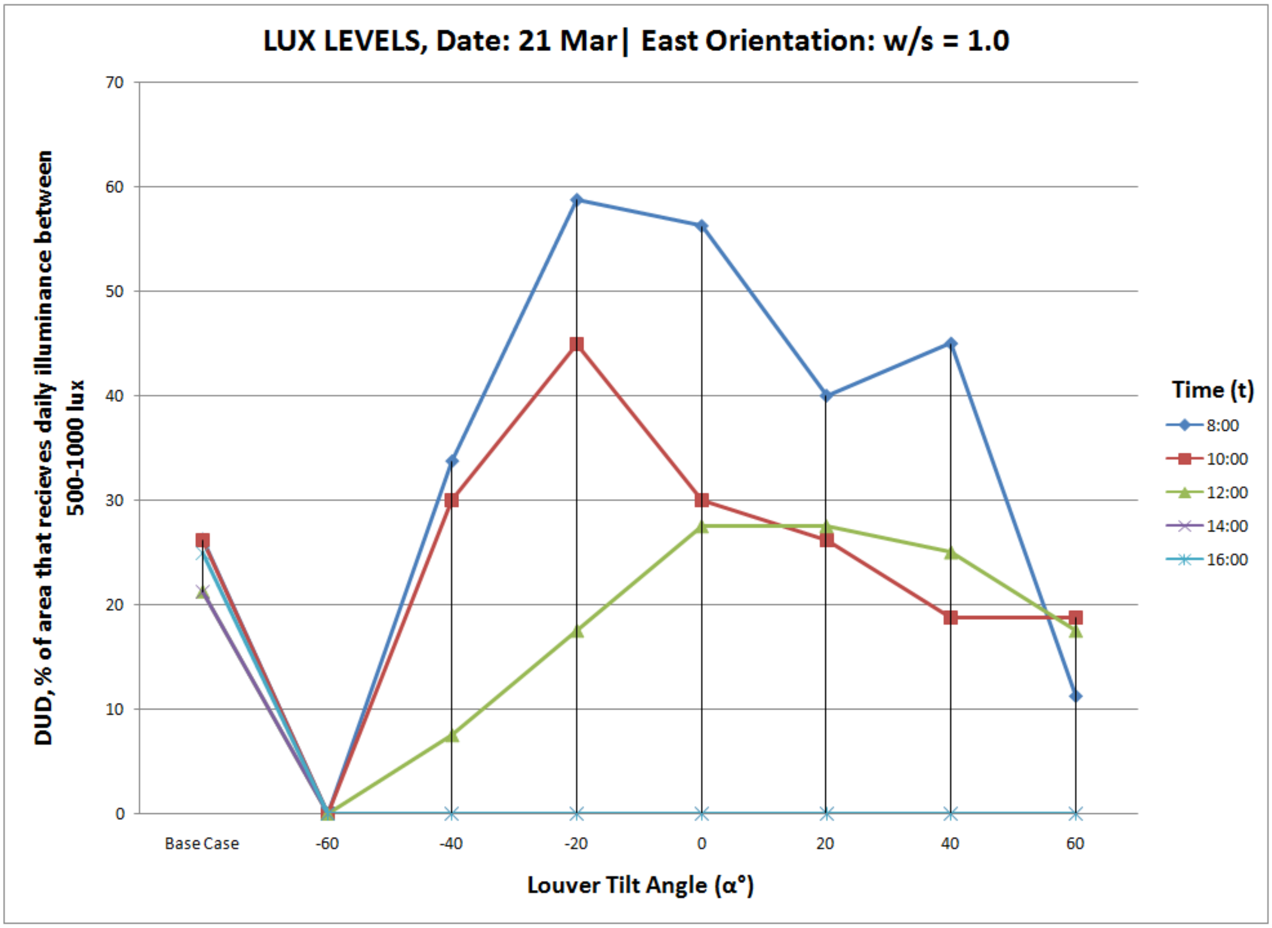


Figure 4.86: DUD analysis, 21 Mar, w/s=1.0 (East)

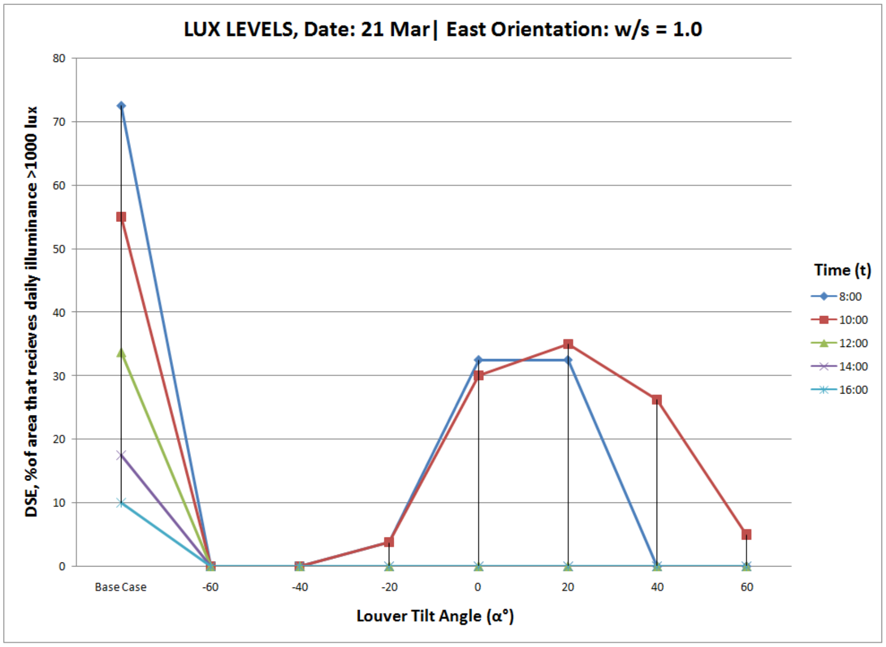


Figure 4.87: DSE analysis, 21 Mar, w/s=1.0 (East)

Figure 4.86 and Figure 4.87 show the daylight analysis for March 21 using W/S=1.0 on the eastern orientation.

Discussion:

Figure 4.86 shows that at t=08:00, the maximum DUD% occurs at α=-20° where it equals to 59% compared to 26% only, in the base case scenario. However, at α=-20°, DSE% equals to 4% compared to 72.5% in the base case scenario. Although at α=-40° and α=-60° DSE% equal to 0%, DUD% at these angles do not represent the maximum DUD% for this particular time. Thus, the author will consider using α=-20° as the optimal daylight angle for t=08:00 regardless of the slight sunlight exposure, as shown in Figure 4.88.

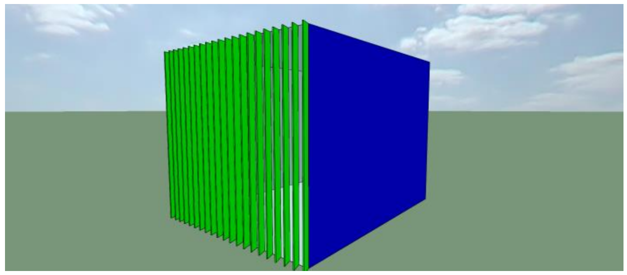


Figure 4.88: 3D Model of the optimal angle α=-20° at t=08:00 on 21 Mar (W/S=1.0, East)

Furthermore, at t=10:00, the maximum DUD% occurs at α=-20° where it equals to 45% compared to 26% only, in the base case scenario. However, Figure 4.87 shows that at α=-20°, DSE% is 4%, which is within the acceptable range, compared to DSE% of 55% in the base case scenario. Thus, α=-20° is the optimal angle for t=10:00.

Additionally, at t=12:00, the maximum DUD% occurs at α=0° and α=20° where it equals to 27.5% compared to 21% only, in the base case scenario. Looking at DSE% in Figure 4.87, DSE% is 0% at both α=0° and α=20° which make both tilt angles suitable for this particular time of the day. However, the author will select α=0° to be the optimal angle for t=12:00, as shown in Figure 4.89.

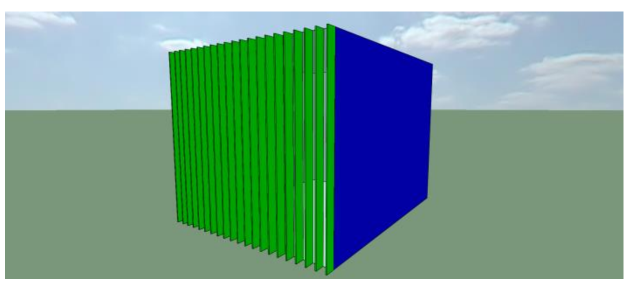


Figure 4.89: : 3D Model of the optimal angle α=0° at t=12:00 on 21 Mar (W/S=1.0, East)

Moreover, at t=14:00 and t=16:00, the maximum DUD% occurs in the base case scenario (the louvers will be hidden) where DUD% is 21% at t=14:00 and 25% at t=16:00. Also, DSE% for the base case scenario at t=14:00 is 17.5% and 10% at t=16:00. Although DSE%

of 17.5% and 10% are considered excessive and high, respectively, the author will accept them since the base case scenarios at theses times provides the maximum DUD% over the shading louvers scenarios at various angles which provide DUD% values of 0%.

Appendix F shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=1.0

Findings:

Table 4.45: Daylight analysis (Average DUD%) - Mar 21, East (W/S=1.0)

Dynamic Useful Daylight Analysis (DUD%) - March 21, East (W/S=1.0)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	26%	0%	34%	59%	56%	40%	45%	11%
10:00	26%	0%	30%	45%	30%	26%	19%	19%
12:00	21%	0%	7.5%	17.5%	27.5%	27.5%	25%	17.5%
14:00	21%	0%	0%	0%	0%	0%	0%	0%
16:00	25%	0%	0%	0%	0%	0%	0%	0%
Avg. DUD%	**24%**	**0%**	**14%**	**24%**	**23%**	**19%**	**18%**	**9.5%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00				59%				
10:00				45%				
12:00					27.5%			
14:00	21%							
16:00	25%							
Avg. DUD%	**36.5%**							

Table 4.46: Daylight analysis (Average DSE%) - Mar 21, East (W/S=1.0)

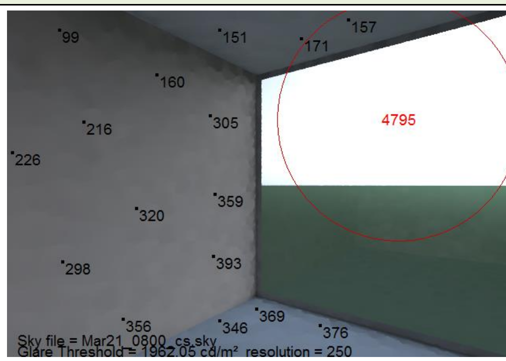
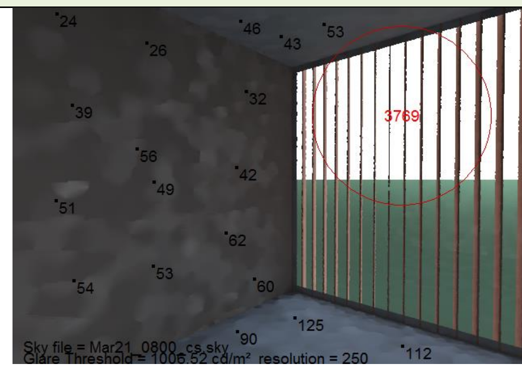
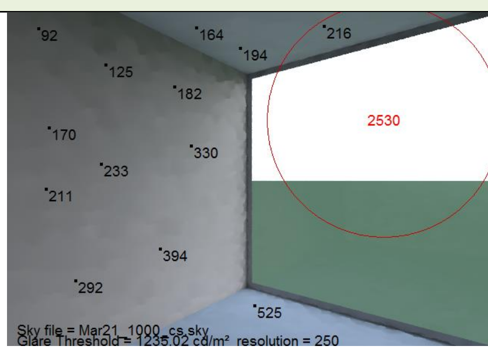
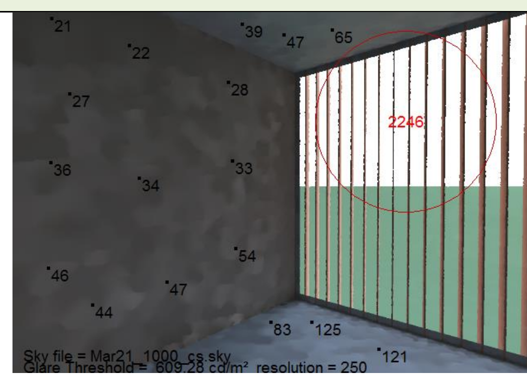
Dynamic Sunlight Exposure Analysis (DSE%) - March 21, East (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	72.5%	0%	0%	4%	32.5%	32.5%	0%	0%
10:00	55%	0%	0%	4%	30%	35%	26%	5%
12:00	34%	0%	0%	0%	0%	0%	0%	0%
14:00	17.5%	0%	0%	0%	0%	0%	0%	0%
16:00	10%	0%	0%	0%	0%	0%	0%	0%
Avg. DSE%	**38%**	**0%**	**0%**	**2%**	**12.5%**	**13.5%**	**5%**	**1%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00				4%				
10:00				4%				
12:00					0%			
14:00	17.5%							
16:00	10%							
Avg. DSE%	**7%**							

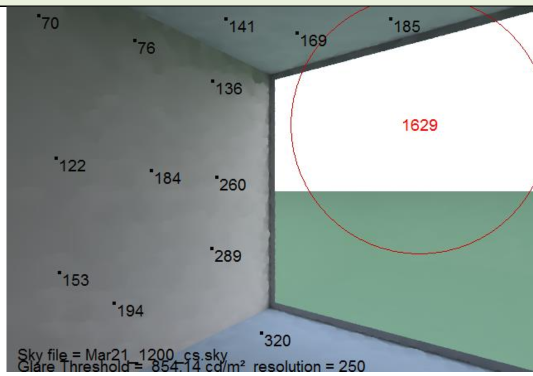
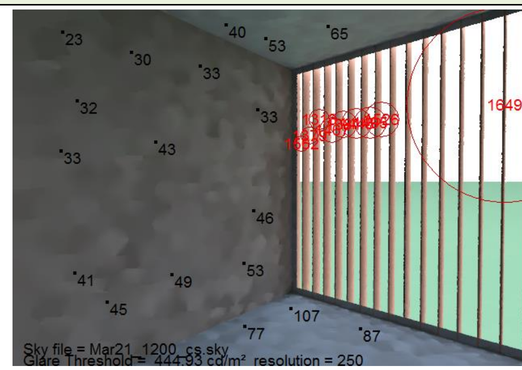
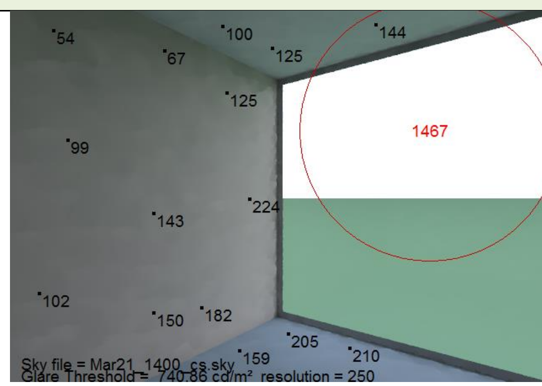
Table 4.45 shows that the maximum average DUD% occurs when using dynamic shading louvers which equals to 36.5% compared to 24% only, when using no louvers at all. However, Table 4.46 shows that the average DSE% when using dynamic shading louvers equals to 7% which does not represent the minimum average DSE% among all configurations. Furthermore, fixed shading louvers at α=-60°, α=-40°, α=60°, and α=40° have average DSE% values of 0%,0%,1%, and 5%, respectively, which are less than the average DSE% when using dynamic shading louvers. However, looking at the average DUD% at these angles, the values do not represent the maximum average DUD%, thus, the author will select the configuration that provides the maximum average DUD% for this scenario and that is dynamic shading louvers. Therefore, in this case, average DSE% of 7% will be acceptable.

- **Glare Analysis**

In this section, the results of glare analysis will be presented for the base case scenario as well as the dynamic shading louvers scenario which was chosen to be the optimal daylight configuration, as per the daylight analysis.

Table 4.47: Summary of the Glare Analysis - March 21, East (W/S=1.0)

<table>
<tr><th colspan="3">Glare Analysis for March 21, East (W/S=1.0)</th></tr>
<tr><td>t=08:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=10:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=0°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td colspan="2">Base Case (The optimal configuration for this time)</td></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>t=16:00</td><td colspan="2">Base Case (The optimal configuration for this time)</td></tr>
</table>

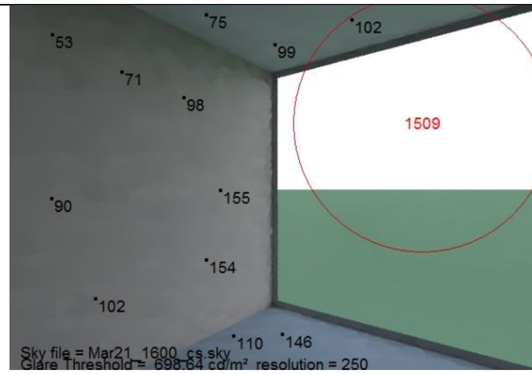
	

Table 4.47 shows the summary of the glare analysis for March 21 using W/S=1.0 on the eastern orientation.

Discussion:

As expected, the luminance level on the surface of the glazing reduces with the addition of the vertical dynamic shading louvers at t=08:00, t=10:00, and t=12:00. As a result, the luminance on the wall, ceiling and floor reduce accordingly due to the lower sun penetration inside the office with the presence of the louvers. However, at t=14:00 and t=16:00 where no louvers are used, the internal wall, ceiling and floor still do not experience any intense or direct sunlight due to the sun position in the sky at these times where the sun has passed the eastern side of the office.

Findings:

Table 4.48: Glare analysis Summary - Mar 21, East (W/S=1.0)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	t=10:00	t=12:00	t=14:00	t=16:00	Avg. Luminance (cd/m2)

Base Case	4795	2530	1629	1467	1509	**2386**
Optimal Case	3769	2246	1649	1467	1509	**2128**

Table 4.62 shows that the average luminance level in the base case scenarios is 2386 cd/m2 compared to 2128 cd/m2 in the optimal case scenarios. The results show a decrease in the average luminance level , thus, a decrease in glare can be achieved. This result is aligned with the results obtained from the daylight analysis where dynamic shading louvers were obtaining better DUD% and less DSE% than the base case scenario.

4.3.5. Daylight and Glare Analysis for June 21, W/S=1.0

- **Daylight Analysis**

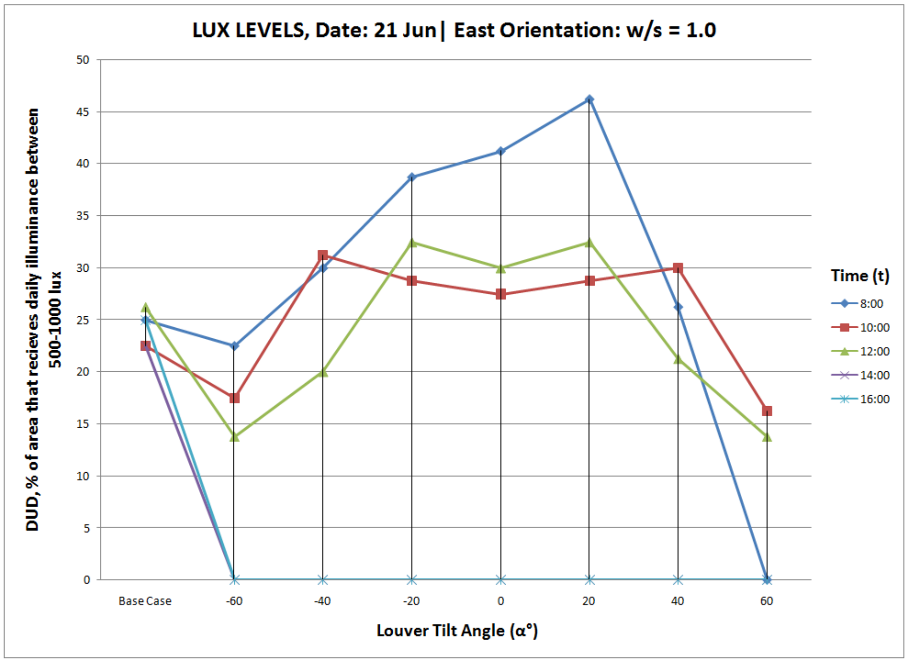


Figure 4.90: DUD analysis, 21 Jun, w/s=1.0 (East)

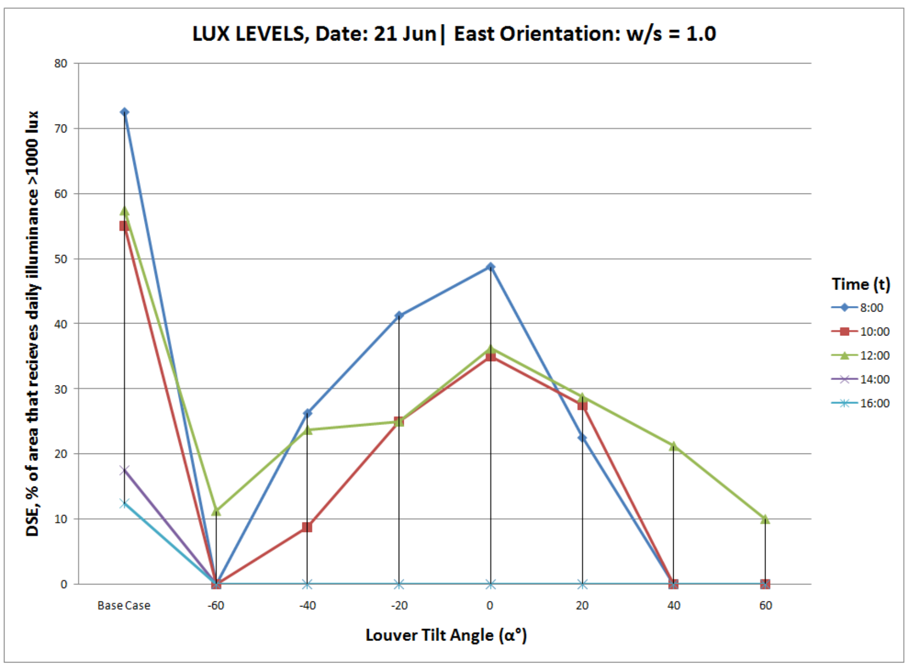


Figure 4.91: DSE analysis, 21 Jun, w/s=1.0 (East)

Figure 4.90 and Figure 4.91 show the daylight analysis for June 21 using W/S=1.0 on the eastern orientation.

Discussion:

Figure 4.90 shows that at t=08:00, the maximum DUD% is 46% and occurs at α=20° compared to 25% only, in the base case scenario. However, Figure 4.91 shows that at α=20°, DSE% equals to 22.5% compared to 72.5% in the base case scenario. Obviously, DSE% of 22.5% is considered excessive, however, at the angles where DSE% is 0%, DUD% is much less than DUD% of 46% that occurs at α=20°. Thus, the author will consider choosing the maximum DUD% in this case over the minimum DSE%. Therefore, α=20° is the optimal angle for t=08:00, as shown in Figure 4.92.

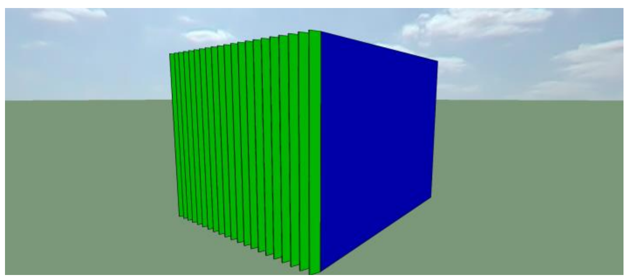


Figure 4.92: 3D Model of the optimal angle α=20° at t=08:00 on 21 Jun (W/S=1.0, East)

Furthermore, at t=10:00, the maximum DUD% occurs at α=-40° where it equals to 31% compared to 22.5% only, in the base case scenario. Also, Figure 4.91 shows that at α=-40°, DSE% is 9% compared to 55% in the base case scenario which is too high. Although at α=-60°, α=40°, and α=60°, DSE% is 0%, DUD% at these angles are much less than DUD% at α=-40°. Thus, the author will select α=-40°to be the optimal angle at t=10:00 ,specially since 9% of DSE% is not within the excessive range of dynamic sunlight exposure.

Additionally, at t=12:00, the maximum DUD% occurs at α=-20° and α=20° where it equals to 32.5% compared to 26% only, in the base case scenario. However, DSE% values at α=-20° and α=20° are 25% and 29%, respectively. Of course, in this case, dynamic shading louver tilted at α=-20° is better in terms of providing maximum DUD% and lower DSE% than α=20°. Although DSE% values at α=-60°, α=-40°, α=40° and α=60° are lower than DSE% at α=-20°, DUD% at these angles are less than DUD% at α=-20°. Therefore, α=-20° will be considered as the optimal angle for t=12:00, as shown in Figure 4.93.

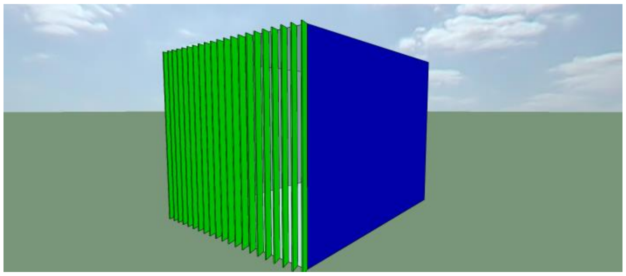


Figure 4.93: 3D Model of the optimal angle α=-20° at t=12:00 on 21 Jun (W/S=1.0, East)

Moreover, at t=14:00 and t=16:00, the base case scenarios (where louvers will be hidden) happen to achieve the maximum DUD% values which are 22.5% and 25%, respectively, compared to DUD% of 0% when using shading louvers at any angle. On the other hand, Figure 4.91 shows that DSE% values of 17.5% and 12.5% are achieved in the base case scenarios at t=14:00 and t=16:00, respectively. Although using shading louvers at any tilt angle achieve 0% of DSE%, the poor daylight performance due to the absence of dynamic useful daylight (DUD%) when using shading louvers does not worth having 0% of dynamic sunlight exposure (DSE%). Thus, using no louvers for t=14:00 and t=16:00 is the optimal configuration, in this case.

Appendix G shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=1.0

Findings:

Table 4.49: Daylight analysis (Average DUD%) - Jun 21, East (W/S=1.0)

Dynamic Useful Daylight Analysis (DUD%) - June 21, East (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	25%	22.5%	30%	39%	41%	46%	26%	0%
10:00	22.5%	17.5%	31%	29%	27.5%	29%	30%	16%
12:00	26%	14%	20%	32.5%	30%	32.5%	21%	14%
14:00	22.5%	0%	0%	0%	0%	0%	0%	0%
16:00	25%	0%	0%	0%	0%	0%	0%	0%
Avg. DUD%	**24%**	**11%**	**16%**	**20%**	**20%**	**21.5%**	**15%**	**6%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00						46%		
10:00			31%					
12:00				32.5%				
14:00	22.5%							
16:00	25%							
Avg. DUD%	**31%**							

Table 4.50: Daylight analysis (Average DSE%) - Jun 21, East (W/S=1.0)

Dynamic Sunlight Exposure Analysis (DSE%) - June 21, East (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	72.5%	0%	26%	41%	49%	22.5%	0%	0%
10:00	55%	0%	9%	25%	35%	27.5%	0%	0%
12:00	57.5%	11%	24%	25%	36%	29%	21%	10%
14:00	17.5%	0%	0%	0%	0%	0%	0%	0%
16:00	12.5%	0%	0%	0%	0%	0%	0%	0%
Avg. DSE%	**43%**	**2%**	**12%**	**18%**	**24%**	**26%**	**4%**	**2%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00						22.5%		
10:00			9%					
12:00				25%				
14:00	17.5%							
16:00	12.5%							
Avg. DSE%	**17%**							

Table 4.49 shows that the maximum average DUD% when using dynamic shading louvers is 31% compared to 24% only, in the base case scenario. On the other hand, Table 4.50 shows

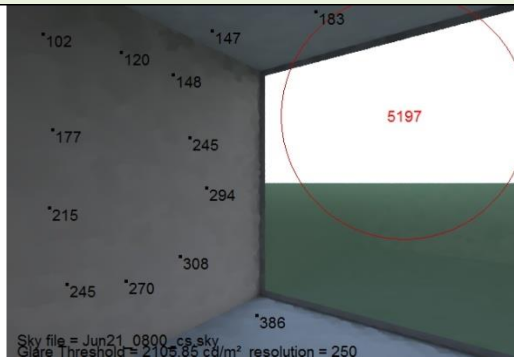
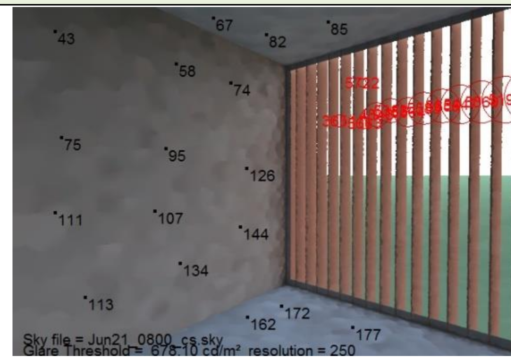
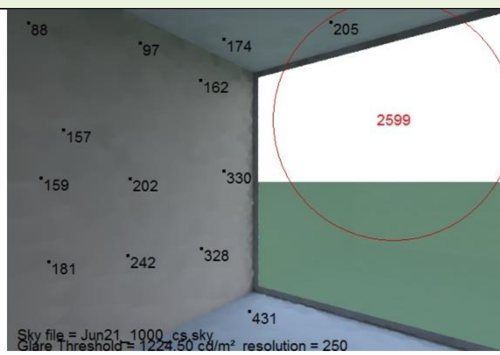
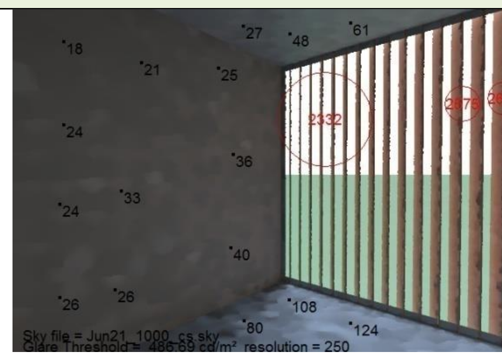
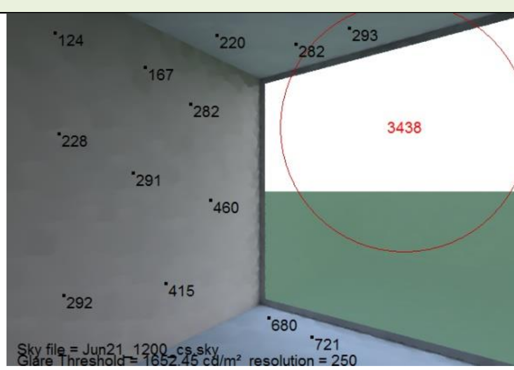
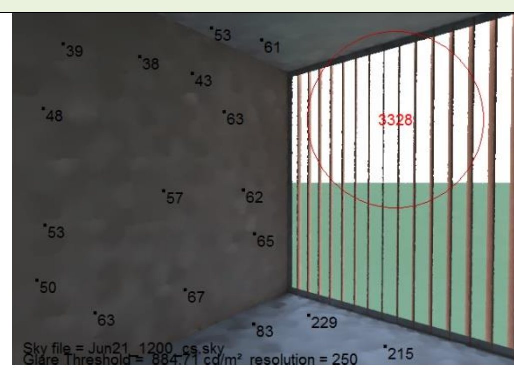
that an average DSE% of 17% is achieved when using dynamic shading louvers as opposed to 43% in the base case scenario.

As observed, when using fixed shading louver at α=-60°, α=60°, α=40° and α=-40°, the average DSE% values are 2%, 2%, 4% and 12%, respectively, which are all lower than the average DSE% when using dynamic shading louvers. However, at α=-60°, α=60°, α=40° and α=-40°, the average DUD% values are 11%, 6%, 15%, 16%, respectively, which are all lower than the average DUD% when using dynamic shading louvers. Thus, the author will feature the maximum average DUD% over the minimum average DSE% which means that using dynamic shading louvers is the best configuration for this specific scenario.

