A PROPOSAL FOR A RETROFITTING MODEL FOR EDUCATIONAL BUILDINGS IN TERMS OF ENERGY EFFICIENT LIGHTING CRITERIA

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ABSTRACT

A PROPOSAL FOR RETROFITTING MODEL FOR EDUCATIONAL BUILDINGS IN TERMS OF ENERGY EFFICIENT LIGHTING CRITERIA

It has been crucial to benefit from daylighting and artificial lighting together as an integrated system in educational buildings to use energy efficiently during the day, since a well-designed lighting increases learning and working performance. The aim was to find the optimum values for daylighting to achieve visual comfort conditions and artificial lighting design parameters for minimum energy consumption for an educational building. For this purpose, six rooms having different orientations, sizes, function and façade configuration were selected from case building, Department of Mechanical Engineering in İzmir Institute of Technology, to evaluate and propose energy efficient lighting design by retrofitting scenarios. The main concern was that none of the rooms had its own proper solution for façade design according to the recommendations for daylighting and energy efficient usage. Input paramaters such as fenestration, light shelves, shading devices, surface colours, lighting fixture types and layouts were studied in scenarios by using daylighting simulation tool, DIALux.

In real life application, it is possible to benefit from daylighting effectively and to minimize energy consumption by using intelligent sensors connected to the shading automation systems. This would be the best solution for visual comfort and energy efficiency in buildings. Thus, this study focused on optimum values of the input parameters which would provide such foreknowledge for such systems.

In order to obtain energy efficient lighting performance in an educational building, it is important to evaluate the results for retrofitting that will be a guide for designers, architects and researchers.

ÖZET

EĞİTİM BİNALARI İÇİN ENERJİ ETKİN AYDINLATMA ÖLÇÜTLERİ AÇISINDAN BİR İYİLEŞTİRME MODELİ ÖNERİSİ

Öğrenme ve çalışma performansını arttırması ve tüm gün kullanılan mekanlar olması nedeniyle, eğitim yapılarında enerjinin etkin kullanımı açısından doğal aydınlatmanın yapay aydınlatma ile birlikte verimli bir şekilde değerlendirilmesi önemlidir. Bu çalışmanın amacı, seçilen mekanlar için görsel konfor koşullarına uygun olarak optimum günışığı değerleri ile minimum enerji tüketimi için yapay aydınlatma tasarım parametrelerini araştırmaktır. Bu amaca yönelik olarak, bir eğitim yapısı olan İzmir Yüksek Teknoloji Enstitüsü Makine Mühendisliği Binası'nda farklı yönlere bakan, farklı büyüklük, işlev ve cephe tasarımına sahip altı adet mekan seçilmiş, değerlendirme yapılarak iyileştirme önerilerinde bulunulmuştur. Seçilen bu mekanların ortak sorunu, günışığı doğal aydınlatma ve enerji etkin kullanım açısından sahip oldukları özelliklere göre uygun cephe tasarımlarına sahip olmamalarıdır. İyileştirme çalışmalarında; pencere cam geçirgenliği, çerçeve katsayısı, ışık rafı, gölgeleme elemanları, yüzey renkleri, armatür tipi ve düzeni gibi çeşitli parametreler üzerinden oluşturulan senaryolarda DIALux programı kullanılarak hesaplamalar yapılmıştır.

Uygulamada, gölgeleme otomasyon sistemine bağlı olarak çalışan akıllı sensörler yardımıyla, günışığından optimum düzeyde faydalanma ve minimum enerji tüketimi sağlanabilir. Bu da görsel konfor ve binalarda enerji etkinliği için iyi bir çözüm olacaktır. Benzer sistemler için ön bilgi oluşturacak girdi parametrelerinin optimum değerlerinin belirlenmesi çalışmanın odak noktasıdır.

Enerji etkin aydınlatma performansına sahip bir eğitim yapısı için yapılacak iyileştirmelere yönelik farklı senaryolara göre elde edilen sonuçların değerlendirilmesi tasarımcılar, mimarlar ve araştırmacılar için bir rehber niteliğinde olacaktır.

To my loved family,

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LIST OF ABBREVIATIONS

a : Annual

BC : Base Case

BIM : Building Information Modelling

CAD : Computer Aided Design

cd : Candela

CE : Conformité Européenne

CFD : Computational Fluid Dynamics

CFL : Compact Fluorescent Lamp

CIBSE : Chartered Institution of Building Services Engineers

CIE : Commission Internationale de l’Eclairage
International Commission on Illumination

d : Day

DOE : The US Department of Energy

dPOE : Dynamic Prismatic Optical Element

E : Illuminance [lx]

E_M : Measured Daylighting Illuminance

E_S : Simulated Daylighting Illuminance

FC : Fenestration Color

FL : Fluorescent

FT : Fenestration Transmittance

gmt : Greenwich Mean Time

h : Horizontal

HID : Hight Intensity Discharge

HSD : Horizontal Shading Device

HVAC : Heating, Ventilating and Air Conditioning

IEA : International Energy Agency

IESNA : Illuminating Engineering Society of North America

İYTE : İzmir Institute of Technology

k : Kilo

L : Luminance [cd/m^2]

l : Lower

LCP : Laser Cut Panel

LED	**:** Light Emitting Diode
LEED	**:** Leadership in Energy and Environmental Design
LENI	**:** Lighting Energy Numeric Indicator [kWh/a.m^2]
LL	**:** Lighting Fixture Layout
lm	: Lumen
LS	**:** Light Shelf
LT	**:** Lighting Fixture Type
lx	**:** Lux
n	**:** Number of Lighting Row (on)
OLED	**:** Organic Light Emitting Diode
p	**:** Period (refers to 75 days)
ρ	**:** Reflectance of the Surface Material
RE	**:** Relative Error
S	**:** Scenario
SC	**:** Surface Color
SD	**:** Shading Device
U	**:** Uniformity
u	**:** Upper
UV	**:** UltraViolet
v	**:** Vertical
VSD	**:** Vertical Shading Device
W	**:** Watt
WFR	**:** Window-to-Floor Ratio
WWR	**:** Window-to-Wall Ratio
w/o	**:** Without
W/S S&E	**:** Winter/Summer Solstices & Equinoxes

CHAPTER 1

INTRODUCTION

1.1. Theoretical Framework

Global warming, environmental pollution and limitation of natural sources have led the energy efficiency being a crucial concept in our daily lives and in a wide range of sectors recently (Daly, Cooper, & Ma, 2014). Building sector causing approximately 40% of CO_2 emission has the priority with economical and social aspects in this sense (Ağırman, 2013). Developments in energy efficient applications have been rapidly increased gradually and progressively in order to reduce the energy consumption in the building sector (Casamayor & Su, 2013). In relation to this, lighting is one of the critical components among energy consumption sources. It is obvious that improving daylighting usage is crucial for energy efficient buildings. However, artificial lighting usage is an inevitable need. In this context, relevant cost, payback cost, lighting design, visual comfort requirement and energy efficiency of the artificial lighting selection are substantial. Appropriate and applicable usages of artificial lighting provide a reasonable reduction in energy consumption (Ahn, et al., 2013).