- **Glare Analysis**

In this section, the results of glare analysis will be presented for the base case scenario as well as the dynamic shading louvers scenario which was chosen to be the optimal daylight configuration, as per the daylight analysis.

Table 4.51: Summary of the Glare Analysis - June 21, East (W/S=1.0)

<table>
<tr><th colspan="3">Glare Analysis for June 21, East (W/S=1.0)</th></tr>
<tr><td>t=08:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=10:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-40°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
</table>

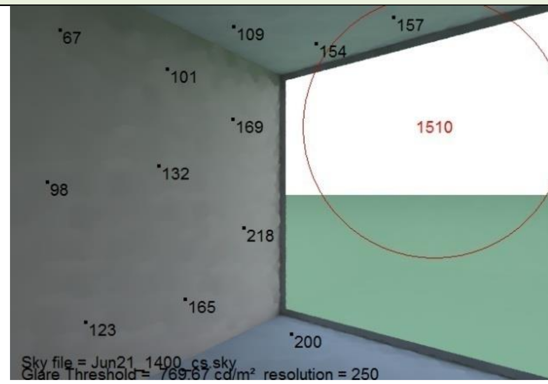
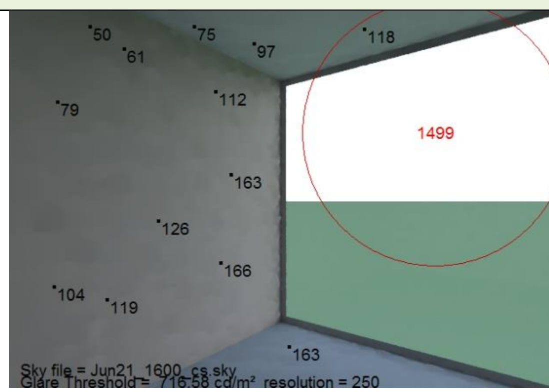
t=14:00	**Base Case (The optimal configuration for this time)**	
		
t=16:00	**Base Case (The optimal configuration for this time)**	
		

Table 4.51 shows the summary of the glare analysis for June 21 using W/S=1.0 on the eastern orientation.

Discussion:

Table 4.51 shows that at t=08:00, t=10:00 and t=12:00, adding dynamic shading louvers that change every hour to achieve the maximum daylight led to a decrease in the luminance level on the glazing surface of the office as well as the internal surfaces in general. However, at t=14:00 and t=16:00, the luminance on the glazing without any louvers is much less than the luminance on the glazing without any louvers at the other times of the day. Because the luminance levels on the glazing at t=14:00 and t=16:00 are relatively low compared to the other times of the day, there is no need to add any shading louvers since the sun has passed the eastern side at these times of the day and the useful daylight can be maximized without using any louvers that can block it.

Findings:

Table 4.52: Glare analysis Summary - Jun 21, East (W/S=1.0)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	5197	2599	3438	1510	1499	**2849**
Optimal Case	5722	2332	3328	1510	1499	**2878**

Table 4.52 shows that the average luminance level in the base case scenarios is 2849 cd/m2 compared to 2878 cd/m2 in the optimal case scenarios. As observed, the difference is very minor, thus, the slight increase in glare when using dynamic shading louvers can be neglected.

The author will consider dynamic shading louvers as the optimal design configuration based on their outstanding daylight performance.

4.3.6. Daylight and Glare Analysis for December 21, W/S=1.0

- **Daylight Analysis**

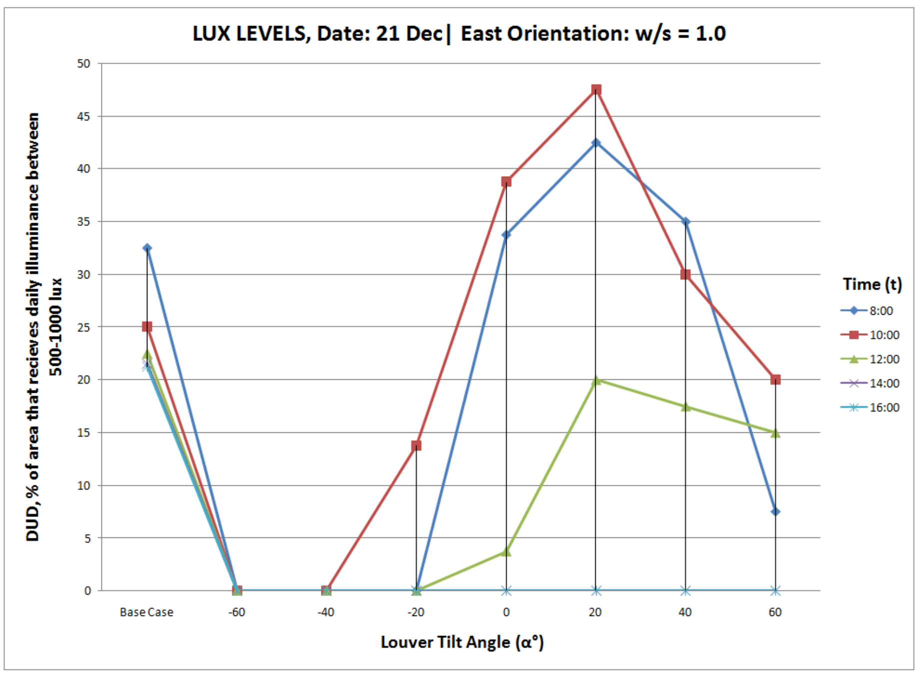


Figure 4.94: DUD analysis, 21 Dec, w/s=1.0 (East)

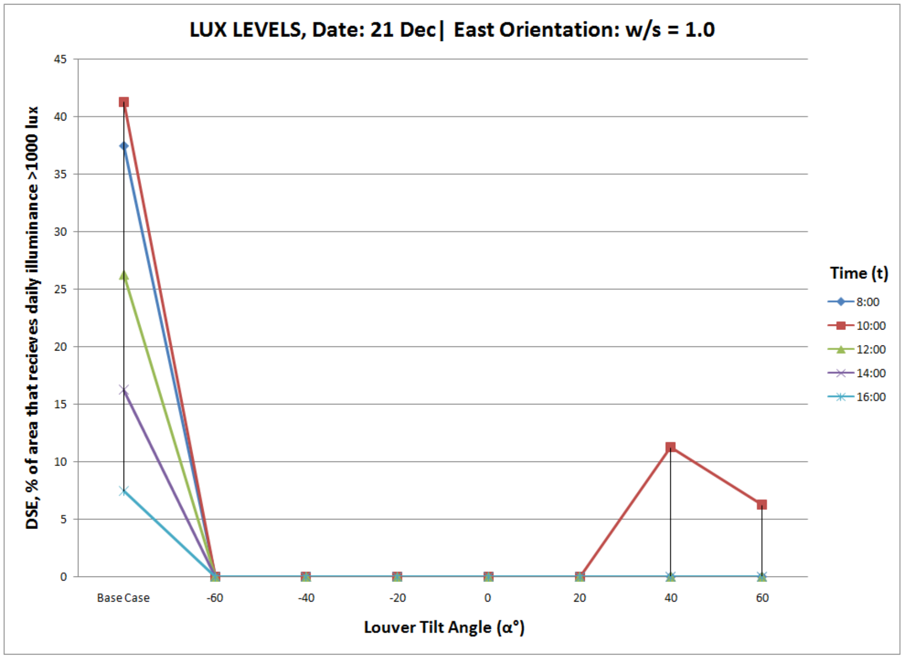


Figure 4.95: DSE analysis, 21 Dec, w/s=1.0 (East)

Figure 4.94 and Figure 4.95 show the daylight analysis for December 21 using W/S=1.0 on the eastern orientation.

Discussion:

Figure 4.94 shows that at t=08:00, the maximum DUD% occurs at α=20° where it equals to 42.5% compared to 32.5% only, in the base case scenario. On the other hand, Figure 4.95 shows that at α=20°, DSE% is 0% compared to 37.5% in the base case scenario which is excessive. Thus, α=20° is considered as the optimal angle for t=08:00.

Moreover, at t=10:00, the maximum DUD% occurs at α=20° as well where it equals to 47.5% compared to 25% only, in the base case scenario. Also, Figure 4.95 shows that DSE% at α=20° is 0%, which is the optimal DSE%, compared to 41% in the base case scenario.

Furthermore, at t=12:00, the maximum DUD% occurs in the base case scenario where it equals to 22.5% and DSE% equals to 26%. However, at the same time and at α=20°, DUD%

equals to 20% while DSE% at this angle is 0%, which is better than DSE% in the base case scenario. Thus, the author will consider α=20° to be the optimal angle for t=12:00 since the difference in DUD% is only2.5% whereas the difference in DSE% is 26% which is very dramatic

Additionally, at t=14:00, the maximum DUD% occurs in the base case scenario where it equals to 21.5% compared to DUD% of 0% when using shading louvers at any angle. However, Figure 4.95 shows that DSE% in the base case scenario is 16% which is a bit high. Nevertheless, the author will still consider the base case (where louvers will be hidden) as the optimal configuration for t=14:00 since it is the only configuration that provides useful daylight as opposed to adding shading louver where no useful daylight penetrates the office.

Finally, at t=16:00, the maximum DUD% also occurs in the base case scenario where it equals to 21%. In fact, the base case scenario is the only scenario in which useful daylight penetrates the office since using shading louvers block most of the light penetration, just like the situation at t=14:00. On the other hand, Figure 4.95 shows that DSE% in the base case scenario is 7.5% which is less than DSE% in the base case scenario at t=14:00. Thus, the base case scenario (where louvers will be hidden) will be considered as the best configuration for t=16:00. The reason why the base case scenarios at t=14:00 and t=16:00 are the best scenarios is due to the sun position within the sky at these times where the sun has already passed the eastern side of the office as opposed to the cases at t=08:00, t=10:00 and t=12:00.

Appendix H shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=1.0

Findings:

Table 4.53: Daylight analysis (Average DUD%) - Dec 21, East (W/S=1.0)

Dynamic Useful Daylight Analysis (DUD%) - December 21, East (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	32.5%	0%	0%	0%	34%	42.5%	35%	7.5%
10:00	25%	0%	0%	14%	39%	47.5%	30%	20%
12:00	22.5%	0%	0%	0%	4%	20%	17.5%	15%
14:00	21.5%	0%	0%	0%	0%	0%	0%	0%
16:00	21%	0%	0%	0%	0%	0%	0%	0%
Avg. DUD%	**24.5%**	**0%**	**0%**	**3%**	**15%**	**22%**	**16.5%**	**8.5%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00						42.5%		
10:00						47.5%		
12:00						20%		
14:00	21.5%							
16:00	21%							
Avg. DUD%	**30.5%**							

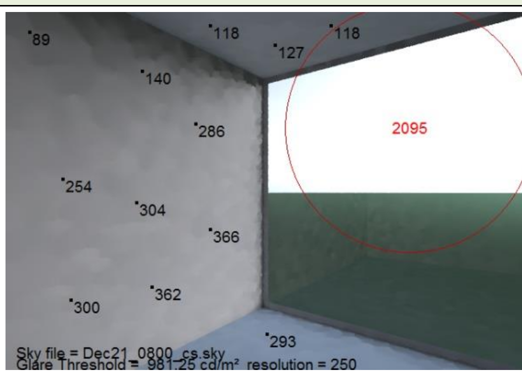
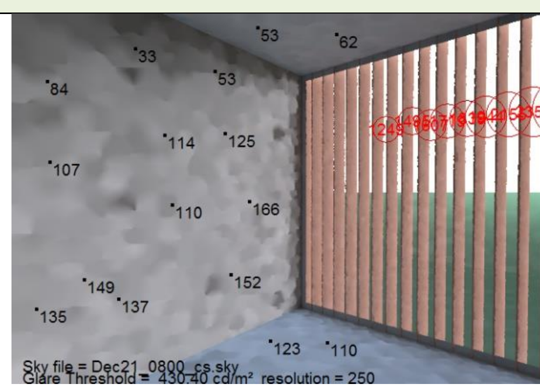
Table 4.54: Daylight analysis (Average DSE%) - Dec 21, East (W/S=1.0)

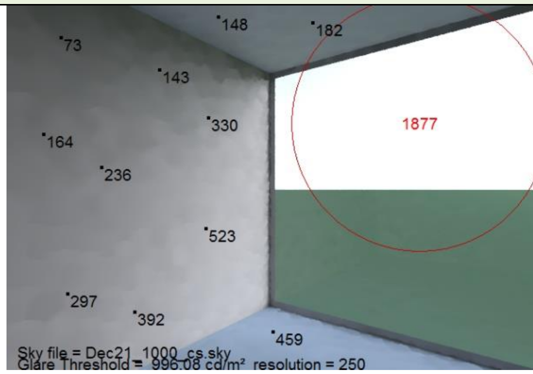
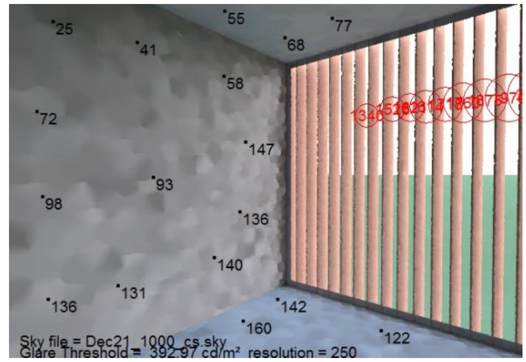
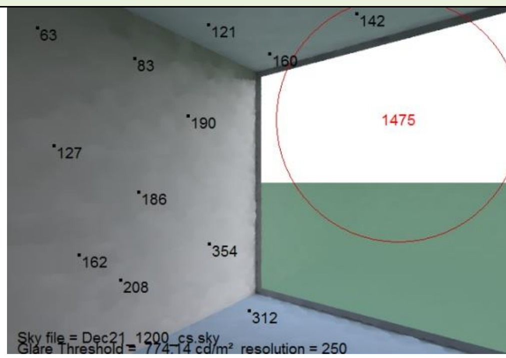
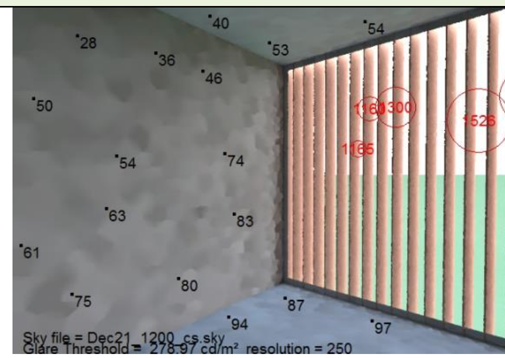
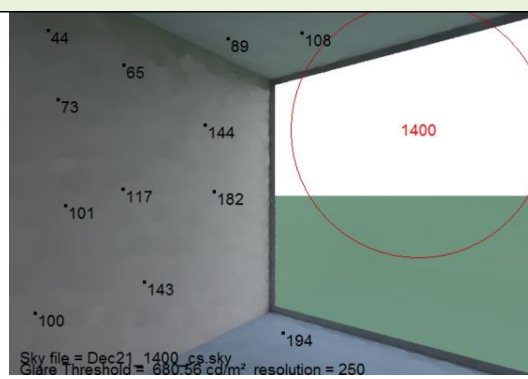
Dynamic Sunlight Exposure Analysis (DSE%) - December 21, East (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	37.5%	0%	0%	0%	0%	0%	0%	0%
10:00	41%	0%	0%	0%	0%	0%	11%	6%
12:00	26%	0%	0%	0%	0%	0%	0%	0%
14:00	16%	0%	0%	0%	0%	0%	0%	0%
16:00	7.5%	0%	0%	0%	0%	0%	0%	0%
Avg. DSE%	**26%**	**0%**	**0%**	**0%**	**0%**	**0%**	**2%**	**1%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00						0%		
10:00						0%		
12:00						0%		
14:00	16%							
16:00	7.5%							
Avg. DSE%	**5%**							

Table 4.53 shows that the maximum average DUD% occurs when using dynamic shading louvers where it equals to 30.5% compared to 24.5% in the base case scenario. However, Table 4.54 shows that the average DSE% when using dynamic shading louvers is 5% compared to 26% in the base case scenario. Although Table 4.54 shows that the average DSE% when using fixed shading louvers at α=-60°, α=-40°, α=-20°, α=0°, α=40°, and α=60° are 0%,0%,0%,0%,0%,2% and 1%, respectively, the average DUD% at these angles are far less than the average DUD% achieved when using dynamic shading louvers. In addition, average DSE% of 5% when using dynamic shading louvers is acceptable since it falls within the acceptable DSE% range, as per the pre-defined assessment criteria. Thus, dynamic shading louvers will be considered as the optimal configuration for this specific scenario.

- **Glare Analysis**

Table 4.55: Summary of the Glare Analysis - December 21, East (W/S=1.0)

Glare Analysis for December 21, East (W/S=1.0)		
t=08:00	**Base Case**	**Dynamic Shading Louvers α=20°**
		

<table>
<tr><td>t=10:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td colspan="2">Base Case (The optimal configuration for this time)</td></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>t=16:00</td><td colspan="2">Base Case (The optimal configuration for this time)</td></tr>
</table>

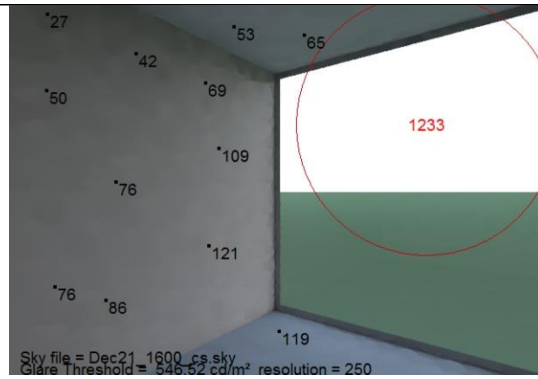
	

Table 4.55 shows the summary of the glare analysis for December 21 using W/S=1.0 on the eastern orientation.

Discussion:

As shown in Table 4.55, using dynamic shading louvers at t=08:00, t=10:00, and t=12:00 reduces the glare occurrence on the glazing through reducing the luminance levels on the surface as well as reducing the overall luminance levels on the internal surfaces which result in less intense light that can cause visual discomfort.

Moreover, at t=14:00 and t=16:00, using no louvers seem to perform well in terms of providing good illumination inside the office without allowing intense sunlight due to the absence of the sun at these times of the day.

Findings:

Table 4.56: Glare analysis Summary - Dec 21, East (W/S=1.0)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**

Base Case	2095	1877	1475	1400	1233	**1616**
Optimal Case	1500	1700	1526	1400	1233	**1472**

Table 4.56 shows that the average luminance level in the base case scenarios is 1616 cd/m2 while the average luminance level in the optimal case scenarios is 1472 cd/m2. Obviously, adding dynamic shading louvers led to a decrease in the average luminance levels, thus, a decrease in the possibility of glare occurrence. This result agree with the results obtained earlier from the daylight analysis.

4.4.West Orientation

In this section, the author will be examining different shading configurations against the base case scenario (without any louvers) to figure out the best configuration that provides the optimal daylight performance with minimum glare. Moreover, the author will be testing the various configurations in March 21, June 21 , and December 21 using W/S=0.5 and W/S=1.0 for the western orientation.

In this orientation, it is expected to obtain daylight performance that is opposite to the daylight performance obtained from the eastern orientation. In other words, in the early morning (e.g. t=08:00), the model when facing the eastern orientation was experiencing high illuminance and luminance levels across the office due to the sunrise. These high values decrease as the time passes throughout the day. However, it is expected that the model when facing the western orientation will experience higher illuminance and luminance levels across the office towards the end of the day (e.g. 16:00) as opposed to the case in eastern orientation due to the sun position at this time of the day where it heads towards west. Also, it is important to note that for louvers, the author will be using vertical dynamic and fixed shading louvers, in this scenario

4.4.1. Daylight and Glare Analysis for March 21, W/S=0.5

- **Daylight Analysis**

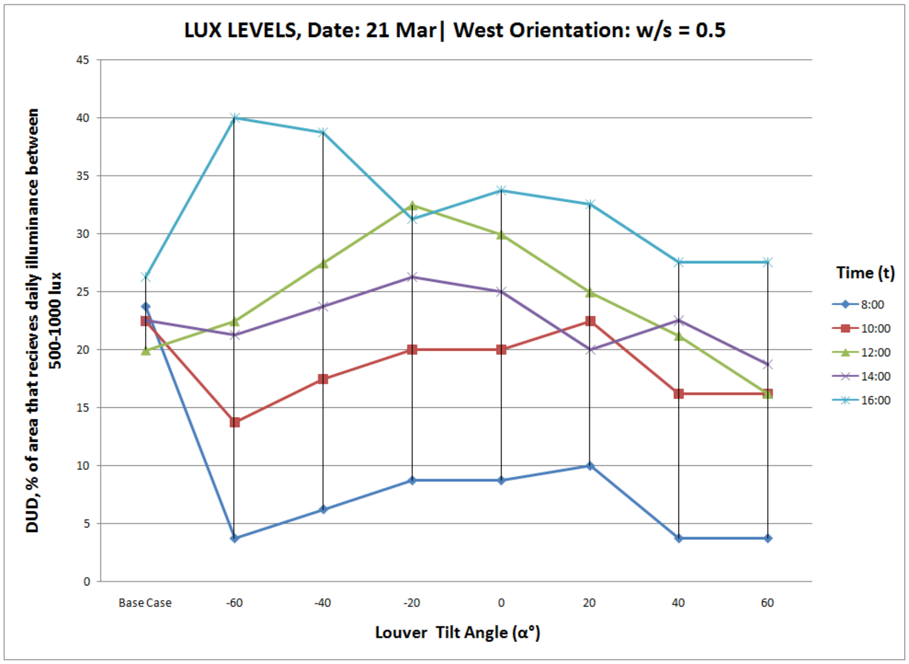


Figure 4.96: DUD analysis, 21 Mar, w/s=0.5 (West)

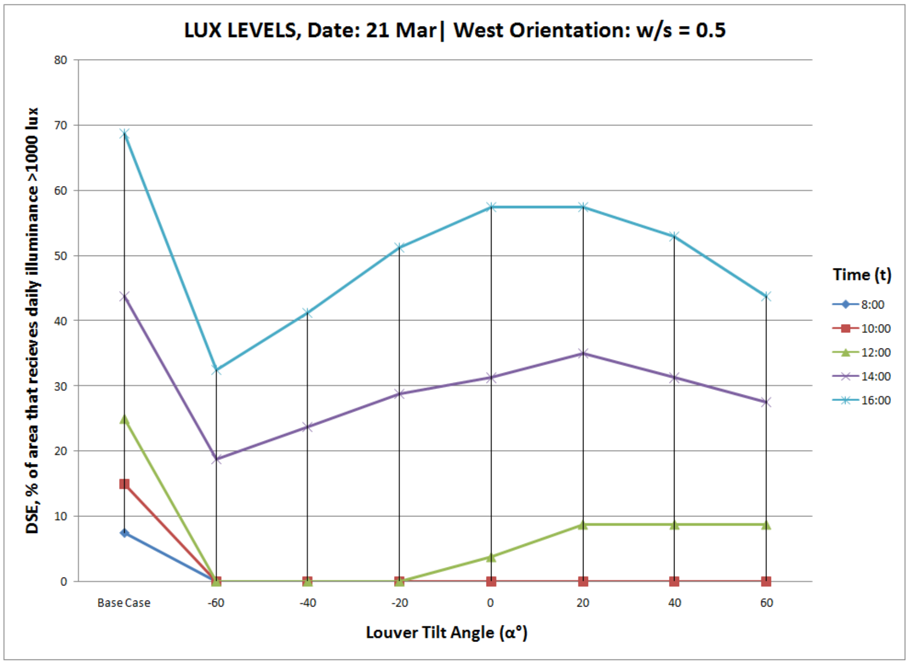


Figure 4.97: DSE analysis, 21 Mar, w/s=0.5 (West)

Figure 4.96 and Figure 4.97 show the daylight analysis for March 21 using W/S=0.5 on the western orientation.

Discussion:

As shown in Figure 4.96, at t=08:00 the maximum DUD% occurs in the base case scenario where it equals to 24%. The result make sense since the sun at this time of the day is still in the eastern side of the office, thus, having no louvers at this particular time will allow the maximum penetration of the useful daylight without having extreme direct sunlight. Therefore, DSE% in the base case scenario at t=08:00 is 7.5% only which can be accepted since the maximum DUD% occurs when using this configuration.

Moreover, at t=10:00, the maximum DUD% occurs in the base case scenario and when using shading louvers at α=20° where it equals to 22.5% in both configurations. However, Figure 4.97 shows that in the base case scenario, DSE% equals to 15% compared to DSE% of 0% when using α=20°, which is the optimal DSE%. Thus, α=20° is the optimal angle for dynamic shading louvers at t=10:00.

Furthermore, at t=12:00, the maximum DUD% occurs at α=-20° where it equals to 32.5% compared to 20% only, in the base case scenario. Also, Figure 4.97 shows that DSE% at α=-20° is 0% compared to 25% in the base case scenario. Therefore, the author is selecting α=-20° to be the optimal daylight angle for the dynamic shading louvers at t=12:00.

Additionally, at t=14:00, the maximum DUD% occurs at α=-20° as well where it equals to 26% compared to 22.5% in the base case scenario. However, DSE% at α=-20° is 29% which is too high. Moreover, looking at α=-60°, DUD% of 21% and DSE% of 19% are achieved using this particular angle. As observed, DUD% at α=-60° is only 5% less than DUD% at α=-20° while DSE% at α=-60° is 10% less than α=-20°, which is a huge reduction. Therefore, the author will select α=-60° to be the optimal daylight angle at t=14:00.

Lastly, at t=16:00, the maximum DUD% occurs at α=-60° where it equals to 40% compared to 26% only, in the base case scenario. However, Figure 4.97 shows that DSE% at α=-60° is 32.5% compared to 69% in the base case scenario. Although DSE% of 32.5% does not represent the optimal DSE%, it is the least DSE% achieved among all other configurations which makes it acceptable, in this case. Therefore, α=-60° will be considered as the optimal daylight angle at t=16:00.

Appendix I shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=0.5

Findings:

Table 4.57: Daylight analysis (Average DUD%) - Mar 21, West (W/S=0.5)

Dynamic Useful Daylight Analysis (DUD%) - March 21, West (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	24%	4%	6%	9%	9%	10%	4%	4%
10:00	22.5%	14%	17.5%	20%	20%	22.5%	16%	16%
12:00	20%	22.5%	27.5%	32.5%	30%	25%	21%	16%
14:00	22.5%	21%	24%	26%	25%	20%	22.5%	19%
16:00	26%	40%	39%	31%	34%	32.5%	27.5%	27.5%
Avg. DUD%	**23%**	**20%**	**23%**	**24%**	**24%**	**22%**	**18%**	**17%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	24%							
10:00						22.5%		
12:00				32.5%				
14:00		21%						
16:00		40%						
Avg. DUD%	**28%**							

Table 4.58: Daylight analysis (Average DSE%) - Mar 21, West (W/S=0.5)

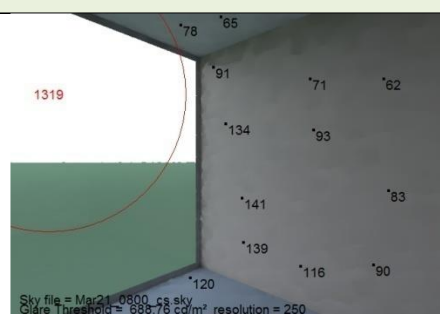
Dynamic Sunlight Exposure Analysis (DSE%) - March 21, West (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	7.5%	0%	0%	0%	0%	0%	0%	0%
10:00	15%	0%	0%	0%	0%	0%	0%	0%
12:00	25%	0%	0%	0%	4%	9%	9%	9%
14:00	44%	19%	24%	29%	31%	35%	31%	27.5%
16:00	69%	32.5%	41%	51%	57.5%	57.5%	53%	44%
Avg. DSE%	**32%**	**10%**	**13%**	**16%**	**18.5%**	**20%**	**19%**	**16%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	7.5%							
10:00						0%		
12:00				0%				
14:00		19%						
16:00		32.5%						
Avg. DSE%	**12%**							

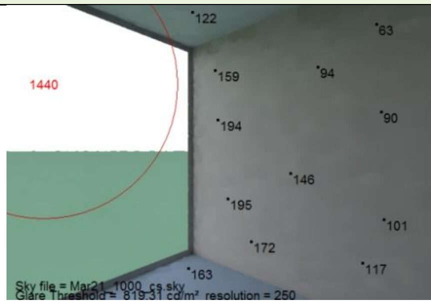
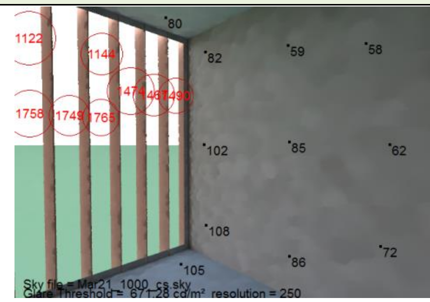
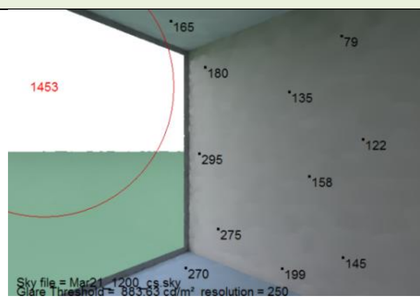
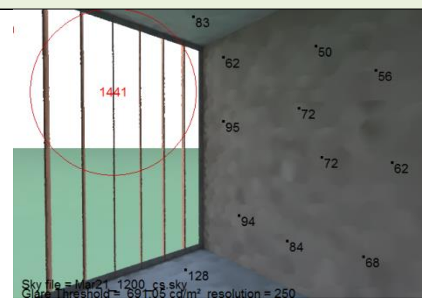
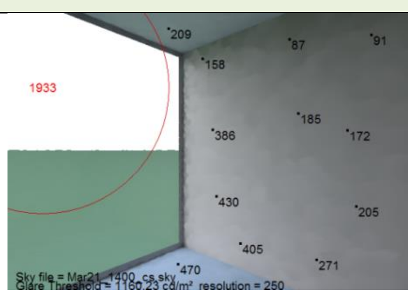
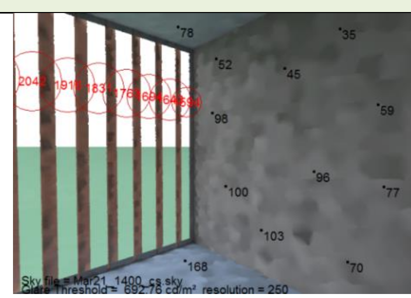
Table 4.57 shows that the maximum average DUD% occurs when using dynamic shading louvers where it equals to 28% compared to 23% only, in the base case scenario. On the other hand, Table 4.58 shows the average DSE% for each configuration where the average DSE% when using dynamic shading louvers is 12% compared to 32% in the base case scenario. Although the average DSE% when using fixed shading louvers at α=-60° is 10% which less than the average DSE% when using dynamic shading louvers, the average DUD% when using fixed shading louvers at α=-60° is 20% only which is less than the average DUD% when using dynamic shading louvers. Therefore, out of all the configurations, dynamic shading louver seem to provide the best daylight performance.

- **Glare Analysis**

In this section, the author will be analyzing glare performance for the western orientation on March 21 for the base case scenario and the obtained optimal daylight angle at each time using W/S=0.5.

Table 4.59: Summary of the Glare Analysis - March 21, West (W/S=0.5)

Glare Analysis for March 21, West (W/S=0.5)	
t=08:00	**Base Case (The optimal configuration for this time)**
	

t=10:00	**Base Case**	**Dynamic Shading Louvers α=20°**
		
t=12:00	**Base Case**	**Dynamic Shading Louvers α=-20°**
		
t=14:00	**Base Case**	**Dynamic Shading Louvers α=-60°**
		

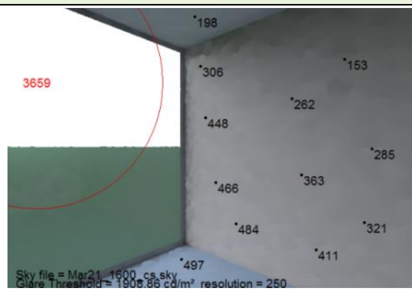
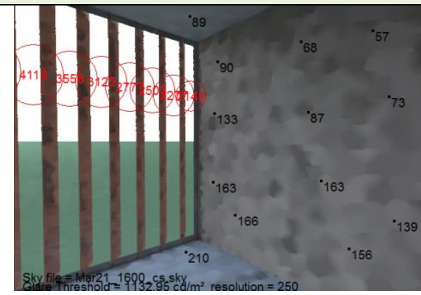
t=16:00	Base Case	Dynamic Shading Louvers α=-60°
		

Table 4.59 shows the summary of the glare analysis for March 21 using W/S=0.5 on the western orientation.

Discussion:

As noticed in Table 4.59, the figures show that at t=08:00, the glare on the glazing is less than the glare at t=10:00, t=12:00, t=14:00 and t=16:00. This low luminance on the glass surface is due to the low direct sunlight at this orientation and at this specific time. Moreover, as the time passes throughout the day, the glass starts to receive more direct sunlight since the sun is moving towards west where the office model is oriented. Therefore, as the time passes, shading louvers will be required to block some of the direct sunlight while maintaining useful daylight penetration.

The glare on the glazing at t=10:00, t=12:00, t=14:00 and t=16:00 decrease with the addition of the vertical louvers as a result from the decreased luminance levels. Moreover, the luminance levels across the entire office space seem to reduce once the dynamic shading louvers are added.

Findings:

Table 4.60: Glare analysis Summary - Mar 21, West (W/S=0.5)

	Luminance Levels on the glazing (cd/m^2)

	t=08:00	t=10:00	t=12:00	t=14:00	t=16:00	Avg. Luminance (cd/m2)
Base Case	1319	1440	1453	1933	3659	**1961**
Optimal Case	1319	1758	1441	2042	4113	**2135**

Table 4.78 shows that the average luminance level on the glazing in the base case scenarios is 1961 cd/m2 compared to 2135 cd/m2 in the optimal case scenarios. Since the difference is not significant, the author will choose dynamic shading louvers as the optimal design configuration since they provide the optimal daylight performance.

4.4.2. Daylight and Glare Analysis for June 21, W/S=0.5

- **Daylight Analysis**

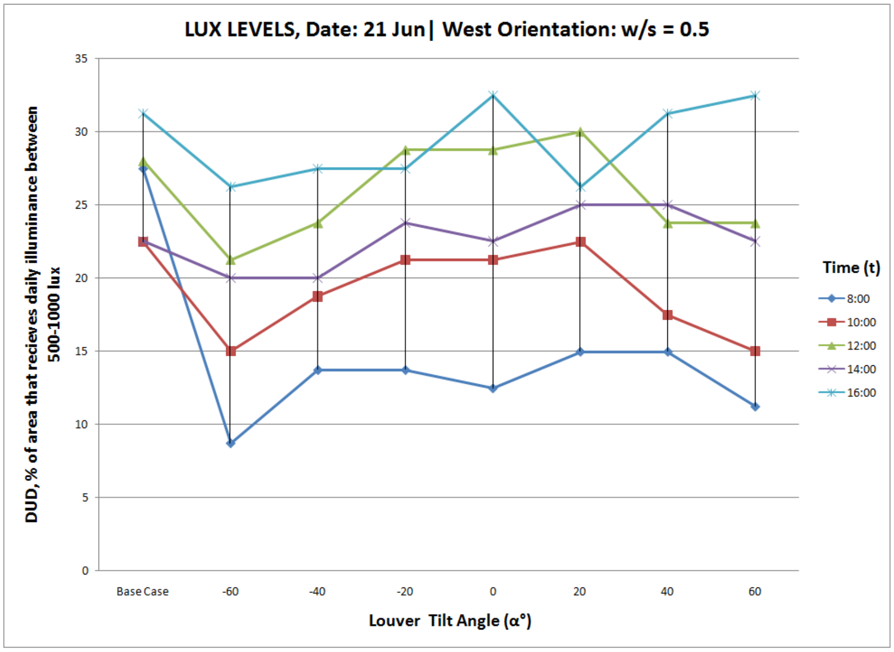


Figure 4.98: DUD analysis, 21 Jun, w/s=0.5 (West)

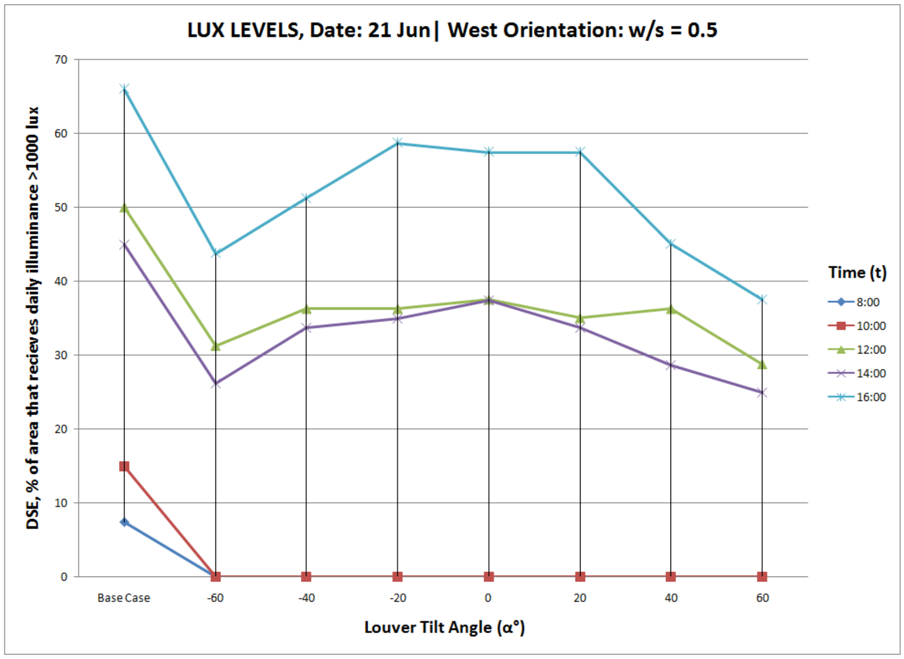


Figure 4.99: DSE analysis, 21 Jun, w/s=0.5 (West)

Figure 4.98 and Figure 4.99show the daylight analysis for June 21 using W/S=0.5 on the western orientation.

Discussion:

Figure 4.98 shows that at t=08:00, the maximum DUD% occurs in the base case scenario where it equals to 27.5 and DSE% equals to 7.5%, as shown in Figure 4.99. Although using shading louvers at this time of the day blocks all the direct sunlight penetration, adding shading louvers also blocks most of the useful daylight penetration which is not desired. Therefore, the author is selecting the configuration that provides the maximum dynamic useful daylight despite the minimal sunlight exposure ,which is the case when using no louvers at all.

Moreover, at t=10:00, the maximum DUD% occurs in the base case scenario and at α=20° where it equals to 22.5% in both cases. However, DSE% shoes that in the base case scenario the value is 15% whereas at α=20°, DSE% is 0%. Therefore, α=20° will be considered as the optimal daylight angle at t=10:00.

Furthermore, at t=12:00, the maximum DUD% occurs at α=20° where it equals to 30% compared to 28% in the base case scenario. On the other hand, DSE% at α=20° is 35% compared to DSE% of 50% in the base case scenario. Since DSE% of 35% is too high, the author will select the angle that provides less DSE% with a good amount of useful daylight which is α=60° where DUD% is 24% and DSE% is 29%.

Additionally, at t=14:00, the maximum DUD% occurs at α=40° where it equals to 25% compared to 22.5% in the base case scenario. However, Figure 4.99 shows that at α=40°, DSE% is 29% compared to 45% in the base case scenario. As observed, DSE% of 29% is too high, thus, the author will select the angle that provides less DSE% which is α=60° where DSE% is 25% and DUD% is 22.5%.

Finally, at t=16:00, the maximum DUD% occurs at α=60° where it equals to 32.5% compared to 31% in the base case scenario. However, Figure 4.99 shows that DSE% at α=60° is 37.5% compared to DSE% of 66% in the base case scenario. Although DSE% of 37.5% is considered high, it is the least DSE% among all other configurations, which makes it acceptable, in this case.

Appendix J shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=0.5

Findings:

Table 4.61: Daylight analysis (Average DUD%) - Jun 21, West (W/S=0.5)

Dynamic Useful Daylight Analysis (DUD%) - Jun 21, West (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	27.5%	9%	14%	14%	12.5%	15%	15%	11%
10:00	22.5%	15%	19%	21%	21%	22.5%	17.5%	15%
12:00	28%	21%	24%	29%	29%	30%	24%	24%
14:00	22.5%	20%	20%	24%	22.5%	25%	25%	22.5%
16:00	31%	26%	27.5%	27.5%	32.5%	26%	31%	32.5%
Avg. DUD%	**26%**	**18%**	**21%**	**23%**	**23.5%**	**24%**	**22.5%**	**21%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	27.5%							
10:00						22.5%		
12:00								24%
14:00								22.5%
16:00								32.5%
Avg. DUD%	**26%**							

Table 4.62: Daylight analysis (Average DSE%) - Jun 21, West (W/S=0.5)

Dynamic Sunlight Exposure Analysis (DSE%) - Jun 21, West (W/S=0.5)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	-40	-20	0	20	40	60
8:00	7.5%	0%	0%	0%	0%	0%	0%	0%
10:00	15%	0%	0%	0%	0%	0%	0%	0%
12:00	50%	31%	36%	36%	37.5%	35%	36%	29%
14:00	45%	26%	34%	35%	37.5%	34%	29%	25%
16:00	66%	44%	51%	59%	57.5%	57.5%	45%	37.5%
Avg. DSE%	**37%**	**20%**	**24%**	**26%**	**26.5%**	**25%**	**22%**	**18%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	7.5%							
10:00						0%		
12:00								29%
14:00								25%
16:00								37.5%
Avg. DSE%	**20%**							

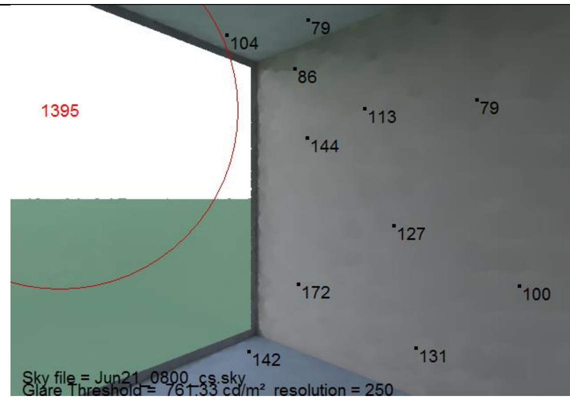
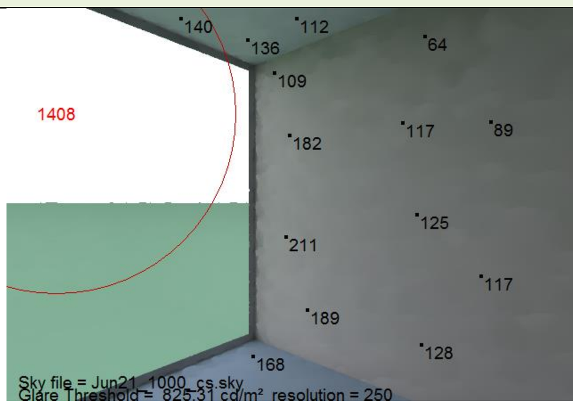
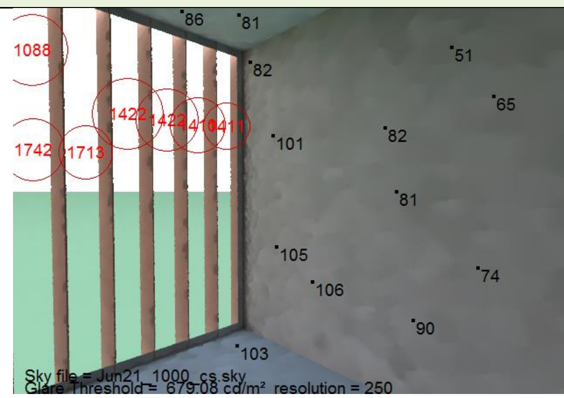
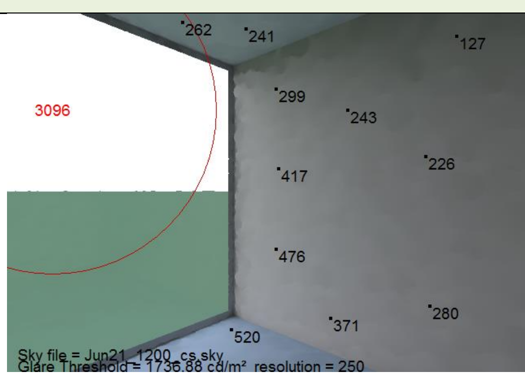
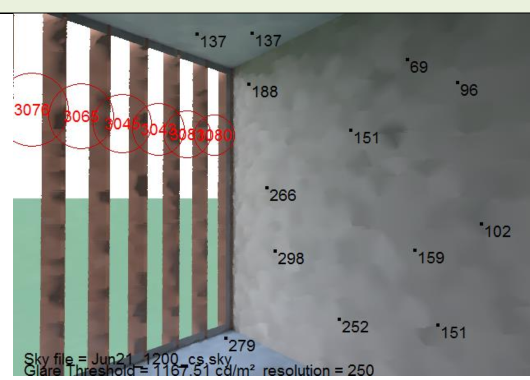
Table 4.61 shows that the maximum average DUD% is 26% and occurs when using dynamic shading louvers as well as in the base case scenario where no louvers are used. However, Table 4.62 shows that the average DSE% when using dynamic shading louvers is 20% as opposed to the average DSE% in the base case scenario where it equals to 37%. Obviously, using dynamic shading louvers is better since it provides the same average DUD% but with much less average DSE%. Moreover, using fixed shading louver at $\alpha=60°$ and $\alpha=-60°$ achieve average DSE% values of 18% and 20%, respectively. However, looking at the average DUD% when using fixed shading louvers at $\alpha=60°$ and $\alpha=-60°$, the values are 21% and 18%, respectively, which are less than the average DUD% when using dynamic shading louvers. As a conclusion, dynamic shading louvers seem to perform the best among all the other configurations in terms of providing maximum useful daylight and minimizing the excessive direct sunlight penetration.

- **Glare Analysis**

In this section, the author will be analyzing glare performance for the western orientation on June 21 for the base case scenario and the obtained optimal daylight angle at each time using W/S=0.5.

Table 4.63: Summary of the Glare Analysis - June 21, West (W/S=0.5)

Glare Analysis for June 21, West (W/S=0.5)	
t=08:00	**Base Case (The optimal configuration for this time)**

<table>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>t=10:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=60°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
</table>

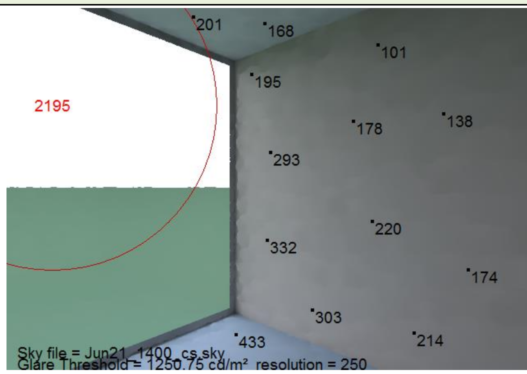
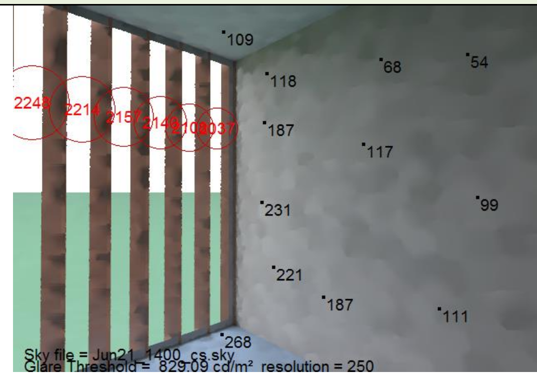
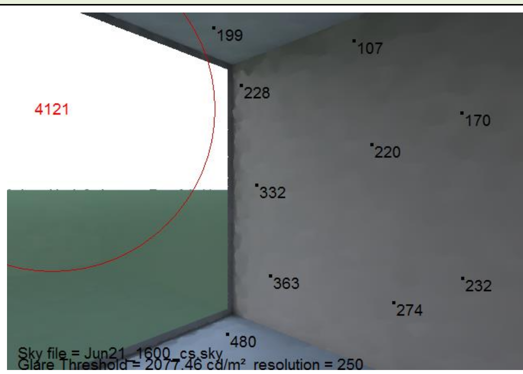
t=14:00	Base Case	Dynamic Shading Louvers α=60°
		
t=16:00	**Base Case**	**Dynamic Shading Louvers α=60°**
		

Table 4.63 shows the summary of the glare analysis for June 21 using W/S=0.5 on the western orientation.

Discussion:

As observed, in most cases, adding shading louvers led to a decrease in the glare intensity of the glazing as well as the overall luminance on the internal surfaces of the office. Similar to the case in March 21, at t=08:00, the least glare is shown on the glazing due to the least luminance level occurring at this time of the day where the sun is at the other side of the glazing (eastern side). This explains why using no louvers is the optimal configuration for this time since there is very minimal direct sunlight penetration, thus, using louvers at this time of the day is useless. In general, a reduction in glare appearance is obvious with the addition of the shading louvers at t=10:00, t=12:00, t=14:00 and t=16:00.

Findings:

Table 4.64: Glare analysis Summary - Jun 21, West (W/S=0.5)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	1395	1408	3096	2195	4121	**2443**
Optimal Case	1395	1742	3076	2249	4503	**2593**

Table 4.64 shows that the average luminance level on the glazing in the base case scenarios is 2443 cd/m2 compared to 2593 cd/m2 in the optimal case scenarios. Since the difference in the average luminance level is very minor, the author will consider dynamic shading louvers (optimal case) to be the best design configuration for this day of the year using W/S=0.5.

4.4.3. Daylight and Glare Analysis for December 21, W/S=0.5

- **Daylight Analysis**

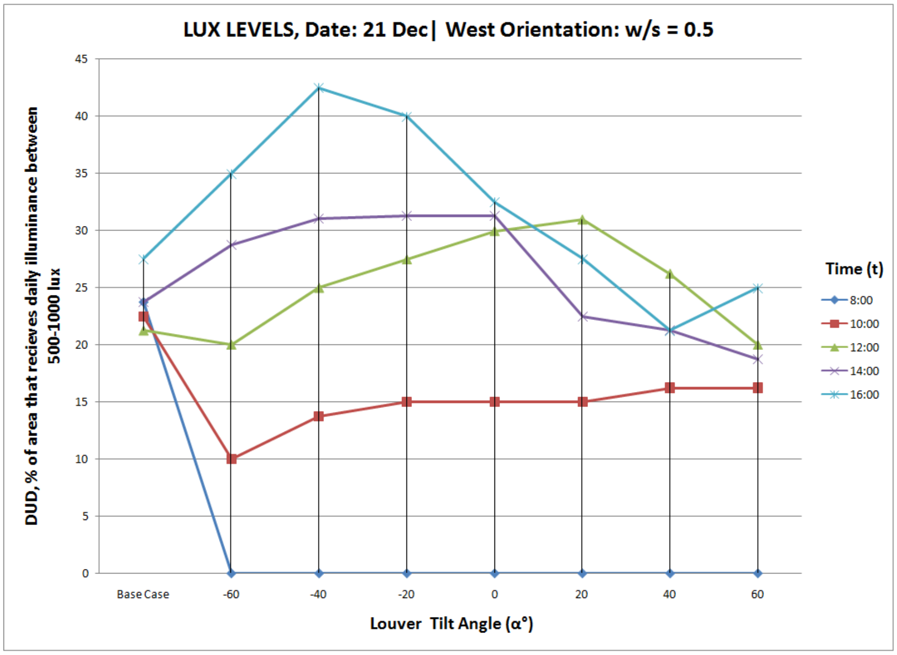


Figure 4.100: DUD analysis, 21 Dec, w/s=0.5 (West)

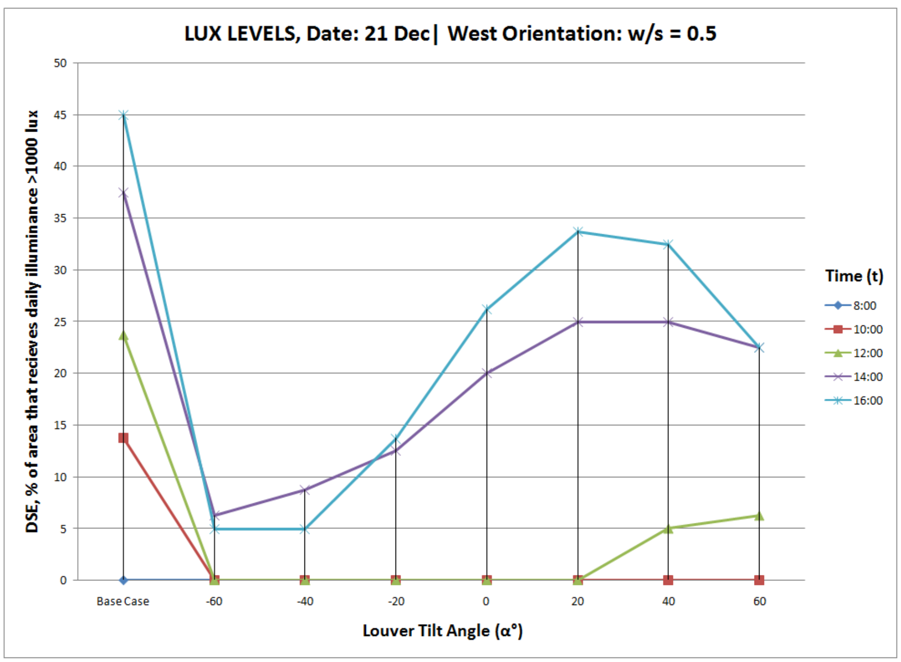


Figure 4.101: DSE analysis, 21 Dec, w/s=0.5 (West)

Figure 4.100 and Figure 4.101show the daylight analysis for December 21 using W/S=0.5 on the western orientation.

Discussion:

Figure 4.100 shows that at t=08:00, the maximum DUD% occurs in the base case scenario where it equals to 24% whereas DSE% equals to 0%, as shown in Figure 4.101. Since this configuration achieves the maximum DUD% and the minimum DSE%, the author will consider using no louvers as the best configuration at t=08:00.

Moreover, at t=10:00, the maximum DUD% occurs at the base case as well where it equals to 22.5%. However, Figure 4.101 shows that in the base case scenario, DSE% is 14%.Although DSE% of 14% is quite high, the author will still consider using the base case scenario as the optimal configuration since other configurations achieve very low DUD% which could lead to visual disability. So, in this case, the base case scenario is the optimal configuration at t=10:00 regardless of the dynamic sunlight exposure (DSE) value.

Furthermore, at t=12:00, the maximum DUD% occurs at α=20° where it equals to 31% compared to 21% only, in the base case scenario. On the other hand, Figure 4.101 shows that at α=20°, DSE% is 0% compared to 24% in the base case scenario. Thus, α=20° is the best louver tilt angle for t=12:00.

Additionally, at t=14:00, the maximum DUD% occurs at α=-40°, α=-20° and α=0° where it equals to 31% compared to 24%, in the base case scenario. However, DSE% values at α=-40°, α=-20° and α=0° are 9%, 12.5% and 20%, respectively. Thus, the author will select α=-40° to be the optimal daylight angle for t=14:00 since it provides the maximum DUD% and the least DSE% among the three angles.

Finally, at t=16:00, the maximum DUD% occur at α=-40° where it equals to 42.5% compared to 27.5% only, in the base case scenario. Moreover, Figure 4.101 shows that at α=-

40°, DSE% is 5% which is within the acceptable DSE% range, as per the pre-defined assessment criteria.

Appendix K shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=0.5

Findings:

Table 4.65: Daylight analysis (Average DUD%) - December 21, West (W/S=0.5)

Dynamic Useful Daylight Analysis (DUD%) - December 21, West (W/S=0.5)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	24%	0%	0%	0%	0%	0%	0%	0%
10:00	22.5%	10%	14%	15%	15%	15%	16%	16%
12:00	21%	20%	25%	27.5%	30%	31%	26%	20%
14:00	24%	29%	31%	31%	31%	22.5%	21%	19%
16:00	27.5%	35%	42.5%	40%	32.5%	27.5%	21%	25%
Avg. DUD%	**24%**	**19%**	**23%**	**23%**	**22%**	**19%**	**17%**	**16%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	24%							
10:00	22.5%							
12:00						31%		
14:00			31%					
16:00			42.5%					
Avg. DUD%	**30%**							

Table 4.66: Daylight analysis (Average DSE%) - December 21, West (W/S=0.5)

Dynamic Sunlight Exposure Analysis (DSE%) - December 21, West (W/S=0.5)

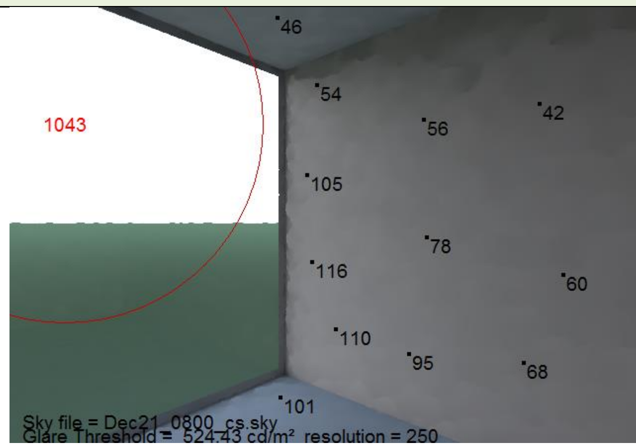
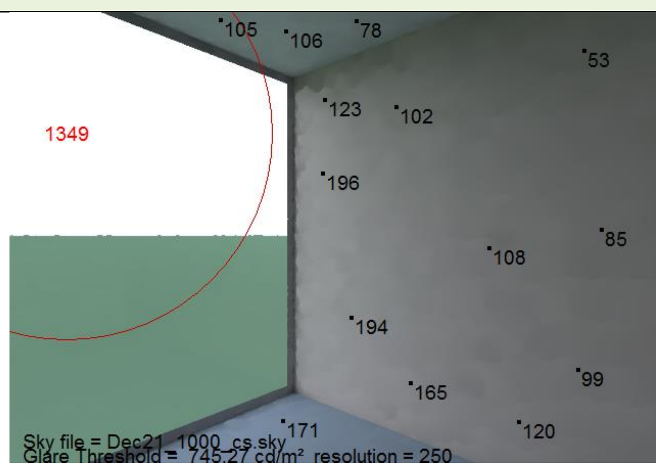
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	0%	0%	0%	0%	0%	0%	0%	0%
10:00	14%	0%	0%	0%	0%	0%	0%	0%
12:00	24%	0%	0%	0%	0%	0%	5%	6%
14:00	37.5%	6%	9%	12.5%	20%	25%	25%	22.5%
16:00	45%	5%	5%	14%	26%	34%	32.5%	22.5%
Avg. DSE%	**24%**	**2%**	**3%**	**5%**	**9%**	**12%**	**12.5%**	**10%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	0%							
10:00	14%							
12:00						0%		
14:00			9%					
16:00			5%					
Avg. DSE%	**6%**							

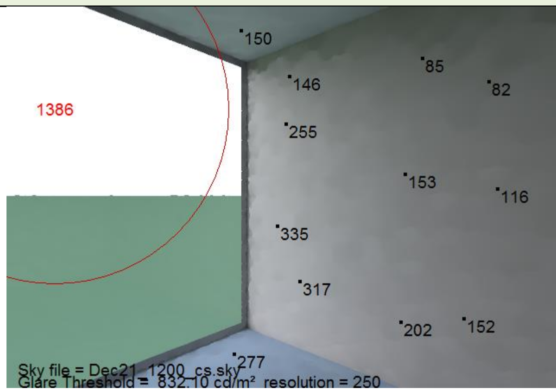
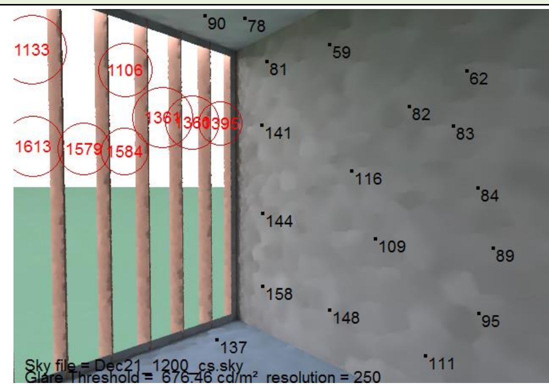
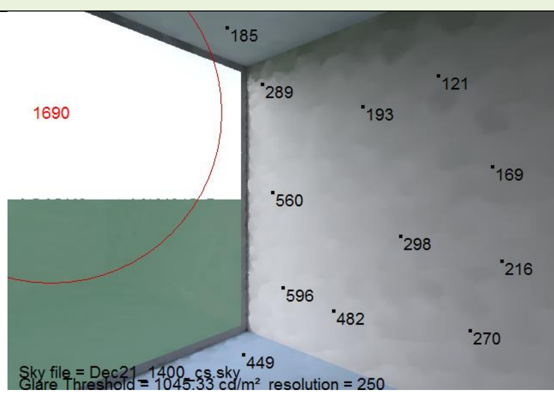
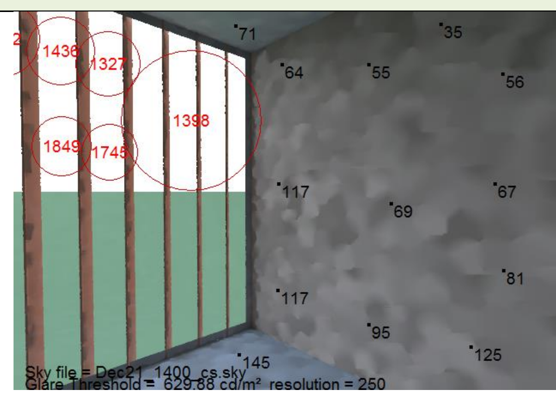
Table 4.65 shows that the maximum average DUD% occurs when using dynamic shading louvers where it equals to 30% compared to 24% only, in the base case scenario. On the other hand, Table 4.66 shows that the average DSE% when using dynamic shading louvers is 6% compared to 24% in the base case scenario. Although using fixed shading louvers at α=-60°, α=-40°, and α=-20° achieve average DSE% of 2%, 3% and 5%, respectively, the average DUD% at these angles are less than the average DUD% when using dynamic shading louvers. Thus, the author will recommend using dynamic shading louvers for this specific scenario since it provide the highest average DUD% value regardless of the average DSE% of 6% which is slightly higher than the acceptable range of DSE%.

- **Glare Analysis**

In this section, the author will be analyzing glare performance for the western orientation on December 21 for the base case scenario and the obtained optimal daylight angle at each time using W/S=0.5.

Table 4.67: Summary of the Glare Analysis - December 21, West (W/S=0.5)

Glare Analysis for December 21, West (W/S=0.5)	
t=08:00	**Base Case (The optimal configuration for this time)**
	
t=10:00	**Base Case (The optimal configuration for this time)**
	

<table>
<tr><td></td><td colspan="2"></td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-40°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=16:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-40°</td></tr>
</table>

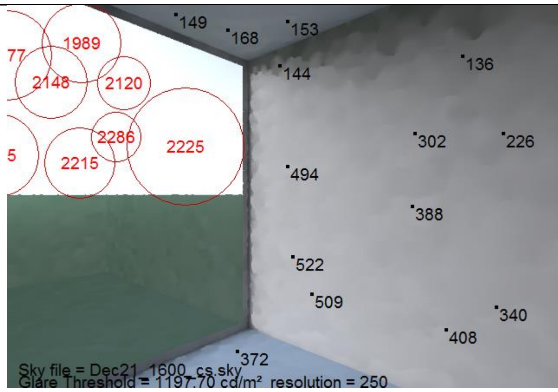
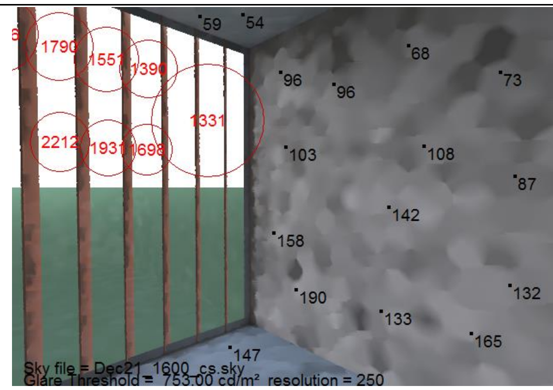
		

Table 4.67 shows the summary of the glare analysis for December 21 using W/S=0.5 on the western orientation.