During the past two decades, many buildings have been refurbished in order to improve poor indoor environment such as air quality, visual environment etc., to reduce high energy consumption and to meet the demand for a new floor layout. Right glazing selection providing solar shading, glare control and redirection of light is the major step in order to meet convenient daylighting strategy while increasing the amount of daylight and decreasing cooling loads (IEA, 2000). In addition to this, there is a big potential to reduce electric lighting operating costs by using energy-efficient light fittings (Stefano, 2000). Combining daylight systems with artifical lighting through control strategy or integration a lamp in an interior light shelf would be a good solution for retrofitting as well as for a new construction (IEA, 2000).

While testing the performance of several daylighting systems and applying them in a building, there are various types of daylighting design tools used by practitioners providing qualitative and quantitative information. These tools are physical models, simple tools such as formulae, tables, nomograms, diagrams, and computer based tools, simulation programs (images, visual comfort calculations etc.). Among these, a simulation program may efficiently predict the daylighting and energy performance within economical and practical limits (IEA, 2000). Kesten (2006), for example, used INSEL and Radiance to simulate the lighting condition of an existing educational building and proposed a new energy efficient lighting system. The author compared the findings in terms of daylight distribution and energy consumption. Kazanasmaz and Fırat (2013), employed a simulation model of an architectural design studio in Ecotect/Desktop Radiance to analyze its daylighting performance. They applied a light shelf and a laser-cut panel in the model and compared the daylighting conditions of the existing model with the proposed ones.

In view of these ongoing considerations, it is necessary to propose new design solutions which let optimum lighting conditions and minimum energy consumption, especially in buildings mostly used in daytime. An educational building is such a daytime-used building. In fact, it is known that daylighting in such education environment has crucial impacts on learning performance and alertness of students.

1.2. Definition of the Problem

Because of being used all day long, educational buildings require high level of daylighting performance and should benefit from daylight to increase educational and working performance of students and academic staff. However daylight may become insufficient to meet the necessary lighting conditions in several times. So, artificial lighting has become necessary. In that case, energy efficient artificial lighting fixtures and light sources should have been selected and located in the right positions and layout.

In educational environment, daylighting has a crucial impact on academic performance and alertness of students, provides a healthier study environment. Besides visual responses, light has other effects on human being such as performance, mood, attention and the synchronization of biological clock. (Bellia, Pedace, & Barbato, 2013). As daylight is considered as the best energy source of light for good color rendering and human visual response, a proper daylight increases the academic performance and provides a healthier study environment (Li, Cheung, Wong, & Lam, 2010).

In many countries, school buildings are designed and constructed almost like any other type of buildings. Inadequate daylighting and inconvenient indoor air quality lead to presence of improperly designed educational buildings. There should be more and specific interest about the lighting problems as well as energy efficiency in school buildings (Theodosiou and Ordoumpozanis, 2008).

There are several studies about environmental conditions of educational buildings. For example, Szepessy (2007) studied the control-oriented occupant behaviour toward systems for shading and lighting. High resolution data for occupancy, temperature and relative humidity, light on/off, internal and external illuminance were collected. Behavioral patterns were defined. The findings showed that the operation of shading and lighting systems were significantly dependent on these parameters. Another study was about electric energy consumption, cooling loads and construction materials of an educational building in Saudi Arabia (Sait, 2013). Thermal analysis in relation to lighting energy consumption was conducted through thermal zone images. Findings showed that air conditioning system and lighting should be precised, insulation curtains and external insulating films should be added and number of lights should be reduced in order to save energy in the educational building. Barbhuiya and Barbhuiya (2013) showed the effect of ventilation strategy of an educational building on its energy consumption and the impact of thermal comfort on its users. Indoor temperature and lighting levels were monitored. Finally, they concluded that, better interior design strategies and adopting dimming profile for lighting control would increase the energy performance of educational buildings significantly and their thermal and visual comfort as well. Krüger and Dorigo (2008) investigated the illuminance and luminance in classrooms by using Radiance and Ecotect. Daylighting analysis have been conducted for several combinations of days, schedules and building solar orientations. Results indicated that, daylighting levels for various positions of the building, have provided the designer to predict the most suitable case for building siting in regards with local aspects and the quality of the resultant indoor space. Shading devices have been designed for each orientation in order to increase building thermal performance and daylighting levels.

Another group of studies are about daylighting performance and energy efficiency in buildings. Li, Tsang and Cheung (2006) evaluated the daylighting performance in heavily obstructed residential buildings by using building parameters. A lighting simulation tool was used. Li and Tsang (2008) conducted a similar study for the office buildings. Daylighting and energy consumption in condominums in Singapore were discussed in another study (Maheswaran and Zi, 2007). They focused on the energy efficient façade design and its criteria such as perimeter area, orientation, time period of façade exposure, shading, the position and sizes of openings and materials used for the façades. Konis (2013), on the other hand, dealt with the daylighting performance to reduce electrical lighting energy consumption in an office building. Visual comfort responses from the users and the percentage of façade glazing, the recommended daylight autonomy were discussed at the end of this study. Nayyar (2010) proposed several lighting retrofit scenarios for a hall in the university campus. The study focused on artificial light sources such as LEDs and different types of fluorescent lamps. The energy consumption for each scenario was calculated and compared with the other scenarios. Krarti, Erickson and Hillman (2005) proposed a simplified method to predict energy savings of artificial lighting use from daylighting. Window and buildings geometry and glazing types were the key parameters.

Regarding the first group of studies, lighting (daylighting and artificial lighting) were considered as an integrated component in the total energy performance of a building. Its relation to the thermal performance of a building was observed as the utmost concern. However, despite these studies conducted in the field of energy consumption, there still exist some deficiencies about integrated approach focusing on energy efficient natural and artificial lighting criteria together such as;

- Window design including area, proportion and glazing properties,
- Shading device properties,
- Indoor surface colors including flooring, ceiling and wall,
- Lighting luminaires design and technical properties,
- Light shelves and light pipes.

It is necessary to conduct the research to focus on the all aspects of energy efficient lighting criteria as mentioned above. In addition to that, as understood from the other studies mentioned above, these criteria have been studied in parts, or one by one in separate studies. However, in this study these criteria as a whole will be examined in detail by finding out their optimum values for an educational building.

Regarding the second group of studies, it is considered that the office buildings and residential buildings were mostly studied in terms of their daylighting performance and energy consumption. And daylighting design criteria and energy efficient artificial lighting were evaluated separately. So, it is necessary to conduct such a study to combine daylighting and artifial lighting design criteria in an educational building.

In this study, an educational building, Department of Mechanical Engineering in Izmir Institute of Technology has become the case building. It has a courtyard and each façade of building block differs from each other. Façade configuration of any room with the identical orientation (fenestration, shading devices, unshaded façades, balconies) varies without considering their dimensions, functions, the needs for visual comfort parameters and daylight penetration during the day. To state in other words, it is expected that each place has to be its own solution according to its specifications. However, the situation does not represent this consideration. For instance, rooms located on the courtyard do not have any shading devices although they are facing Southeast and Southwest; while rooms facing Northeast and Northwest on the outermost of the building have horizontal shading overhangs and vertical cantilevers even unnecessarily. Moreover, lighting energy consumption and energy efficiency are other concerns appeared as a result of insufficient use of daylight. In this study, six different rooms having different functions (classrooms, lecture hall, offices, laboratory), dimensions and façade configurations has been selected from all directions. All those concerns were tested by using a simulation tool, DIALux, to find out solutions suitable for visual comfort by considering the daylight and artificial lighting as an integrated system.