Discussion:

As shown in Table 4.67, at t=08:00 and t=10:00, the glare is present on the glazing while the internal surfaces experience no glare at all. In fact the luminance levels across the office seem more homogenous without using any louvers since the sun is behind the office (east side) at these times of the day.

Furthermore, at t=12:00, t=14:00 and t=16:00, adding the shading louvers led to a various luminance levels on the glazing as opposed to the base case scenario at the mentioned times. In general, the luminance levels on the glazing seem to drop when adding the shading louvers as well as the luminance level range on the internal surfaces which help avoid having intense light penetration that could lead to visual discomfort or disability.

Findings:

Table 4.68: Glare analysis Summary - Dec 21, West (W/S=0.5)

	Luminance Levels on the glazing (cd/m^2)

	t=08:00	t=10:00	t=12:00	t=14:00	t=16:00	Avg. Luminance (cd/m2)
Base Case	1043	1349	1389	1690	2225	**1539**
Optimal Case	1043	1349	1613	1849	2212	**1613**

Table 4.68 shows the average luminance level on the glazing for both the base case scenarios and the optimal case scenarios where dynamic shading louvers are used. As shown, the average luminance level in the base case scenario is 1539 cd/m2 compared to 1613 cd/m2 in the optimal case scenarios. The difference in the average luminance level is 74 cd/m2 only, which is considered very minimal. Thus, the author will choose dynamic shading louvers as the optimal scenarios since they offer very good daylight performance, compared to the base case.

4.4.4. Daylight and Glare Analysis for March 21, W/S=1.0

- **Daylight Analysis**

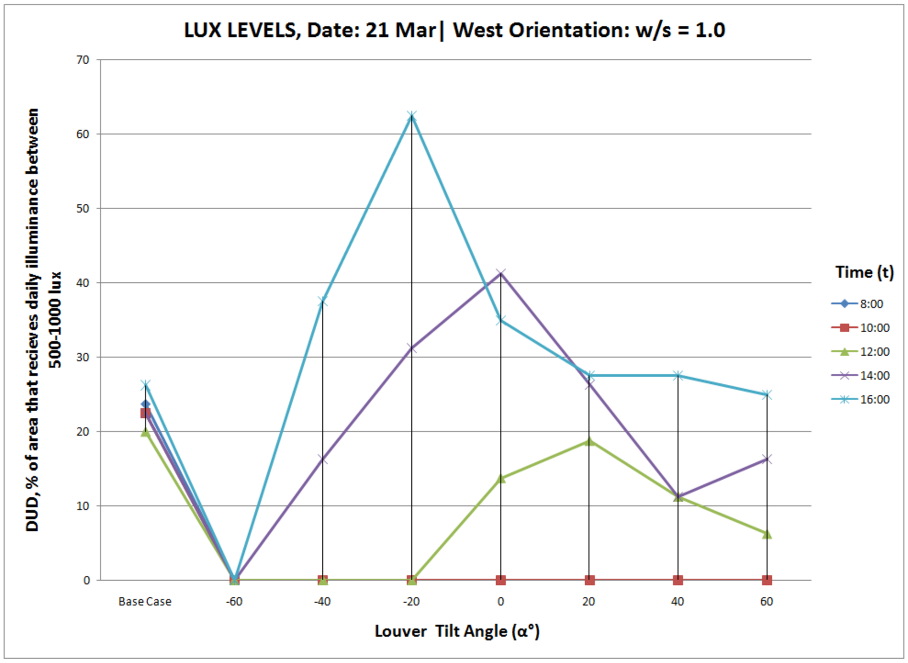


Figure 4.102: DUD analysis, 21 Mar, w/s=1.0 (West)

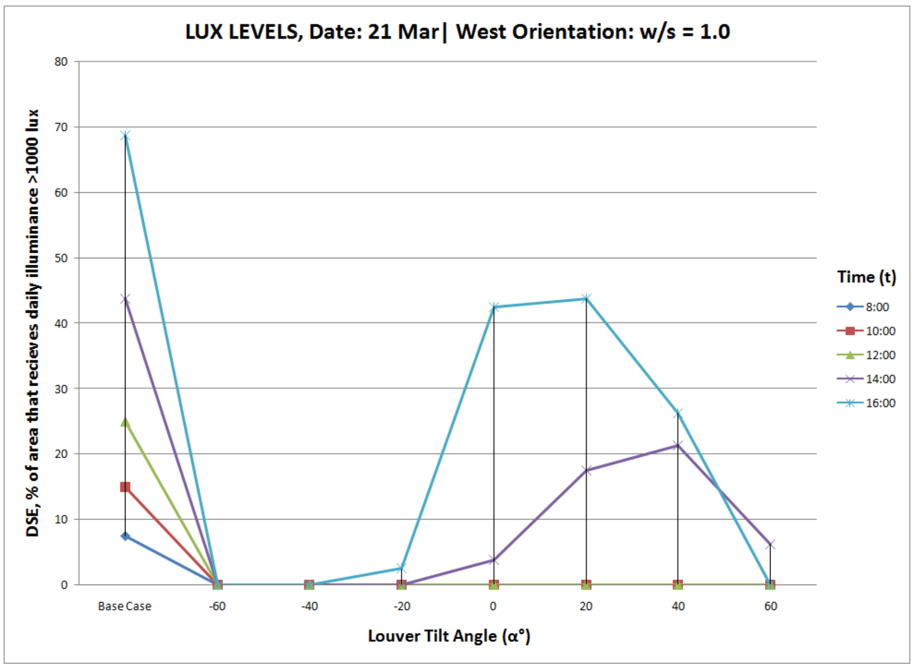


Figure 4.103: DSE analysis, 21 Mar, w/s=1.0 (West)

Discussion:

Figure 4.102 shows that at t=08:00, the maximum DUD% occurs in the base case scenario where it equals to 24% compared to 0% when using shading louvers. Moreover, Figure 4.103 shows that in the base case scenario, DSE% is 7.5% which is slightly higher than the acceptable DSE% range. Nevertheless, DSE% of 7.5% will be accepted since DUD% in the base case scenario represent the maximum DUD%.

Moreover, at t=10:00, Figure 4.102 shows that the maximum DUD% occurs at the base case scenario as well where it equals to 22.5% compared to 0% when using shading louvers at any tilt angle. On the other hand, Figure 4.103 shows that DSE% is 15% in the base case scenario compared to 0% when using shading louvers. Although DSE% of 0% is the optimal DSE% value, the author will not be using shading louvers since they provide no useful daylight penetration. Therefore, using no louvers (base case) at t=10:00 is the best option among all other options

Furthermore, at t=12:00, the maximum DUD% occurs in the base case scenario where it equals to 20% compared to lower DUD% values when using shading louvers at different tilt angles. On the other hand, Figure 4.103 shows that in the base case scenario DSE% of 25% is achieved which is excessive. Therefore, the author will select the second best configuration that provides a high DUD% which is α=20°, in this case, where DUD% equals to 19% and DSE% equals to 0%. Since the difference in DUD% in the base case scenario and DUD% using shading louvers at α=20° is only 1% whereas the difference in DSE% is 25%. The author will consider using dynamic shading louvers at α=20° at t=12:00.

In addition, at t=14:00, the maximum DUD% occurs at α=0° where it equals to 41% compared to 22.5% only, in the base case scenario. On the other hand, Figure 4.103 shows that at α=0°, DSE% is 4% compared to DSE% of 44% in the base case scenario. DSE% at α=0° can is acceptable since it falls within the acceptable DSE% range. This means that dynamic shading louvers at α=0° is the optimal configuration for t=14:00.

Finally, at t=16:00, the maximum DUD% occurs at α=-20° where it equals to 62.5% compared to 26% in the base case scenario. However, DSE% at α=-20° is 2.5%, which is acceptable, compared to 69% in the base case scenario. Thus, α=-20° is the optimal angle at t=16:00.

Appendix L shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=1.0

Findings:

Table 4.69: Daylight analysis (Average DUD%) - March 21, West (W/S=1..0)

Dynamic Useful Daylight Analysis (DUD%) - March 21, West (W/S=1.0)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	24%	0%	0%	0%	0%	0%	0%	0%
10:00	22.5%	0%	0%	0%	0%	0%	0%	0%
12:00	20%	0%	0%	0%	14%	19%	11%	6%
14:00	22.5%	0%	16%	31%	41%	26%	11%	16%
16:00	26%	0%	37.5%	62.5%	35%	27.5%	27.5%	25%
Avg. DUD%	**23%**	**0%**	**11%**	**19%**	**18%**	**15%**	**10%**	**9%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	24%							
10:00	22.5%							
12:00						19%		
14:00					41%			
16:00				62.5%				
Avg. DUD%	**34%**							

Table 4.70: Daylight analysis (Average DSE%) - March 21, West (W/S=1.0)

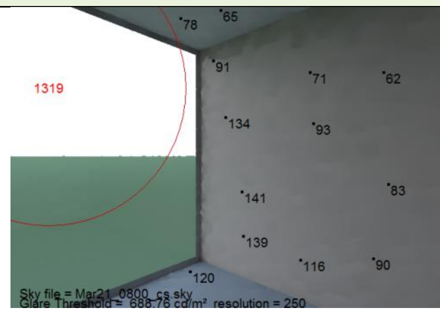
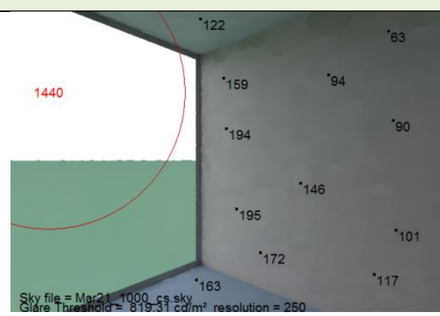
Dynamic Sunlight Exposure Analysis (DSE%) - March 21, West (W/S=1.0)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	7.5%	0%	0%	0%	0%	0%	0%	0%
10:00	15%	0%	0%	0%	0%	0%	0%	0%
12:00	25%	0%	0%	0%	0%	0%	0%	0%
14:00	44%	0%	0%	0%	4%	17.5%	21%	6%
16:00	69%	0%	0%	2.5%	42.5%	44%	26%	0%
Avg. DSE%	**32%**	**0%**	**0%**	**0.5%**	**9%**	**12%**	**9%**	**1%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	7.5%							
10:00	15%							
12:00						0%		
14:00					4%			
16:00				2.5%				
Avg. DSE%	**6%**							

Table 4.69 shows that the maximum average DUD% occurs when using dynamic shading louvers where it equals to 34% compared to 23% only, in the base case scenario. Moreover, Table 4.70 shows that the average DSE% when using dynamic shading louvers is 6% compared to 32% in the base case scenario. Although using fixed shading louvers at α=-60°, α=-40°, α=-20° and α=60° achieve less average DSE% than using dynamic shading louvers, the average DUD% at these angles are less than the average DUD% when using dynamic shading louvers. Therefore, using dynamic shading louvers will be considered as the optimal configuration for this specific scenario in terms of providing the optimal daylight performance.

- **Glare Analysis**

In this section, the author will be analyzing glare performance for the western orientation on March 21 for the base case scenario and the obtained optimal daylight angle at each time using W/S=1.0.

Table 4.71: Summary of the Glare Analysis - March 21, West (W/S=0.1)

<table>
<tr><th colspan="3">Glare Analysis for March 21, West (W/S=1.0)</th></tr>
<tr><td>t=08:00</td><td colspan="2">Base Case (The optimal configuration for this time)</td></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>t=10:00</td><td colspan="2">Base Case (The optimal configuration for this time)</td></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=20°</td></tr>
</table>

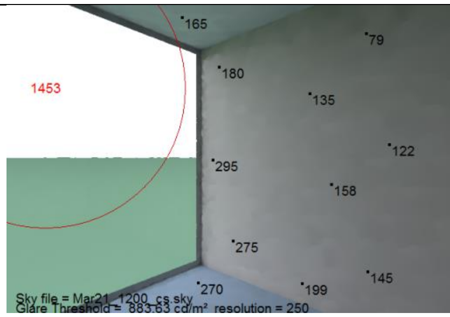
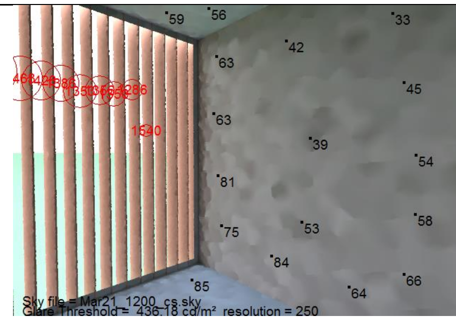
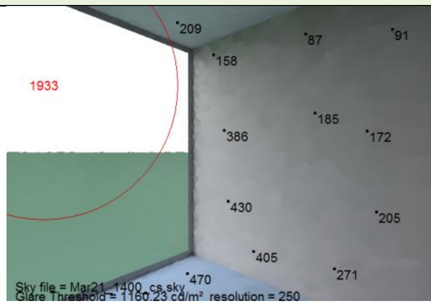
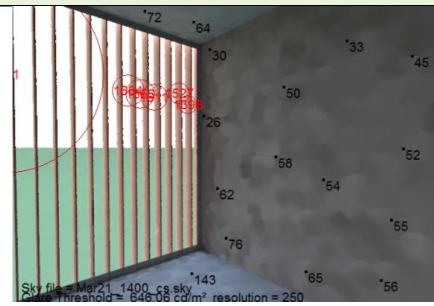
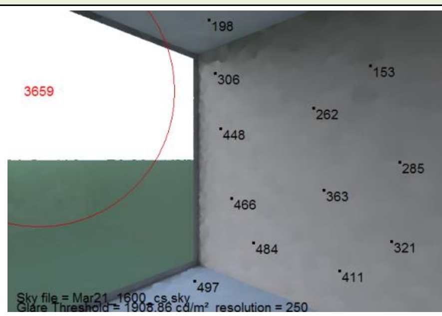
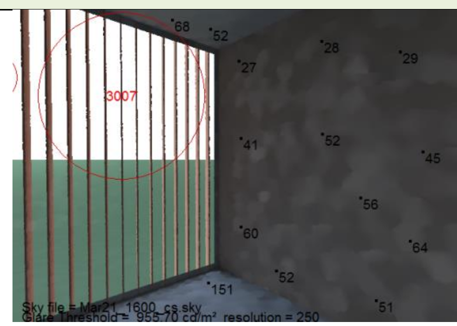
		
t=14:00	**Base Case**	**Dynamic Shading Louvers α=0°**
		
t=16:00	**Base Case**	**Dynamic Shading Louvers α=-20°**
		

Table 4.71 shows the summary of the glare analysis for March 21 using W/S=1.0 on the western orientation.

Discussion:

In general, glare on the surface of the glazing increases as the time passes throughout the day due to the sun position within the sky. As a result, the overall luminance level range on the internal surfaces increase accordingly. However, adding dynamic shading louvers at t=12:00, t=14:00, and t=16:00 provides a control over the increased luminance levels inside the office. In other words, the addition of the shading louvers reduces the penetration of the direct sunlight which reduces the possibilities of glare while maintaining a visual comfort through allowing the penetration of the natural daylight.

Findings:

Table 4.72: Glare analysis Summary - Mar 21, West (W/S=1.0)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	t=10:00	t=12:00	t=14:00	t=16:00	Avg. Luminance (cd/m2)
Base Case	1319	1440	1453	1933	3659	**1961**
Optimal Case	1319	1440	1540	1680	3007	**1797**

Table 4.72 show that the average luminance level is decreased in the optimal case scenarios when dynamic shading louvers are used compared to the base case scenarios. This result is aligned with the results obtained earlier from the daylight analysis which confirms that using dynamic shading louvers is effective in terms of both daylight and glare.

4.4.5. Daylight and Glare Analysis for June 21, W/S=1.0

- **Daylight Analysis**

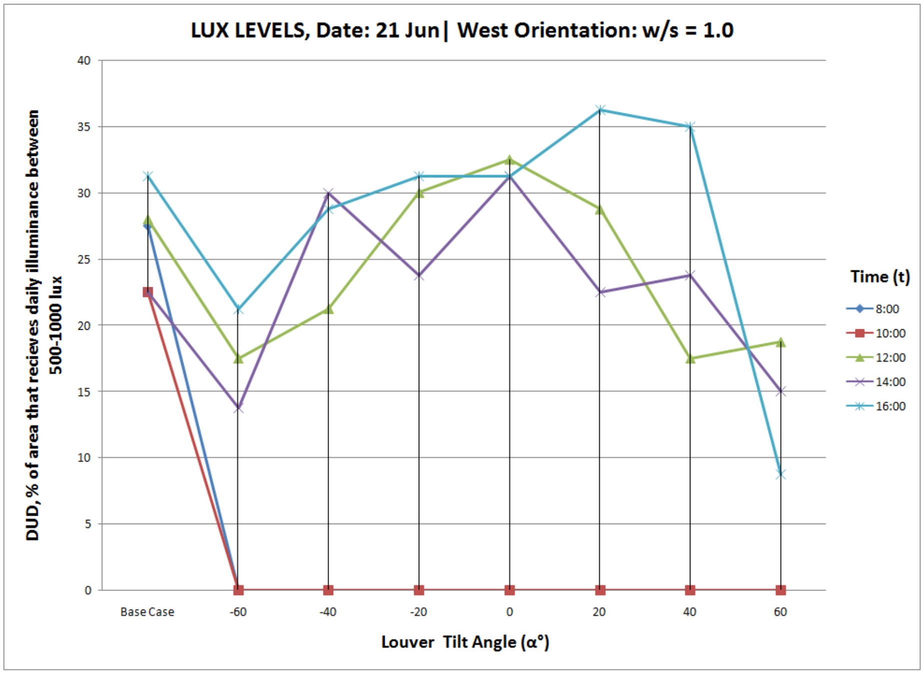


Figure 4.104: DUD analysis, 21 Jun, w/s=1.0 (West)

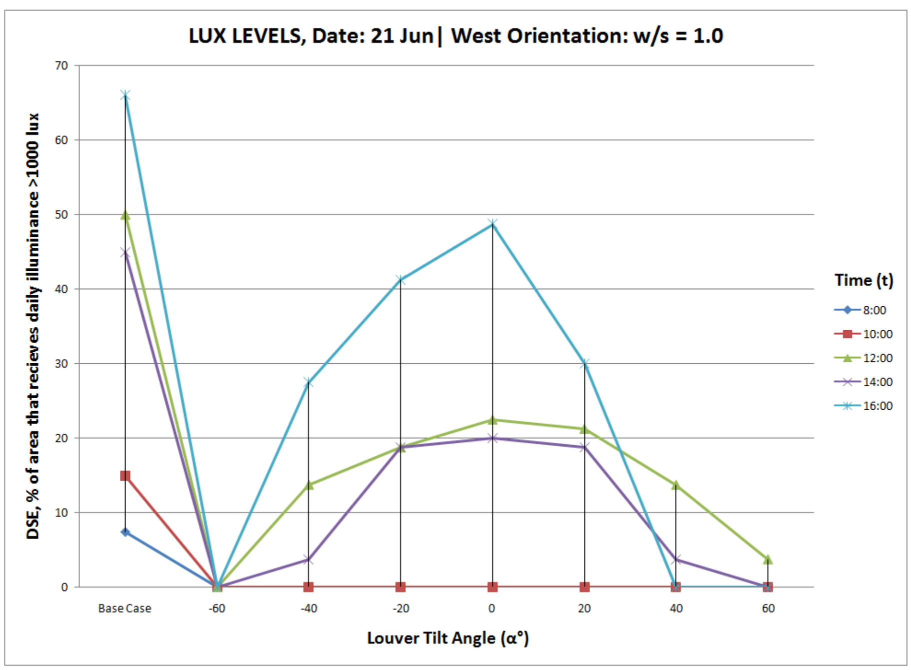


Figure 4.105: DSE analysis, 21 Jun, w/s=1.0 (West)

Discussion:

Figure 4.104 shows that at t=08:00, the maximum DUD% occurs in the base case scenario where it equals to 27.5% compared to DUD% of 0% when using shading louvers at any tilt angle. Moreover, Figure 4.105 shows that DSE% in the base case scenario is 7.5% compared to 0% when using shading louvers at this time of the day. The author will select the base case scenario as the optimal configuration for this time regardless of the DSE% value achieved since it is the only configuration among all options that allows the penetration of desired daylight.

Similarly, at t=10:00, the maximum DUD% occurs in the base case scenario where it equals to 22.5% and DSE% equals to 15%. The author will consider this scenario is the optimal scenario for this time of the year since it is the only scenario that provides useful daylight, just like the case at t=08:00.

Furthermore, at t=12:00, the maximum DUD% occurs at α=0° where to equals to 32.5% while DUD% at the base case is 28%. Moreover, Figure 4.105 shows that DSE% at α=0° is 22.5% compared to 50% in the base case scenario. Although DUD% at α=0° is considered high and good, DSE% at the same angle is too high. Therefore, the author will consider choosing the second best angle that provides a good DUD% while minimize the dynamic sunlight exposure (DSE%) which is α=-40° where DUD% is 21% and DSE% is 14%.

Additionally, at t=14:00, the maximum DUD% occurs at α=0° where it equals to 31% compared to 22.5% in the base case scenario. Moreover. DSE% at α=0° is 20% compared to 45% in the base case scenario. since DSE% at α=0° is considered high, the author will choose α=-40° to be the optimal angle for this time since it has a DUD% of 30% and a

DSE% of 4% only. As noticed, the difference in DUD% is very minimal (%1) whereas there is a reduction of 16% in DSE%.

Finally, at t=16:00, the maximum DUD% occurs at α=20° where it equals to 36% compared to 31% in the base case scenario. Moreover, DSE% at α=20° is 30% compared to 66% in the base case scenario. Of course DSE% of 30% is too high and cannot be accepted. Therefore, choosing α=40° as an optimal angle will achieve DUD% of 35%, which is only 1% less than the maximum DUD%, and DSE% of 0% which is the optimal DSE% value.

Appendix M shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=1.0

Findings:

Table 4.73: Daylight analysis (Average DUD%) - Jun 21, West (W/S=1.0)

Dynamic Useful Daylight Analysis (DUD%) - Jun 21, West (W/S=1.0)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	27.5%	0%	0%	0%	0%	0%	0%	0%
10:00	22.5%	0%	0%	0%	0%	0%	0%	0%
12:00	28%	17.5%	21%	30%	32.5%	29%	17.5%	19%
14:00	22.5%	14%	30%	24%	31%	22.5%	24%	15%
16:00	31%	21%	29%	31%	31%	36%	35%	9%
Avg. DUD%	**26%**	**11%**	**16%**	**17%**	**19%**	**18%**	**15%**	**9%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	27.5%							
10:00	22.5%							
12:00			21%					
14:00			30%					
16:00							35%	
Avg. DUD%	**27%**							

Table 4.74: Daylight analysis (Average DSE%) - Jun 21, West (W/S=1.0)

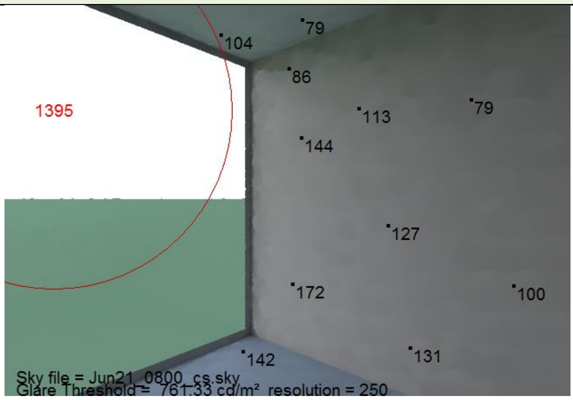
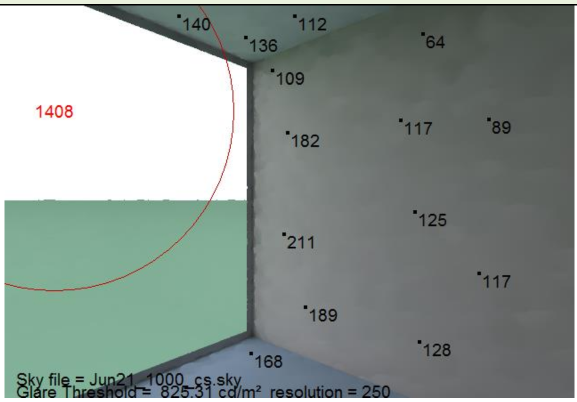
Dynamic Sunlight Exposure Analysis (DSE%) - Jun 21, West (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	7.5%	0%	0%	0%	0%	0%	0%	0%
10:00	15%	0%	0%	0%	0%	0%	0%	0%
12:00	50%	0%	14%	19%	22.5%	21%	14%	4%
14:00	45%	0%	4%	19%	20%	19%	4%	0%
16:00	66%	0%	27.5%	41%	49%	30%	0%	0%
Avg. DSE%	**37%**	**0%**	**9%**	**16%**	**18%**	**14%**	**4%**	**1%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	7.5%							
10:00	15%							
12:00			14%					
14:00			4%					
16:00							0%	
Avg. DSE%	**8%**							

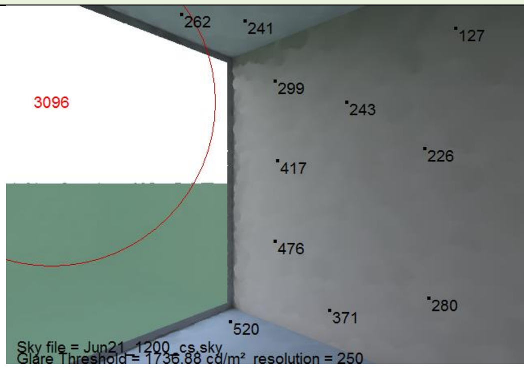
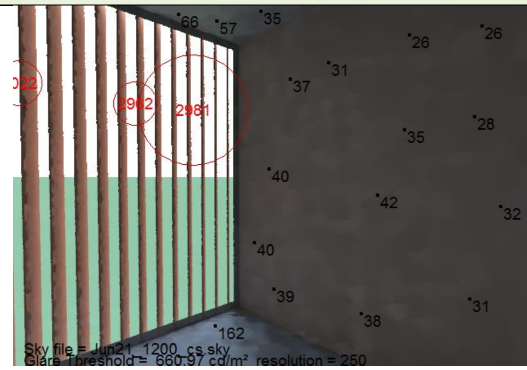
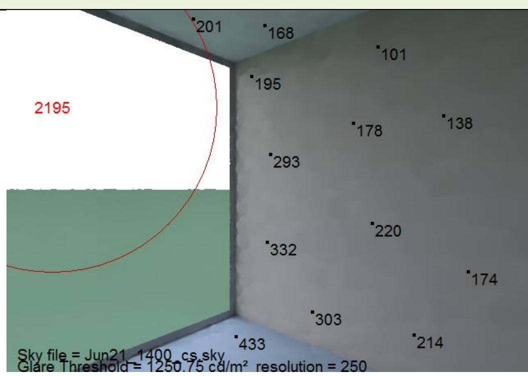
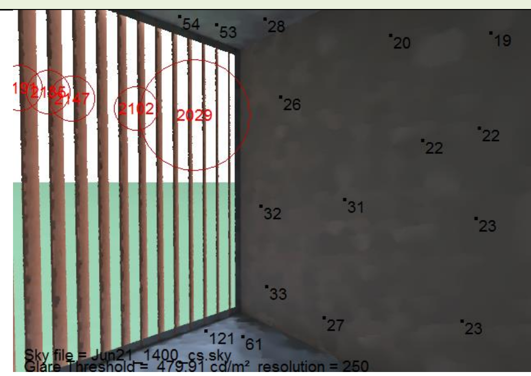
Table 4.73 shows that the maximum average DUD% occurs when dynamic shading louvers configuration where it equals to 27% compared to 26% in the base case scenario. As noticed, the difference in the average DUD% is not significant, however, Table 4.74 shows that the average DSE% when using dynamic shading louvers is 8% compared to 37% in the base case scenario. The difference in DSE% is very dramatic and an average DSE% of 37% cannot be acceptable. Moreover, when using fixed shading louvers at α=-60°, α=60°, and α=40°, Table 4.74 shows that the average DSE% values are 0%, 1%, and 4%, respectively. Although the average DSE% at these angles are less than the average DSE% when using dynamic shading louvers, the average DUD% at these angles are very low. Therefore, the author will give the priority to the maximum average DUD% over the minimum average DSE%, which means that dynamic shading louvers is the best configuration for this specific scenario.

- **Glare Analysis**

In this section, the author will discuss the glare analysis results for the western orientation using W/S=1.0 on 21 June.

Table 4.75: Summary of the Glare Analysis - June 21, West (W/S=1.0)

<table>
<tr><th colspan="2">Glare Analysis for June 21, West (W/S=0.1)</th></tr>
<tr><td>t=08:00</td><td>Base Case (The optimal configuration for this time)</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td>t=10:00</td><td>Base Case (The optimal configuration for this time)</td></tr>
<tr><td></td><td>
</td></tr>
</table>

<table>
<tr><td></td><td colspan="2"></td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-40°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=-40°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=16:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=40°</td></tr>
</table>

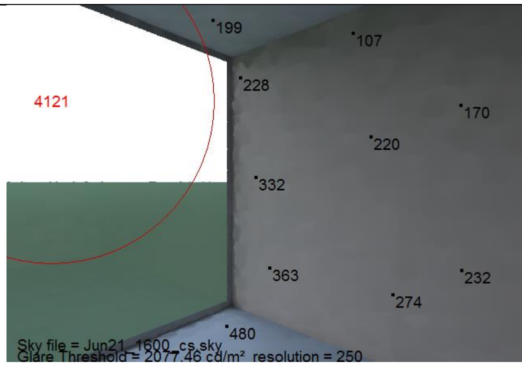
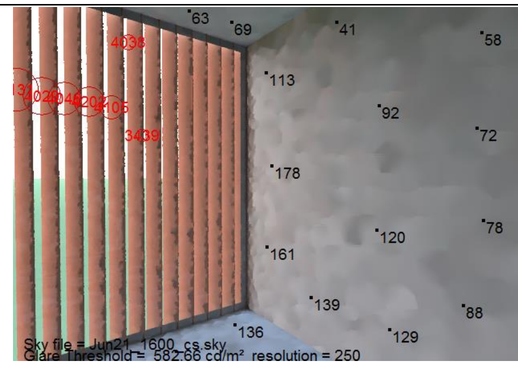
		

Table 4.75shows the summary of the glare analysis for June 21 using W/S=1.0 on the western orientation.

Discussion:

Table 4.75 shows that at t=08:00 and t=10:00, the luminance levels on the glazing are 1395 cd/m2 and 1408 cd/m2, respectively. These values are relatively low when compared to the cases at t=12, t=14:00, and t=12:00 without any louvers.

In the morning times and without any louvers, the internal surfaces of the office seem to perform well in terms of the absence of glare inside the office and the uniform luminance levels across the room which reduces the possibilities of visual discomfort.

However, at t=12:00, t=14:00 and t=16:00, dynamic shading louvers are required as per the daylight analysis for block the maximum amounts of direct sunlight while allowing the penetration of the useful daylight. In terms of glare, the overall luminance levels along the glazing increase as the time passes throughout the day and so does the luminance levels across the internal surfaces. However, adding dynamic shading louvers seem to reduce the glare intensity on the glazing due to the louvers presence that cover some parts of the glazed surface which minimize the light exposure and eventually the glare.

Findings:

Table 4.76: Glare analysis Summary - Jun 21, West (W/S=1.0)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	t=10:00	t=12:00	t=14:00	t=16:00	Avg. Luminance (cd/m2)
Base Case	1395	1408	3096	2195	4121	**2443**
Optimal Case	1395	1408	2981	2185	4029	**2400**

Table 4.76 shows the average luminance level on the glazing for the base case scenarios and the optimal case scenarios. As noticed, the average luminance levels on the glazing is 2443 cd/m2 in the base cases compared to 2400 cd/m2 in the optimal cases. This shows a slight reduction in the luminance levels, thus, a reduction in glare probability can be achieved. This indicates that dynamic shading louvers are the best design configuration compared to the base case scenario in terms of both daylight and glare.

4.4.6. Daylight and Glare Analysis for December 21, W/S=1.0

- **Daylight Analysis**

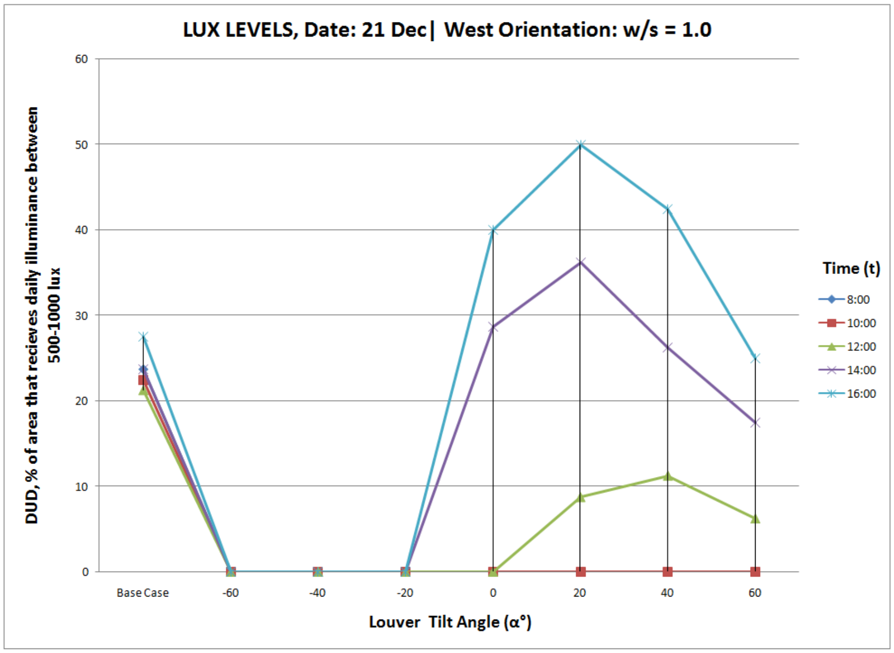


Figure 4.106: DUD analysis, 21 Dec, w/s=1.0 (West)

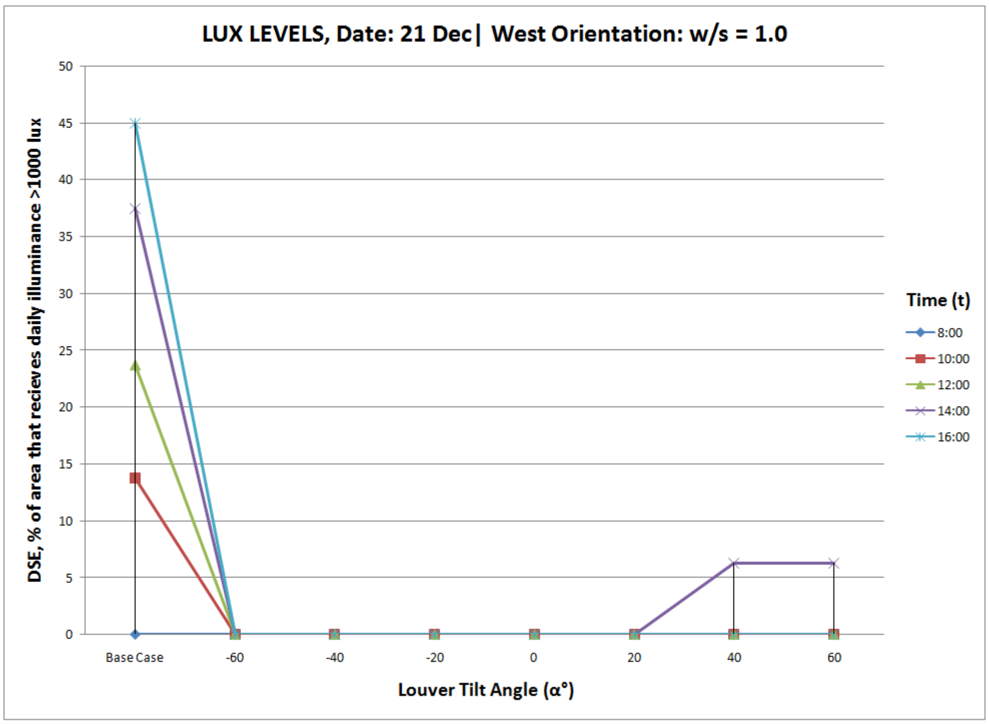


Figure 4.107: DSE analysis, 21 Dec, w/s=1.0 (West)

Discussion:

Figure 4.106 shows that at t=08:00, the maximum DUD% occurs in the base case scenario where it equals to 24% compared to DUD% of 0% when using shading louvers at any tilt angle. Also, Figure 4.107 shows that DSE% in the base case scenario is 0% which is the optimal DSE% value. Thus, using no louvers at all is the optimal configuration for t=08:00.

Moreover, at t=10:00, Figure 4.106 shows that the maximum DUD% occurs in the base case scenario where it equals to 22.5% compared to 0% when using shading louvers. Moreover, DSE% in the base case scenario is 14% compared to 0% when using shading louvers at any angle. DSE% of 14% will be acceptable, in this case, since the base case scenario is the only scenario that allows the penetration of useful daylight as opposed to using shading louvers which block the penetration of the useful daylight (500-1000 lux). Thus, using no louvers at t=10:00 is the optimal configuration for daylight.

Additionally, at t=12:00, Figure 4.106 shows that the maximum DUD% occurs in the base case scenario where it equals to 21% whereas DSE% at the same scenario is 14%. DSE% of 14% will be acceptable, as the case at t=10:00.

Furthermore, at t=14:00, the maximum DUD% occurs at α=20° where it equals to 36% compared to 24% only, in the base case scenario. At the same time and angle, Figure 4.107 shows that DSE% is 0% which is the optimal DSE% value. Therefore, α=20° is the optimal daylight angle for t=14:00.

Finally, at t=16:00, the maximum DUD% occurs at α=20° as well where it equals to 50% compared to 27.5% only, in the base case scenario. Also, Figure 4.107 shows that at α=20°, DSE% equals to 0% which makes this angle the optimal angle for this particular time of the day.

Appendix N shows the illuminance levels results for the base case and the optimal angles for all the simulated times using W/S=1.0

Findings:

Table 4.77: Daylight analysis (Average DUD%) - December 21, West (W/S=1.0)

Dynamic Useful Daylight Analysis (DUD%) - December 21, West (W/S=1.0)								
Time (t)	**Base Case (No Louvers)**	**Fixed shading louvers(α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	24%	0%	0%	0%	0%	0%	0%	0%
10:00	22.5%	0%	0%	0%	0%	0%	0%	0%
12:00	21%	0%	0%	0%	0%	9%	11%	6%
14:00	24%	0%	0%	0%	29%	36%	26%	17.5%
16:00	27.5%	0%	0%	0%	40%	50%	42.5%	25%
Avg. DUD%	**24%**	**0%**	**0%**	**0%**	**14%**	**19%**	**16%**	**10%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	24%							
10:00	22.5%							
12:00	21%							
14:00						36%		
16:00						50%		
Avg. DUD%	**31%**							

Table 4.78: Daylight analysis (Average DSE%) - December 21, West (W/S=1.0)

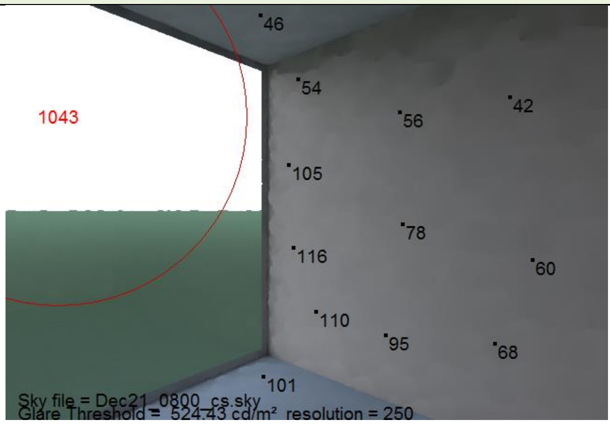
Dynamic Sunlight Exposure Analysis (DSE%) - December 21, West (W/S=1.0)								
Time (t)	Base Case (No Louvers)	Fixed shading louvers(α°)						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	0%	0%	0%	0%	0%	0%	0%	0%
10:00	14%	0%	0%	0%	0%	0%	0%	0%
12:00	24%	0%	0%	0%	0%	0%	0%	0%
14:00	37.5%	0%	0%	0%	0%	0%	6%	6%
16:00	45%	0%	0%	0%	0%	0%	0%	0%
Avg. DSE%	**24%**	**0%**	**0%**	**0%**	**0%**	**0%**	**1%**	**1%**
Time (t)	**Hidden Louvers**	**Dynamic shading louvers at the Optimal Angles (α°)**						
		-60	**-40**	**-20**	**0**	**20**	**40**	**60**
8:00	0%							
10:00	14%							
12:00	24%							
14:00						0%		
16:00						0%		
Avg. DSE%	**7.6%**							

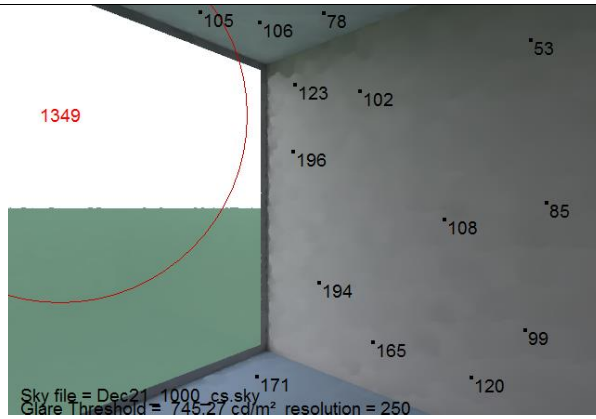
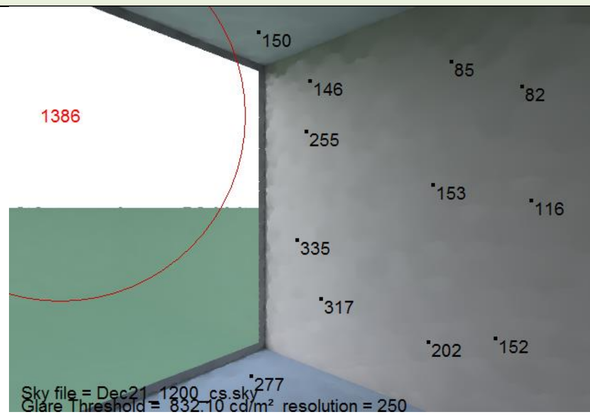
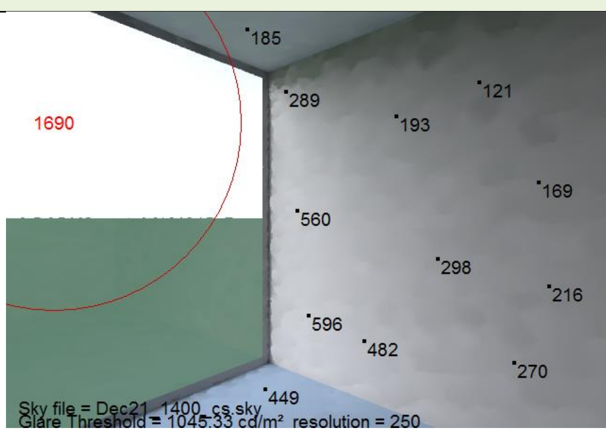
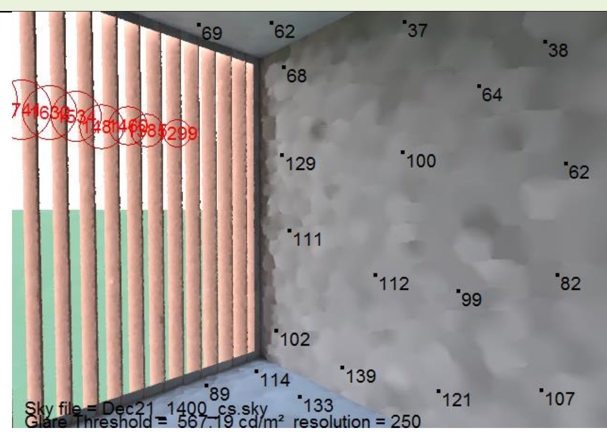
Table 4.77 shows that the maximum average DUD% occurs when using dynamic shading louvers where it equals to 31% compared to the average DUD% of 24% in the base case scenario. Additionally, Table 4.78 shows that the average DSE% when using dynamic shading louvers is 7.6% compared to 24% in the base case scenario which is a significant difference. Looking at Table 4.78, when using fixed shading louvers at any tilt angle seem to achieve less average DSE% than the result obtained when using dynamic shading louvers. However, looking back at Table 4.77, using fixed shading louvers seem to achieve less average DUD% compared to the result obtained when using dynamic shading louvers. This concludes that using dynamic shading louvers for this scenario is the most effective configuration to maximize the natural daylight in the office.

- **Glare Analysis**

In this section, the author will be analyzing glare performance for the western orientation on December 21 for the base case scenario and the obtained optimal daylight angle at each time using W/S=1.0.

Table 4.79: Summary of the Glare Analysis - December 21, West (W/S=1.0)

Glare Analysis for December 21, West (W/S=1.0)	
t=08:00	**Base Case (The optimal configuration for this time)**
	
t=10:00	**Base Case (The optimal configuration for this time)**

<table>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>t=12:00</td><td colspan="2">Base Case (The optimal configuration for this time)</td></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Dynamic Shading Louvers α=20°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
</table>

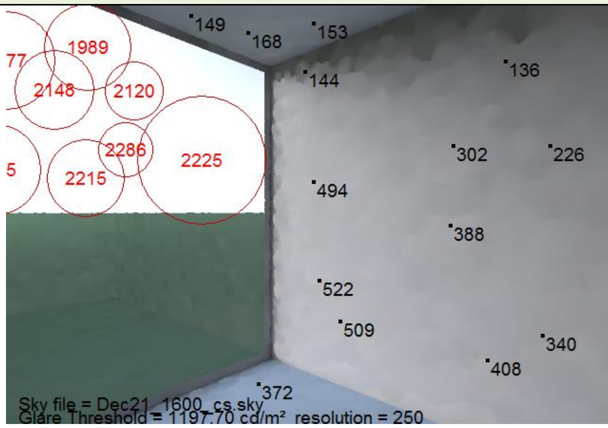
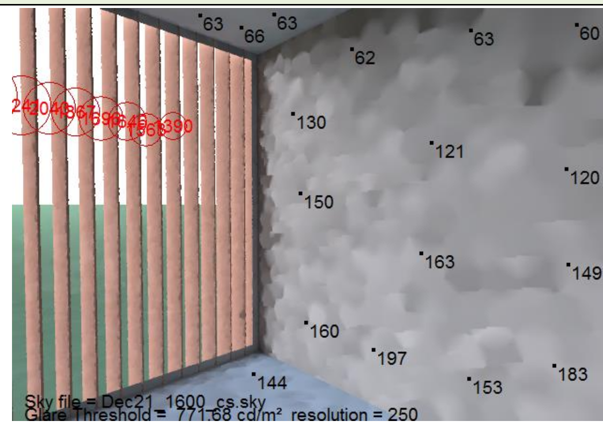
t=16:00	Base Case	Dynamic Shading Louvers α=20°
		

Table 4.79 shows the summary of the glare analysis for December 21 using W/S=1.0 on the western orientation.

Discussion:

As shown in the table, the first half of the day requires no louvers at all as obtained from the daylight analysis. In terms of glare and luminance levels, the luminance levels on the internal surfaces at t=08:00, t=10:00, and t=12:00 are 1043 cd/m2, 1349 cd/m2 and 1386 cd/m2, respectively. As noticed, the luminance levels is directly proportional to the time of the day in this scenario since the glazing is facing west and the sun light is more intense in this orientation as the time of the day passes. However, at t=14:00 and t=16:00, the luminance levels on the glazing as well as the luminance levels on the internal surfaces of the office increase which explains the need for shading louvers to minimize the direct sunlight penetration.

When comparing the base case scenario to the optimal scenarios at t=14:00 and t=16:00, it can be noticed that the luminance levels across the internal surfaces have reduced to almost the half when using the dynamic shading louvers. This reduction will ensure the prevention of glare appearance on the surfaces as well as providing visual comfort.

Findings:

Table 4.80: Glare analysis Summary - Dec 21, West (W/S=1.0)

	Luminance Levels on the glazing (cd/m^2)					
	t=08:00	**t=10:00**	**t=12:00**	**t=14:00**	**t=16:00**	**Avg. Luminance (cd/m2)**
Base Case	1043	1349	1386	1690	2225	**1539**
Optimal Case	1043	1349	1386	1741	2040	**1512**

Table 4.80 shows that the average luminance level on the glazing is decreased with the addition of the dynamic shading louvers (optimal case). Although the decrease is very minimal, the increase in DUD% when using dynamic shading louvers is very significant compared to the base case scenario. This indicates that using such shading louvers is effective in terms of stabilizing glare occurrence while maximizing dynamic useful daylight (DUD) and minimizing dynamic sunlight exposure (DSE)

5. CHAPTER 5: FINDINGS SUMMARY & CONCLUSION

5.1. Findings Summary

In this section of the chapter, the author will summarize the findings for each orientation independently.

- Daylight Summary:

Table 5.1 shows the summary of the best configurations for maximizing daylight and reducing glare for the four orientations, as obtained from the discussions. The table shows that using dynamic shading louvers is the best configuration for most simulated scenarios except for two scenarios. Specifically, using fixed shading louvers at α=40° on December 21st for the southern orientation (W/S=0.5) have proven that it is more effective in terms of glare and daylight performance than alternating the louvers tilt angles at every time of the day. Also, using fixed shading louvers at α=-20° on March 21st for the southern orientation (W/S=1.0) have shown its effectiveness over using dynamic shading louvers for enhancing daylight and glare performance.

Table 5.1: Summary of the Best Configurations for Daylight and Glare performance

	Summary of the Best Configurations for Daylight and Glare performance			
	South		**North**	
Day	**W/S=0.5**	**W/S=1.0**	**W/S=0.5**	**W/S=1.0**
21-Mar	Dynamic	Fixed at α=-20°	Dynamic	Dynamic
21-Jun	Dynamic	Dynamic	Dynamic	Dynamic
21-Dec	Fixed at α=40°	Dynamic	Dynamic	Dynamic
	East		**West**	
Day	**W/S=0.5**	**W/S=1.0**	**W/S=0.5**	**W/S=1.0**
21-Mar	Dynamic	Dynamic	Dynamic	Dynamic
21-Jun	Dynamic	Dynamic	Dynamic	Dynamic
21-Dec	Dynamic	Dynamic	Dynamic	Dynamic

Now, the author will illustrate the summary of the average dynamic useful daylight (avg. DUD%) for each orientation using W/S=0.5 and W/S=1.0 to determine the best design for each day that provides the higher DUD%. The reason behind focusing on the maximum average DUD% is because it is the core of this paper and usually higher DUD% means lower DSE%.

- **Summary of the Southern Orientation**

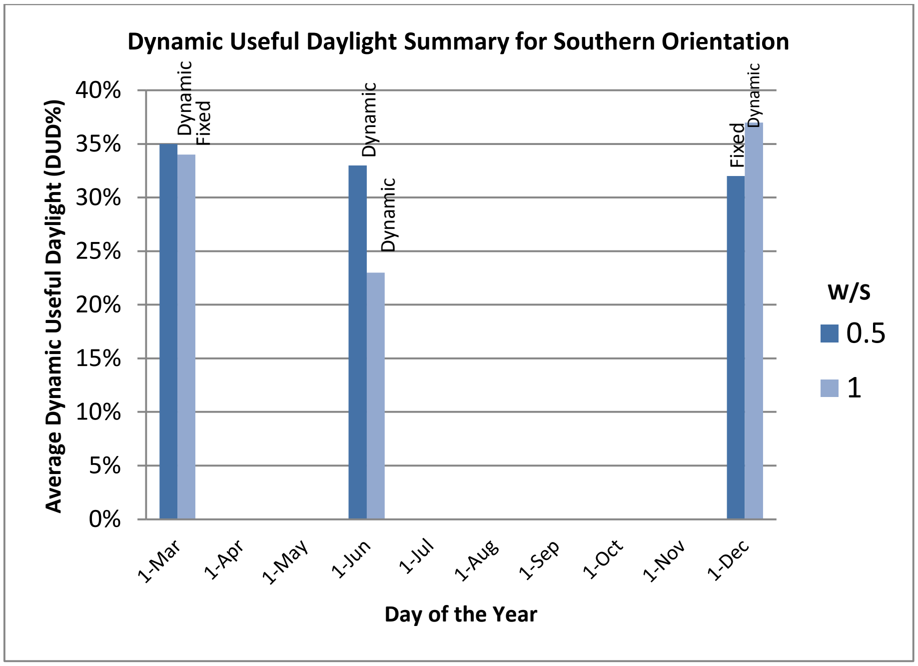


Figure 5.1: Dynamic Useful Daylight Summary for Southern Orientation

Figure 5.1 shows that on March 21 (South), using W/S=0.5 provides an average DUD% of 35% compared to 34% when using W/S=1.0. This means that it is better to use W/S=0.5 at this time of the year rather than W/S=1.0, although the difference is very minimal. Similarly, on June 21 (South) the daylight performance is better when using W/S=0.5 over W/S=1.0 where the average DUD% is 33% when using W/S=0.5 compared to an average DUD% of 23% when using W/S=1.0. However, on December 21 (South), the daylight performance when using W/S=1.0 is better than W/S=0.5 since the average DUD% when using W/S=1.0 is 37% compared to 32% when using W/S=0.5. As observed, dynamic shading louvers always provide a better average DUD% than fixed shading louvers.

- **Summary of the Northern Orientation**

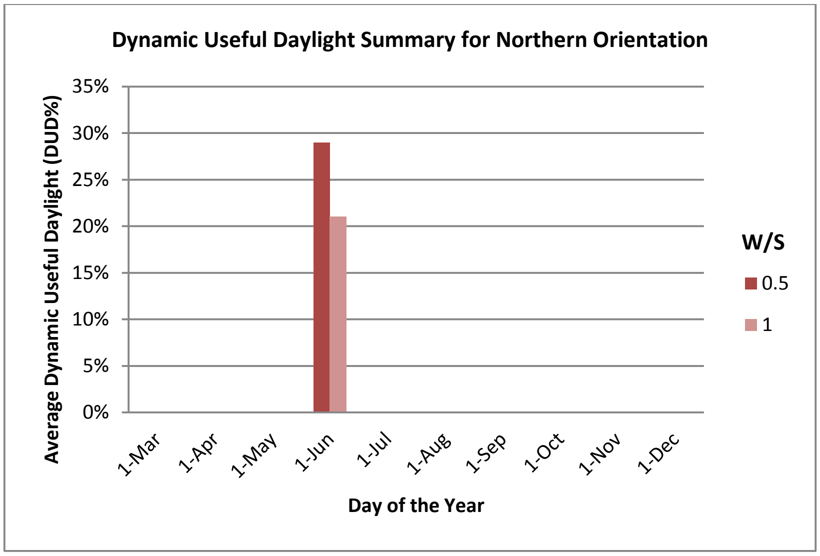


Figure 5.2: Dynamic Useful Daylight Summary for Northern Orientation

Figure 5.2 shows that an average DUD% of 29% is achieved when using W/S=0.5 on June 21st (North) compared to an average DUD% of 21% only, when using W/S=1.0. For both design options, dynamic shading louvers were used. This indicates that using W/S=0.5 for this orientation and for this specific day is the optimal design configuration.

- **Summary of the Eastern Orientation**

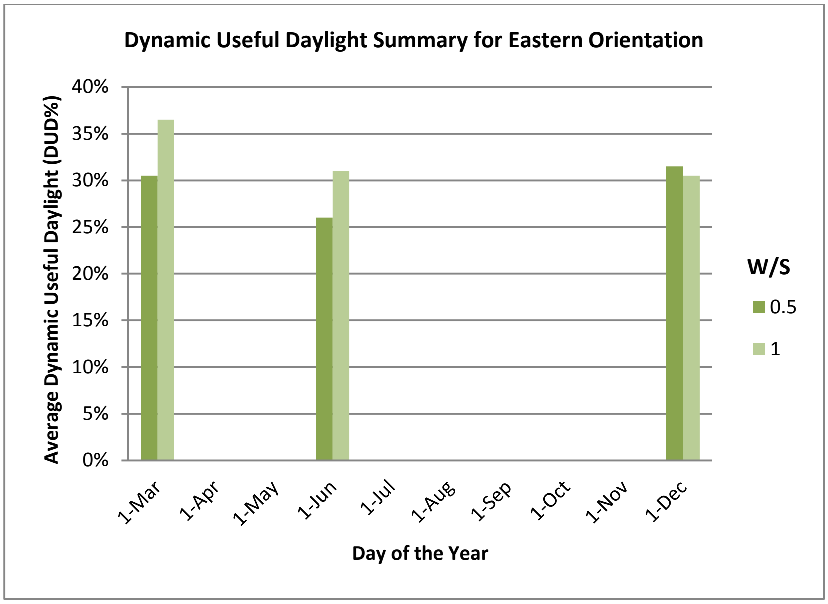


Figure 5.3: Dynamic Useful Daylight Summary for Eastern Orientation

Figure 5.3 shows that the average DUD% when using W/S=1.0 on March 21st (East) is 36.5% compared to an average DUD% of 30.5% when using W/S=0.5. Therefore, using dynamic shading louvers with W/S=1.0 is better in maximizing the daylight.

Moreover, the average DUD% when using W/S=1.0 on June 21st (East) is 31% compared to 26% only, when using W/S=0.5. Therefore, W/S=1.0 is better for this case.

Furthermore, the average DUD% when using W/S=1.0 on December 21st (East) is 30.5% compared to 31.5% when using W/S=0.5, which means that the design configuration using W/S=0.5 is better for daylight, in this case.

- **Summary of the Western Orientation**

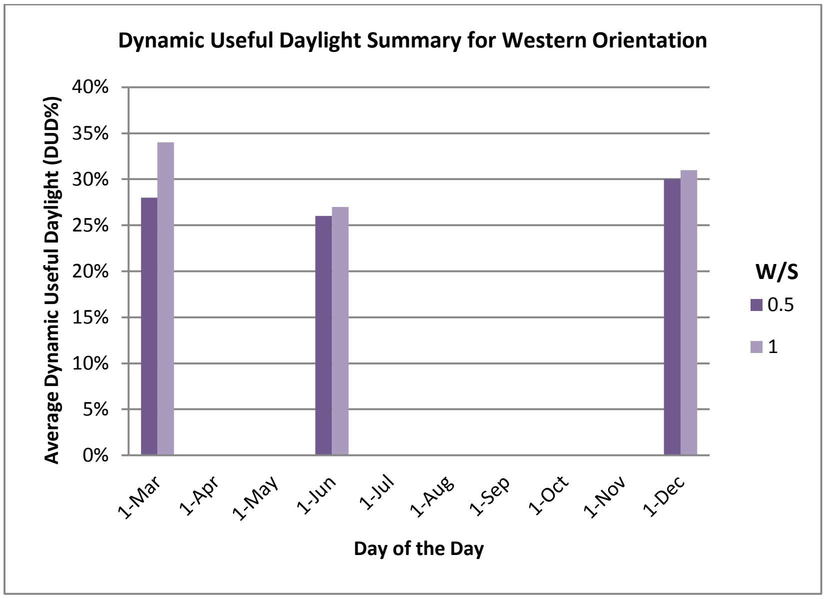


Figure 5.4: Dynamic Useful Daylight Summary for Western Orientation

Figure 5.4 shows that the average DUD% when using W/S=0.5 on March 21st (West) is 28% compared to 34% when using W/S=1.0. Thus, a design configuration using W/S=1.0 is better for this specific scenario.

Additionally, the figure shows that on 21st of June (West), the average DUD% when using dynamic shading louvers and W/S=0.5 is 26% compared to 27% when using W/S=1.0. This indicates that using dynamic shading louvers with equal spacing and width is better than using W/S=0.5 in terms of providing maximum useful daylight.

Lastly, using dynamic shading louvers on 21st of December (West) with W/S=0.5 achieves an average DUD% of 30% compared to an average DUD% of 31% when using W/S=1.0. Therefore, using W/S=1.0 is better in providing optimal daylight than using W/S=0.5, for this scenario.

- **Summary of the Annual Average Dynamic Useful Daylight**

  Finally, Table 5.2 shows the annual average dynamic useful daylight for each orientation. The configuration used is dynamic, thus, W/S changes as the time of the year changes according to the maximum average DUD% for each day. This practically means that only the spacing gets wider and narrower as the time changes since W/S=0.5 and W/S=1.0 have different spacing with similar width (spacing 0.4m for W/S=0.5 and 0.2m for W/S=1.0 while the width is 0.2m for both).

  As noticed, dynamic shading louvers perform at its best when placed on the southern orientation where the annual average DUD% is 35%. On the other hand, the dynamic shading louvers perform at its lowest on the northern orientation where the annual average DUD% is 29% due to the lack of sun penetration from this orientation. Therefore, using dynamic shading louvers with lower W/S (e.g. W/S=0.33 where W=0.2m and S=0.6m) might have a better daylight performance on the northern orientation than the ones used in this research since the spacing between the louvers is wider, thus, the sun penetration will probably be better.

Table 5.2: Summary of the Annual Average Dynamic Useful Daylight

SOUTH		
DAY	**Average DUD%**	
	W/S = 0.5	**W/S = 1.0**
MARCH 21	**35%**	**34%**
JUNE 21	**33%**	**23%**
DECEMBER 21	**32%**	**37%**
Annual Average DUD%	**35%**	
NORTH		

DAY	Average DUD%	
	W/S = 0.5	W/S = 1.0
JUNE 21	29%	21%
Annual Average DUD%	29%	
EAST		
DAY	Average DUD%	
	W/S = 0.5	W/S = 1.0
MARCH 21	31%	37%
JUNE 21	26%	31%
DECEMBER 21	32%	31%
Annual Average DUD%	33%	
WEST		
DAY	Average DUD%	
	W/S = 0.5	W/S = 1.0
MARCH 21	28%	34%
JUNE 21	26%	27%
DECEMBER 21	30%	31%
Annual Average DUD%	31%	

- Glare Summary:

As noticed from the previous chapter, the glare analysis results did not always agree with the results obtained from the daylight analysis. Regardless, the author was prioritizing the daylight analysis results over the glare analysis results due to the following reasons:

1- Glare is a subjective factor which means it varies in terms of comfort and discomfort from a person to another and from a certain field of view to another.

2- Daylight analysis results show a breakdown of the percentages of DUD% and DSE% which could contribute to energy savings by controlling the direct sunlight penetration while maximizing the useful daylight penetration. Glare analysis results, however, usually do not affect the energy load of a certain building or space.

5.2.Conclusion

A new metric to measure daylight performance of Dynamic Façade was developed. Dynamic Useful Daylight (DUD) measures the area of the regularly occupied floor that receives illuminance between 500 to 1000 lux. Dynamic Sunlight Exposure (DSE), however, measures the floor area that receives illuminance over 1000 lux. The advantages of this developed metric is that it allows designers to determine the most suitable configuration for dynamic shading louvers in terms of daylight performance. This metric provides flexibility through its ability to analyze different design options under different conditions, time frames and different days within the year, unlike other daylight metric such as sDA and ASE which analyses daylight annually.

In this paper, dynamic shading louvers have been examined under several scenarios to evaluate their performance in terms of daylight and glare analysis. In addition to the dynamic shading louvers, base case scenario, where no louvers are used, and fixed shading louvers were also examined to conduct a comparison between the three design configurations in terms of daylight and glare.

The author have selected two main design configuration for the dynamic and fixed shading louvers which are W/S=0.5 and W/S=1.0 to be examined in three different days (21 March, 21 June, and 21 December) for 4 main orientations which are South, East, North, West.

Each design configuration perform differently under different simulation scenarios, However, using dynamic shading louvers is recommended as they proved their capability in providing better daylight and glare performance as opposed to the base case as well as the fixed shading louvers.

Although the dynamic shading louvers behaved quite well in terms of daylight compared to the other configurations, the author believes that the improvements in daylight are not that significant to the extent that the users will abandon using electrical lighting. However, the author do believe that reducing the usage of electrical lights through enhancing the natural daylight will have a positive impact on the lighting loads which will eventually have a good impact on the overall annual energy consumption of the building.