1.3. Significance of the Study and Limitations

Different parameters was considered together to retrofit the case building in terms of energy efficient lighting criteria. Investigation of various parameters' effects on daylighting performance has been taken part in literature. However, they were the subject of each study individually. On the other hand, artificial lighting depending upon energy efficiency has been the subject of different studies. However, in this study, both daylighting and artificial lighting will be considered together as an integrated system. In addition, the values of parameters (fenestration, shading design, surface colors and lighting fixtures layout/type) were evaluated comparatively and determined correspondingly under different design scenarios for an educational building's lighting retrofit. So, an integrated approach would be proposed in lighting design and retrofit applications.

On the other hand there were some limitations in this study such as:

- Artificial lighting performance has been evaluated according to existing of lighting fixture layout in the case building. For further researches, lighting fixtures places can be modified,
- Selected parts have some obstacles for daylight penetration due their existing furnishings. Different results could be achieved for different furnishings,
- DIALux was used for the simulation analyses. Other different simulation tools could be used in order to prepare the model and to compare the results
- Shading device proposed for this study has been modeled as a rectangular prismatic shape. Other simulation tools can provide to achieve more realistic models,
- Energy consumption has been manually calculated, because DIALux is not able to calculate for selected specific hour periods,
- Field study measurements have been taken for certain time (day and hour). For further researches, measurements could include all year long.

As a result, the focus of the outcome would be the optimum values of these relevant parameters and shading devices facing different orientations. In this way, this study will be an instructive one for new or retrofitted constructions by providing new information about energy efficient lighting performance. In this sense, it would be a guide for designers, architects and researchers.

1.4. The Purpose of the Study

The purpose of this study is to evaluate and propose an energy efficient lighting design for an educational building, department of Mechanical Engineering in İzmir Institute of Technology. The aim is to find the optimum values of the daylighting and artificial lighting design parameters, such as about fenestration (type and transmittance of glazing), shading device (slat angle and position), surface colours and lighting fixture (layout and type). To achieve this, several scenarios for each criteria and combination of their different values were tested by DIALux.

1.5. Research Questions and Hypothesis

The research questions about this study may be stated as below:

- How does the selection of lighting design criteria affect the lighting performance?
- What is the amount of daylighting availability in rooms with different orientations for the winter/summer solstices and equinoxes?
- What is the amount of floor area in a room which receives adequate daylight?
- What is the duration of adequate daylight in a room?
- How do the different shading devices according to slat orientation and angle affect the lighting performance of differently-oriented rooms?
- How long does a room require operating the artificial lighting?

The first hypothesis is that, daylighting and artificial lighting design ctiteria have noteworthy impact on the lighting energy retrofitting of an educational building.

The second hypothesis is that, the lighting energy performance of an existing educational building may be improved by simple daylighting and artificial lighting design strategies.

The third hypothesis is that, the lighting energy efficient design strategies that may be applied in such rooms with certain orientation differ from the ones that may be applied in other rooms with different orientation in terms of retrofitting the lighting performance.

1.6. The Structure of the Thesis

This thesis aimed to evaluate and propose an energy efficient lighting design for an educational building by both considering daylighting and artificial lighting together using a simulation tool. For this purpose, this study was carried out under five chapters.

In the first chapter, importance of daylighting in educational buildings was defined by explaining studies conducted about the subject. Necessity of proposing new design solutions by both considering daylighting and artifical lighting together was emphasized. Research questions about the problems existing in the case building were generated and hypothesis were developed.

In the second chapter, related literature about energy efficient lighting criteria in the buildings, history of technological developments of artificial lighting sources, importance of simulation analysis in energy efficiency determination daylighting simulation tools and selected studies was reviewed.

In the third chapter, description of the case building, Mechanical Engineering Department in Izmir Institute of Technology was introduced. Six different rooms (intitled Part A-F) having different orientation, size, function, façade organization were selected from the building complex were geometrically defined. Field measurements taken in different parts on the December 4^{th}, 2014 were given in order to validate the simulation results conducted in DIALux. In order to achieve proper visual comfort conditions and energy efficient lighting design, seven different scenarios were studied for 9:00 AM, 12:00 PM, 3:00 PM for December 21^{st} with various parameters such as fenestration, surface color, shading device and lighting fixture. These scenario steps were explained by the help of flowcharts. Input and output parameters were defined and input parameter values given in the scenarios were indicated. All the parts were modeled in the current situation and retrofitting studies were conducted by appliying scenarios using DIALux.

In the fourth chapter, daylighting and energy consumption results for all parts were explained. Daylighting results were given as illuminace E_{avg}, E_{min}, E_{max} (lx) and uniformity as E_{min}/E_{avg}, E_{min}/E_{max}. Base case and retrofit scenario daylighting results were evaluated. Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices were evaluated in terms of daylighting and energy consumption (kWh/a) results. Annual energy consumption in winter/summer solstices and equinoxes were evaluated for all parts by the help of tables and graphics.

In the fifth chapter, case building problems were discussed in terms of visual comfort conditions and energy consumption. Proposals were made according to the energy efficient lighting design criteria. Importance of the study for real life application was mentioned in order to maintain proper daylighting and energy savings.

CHAPTER 2

REVIEW OF THE RELATED LITERATURE

It is known that, primary energy sources are consumed in buildings in a high rate in many countries and there is a big potential for reducing consumed energy in the existing buildings by using energy efficient design strategies. Lighting is one of the powerful driving components in building energy consumption. Several design strategies may be proposed to reduce lighting energy consumption nowadays.

In relation to these issues, several regulations and laws (i.e. Directive 2010/31/EC) have been complied by the countries. These rules propose the evaluation for the energy consumption of buildings, the classification of buildings and determination of minimum energy performance requirements of existing buildings for their renovation. So, the main aim should be to find the sustainable ways for constructing new buildings and to improve the energy efficiency of the existing buildings' by meeting comfort requirements of users in the building at the same time. In this context, building energy simulation tools provide to find out dealing ways in design, management and retrofitting stages of the buildings.

2.1. Energy Efficient Lighting Criteria in Buildings

Daylight illuminance inside the buildings depends on season, location, lattitude and cloudiness. So, it is a dynamic light source. It is necessary to take into account the parameters affecting natural lighting in building design since utilizing daylighting inside the building as much as possible will result in minimizing the energy consumed for lighting (IEA,2000).

On the other hand, to benefit from only daylighting is unfortunately unrealistic. Since, electric lighting is necessary and is a major component in energy use. It also affetcs the cooling and heating loads. It is possible to increase the effciency of building illuminations and reducing negative environmental impacts of electricity generation by extending the usage of higher-efficiency lamps and ballasts and by improving effectiveness of fixtures (IEA,2000).

Table 2.1 Options and elements to be considered in lighting design (DfEE, 1999)

<table>
<tr><th>Natural
Lighting Design</th><th></th><th>Electric
Lighting Design</th></tr>
<tr><td>Room orientation</td><td rowspan="6">Room size and shape
Furnishings
Room surface colors
Room surface colors
& reflectances
Maintenance</td><td rowspan="2">Lamps</td></tr>
<tr><td>External obstruction</td></tr>
<tr><td>Sun-screening & redirection</td><td>Luminaires</td></tr>
<tr><td>Windows in relation to view</td><td>Lighting controls</td></tr>
<tr><td>Rooflights
& clerestories</td><td rowspan="2">Lighting installation</td></tr>
<tr><td>Atria & borrowed light</td></tr>
<tr><td colspan="3">Integrated Daylighting Design</td></tr>
</table>

In order to define the energy efficient lighting design, it is possible to mention about three factors: lamp, luminaire and volume of the space. Energy efficient lighting design requires minimizing the artificial lighting operating time by profitting from natural lighting as much as possible. First requirement for energy efficiency is choosing energy efficient lamps having optimal spectrum (color temperature and color rendering index) and optimal luminaire light output ratio (LOR, %). Luminaires with high value of LOR and reasonable control system should be essential in order to obtain significant visual and ecological lighting design (Kazanasmaz et al., 2014).