5.3.Future studies

There are always areas for improvements and future studies. Below are some of the topics related to dynamic shading louvers that can be investigated to extend the knowledge about the potentiality and effectiveness of using such systems in terms of daylight.

1. Buildings perform differently under different climatic conditions, thus, examining the dynamic shading louvers in different locations that have different climates will determine

the potential of the system in providing proper daylight under different circumstances. In this research paper, the author selected Dubai, UAE as a hot humid climate. However, selecting different climates (e.g. polar climates) might have completely opposite results where dynamic shading louvers might worsen the daylight penetration.

2. In addition to the climatic conditions, studying dynamic shading louvers under different sky conditions (e.g. clear, overcast,..etc.) will most probably have different impact on the effectiveness of the system. In this research paper, the author selected clear sky conditions for all the scenarios. Selecting different sky conditions for the same location will probably have different results.
3. The parameter (W/S) used in this research papers were two which are W/S=0.5 and W/S=1.0. There are many values of W/S that were not covered in this research paper. However, different geometry of the louver and different values of W/S will have different impacts on the daylight and glare performance.
4. This research have covered a small personal office to evaluate the daylight performance using dynamic shading louver. However, future studies can cover different case study (e.g. open plan office) which will probably give a deeper understanding of the performance of the system
5. Different louver types on different orientations might have different effect. Future studies can alternate the louvers types used in this research to evaluate the different louver configuration. For instance, this research used vertical louvers for the eastern orientation, however, using horizontal louvers instead might have different impact of the daylight profile.

6. Economical analysis for using such dynamic shading louvers for daylight enhancement to be conducted to determine whether the initial cost, the payback period and the maintenance cost will be worth the investment over the traditional fixed shading louvers.

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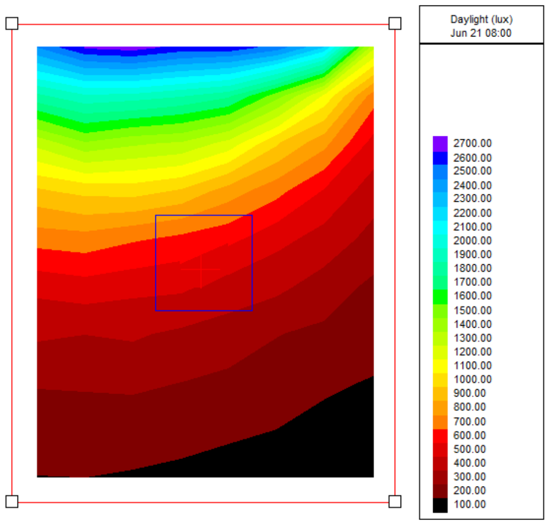
APPENDIXES

Appendix A - Illuminance Levels for June 21, North (W/S=0.5)

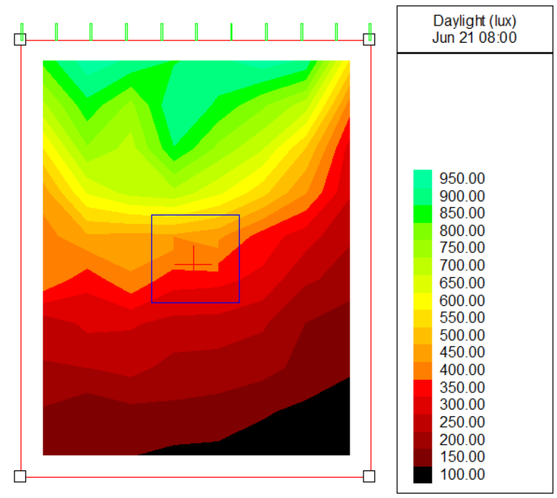
Illuminance Levels for June 21, North (W/S=0.5)

t=08:00

Base Case

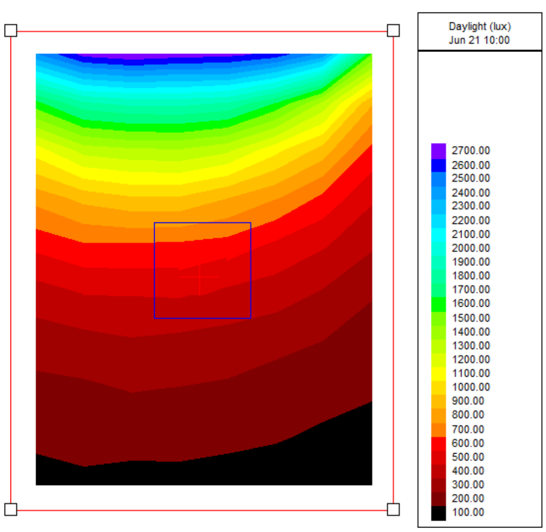


Optimal Daylight Angle α=0°

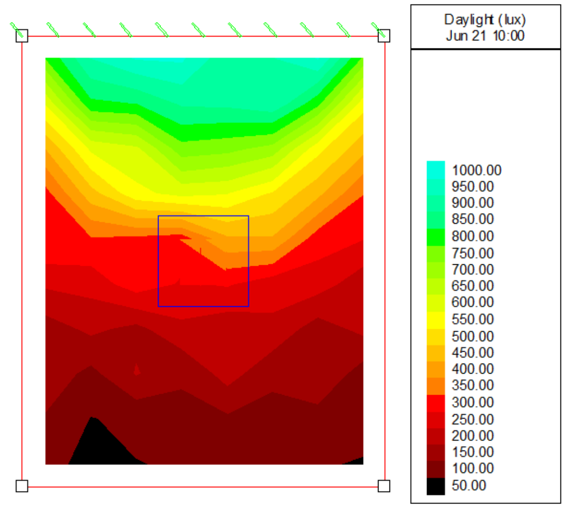


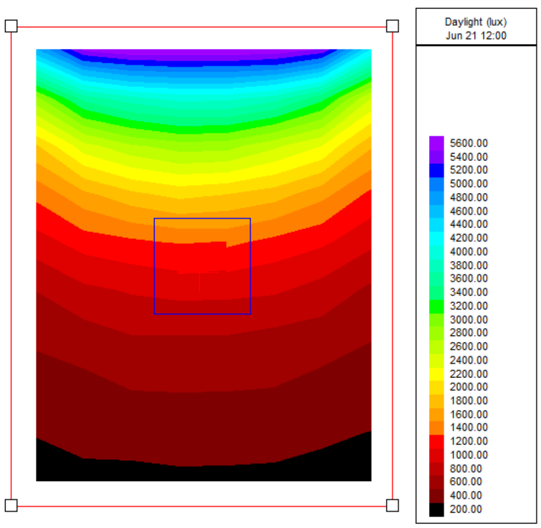
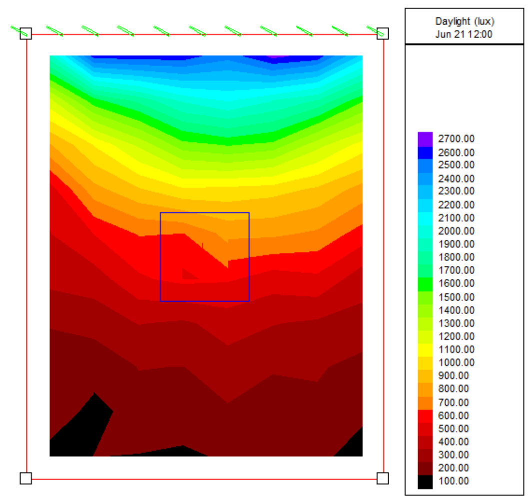
t=10:00

Base Case



Optimal Angle α=-40°



<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Optimal Angle α=-60°</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Optimal Angle α=40°</td></tr>
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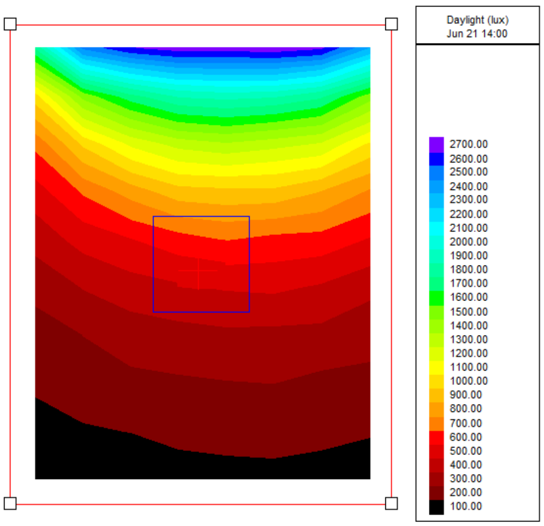
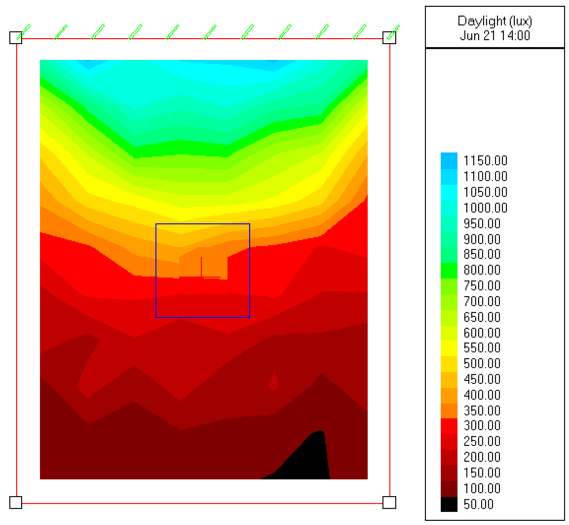
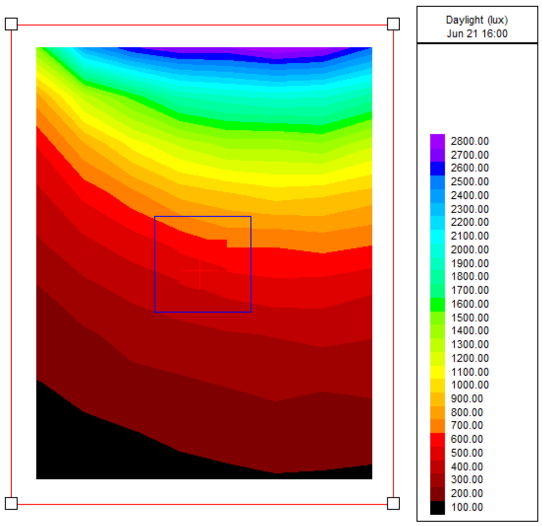
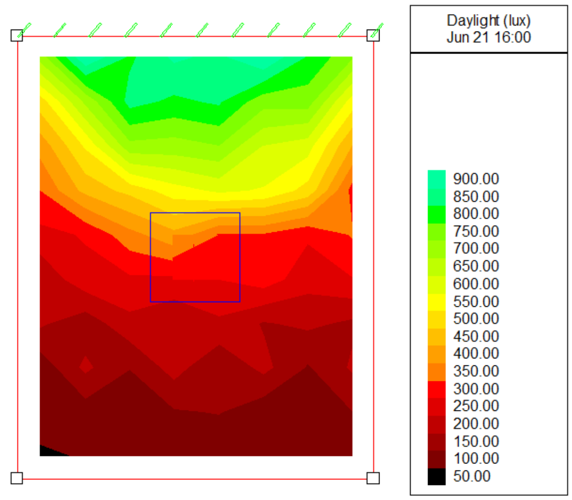
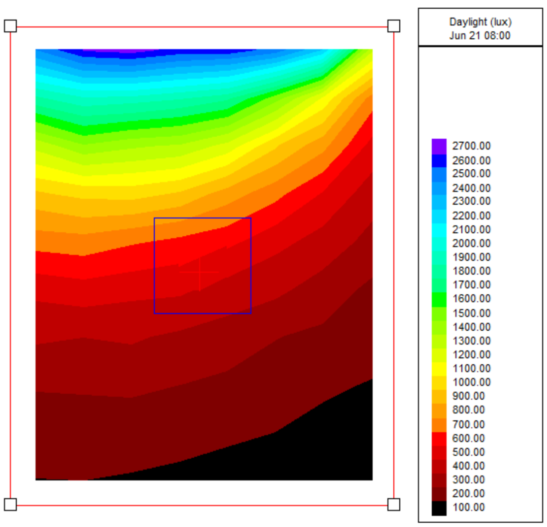
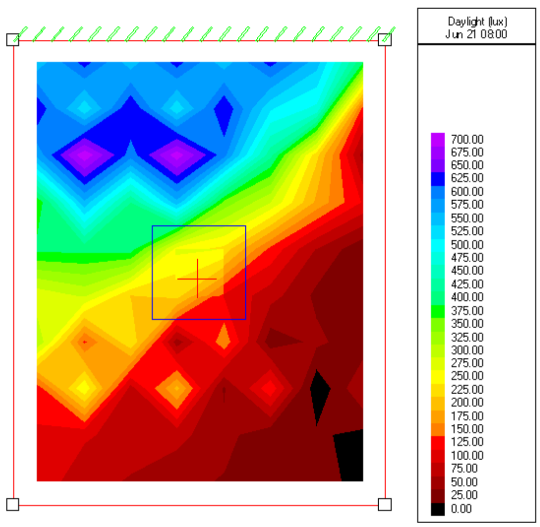
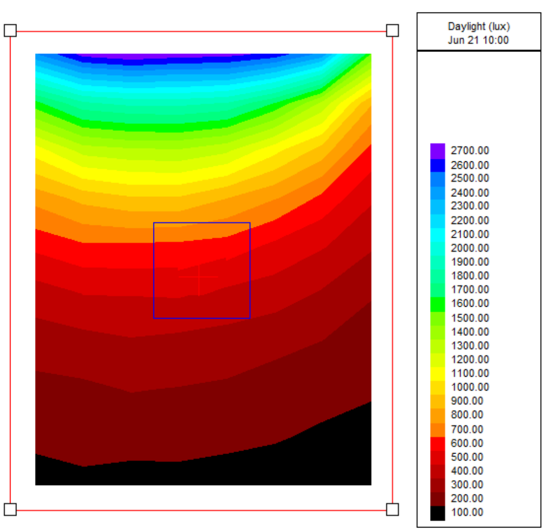
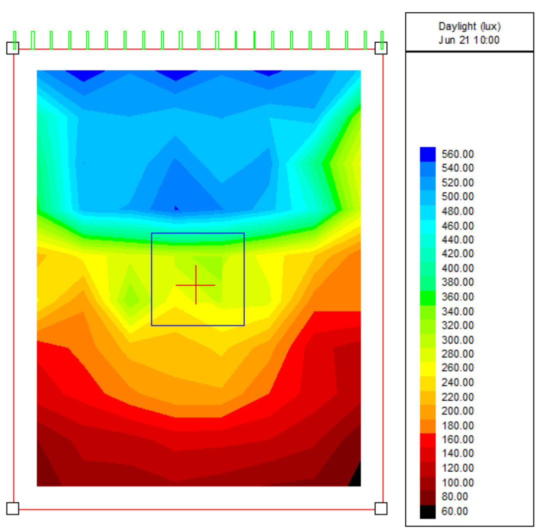
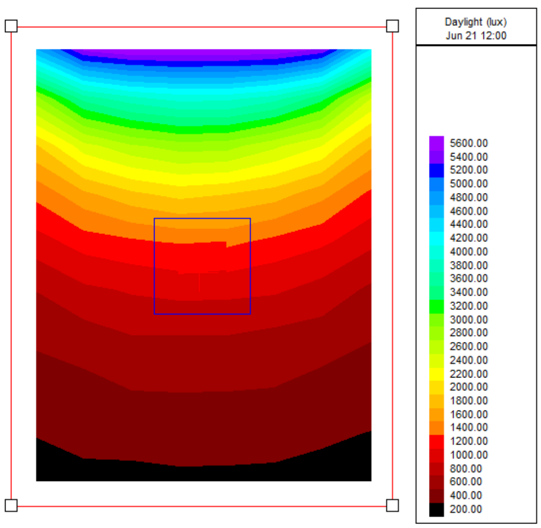
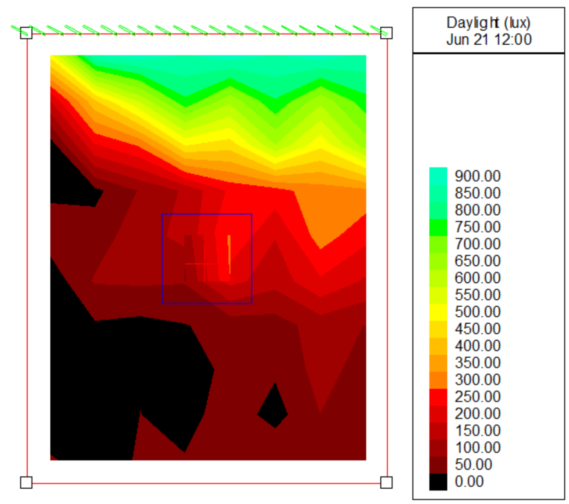
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=16:00</td><td>Base Case</td><td>Optimal Angle α=40°</td></tr>
</table>

	 Daylight (lux) Jun 21 16:00 2800.00 2700.00 2600.00 2500.00 2400.00 2300.00 2200.00 2100.00 2000.00 1900.00 1800.00 1700.00 1600.00 1500.00 1400.00 1300.00 1200.00 1100.00 1000.00 900.00 800.00 700.00 600.00 500.00 400.00 300.00 200.00 100.00	 Daylight (lux) Jun 21 16:00 900.00 850.00 800.00 750.00 700.00 650.00 600.00 550.00 500.00 450.00 400.00 350.00 300.00 250.00 200.00 150.00 100.00 50.00

Appendix B - Illuminance Levels for June 21, North (W/S=1.0)

Illuminance Levels for June 21, North (W/S=1.0)		
t=08:00	**Base Case**	**Optimal Daylight Angle α=40°**
		
t=10:00	**Base Case**	**Optimal Angle α=0°**
		

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Optimal Angle α=-60°</td></tr>
<tr><td></td><td>
</td><td>
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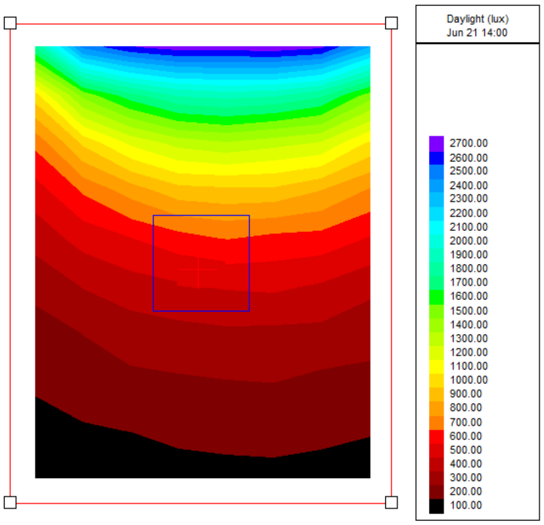
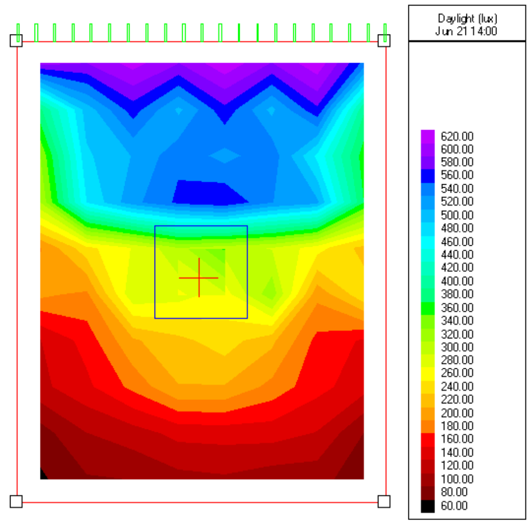
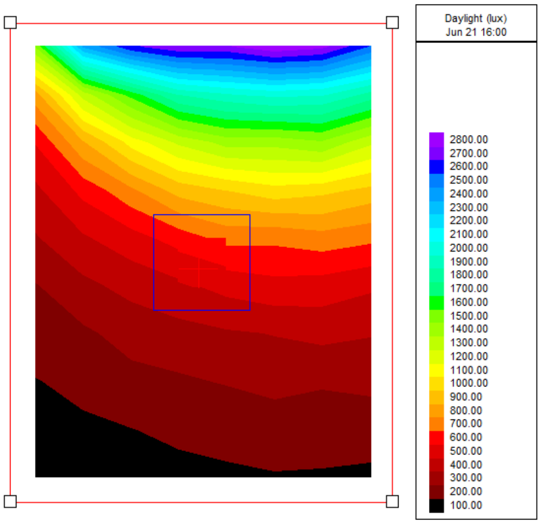
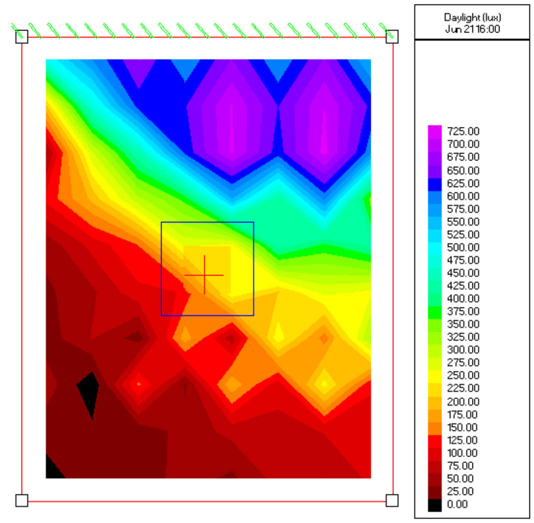
</table>



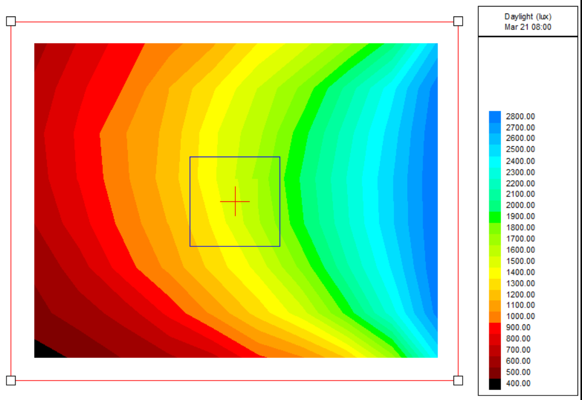
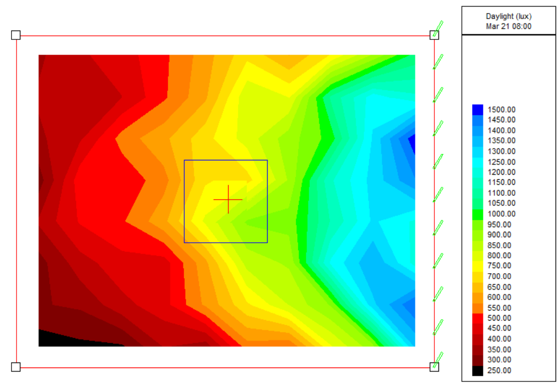


t=16:00	Base Case	Optimal Angle α=-40°





Appendix C - Illuminance Levels for March 21, East (W/S=0.5)

Illuminance Levels for March 21, East (W/S=0.5)		
t=08:00	**Base Case**	**Optimal Daylight Angle α=-60°**
		
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	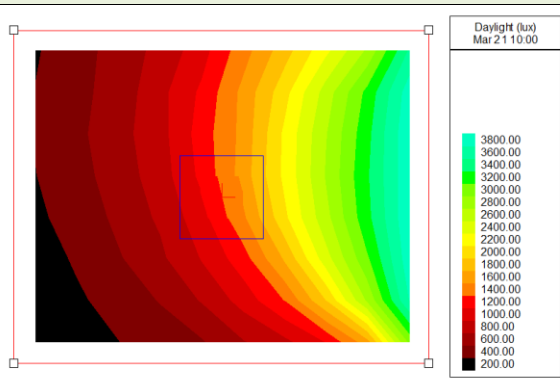	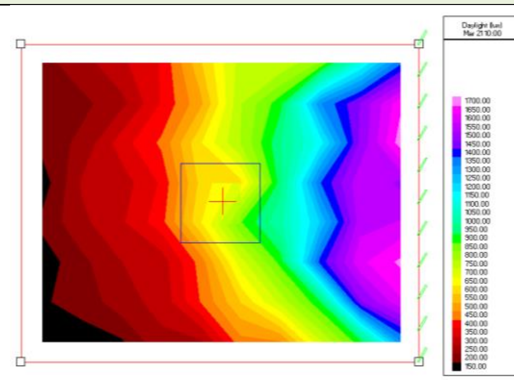

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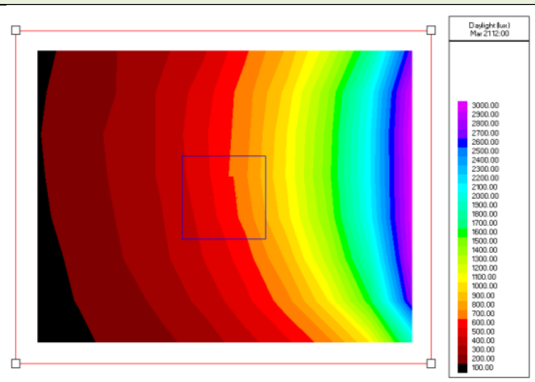
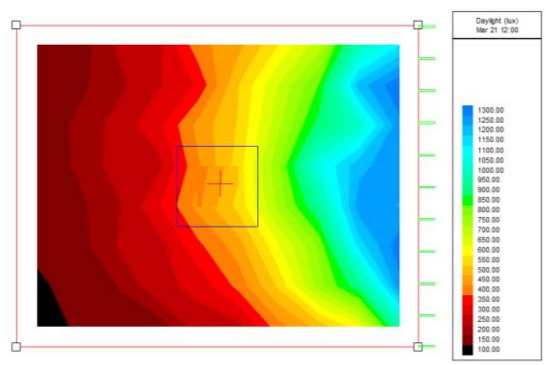
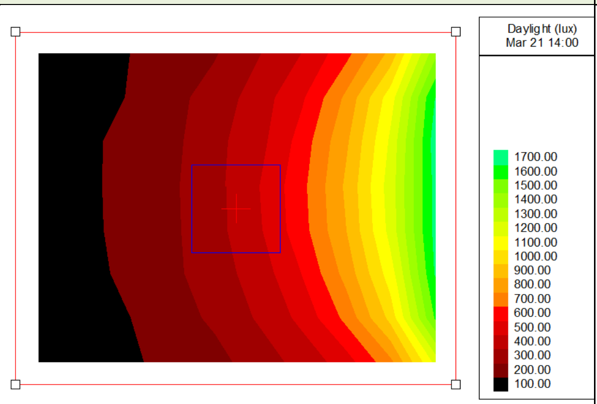
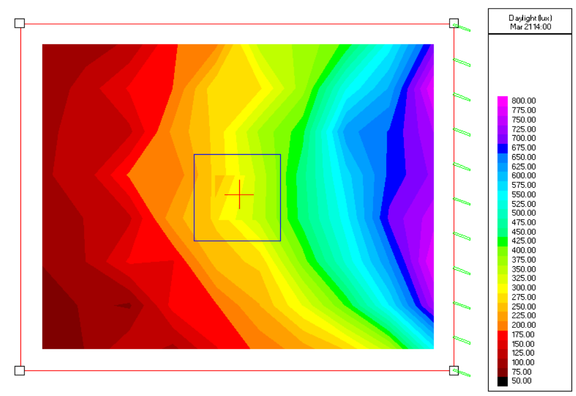
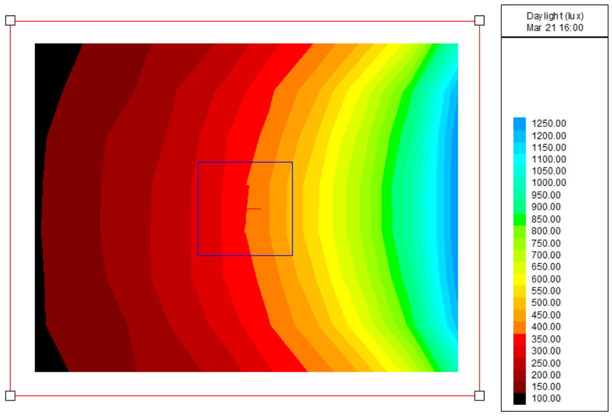
<tr><td></td><td></td><td></td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Optimal Angle α=20°</td></tr>
<tr><td></td><td>
</td><td></td></tr>
<tr><td>t=16:00</td><td colspan="2">Base Case (the optimal configuration for this time)</td></tr>
</table>


Daylight (lux)
Mar 21 16:00
1250.00
1200.00
1150.00
1100.00
1050.00
1000.00
950.00
900.00
850.00
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00

Appendix D - Illuminance Levels for June 21, East (W/S=0.5)

<table>
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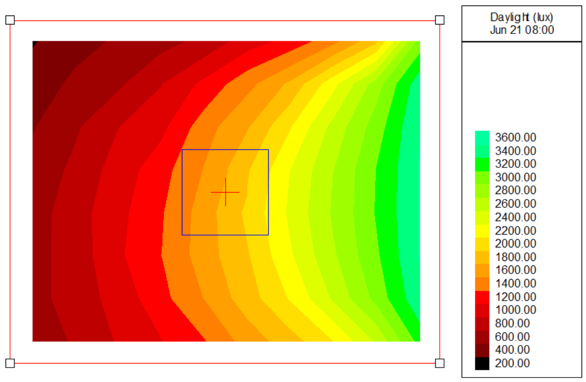
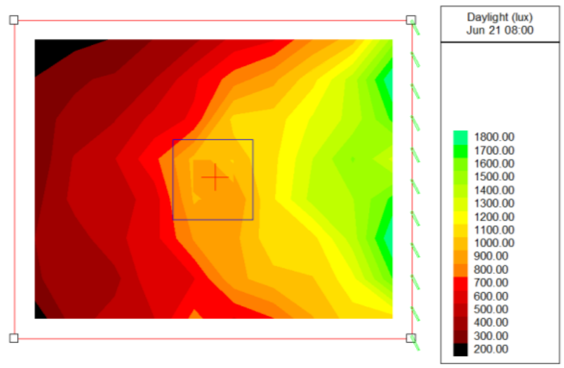
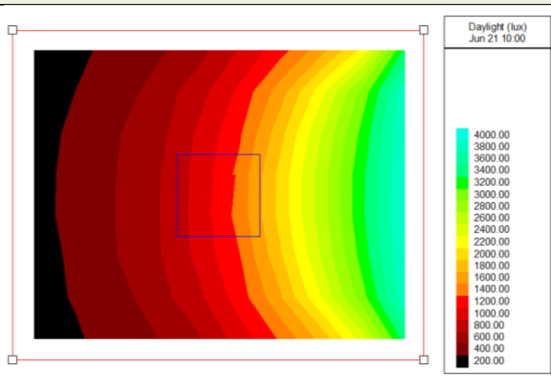
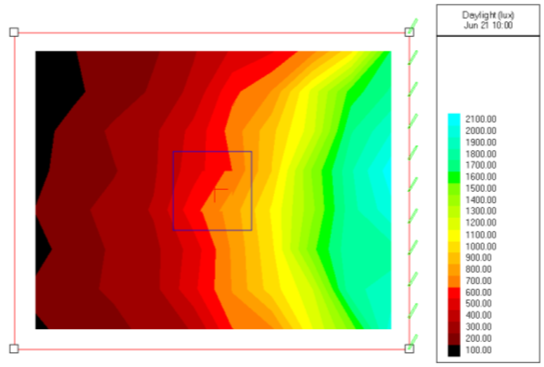
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=10:00</td><td>Base Case</td><td>Optimal Angle α=-60°</td></tr>
<tr><td></td><td>
</td><td>
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<tr><td>t=12:00</td><td>Base Case</td><td>Optimal Angle α=-60°</td></tr>
</table>