Electric lighting and daylighting control systems are needed for adapting the lighting systems to the variations in lighting conditions in order to use energy efficiently and to maintain visual comfort conditions (IEA, 2000).

2.1.1. Providing Energy Efficiency by Natural Lighting

Daylight, which is the the primary and free light source, should be used properly. It is necessary for visual comfort and human health, especially for people who spend their time mostly inside the buildings. Lighting in office buildings constituting

25-35% of total energy consumption causes to find out new solutions for profiting more from daylight in order to have energy savings (Pandharipande & Caicedo, 2010).

Sunlight and skylight are the two components of daylight. The main point in daylighting design is controlling not only light levels but also the direction and the distribution of light. Daylighting has two different strategies: sidelight systems and toplight systems (Boubekri, 2008).

Using systems bringing more daylight to inner parts of these deeper spaces would be a good way for both illumination and air conditioning. Light pipes and light shelves are some of the convenient solution in the way of exploiting from daylight in deeper spaces.

Sidelight systems: These systems operate by reducing excessive daylight levels near the openings, increasing them in areas away from windows. Side windows, clerestory system, combined side-system, light shelf system, variable area light shelf system (dynamic system), louver system, prismatic system (it changes direction of incoming sunlight and redirect it by way of refraction and reflection) and anidolic zenithal collector system (two concentrating mirrors of parabolic shape that capture the incoming light flux over a wider area and distribute it) are the examples of sidelight systems (Boubekri, 2008).

Toplight systems: Light pipe system which transport system could be simple opening shaft or prism or fiber optic system skylight system, roof monitor and saw tooth system are some of the examples of toplight systems (Boubekri, 2008).

2.1.2. Building Parameters Affecting Natural Lighting

In general, the daylighting performance of a building depends on certain factors;

- Building area and orientation,
- Building and interior geometry,
- Interior finishing materials (their reflectance),
- Window area,
- Glass type,
- Shading and external obstruction.

Apart from the daylight entering directly from the window, diffused light that a building is exposed depends on both internal and external factors. Internal factors are the size and position of the windows, wall and surface colors, the depth and shape of the room. External factors are the reflected light from the outdoor ground and opposite façades (Li, Wong, Tsang, & Cheung, 2006).

2.1.2.1. Building Geometry and Orientation

Building geometry and orientation have been investigated in different studies in order to show their impact on energy consumption in the buildings. Krüger and Dorigo (2008) examined the daylighting levels for various positions of the building by using Radiance and Ecotect simulation programs. The luminic qualities of classrooms located in Curitiba, Brazil have been simulated for several combination of days, schedules and building solar orientations. Results provided the designer to predict the most suitable cases for building siting in regards with local aspects and the quality of the resultant indoor space. Another study was conducted by Kazanasmaz et al. (2011) to specify relationship between energy performance of residential buildings and their architectural configuration. A total of 30 buildings with 5-11 storey residential blocks have been selected from Izmir, Turkey and classified with reference to zoning status, orientation, floor numbers, designers and construction years. These examples have been determined by using TS825 which was a calculating method according to the Thermal Insulation Requirements for Buildings. Static methods provided to estimate the monthly heating load and to find an idea for reducing heat loss. As a result, it was suggested to take simple and inexpensive precautions in design process for instead of renovating of existing buildings' energy performance with limited solutions.

2.1.2.2. Window Area

Window openings have mainly two functions. The first one is penetrating natural light interior and providing a pleasing atmosphere. The second one is that, window allow people to have a visual contact with outdoor. A proper window design contributes to increase electrical energy savings. It is indispensable to have an increase in designing daylight-efficient building demand. Window area which is a critical factor in terms of daylight entering in a building is commonly represented by the window-to-wall ratio (WWR). This ratio is defined as the ratio of the total area of windows to the overall façade area including windows. On the other hand, apart from energy savings, window area has a vital importance in order to increase the productivity of occupants (Li & Tsang, 2008).

2.1.2.3. Glass Type

Glass type allows controlling the amount of daylight coming interior in terms of light transmittance which is directly proportion to the DF. Double glazing glass type is mainly used for acoustical reasons rather than thermal or visual problems. Clear glass type gives an opportunity for high transmission of daylight with typical visible transmittance (VT) of 0.88. On the other hand, it allows a large amount of solar heat to enter into the building. Tinted glass type absorbs infrared with some loss of visible light. Reflective glass provides good reflective characteristics in infrared range with some loss of VT and is able to absorb more heat than tinted glass. However, reflective glass can cause visual discomfort for users. Low-e glass cuts down heat gain without reducing daylight transmittance due to having a thin coating of metal oxide and it is effective for minimizing solar heat gain when short wave radiation exists. Occupants will be in comfort while getting more natural light with proper VT values (Li & Tsang, 2008).

By the development of glazing industry many studies have been done to designate better solutions for energy efficient buildings. One of this research was about the technical potential for energy savings from vertical daylighting strategies (Shebabi et al., 2013). Using Radiance simulation program, daylighting simulations were generated by using three-phase method which was already validated. This method utilized bidirectional scattering distribution functions (BSDF) provided relatively quick annual daylight simulation for modelling complex fenestration. Two reference fenestration models, venetian blinds and dynamic (automatic) venetian blinds, have been modeled in order to predict marginal benefit of dPOE window coatings. Results helped the acceleration for the development process and brought a new daylighting strategy by providing insight into energy and cost performance targets for dPOE coatings. Another study carried by Mabb (2001) showed the possibility of increasing thermal and daylight performance of the atrium building by modifying glazing with the inclusion of LCP (Laser Cut Panel). The temperature and thermal stratification in clear glazed roof atriums versus that of atriums that incorporate the use of the angle selective LCP compared by conducting BASIC and MATLAB computer simulation tools and by collected field data. The modified glazing (LCP) provided a lower temperature in the middle of the day within the atrium and a higher level of illuminance was achieved under clear sky conditions. LCP glazed had more advantages in the way of improving energy performance of the building and visual comfort of the occupants comparing clear glazed. The ways for improving the performance of future daylit buildings and daylighting design strategies were investigated in another study (Konis, 2013). Daylighting performance over daily and seasonal changes in sun and sky conditions in core and perimeter zones have been examined for a side-lit open-plan office building in San Francisco, California. Electric lighting energy has been measured, occupants' modification to the façade has been observed and interior lighting conditions paired with occupant subjective assessments using novel desktop polling station have physically measured in order to find daylighting performance of the building. According to results, a large percentage of façade glazing covered by interior shading devices caused visual discomfort responses at both perimeter and core workplaces.

2.1.2.4. Shading

Shading devices being an important issue in energy savings, many researches took place for determining their impact on energy efficiency in the buildings. As mentioned before, artificial lighting has an undeniable effect on providing a slight reduction in energy consumption. Besides artificial lighting, proper selection of glazing providing solar shading, glare control and redirection of light is the major step in order to meet convenient daylighting strategy while increasing daylight and decreasing cooling loads (IEA, 2000).

Shading devices prevent interior to be exposed direct sun but allow penetrating diffuse light. Buildings completed between 60s and mid 80s had generally overhangs and side-fins with clear glass. After late 80s external shading devices weren't popular until the end of 90s due to having tendency to use curtain walls in large scale buildings (Li & Tsang, 2008).

Shading devices being an important issue in energy savings, many researches took place for determining their impact on energy efficiency in the buildings. For example, Jenkins, Peacock and Banfill (2009) studied the proper shading strategy in order to meet thermal comfort and internal air quality standards for schools without using mechanical ventilation and air-conditioning. Simulations conducted on school buildings templates showed that small power and lighting energy use could reduce the overheating of school teaching areas. Horizontal shading devices have been placed above every window and overheatings in the buildings estimated. As a result, it was deducted that overheating could be reduced by use of proper ventilation and shading strategy. Alameddine (2011) studied the importance of alternative design options for the thermal performance of office buildings by choosing different office buildings and proposing multiple design alternatives included lighting, shading types, shading schedules, thermal insulation, glazing and ventilation scenarios. Their performance was modeled by using a numerical thermal simulation application. A significant proceeding was achieved in the way of find out the design measures which could reduce the energy demand of office buildings. Another study made a contribution in understanding the relationship between daylight performance and shading device design in the perimeter area of buildings (Chou, 2004). Different factors such as shading device type, material reflectance, windows design, opening ratio and daylight distribution for the statistical multivariable model (used for validating the theoretical model) were considered. These models were based on horizontal, vertical and eggcrate types of shading devices. These data have been validated within the statistical program which was found very reliable as a result. Freewan (2014) focused on impact of shading devices on air temperature, visual comfort of users and offices facing with Southwest façade located at Jordan University of Science. Real-time experiments and computer simulations (IES/SunCast and Radiance) were conducted in order to find the effect of shading devices in controlling air temperature and improvement in illuminance level. Vertical fins, diagonal fins and eggcrate fins were installed in three different offices in order to monitor and compare the air temperature, illuminance level, thermal and visual environment with a non-shaded office. Air temperature significantly reduced in offices with shading devices compared to the office without shading devices. Another study was carried out to find the impact of shading devices on energy savings and the quality of daylight of the buildings (Alzoubi and Al-Zoubi, 2010). A typical small office space was selected and the amount of light flux and associated solar energy have been evaluated by using a building simulation program in order to understand the effect of vertical and horizontal shading devices on illuminance level of the space with room geometry. Vertical shading devices were good for south exposure and provided a good daylighting as well as minimum heat gain in the office space. It was seen that an optimal shading device orientation would keep the internal level within a reasonable range with minimum amount of solar heat gain.

2.1.2.5. Daylight Redirecting Systems

Light pipe is used for the illumination of the space in case of inadequate daylight during the daytime. Light pipe system consists of three parts. The first part is dome produced from polycarbonate material. It collects the diffuse and direct light and transfers into the light pipe. This dome has been designed to remove undesired UV light and has a shape oriented to prevent snow, dust and rain penetrating into to tube. The second part of the light pipe is made up of one or more hollow tubes connected to each other. These tubes transfer the collected daylight by the dome to the diffuser being the third part of the light pipe which is placed on the ceiling of the room. On the other hand, sometimes light pipe cannot provide sufficient illumination for deeper parts depending on weather conditions and artificial lighting becomes indispensable (Görgülü & Ekren, 2013).

Light shelves being another way to bring the daylight into the building provide less use of electric lighting than those in regular window design area. Light shelves are generally used in side-lit rooms in order to provide shading by redirecting sunlight and to introduce daylight into to space. Studies showed that light shelves improve the uniformity of daylight in the room. It is a horizontal or inclined plane projected over a view window may be external or internal or both with a convenient upper reflective surface. Light shelves are both a shading device blocking the direct sunlight and a daylighting system improving the uniformity and reflecting light into interior of the room. On the other hand, light shelves are found to be one of the most effective and reliable system among the other daylight delivery systems (Sanati & Utzinger, 2013). Its performance depends on its reflectivity and slope, its dimensions and location, ceiling geometry and height. Light shelves have their maximum efficiency when they have a direct sunlight (Freewan, Shao, & Riffat, 2008).

Light shelves are uniques to the building and they affect the architectural and structural designs of the building. Lights shelves can be applied in climates with significant direct sunlight on a south orientation in the northern hemisphere. However, they can not show the same performance on West and East directions and in climates dominated by overcast sky conditions (IEA, 2000).

Light shelves and light pipes studied in many researches in order to understand their effects on energy savings. For example, Sanati and Utzinger (2013) studied the impact of interior shading system on electrical energy usage reduction while still meeting user satisfaction. An open-plan studio space was selected due to its potential to be a well-daylit space with windows extending to the ceiling and having a narrow floor plan. According to the results, it was seen that, users working within the light shelf zone have demonstrated a lower window occlusion than those working in the area with conventional windows. So, light shelves provided less electric usage on average without affecting user satisfaction. Another study was carried in order to explore the impact of ceiling geometry and louver paramaters on the performance of daylighting by using Radiance simulation program and physical model experiments (Freewan, Shao and Riffat, 2008). The illuminance level and its distribution uniformity have been investigated as performance indicators for daylighting performance in a subtropical climate region. Physical model experiments and Radiance simulations have been compared. As a result, it was seen that the performance of the the louvers could be improved by differing the ceiling geometry. Light pipe and dimmable ballasts have been investigated about the lighting energy savings by illuminating a windowless room in Görgülü and Ekren (2013) study's. Electronic ballasts and fluorescent lamps have been used as artifical lighting in case of inadequate illuminance and a fuzzy logic control system supervised to limit the illumination level at 300 lx. Illumination obtained from light pipe has varied during the day and artifcial lighting has been operated at different stages. Energy savings could be achieved as the system only operated when motion sensor was active and daylight provided by light pipe was inadequate.

2.1.3. History of Technological Developments of Artificial Light Sources

The lamps as the artificial light sources have been used nearly for a century to architectural lighting. However, they remain proper only for a quite small segment of parking lot and industrial applications. There exist six general families of electric lamps for the purpose of architectural lighting design and can be listed according to the chronological age such (Steffy, 2008);

- Filament,
- Cold Cathode,
- Fluorescent,
- High Intensity Discharge (HID),
- Electrodeless,
- Solid State (LEDs and OLEDs).

The initial electric lamp whose main structure is a thin carbon wire was produced in 1879. This lamp's efficiency factor, that is called the "efficacy" was 2 lm/W and could be upgraded to 4.5 lm/W after some studies. After setting into motion the tungsten wire which is heat-resistant and used in incandescent lamps instead of carbon wire, lamp efficiency became to 8 lm/W. At the end of the 1950s incandescent lamps were filled with iodic gases and lamp efficiency reached to 10-22 lm/W. The development of artificial lighting source was not restricted with incandescent lamps. So, in 1930s discharge lamps started to be produced. In these years, low pressure sodium vapour lamps and high pressure mercury vapour lamps were commonly used, but because of their poor color specifications they could'nt be more than a street lamp. In 1950s glasses of these lamps were covered with red phosphore, and their color and optical rendering indexes have been increased. In 1960s metal halide lamps were produced by adding some salt into mercure vapour and increase in color rendering abilities were provided. Fluorescent lamps first used after 1938, but they containing many hazardous substances on human health. After 1948 halophosphate has been used which were'nt risky for human health. By the use of triphosphates, color rendering indexes and efficiency of the fluorescent lamps were increased (Ünal, 2009).