<table>
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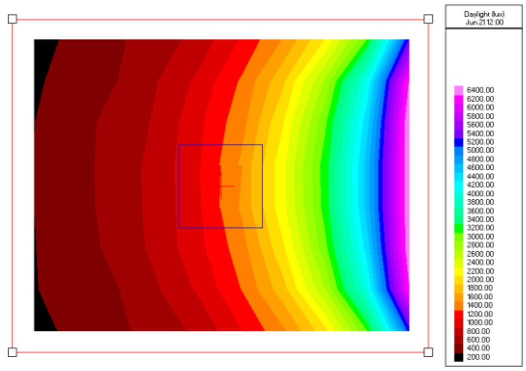
<td>
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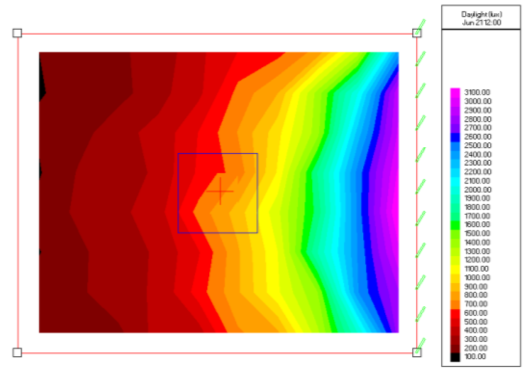
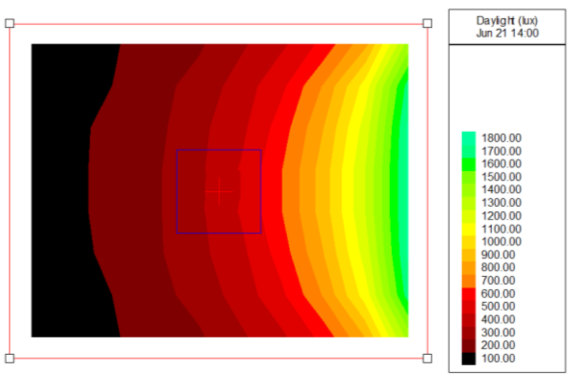
<td>
</td>
</tr>
<tr>
<td>t=14:00</td>
<td>Base Case</td>
<td>Optimal Angle α=0°</td>
</tr>
<tr>
<td></td>
<td>
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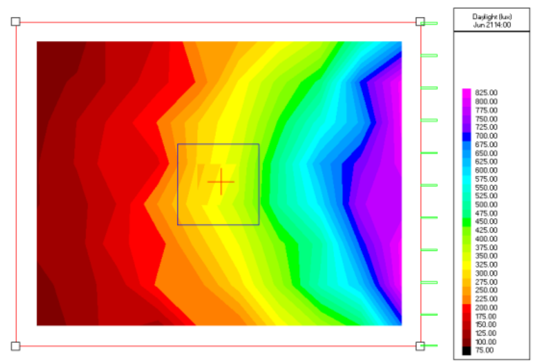
<td>
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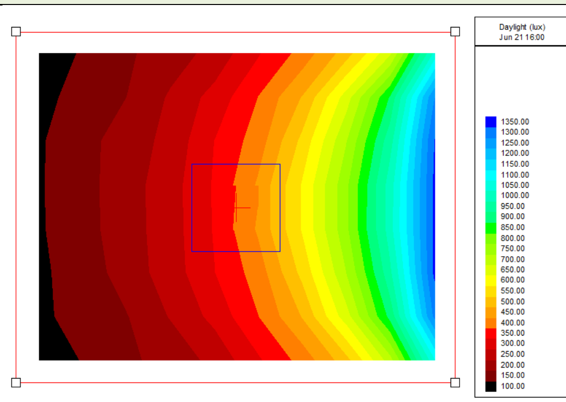
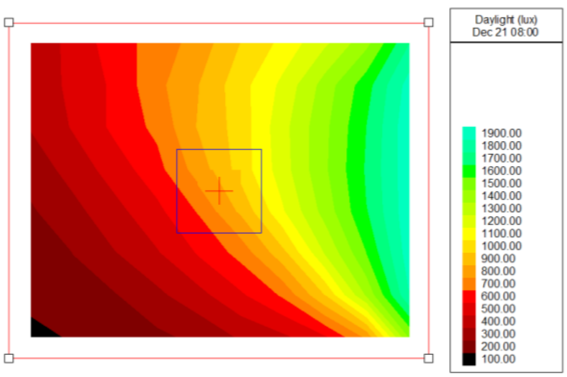
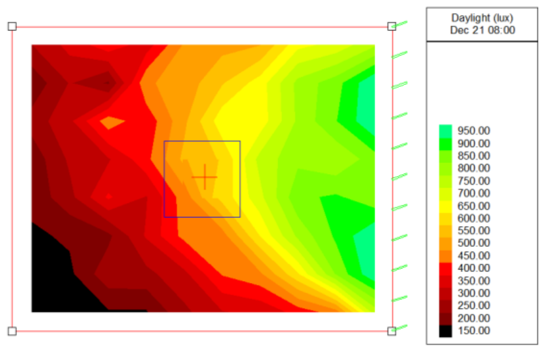
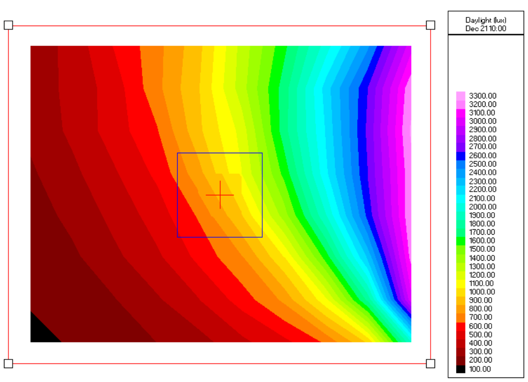
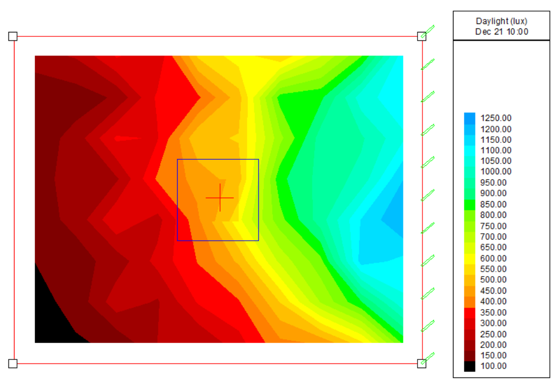
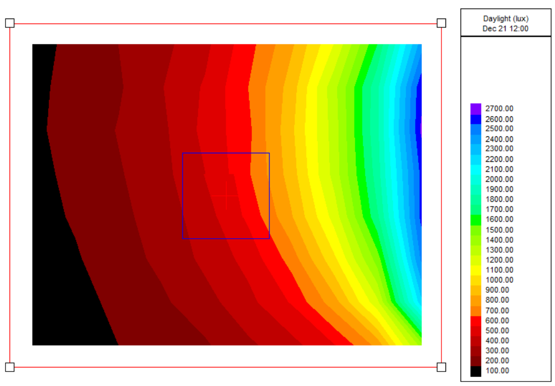
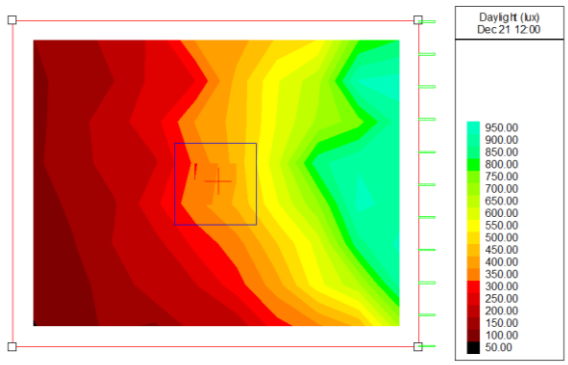
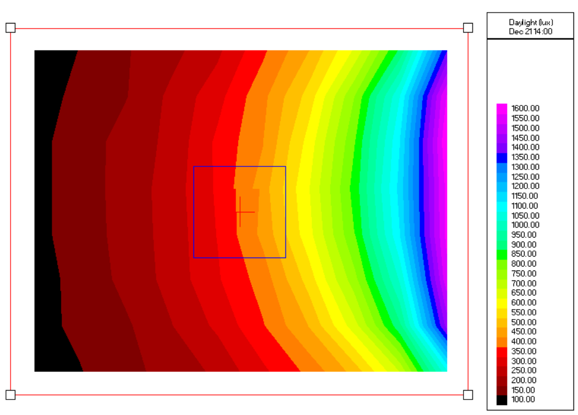
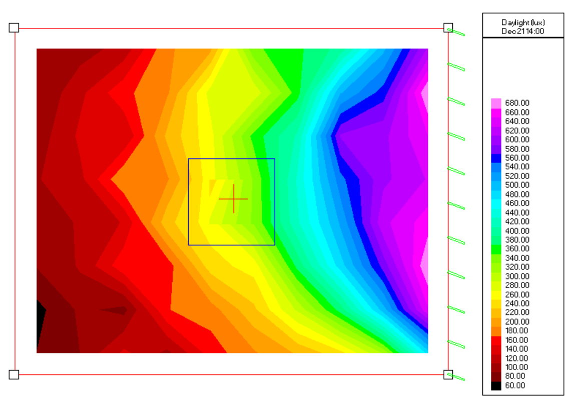
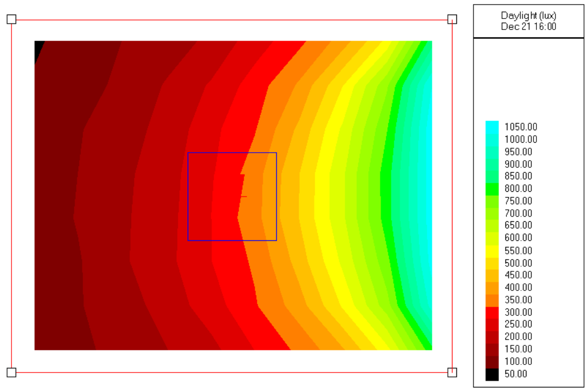
</tr>
<tr>
<td>t=16:00</td>
<td colspan="2">Base Case (the optimal configuration for this time)</td>
</tr>
<tr>
<td></td>
<td colspan="2">
</td>
</tr>
</table>

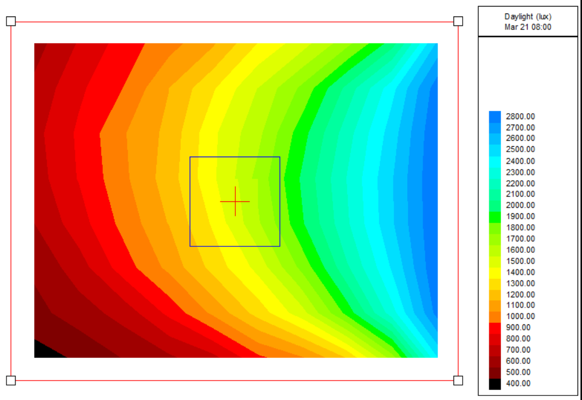
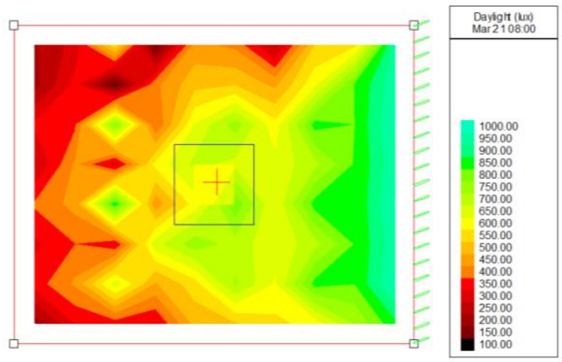
Appendix E - Illuminance Levels for December 21, East (W/S=0.5)

Illuminance Levels for December 21, East (W/S=0.5)		
t=08:00	**Base Case**	**Optimal Daylight Angle α=-20°**
		
t=10:00	**Base Case**	**Optimal Angle α=-40°**
		

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Optimal Angle α=0°</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Optimal Angle α=20°</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>t=16:00</td><td colspan="2">Base Case (the optimal configuration for this time)</td></tr>
</table>

	Daylight (lux) Dec 21 16:00 1050.00 1000.00 950.00 900.00 850.00 800.00 750.00 700.00 650.00 600.00 550.00 500.00 450.00 400.00 350.00 300.00 250.00 200.00 150.00 100.00 50.00

Appendix F - Illuminance Levels for March 21, East (W/S=1.0)

<table>
<tr><th colspan="3">Illuminance Levels for March 21, East (W/S=1.0)</th></tr>
<tr><td>t=08:00</td><td>Base Case</td><td>Optimal Daylight Angle α=-20°</td></tr>
<tr><td></td><td>
</td><td>
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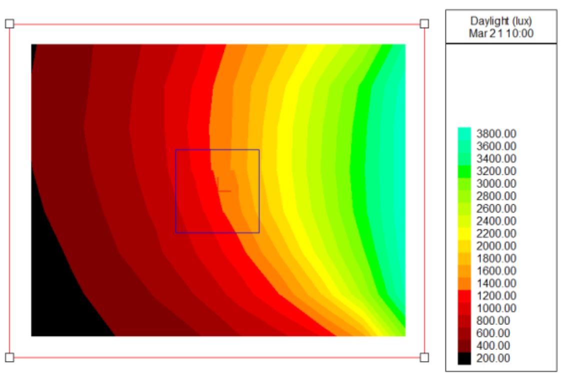
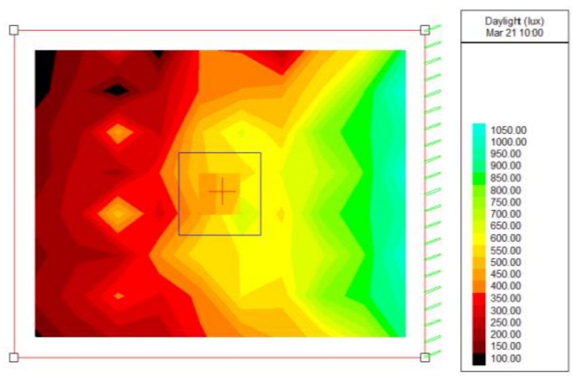
<tr><td></td><td>
</td><td>
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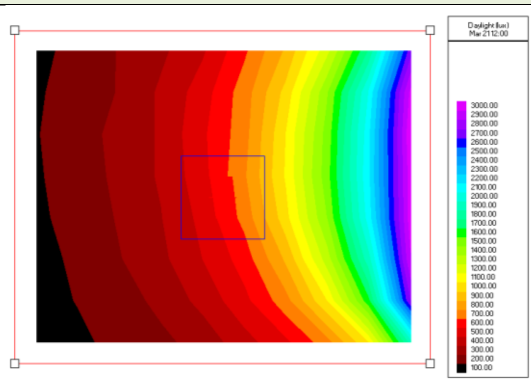
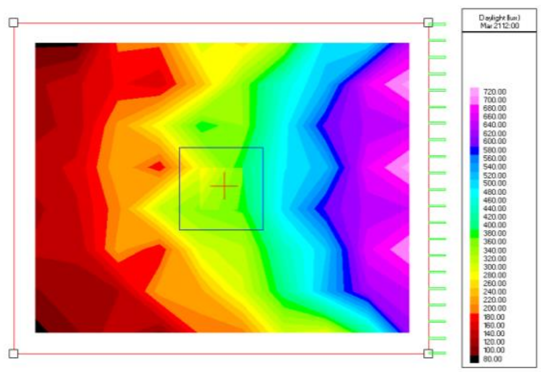
</table>

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Optimal Angle α=0°</td></tr>
<tr><td></td><td>
</td><td>
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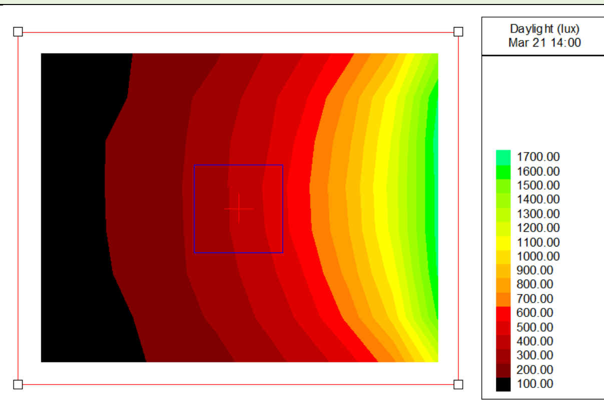
<tr><td></td><td colspan="2">
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<tr><td>t=16:00</td><td colspan="2">Base Case (the optimal configuration for this time)</td></tr>
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	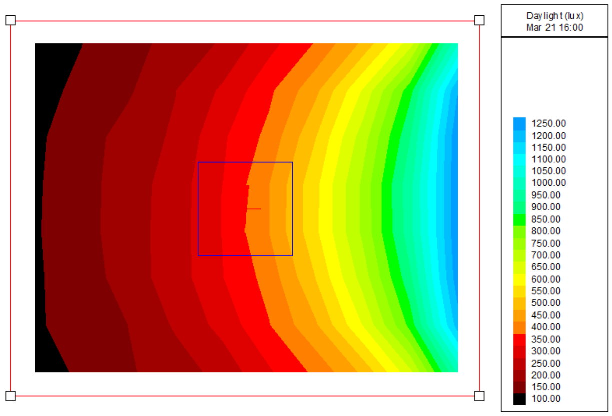 Daylight (lux) Mar 21 16:00 1250.00 1200.00 1150.00 1100.00 1050.00 1000.00 950.00 900.00 850.00 800.00 750.00 700.00 650.00 600.00 550.00 500.00 450.00 400.00 350.00 300.00 250.00 200.00 150.00 100.00

Appendix G - Illuminance Levels for June 21, East (W/S=1.0)

<table>
<tr><th colspan="3">Illuminance Levels for June 21, East (W/S=1.0)</th></tr>
<tr><td>t=08:00</td><td>Base Case</td><td>Optimal Daylight Angle α=20°</td></tr>
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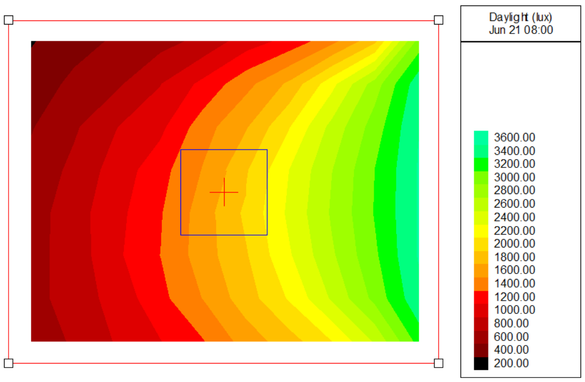

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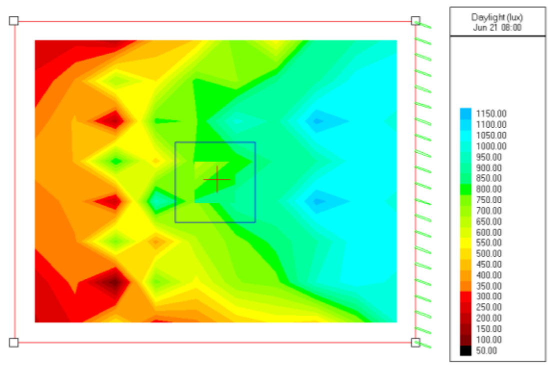

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<tr><td>t=10:00</td><td>Base Case</td><td>Optimal Angle α=-40°</td></tr>
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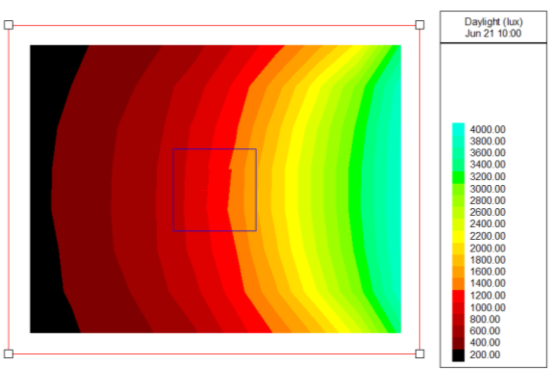

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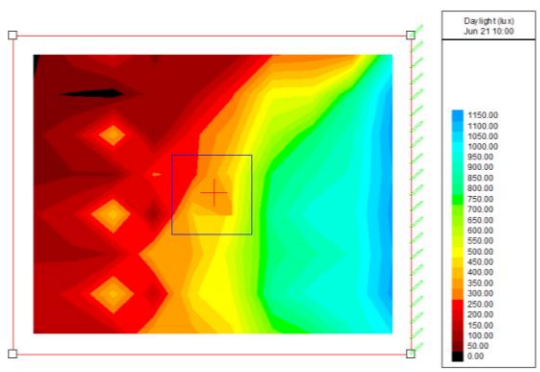

</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Optimal Angle α=-20°</td></tr>
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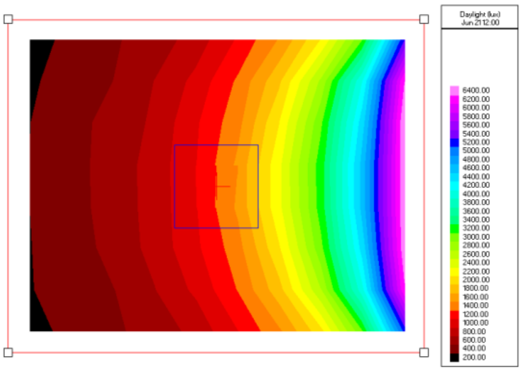
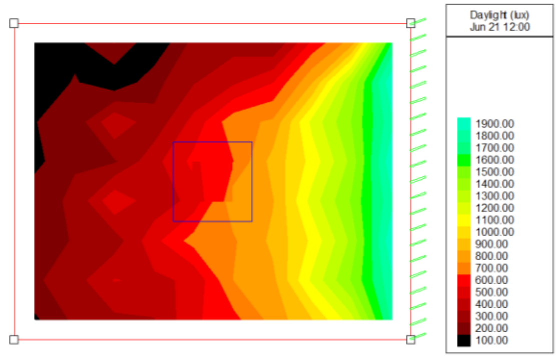
<tr><td></td><td>
</td><td>
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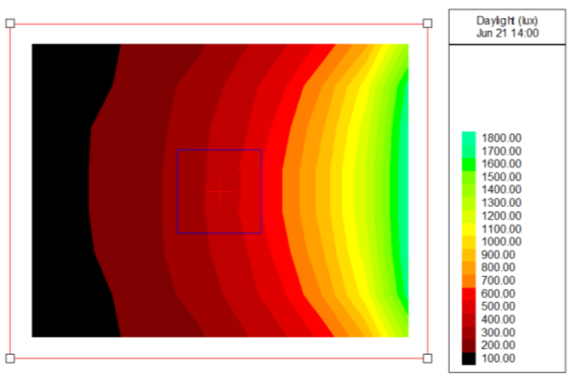
<tr><td>t=14:00</td><td colspan="2">Base Case (the optimal configuration for this time)</td></tr>
<tr><td></td><td colspan="2">
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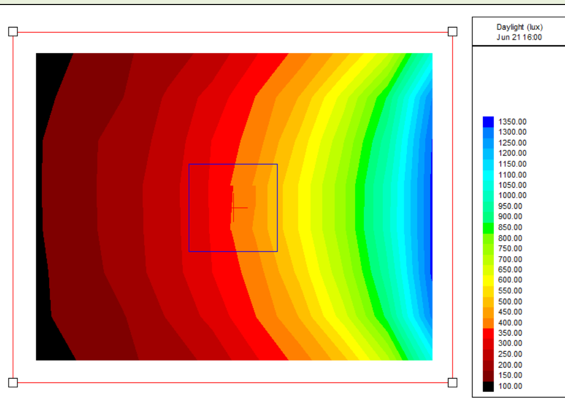
<tr><td>t=16:00</td><td colspan="2">Base Case (the optimal configuration for this time)</td></tr>
<tr><td></td><td colspan="2">
</td></tr>
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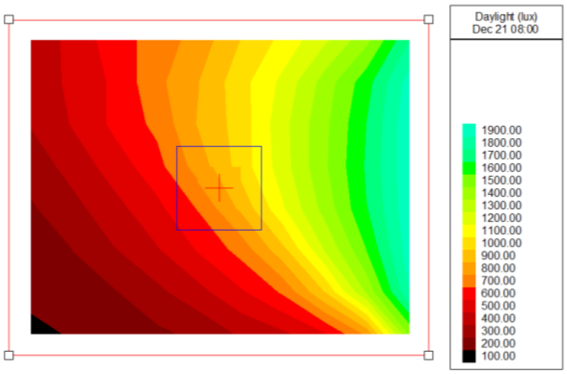
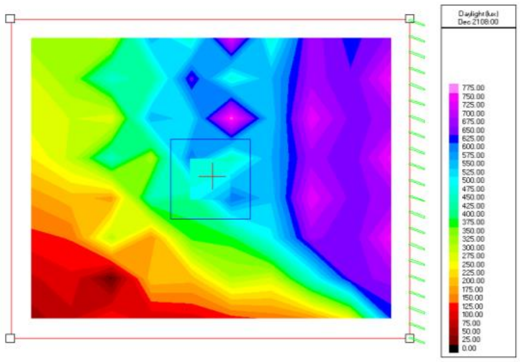
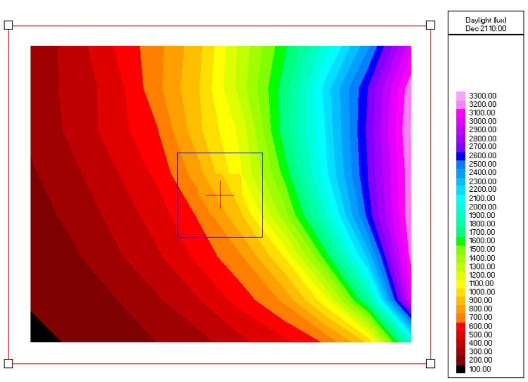
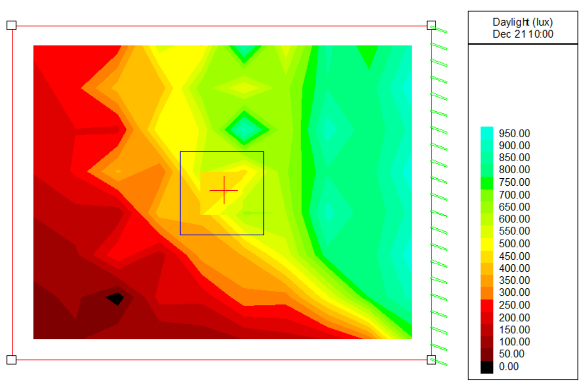
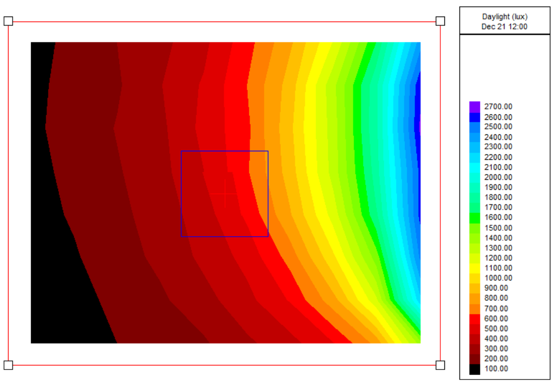
Appendix H - Illuminance Levels for December 21, East (W/S=1.0)

Illuminance Levels for December 21, East (W/S=1.0)		
t=08:00	**Base Case**	**Optimal Daylight Angle α=20°**
		
t=10:00	**Base Case**	**Optimal Angle α=20°**
		

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Optimal Angle α=20°</td></tr>
<tr><td></td><td>


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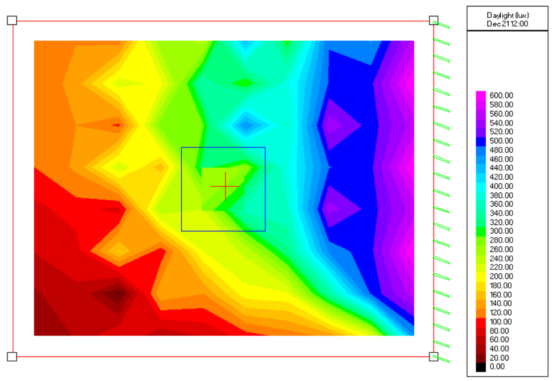
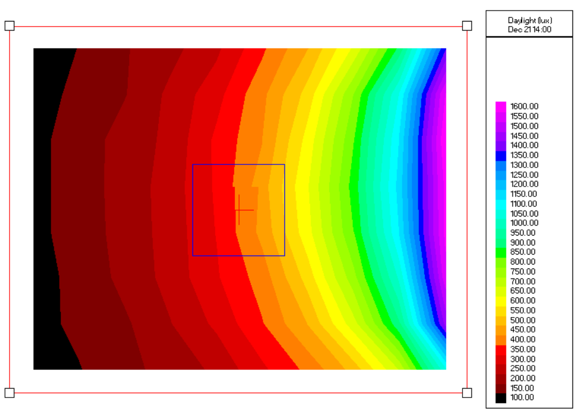
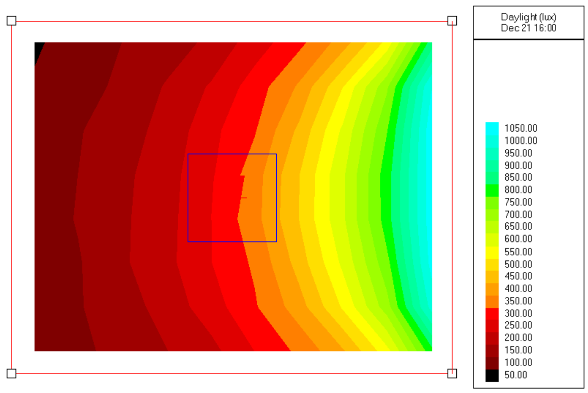


</td></tr>
<tr><td>t=14:00</td><td colspan="2">Base Case (the optimal configuration for this time)</td></tr>
<tr><td></td><td colspan="2">


</td></tr>
<tr><td>t=16:00</td><td colspan="2">Base Case (the optimal configuration for this time)</td></tr>
</table>


Daylight (lux)
Dec 21 16:00
1050.00
1000.00
950.00
900.00
850.00
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00

Appendix I - Illuminance Levels for March 21, West (W/S=0.5)

<table>
<tr><th colspan="3">Illuminance Levels for March 21, West (W/S=0.5)</th></tr>
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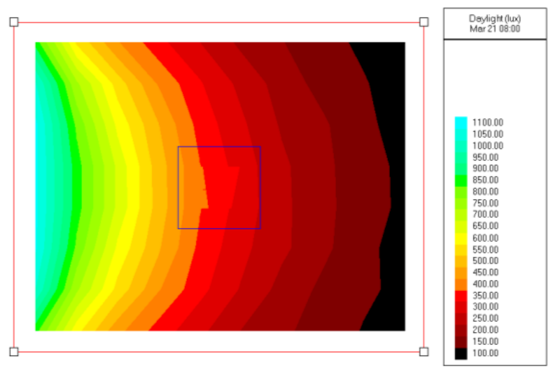
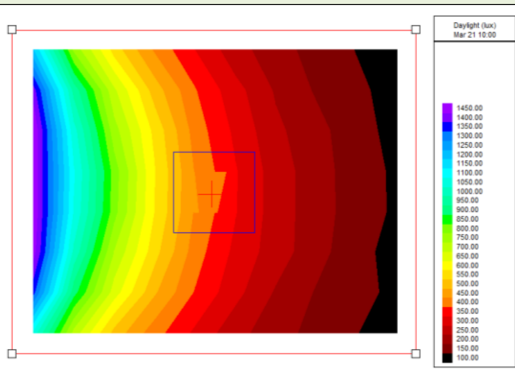
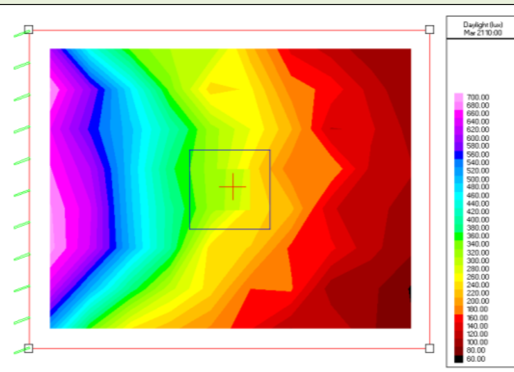
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>t=10:00</td><td>Base Case</td><td>Optimal Angle α=20°</td></tr>
<tr><td></td><td>
</td><td>
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<tr><td>t=12:00</td><td>Base Case</td><td>Optimal Angle α=-20°</td></tr>
</table>