As mentioned before, artificial lighting is an important need for buildings which are used during the day. Its impact on energy consumption is inevitable and should not be underestimated.

> "*Statics support the energy argument. Lighting is responsible for 30% to 50% of all energy utilized in commercial and office buildings. Some surveys indicate even higher percentages. For commercial and office buildings occupied during the day studies have shown that total electricity and peak demand savings of 20-40% in lighting and cooling can be achieved with the proper use of daylight photosensors along with other energy-saving systems"* (Boubekri, 2008, p.8).

Besides energy efficiency effects, artificial lighting usage has an importance on visual comfort also. Lighting should be conveniently adjusted in order to provide an appropriate perception of objects and environment. Excessive lighting causes glare while inadequate lighting causes imperceptions of environment.

> "*The quality of light is a major requirement for good visual perception, especially in place where the visual medium is an art object. The quality of light is the fundamental issue of contemporary lighting. It has a strong effect on how the illuminated object is perceived in its formative, dimensional, textural, surface and color properties"* (Dikel & Yener, 2007).

While equipment is primarily responsible about the electric lighting, it is crucial to take into account the reflectance of the main surfaces of the space such as furnishings and the possible light obstruction caused by the furnitures also (DfEE, 1999).

Table 2.2 Technical properties of lamps generally used in educational buildings
(Source: Philips Product Catalog Indoor Luminaires)

Type	Power [W]	Efficacy [lm/W]	Lifetime [h]	Color Temperature [K]	Color Rendering Index (Ra)
Incandescent	15-200	6-16	1000	2700-3000	100
Tungsten Halogen	25-500	16-19	2000-4000	2700-3000	100
CFL (internal ballast)	5-33	42-65	12000	3000, 4000, 6500	>70
CFL (external ballast)	10-26	60-69	12000	3000, 6500	>70
FL	14-54	86-93	12000-20000	3000, 4000, 6500	>70
Metal Halogen	35-150	86-97	6000-20000	3000, 4000, 6500	>70
LED	Variant	Variant	30000-60000	Variant	>70

2.1.3.1. Incandescent Lamps

Incandescent lamps (IL) are the lamps that the light is produced by heating in tungsten filament and their efficacy is between 10-20 lm/W depending on their construction and the filament operating temperature. Lifetime of IL is usually 1000 h and it is found inefficient due to 90% of its input energy is lost as heat output. Halogen gas that reacts with the evaporated tungsten back to the filament was added into IL in order to increase its rated lifetime. Those lamps are called Halogen lamps (HL) and has a longer lifetime of 2000-4000 h and an efficacy around 12-35 lm/W (Aman et al., 2013).

2.1.3.2. Discharge Lamps

Discharge lamp principle is based on creation of light by an electric discharge within a gas or vapor. Discharge lamps have longer lifetime and higher efficacy than IL. Compact fluorescent lamps (CFL) and fluorescent lamps (FL) are the types of discharge lamps (Aman et al., 2013).

CFL is a discharge lamp in which the light is created by an electric discharge within a gas or vapor. A special phosphor material is used, which converts UV light into the visible light output. The presence of a small amount of Hg in the fluorescent tube for illumination purpose requires special treatment for its safe disposal. In CFL, luminous flux changes inversely proportional to the square of the distance between light source and illuminated object and in CFL only electronic ballasts are used due to heavy weight of electromagnetic ballast. Its efficacy ranges from 50-70 lm/W (Aman, Jasmon, Mokhlis, & Bakar, 2013).

Compact fluorescent lamps have been produced as an alternative to incandescent lamps (bulb) because of its lower energy consumption and longer life. A 23W CFL produces same luminous flux as a 100W bulb. It means that, a bulb consumes 2-5 times more power, moreover it lasts 8-10 times shorter over its life compared to a CFL. CFL can not operate in refrigerators, humid indoor or outdoor locations. It shows an optimum performance at 20 °C and its efficiency decreases in higher and lower temperatures. On the other hand CFLs have 9-10 times lower lives compared to LEDs and electrode less induction lamps and it emits UV and pollutes the environment with mercury (Khan & Abas, 2011).

CFL and LED lighting systems were compared in many studies in the field of energy efficiency. For example, Gan et al. (2013) suggested that LED tube had many advantages comparing to conventional fluorescent lamps in terms of energy savings and payback period. However, LED lamps have poorer total harmonic distortion performance and quantity and the quality of illumination level on the work plane. Three block buildings have been selected as case example where the majority of the existing lighting consisted of T8 fluorescent lamps. Motion or infrared sensors have been installed in order to optimize and reduce the overall energy consumption and many alternatives have been proposed by using T8, As a result, it was observed that LED T8 and LED T8 with sensors were the most effective ones in terms of electricity bill reduction. In another study, Sekyere, Fokson and Akuffo (2012) investigated the convenience of solar-powered LED and CFL lighting system as replacement of kerosene lanterns in Ghana by doing technical analysis through measuring luminous flux of each lighting system on a flat surface. Radiant flux, average luminous flux and luminous efficacy were captured and total cost of ownership was evaluated. The solar-powered LED and CFL systems showed up as the most cost effective solution. So, as an alternative to fuel-based lighting system in rural Ghana, solar-powered LED and CFL lighting systems were found applicable in terms of cost effective off-grid lighting.

2.1.3.3. LEDs

Light-emitting diodes (LEDs) that convert electricity directly into light are a semiconductor technology developed 50 years ago. The concept of using LEDs in educational building is not common, since the fluorescent lights are still quite effective and are cheaper than LEDs. LEDs have many advantages such as compactness, long life and adjustable intensity and these make them good candidates to replace incandescent or CFL (compact fluorescent lamp) in the future.

> *"Artificial light sources essential in the daily life of most of human being consumes around 2650 billion MWh/year which represent almost 19% of the worldwide production. The European Directive for the eco-design of Energy Using Products (2005/32/CE) recommends improving the energy performances of domestic use products in order to protect the environment. By the first of September 2016, no more incandescent lights will be available in Europe for domestic lighting, and inorganic or organic LEDs could become the next generation light sources due to their energy saving performances" (Behar-Cohen, et al., 2011).*

LEDs are filled with gases and coated with different phosphor materials. LED light output is monochromatic and in order to achieve white light output, phosphor conversion method and RGB method are used. (Aman, Jasmon, Mokhlis, & Bakar, 2013).

The first commercialized LED was red, but today it is possible to achieve all saturated colors. Obtaining a "high power efficient white LED is one of the key issues for LED technology. There exist three methods in order to obtain white light from LEDs (Behar-Cohen, et al., 2011):

- Combining a diode at a short wavelength with a phosphor emitting at a larger wavelength,
- Using a diode emitting in the near UV coupled with one or several phoshpors,
- Using at least three diodes emitting at different visible wavelengths which then combining themselves to produce white light.

LEDs working principle is totaly different from compact fluorescent lamps (CFL). In LED lighting technology, when an electron recombines with a hole, energy releases in the form of light which is known as photon. A compact AC/DC converter should be used in one lighting fixture in order to supply DC current to high brightness LED chips. This introduces non-linearity to a system and LED lamps produce highly distorted currents (Uddin, Shareef & Mohamed, 2013).

Current efficiency of LED lighting is quite similar to fluorescent lighting. Cool white LED light has an efficiency of 60-150 lm/W while linear fluorescent light has 50-100 lm/W. 75-85% of the light electric power of LED is generated as heat despite the development in heat generation and thermal management technologies. Generated heat from lighting is divided into visible light, convective and radiant heat (Ahn, et al., 2013).

LEDs are very popular in lighting industry due thier energy efficiency and many studies can be found in this field. For example, Pandharipande and Caicedo (2010), considered the energy efficient illumination control design by using LED based systems in offices buildings. The focus was to find the optimum dimming levels in order to reduce lighting electric consumption. Uniform illumination at a given illumination level in an occupied workspace region and a minimum illumination level of lower value in an unoccupied workspace region have been rendered. An ultrasound array sensor solution was used to determine occupant locations and this localization information was the input to the illumination control algorithm to optimize dimming levels of LEDs to provide desired illumination rendering. Their study proposed a method in order to predict and disaggregate illumination contributions of daylight and the different LED sources at the workspace region. The heating properties of LED lighting and establishing a strategy for reducing energy used in the building for heating and cooling were studied in another research (Ahn et al., 2013). A Green Building located in Daejeon, Korea was selected, and its energy consumption was simulated by using EnergyPlus. The virtual building provided by U.S. Department of Energy (DOE) was computed according for different light fixtures. For the cooling system of the building, a control strategy has been found more feasible for LED lighting than a fluorescent lighting by reason of the use of return-air duct and the heat sinks on the LED fixtures provided the heat easily directed. It was seen that LED lighting in combination with control strategy could reduce the energy consumption in the building.

National LED lighting projects have been implemented in many countries such as US, Japan, Korea and EU countries in order to reduce lighting energy consumption. US proposes to develop LED technology with a luminous efficiency of 200 lm/W through the “Next Generation Lighting Inititative” and to obtain 50% in the share global lighting market by 2020. Japan is planning to reduce 20% lighting energy through “Light for the 21st Century project” by extensive installation of white LED lighting and development of 120 lm/W technology. Korean government had planned to replace 30% of the existing lighting fixtures in public institutions with LED lights by the end of 2012 and had set new rules for installing LED products in new constructions and in the expansion of reconstruction of existing buildings (Ahn, et al., 2013).

LEDs offering long life times, energy efficiency and flexible tunability, will become the dominant source of artificial lighting in the future. LEDs provide dynamic lighting effects and flexibility in both design and controlling. The flexibility in controlling individual LEDs are used to render dynamic lighting in LED based system and also contributes energy savings (Pandharipande & Caicedo, 2010).

Light lamps can be characterized according to their energy consumption, price, efficacy, efficiency, repair, glare, pollution, bio-effects and lamp life. Cyristalline LEDs have relatively longer life and efficiency compared to Organic LEDs (OLED) called polymer LED (PLED) or flexible LED (FLED) (Khan & Abas, 2011).

2.1.3.4 Fiber Optic Lighting

Fiber optic became a widely used system in lighting, energy transmission control system, medicine and industry. Basically, it is based on the movement of light from one point to another point in fiber cable with reflections. Aim of the fiber optic lighting is to enhance intense and cool illumination for a number of optical or imaging applications. It usually consists of fiber optic illuminators integrated with one or multiple light guides which direct illumination towards a specific application. Its working principle is simple: a light shines into the end of the fiber optic tube and makes a beam when travels down. Then, the beam scatters but the coating reflects it back and sends it down the tube without losing any light. Finally, after reaching to the end of the fiber optic tube, light continues to travel forward and make a little point of light (Batur, Paralı, & Uçan, 2011).

Outside the buildings, fiber optic lighting has many area of usage: decorative effects such as lighting walkways, staircases, landscaping. Inside the building, hybrid lighting system became useful in order to provide energy savings. Gathered sunlight on the roof is piped through the optical fibers and combination of natural and artificial light is procured. Light from the fiber optic system does not emit heat, so reduction of air conditioning can be easily achieved (DeCusatis & DeCusatis, 2006).

A source, a fiber and a reciever are the three basic components of each fiber optic systems and all types of this system require a light source which could be any type of conventional light bulb. Serving as light guide, an optical fiber aim is to convey light from the source to the desired destination. So, in optical communication systems, the source of light is called transmitter (DeCusatis & DeCusatis, 2006).

2.1.4. Luminaires

Luminaires are supplementary lighting devices to deliver light and to house lamps. They connect lapms with the ballasts, drivers, dimming modules, data interfaces, and/or transformers, sockets and wiring components (Steffy, 2008).
The function of most luminaires can be specified as (King, 2003);

- Redirecting light in a preffered direction with a minimum of loss,
- Reducing glare from light source,
- Making a contribution to the decor of surroundings.

Moreover, luminaires should provide other aspects such as (King, 2003); lamp protection, electrical safety, heat dissipation, and finishing. In detail, electric map, the lampholder and associated wiring should be supported and protected. Heat-sensitive parts and surfaces adjacent to the luminare should be conducted away. Metalworks should be protected against corrosion. Plastic material may be preffered for corrosive atmosphere for proof luminaires.

Due to the decisive role that luminaire plays in the overall efficiency of lighting systems, it is indispensable to select proper luminaires considering many different factors such as; performance criteria (efficiency, components, construction, optical and glare control, distribution pattern, ease of installation), maintenance, aesthetics and architectural integration, special concerns such as safety and hazardous conditions. Luminaire efficiency is the most important specification in selecting proper luminaire.

Luminaire efficiency is the ratio of total luminous flux emmited from the lighting source to luminous flux exuded from the device (Ünal, 2009).

2.1.5. Electric Lighting Control Systems

Lighting energy monitoring and diagnostics, dimming capabilities and responding real-time utility pricing signals became possible by using lighting controls. Usage of daylight-linked control systems provided sustainable reductions of 30-41% in electrical energy. As well as providing energy savings, a lighting control system should be reliable to lighting standards, have a reasonable payback period and should ensure visual comfort of occupants (IEA, 2000).

Controls have an undeniable influence on reducing consumed energy for lighting and have an impact on reducing carbon emissions, manufacturing and transportations resources (Steffy, 2008).

By the use of sensors and controllers it is possible to reduce and even eliminate the consumption of electrical lighting required to provide proper illuminance levels in the buildings. Field monitoring and simulation analysis studies showed that daylighting control provide a considerable reduction in energy consumption from 30% to 77%. Cost effectiveness of daylighting control depends on various factors such as shape, location, window area and glazing of the building (Ihm, Nemri, & Krarti, 2009).

It is crucial to consider design decisions for a comfortable daylighting in the building with other design criteria such as energy consumption, heating and cooling loads, acoustic and economics. There exist at least two different dimensions of daylight responsive controls mentioned below and for both of these systems occupant satisfaction is very important. System effectiveness would reduce with dissatisfaction of users in terms of visual comfort (glare, brightness problems, irritating mechanical noise). These systems are: (IEA, 2000)

<u>The control of the input to the space:</u> This control is critical in order to procure adequate quantity and quality of daylight in interior spaces.