<table>
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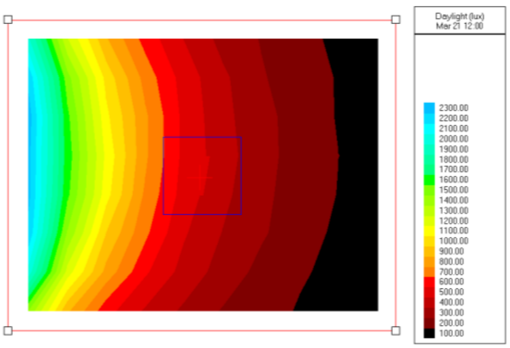
<td>
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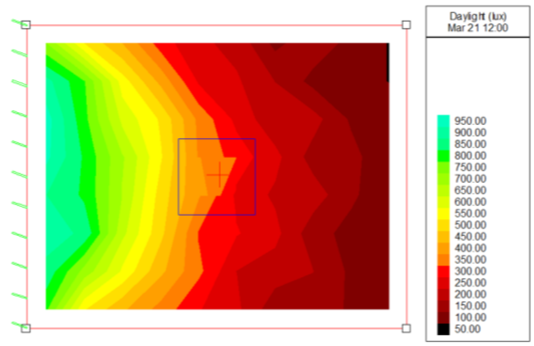
<td>
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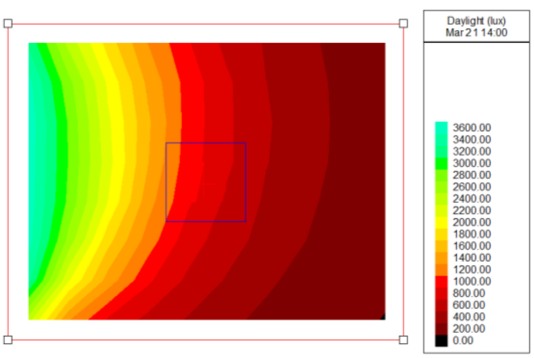
</tr>
<tr>
<td>t=14:00</td>
<td>Base Case</td>
<td>Optimal Angle α=-60°</td>
</tr>
<tr>
<td></td>
<td>
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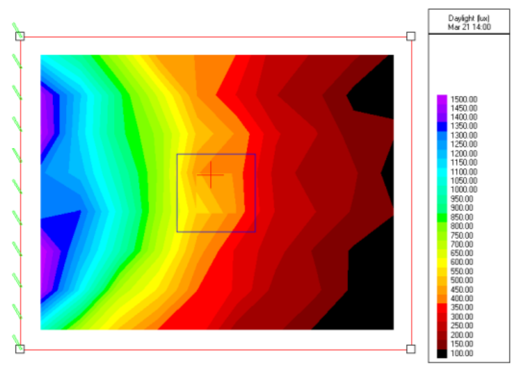
<td>
</td>
</tr>
<tr>
<td>t=16:00</td>
<td>Base Case</td>
<td>Optimal Angle α=-60°</td>
</tr>
<tr>
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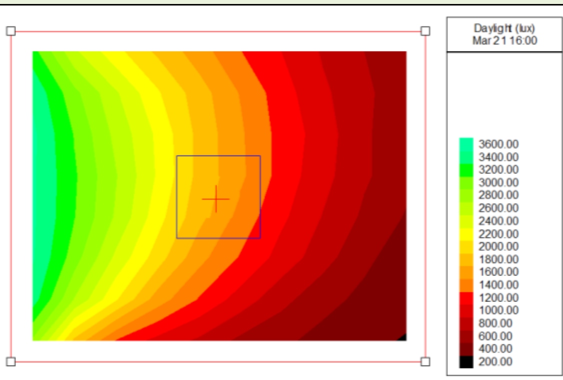
<td>
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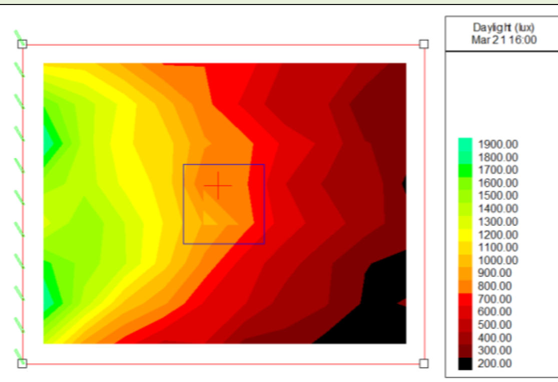
<td>
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Appendix J - Illuminance Levels for June 21, West (W/S=0.5)

<table>
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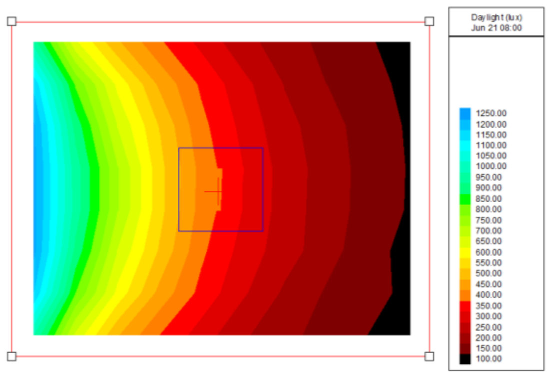

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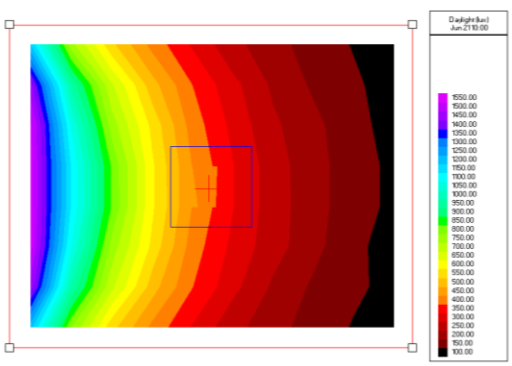

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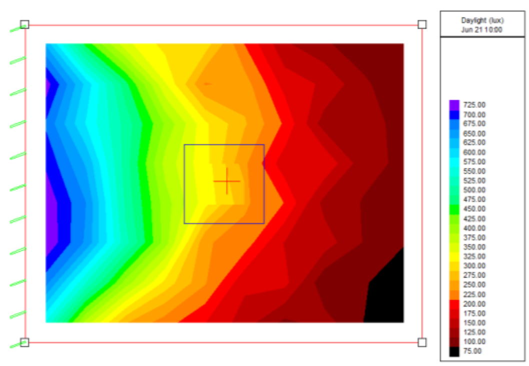

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<tr><td>t=12:00</td><td>Base Case</td><td>Optimal Angle α=60°</td></tr>
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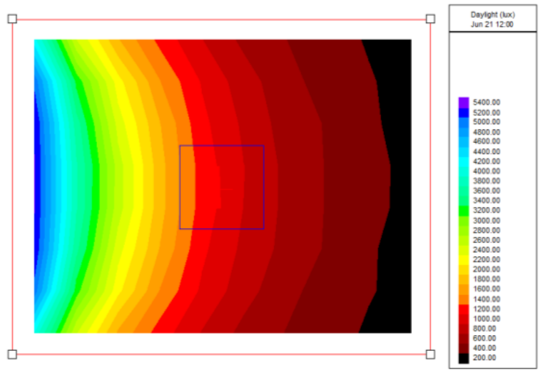
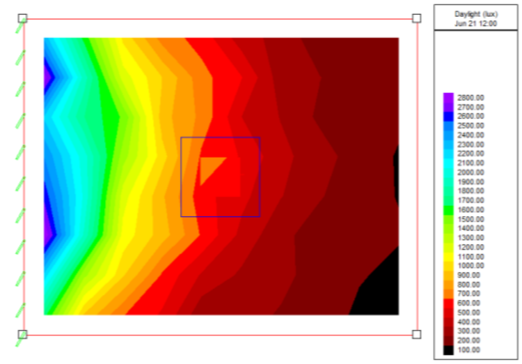
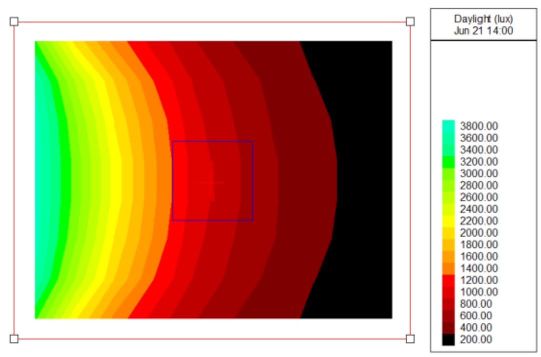
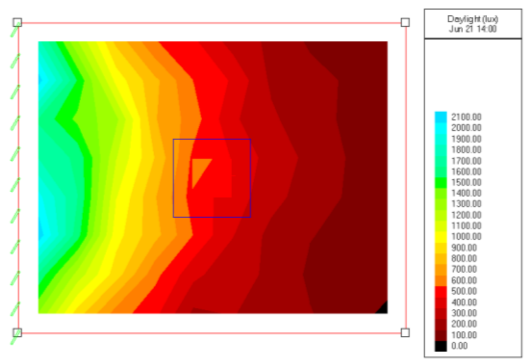
<table>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Optimal Angle α=60°</td></tr>
<tr><td></td><td>
</td><td>
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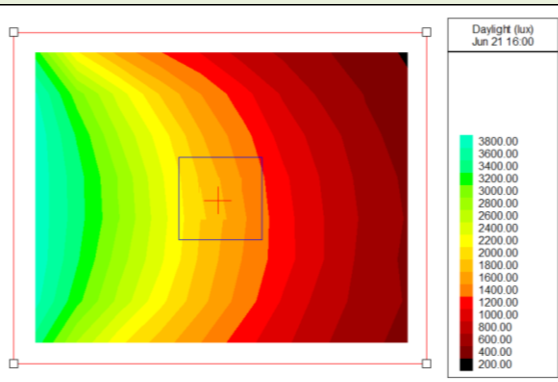
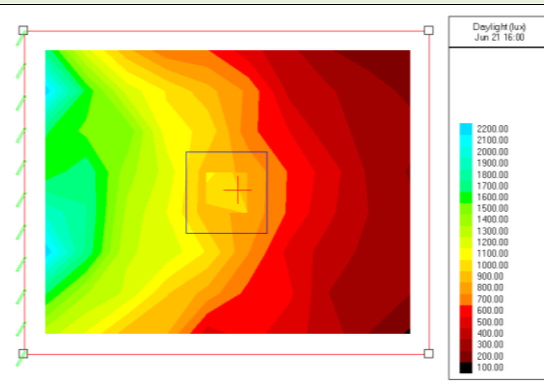
<tr><td></td><td>
</td><td>
</td></tr>
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Appendix K - Illuminance Levels for December 21, West (W/S=0.5)

<table>
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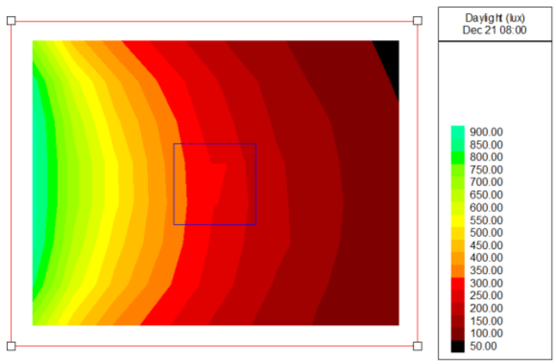
<tr><td></td><td colspan="2">
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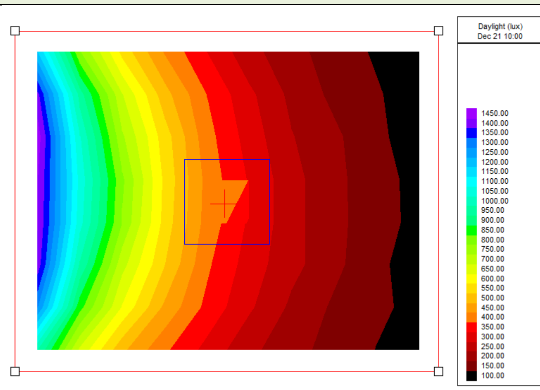
<tr><td></td><td colspan="2">
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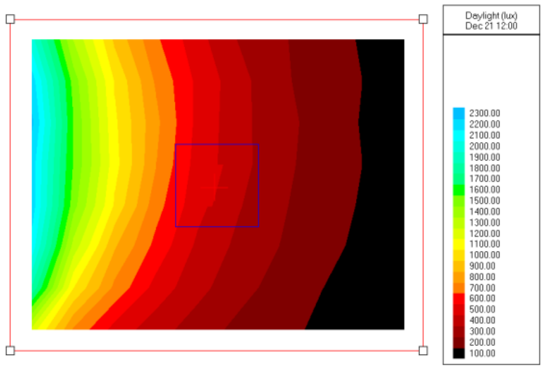
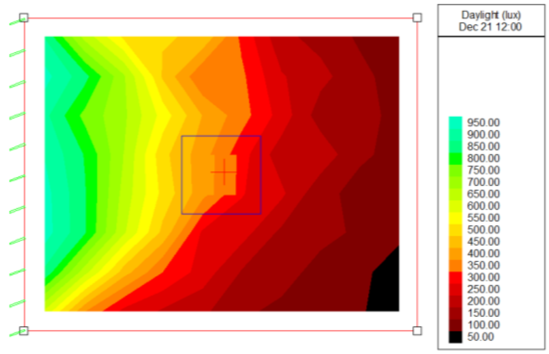
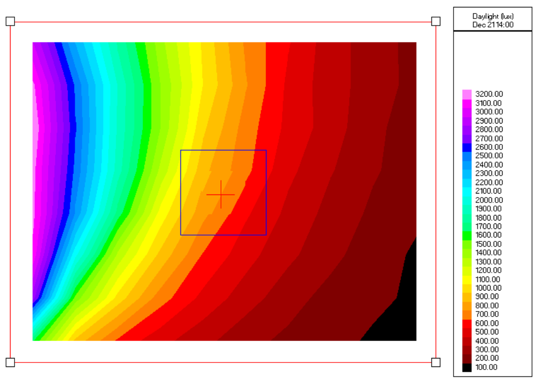
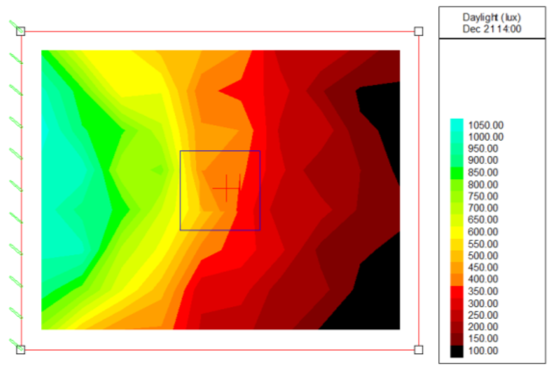
<tr><td></td><td></td><td></td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Optimal Angle α=-40°</td></tr>
<tr><td></td><td></td><td></td></tr>
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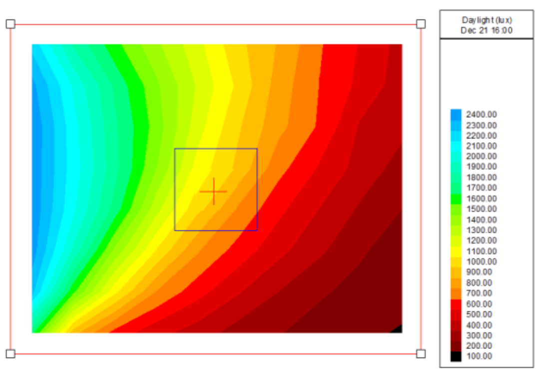
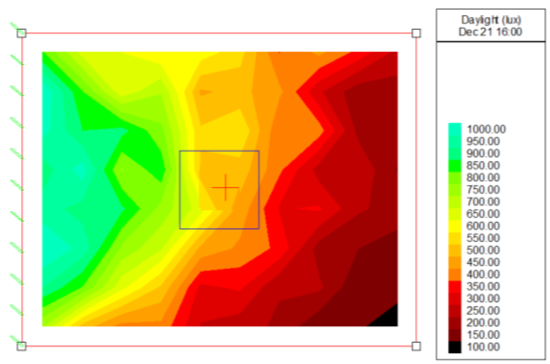
<tr><td></td><td></td><td></td></tr>
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Appendix L - Illuminance Levels for March 21, West (W/S=1.0)

<table>
<tr><th colspan="3">Illuminance Levels for March 21, West (W/S=1.0)</th></tr>
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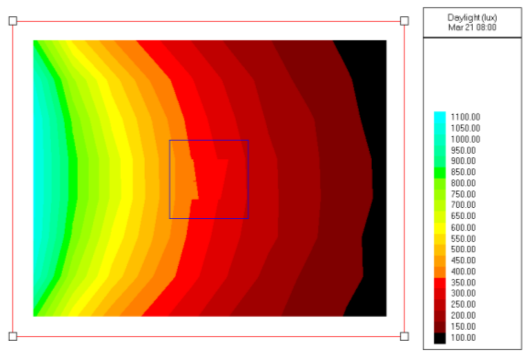
<tr><td></td><td colspan="2">
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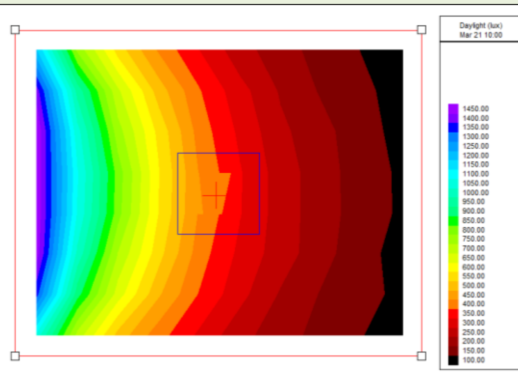
<tr><td></td><td colspan="2">
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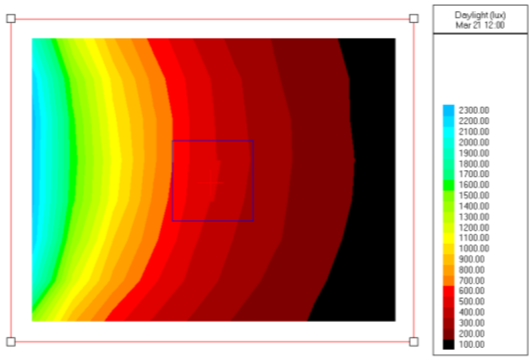
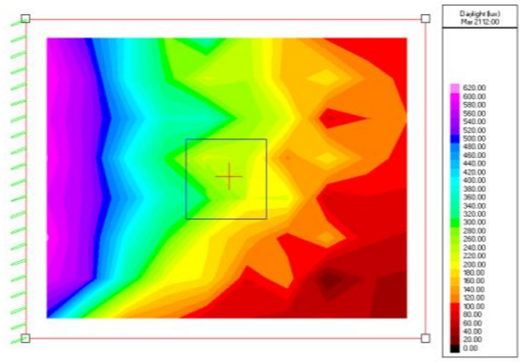
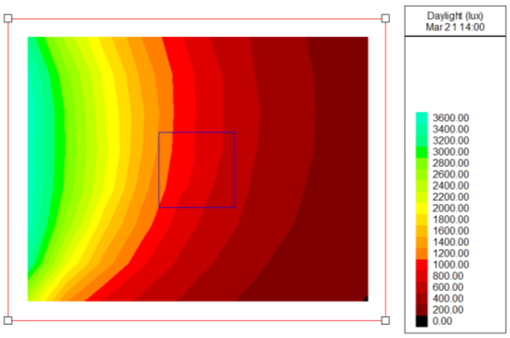
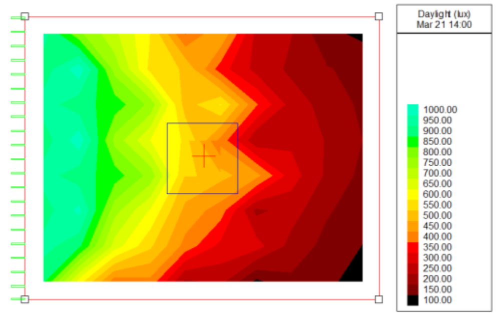
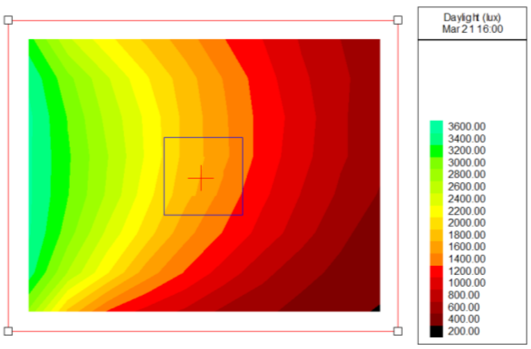
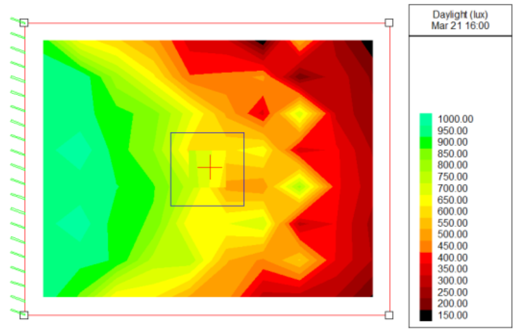
<tr><td></td><td></td><td></td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Optimal Angle α=0°</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>t=16:00</td><td>Base Case</td><td>Optimal Angle α=-20°</td></tr>
<tr><td></td><td></td><td></td></tr>
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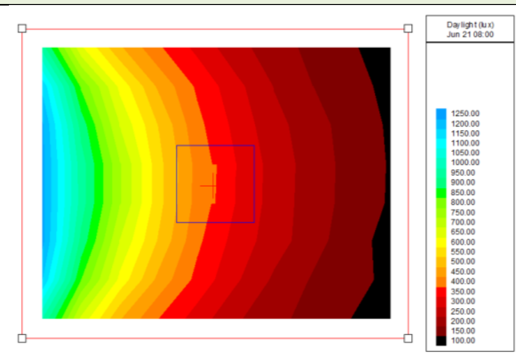
Appendix M - Illuminance Levels for June 21, West (W/S=1.0)

<table>
<tr><th colspan="3">Illuminance Levels for June 21, West (W/S=1.0)</th></tr>
<tr><td>t=08:00</td><td colspan="2">Base Case (the optimal configuration for this time)</td></tr>
<tr><td></td><td colspan="2">
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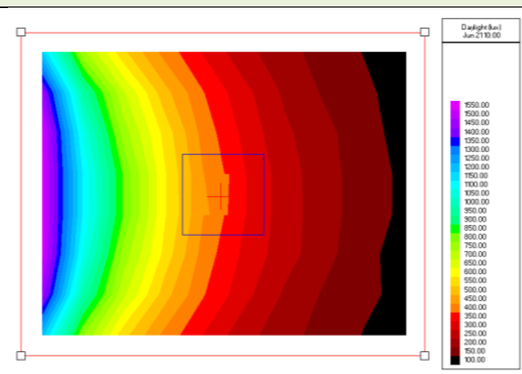
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>t=12:00</td><td>Base Case</td><td>Optimal Angle α=-40°</td></tr>
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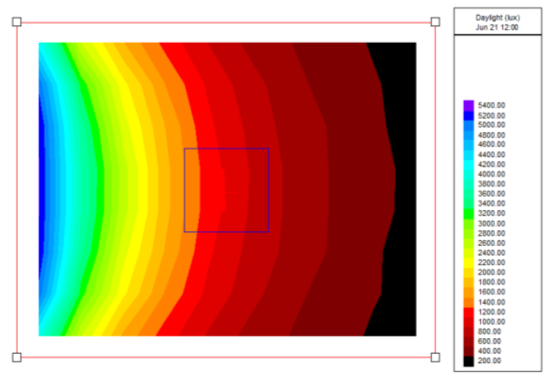
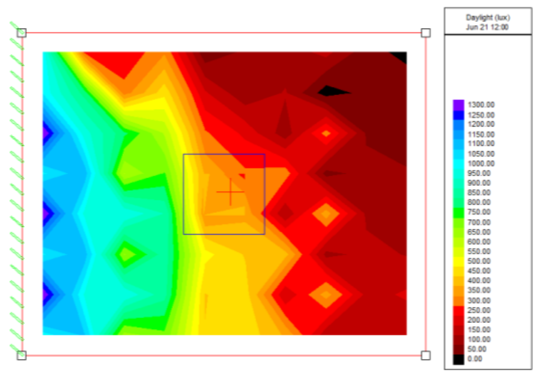
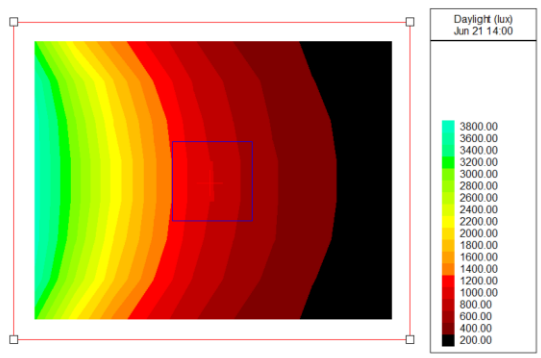
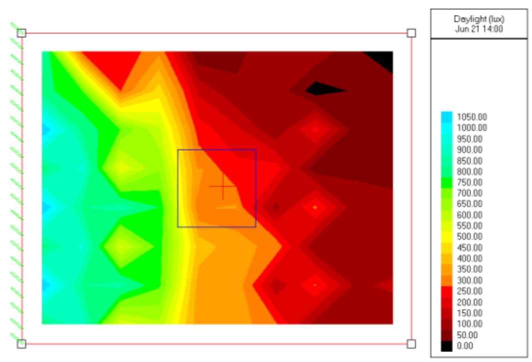


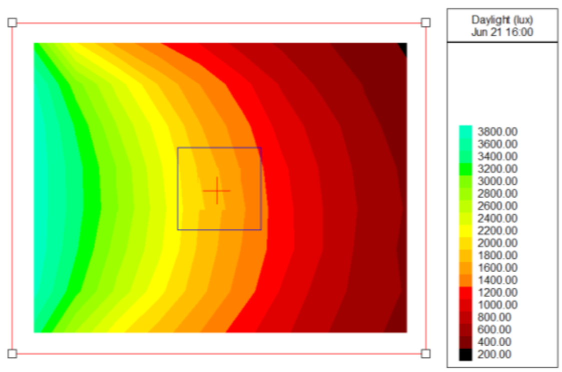


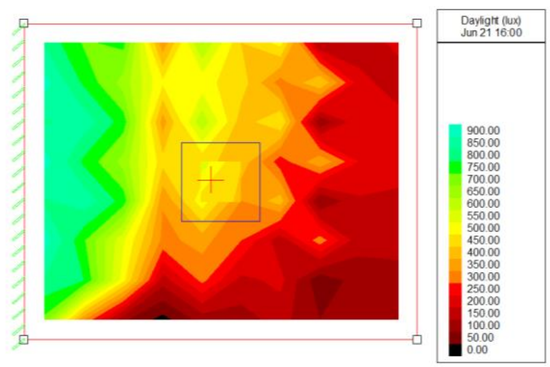
t=14:00 | **Base Case** | **Optimal Angle α=-40°**



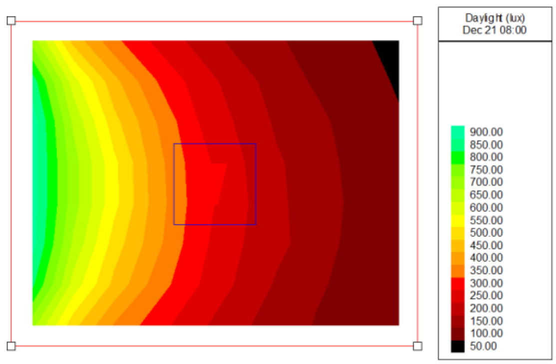
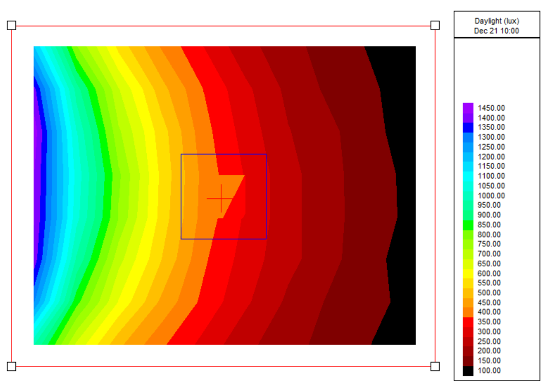


t=16:00 | **Base Case** | **Optimal Angle α=40°**





Appendix N - Illuminance Levels for December 21, West (W/S=1.0)

Illuminance Levels for December 21, West (W/S=0.5)	
t=08:00	**Base Case (the optimal configuration for this time)**
	
t=10:00	**Base Case (the optimal configuration for this time)**
	
t=12:00	**Base Case (the optimal configuration for this time)**

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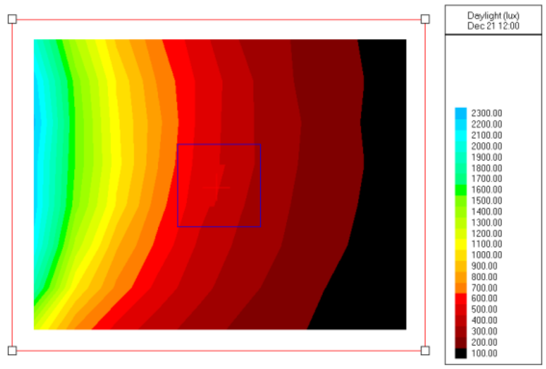
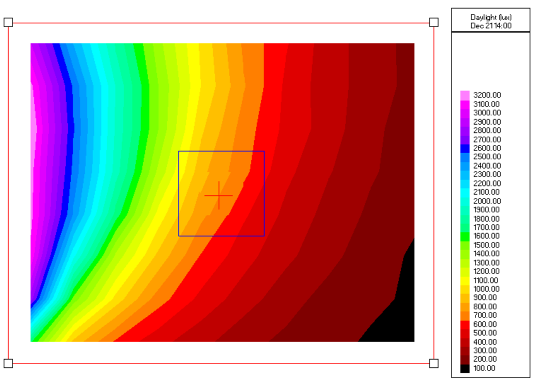
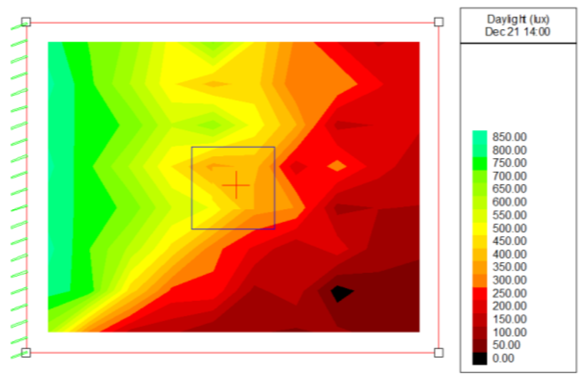
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>t=14:00</td><td>Base Case</td><td>Optimal Angle α=20°</td></tr>
<tr><td></td><td>
</td><td>
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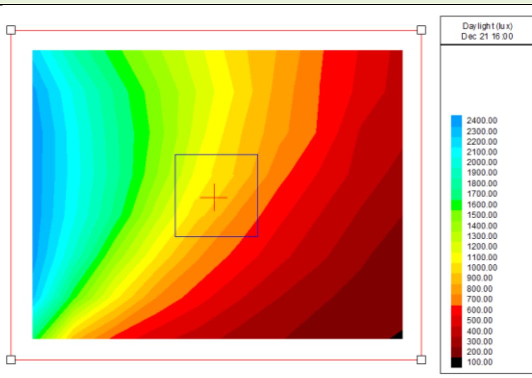
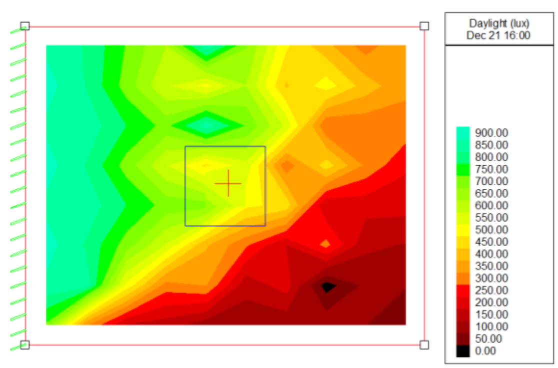
<tr><td>t=16:00</td><td>Base Case</td><td>Optimal Angle α=20°</td></tr>
<tr><td></td><td>
</td><td>
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