<u>The control of the electric lighting input:</u> This control help to reduce the consumed energy and it improves the overall distribution of light when necessary. Photoelectric controls being very effective in reducing lighting, cooling and heating loads are used in offices, industrial, educational and residential buildings. Control by switching or

dimming is one standard way to control lighting and provides reduction in energy consumption (IEA, 2000).

> "*Lighting control strategies have involved automatically dimming the lights in response to daylight, dimming and switching luminaires on or off according to occupancy, and performing lumen maintenance, i.e., automatic compensation for long-term lumen losses. However these systems have proved in some instances difficult to calibrate and commission in actual practice" (IEA,2000).*

The components of electric lighting systems are;

- **Photoelectric sensors:**

It is usually located on the ceiling and after detecting the presence and absence of daylight, it sends a signal to the controller that will adjust the lighting accordingly (IEA,2000).

- **Controllers:**

It is located at the beginning of the curcuit and it produces an algorithm to process the signals obtained from photosensors to convert into a command signals (IEA,2000).

- **Dimming and switching units:**

A dimming unit varies the light output of electric lights changing the amount of power flowing the lamps. If the lamps are dimmed at the start of their lifetimes, it provides to save more energy than switching when they are linked to daylight. However, it can annoy occupants and reduce lamp life while daylight levels fluctate rapidly around the switching illıminance. For this, different techniques have been developed such as differential switching control and photoelectric switching with a time delay that can procure a delay in the swithcing process (IEA,2000).

All the lamps could be dimmed except metal halide, self-ballasted mercury lamps and low pressure mercury lamps becase of their structures. Dimming metal halide lamps will cause many problems such as deviation in luminous color, decrease in its efficiency, luminous vibraiton and decrease of lamp life (Ünal, 2009).

- **Occupancy sensors:**

These sensors are proper for buildings where occupants are away from offices/spaces for a longer time than a few minutes. In order to prevent disturbing the other people working while certain zone is already switched off, a system has been developed which allows a very smooth dimming down instead of sudden switching (IEA,2000).

There are two types of control strategies: closed loop systems and and open loop systems that their calibration and the photosensor locations are quite different from each other. In a closed loop system, photosensor is located and is able to detect both the electric light and available daylight. In an open loop system, photosensor is designed and located and it only detects daylight and it is not sensitive electric light. Components of electric light system are photoelectric sensors, controllers, dimming and switching units and occupancy sensors (IEA, 2000).

Mokamelkhah (2007) study's made a contribution on observing the importance of users' behavior on energy consumption of the building. They concluded that indoor and outdoor environmental parameters such as state of occupancy (presence/absence), state of light (on/off), indoor and outdoor illuminance, temperature, relative humidity, state of shades and windows (open/close) have significantly affected the operation of building systems (natural ventilation, shading and lighting). So, it is necessary to obtain the accurate information about user control behavior in the way of predicting building energy performance and energy consumption.

2.2. Selected Studies About Lighting in Educational Buildings

In educational environment, daylighting has a crucial impact on performance and alertness of students. Besides visual responses, light has other effects on human being such as performance, mood, attention and the synchronization of biological clock. There are several factors having impacts on human circadian rhythm like duration, intensity, timing, spectral power distribution of the light (Bellia, Pedace, & Barbato, 2013).

> *"The lighting design for a school needs to provide a lit environment which is appropriate for the particular interior and indeed exterior, achieving lighting which enables students and staff to carry out their particular activities easily and comfortably in attractive and stimulating surroundings"* (DfEE, 1999).

Daylight is considered the best energy source of light for good color rendering and human visual response. It is seen that a proper daylight increases the academic performance and provides a healthier study environment (Li, Cheung, Wong, & Lam, 2010).

In school buildings, achieved thermal and visual comforts, indoor air quality take precedence over running costs for heating, cooling and ventilation. However, in many countries, school buildings are designed and constructed almost like any other type of building. Inadequate daylighting and inconvenient indoor air quality lead to presence of improper educational buildings. There should be more and specific interest about the air quality and lighting problems as well as energy efficiency in school buildings (Theodosiou and Ordoumpozanis, 2008).

However, there are still some studies about environmental conditions of educational buildings. For example, Szepessy (2007) studied the occupants' interaction with the environmental control systems in educational office buildings. The focus was on the control-oriented occupant behaviour toward systems for shading and lighting. High resolution data for occupancy, temperature and relative humidity, light on/off, internal and external illuminance were collected. Behavioral patterns were defined. The operation of shading and lighting systems were significantly dependent on these parameters. Consequently, it is necessary to convert such behavioral patterns into realistic user action models. So, it would be possible to improve the accuracy of building performance simulations. Another study was about electric energy consumption, cooling loads and construction materials of an educational building in Saudi Arabia (Sait, 2013). Thermal analysis in relation to lighting energy consumption was conducted through thermal zone images. This study stated a Building Management System (BMS) was a good choice in order to control and maintain air conditioning system control besides reduction of energy consumption. As a result, air conditioning system and lighting should be precised, insulation curtains and external insulating films should be added and number of lights should be reduced in order to save energy in the educational building. Barbhuiya and Barbhuiya (2013) showed the effect of ventilation strategy of a typical educational building on energy consumption of the building and the impacts of the thermal comfort of the users. Loughborough University's Civil & Building Engineering department has been selected as a case study and the influence of occupants' behaviour in terms of quantifying the use of natural light has been investigated. Indoor temperature and lighting levels have been monitored and the trends of thermal and visual comfort have been discussed. Dynamic thermal simulation was carried out by using IES as a simulation tool. Results have been compared according to reduction in energy consumption which showed that the thermal comfort couldn't adequately achieved. The average working plane illuminance in winter was below the CIBSE limit of 300 lx for office spaces which led to increase lighting electricity consumption. It was found that, ground offices' indoor temperature were below the lower limit of 19ºC. As a result, better interior design strategies and adopting dimming profile for lighting control would help increasing educational building energy performance significantly as well as increasing thermal and visual comfort.

2.3. Importance of Simulation Analysis in Energy Efficiency Determination

By the help of a simulation tool, prediction of the building performance has become possible within economical and practical limits. Simulation is a numerical experiment on a mathematical model which is used to find out the possible results depending on changing inputs or the models. The input parameters should be adjusted according to the simulation result evaluations (Karlsson, 2006). Nowadays, accurate and efficient performance modelling and its simulation have become inseparable part of the decision making period in order to design high performance building and retrofitting.

Nowadays building simulation tools became widespread while designing a new construction or retrofitting a building. These tools enable designers to evaluate energy consumption, thermal, visual and acoustical comfort as well as to analyze the design options to ensure optimum performance throughout their service life (Barbhuiya & Barbhuiya, 2013).

Energy simulation tools provide analyzing the energy performance of buildings and thermal comfort of their users. They differ from each other according to their thermodynamic models, their purpose of use, their ability to exchange data with other software applications etc. Most of them contain mathematical and thermodynamic algorithms enabling to calculate the energy performance according to the model.

Energy simulation tools are based on assumptions due to the complexity of the building. The weather data and user factors are also based on assumptions and simulations. So, we cannot provide totally correct results as in real life (Maile, Fischer, & Bazjanac, 2007).

As Yılmaz (2010) mentioned, simulation tools are generally need some inputs:

- Climatic inputs,
- Building geometry,
- Building environment and building material features,
- Building zones,
- Heating, cooling and air conditioning systems,
- Lighting systems,
- Shading systems,
- Indoor equipment,
- Economic inputs.

In case of releasing undetailed information of the buildings, results could be deceptive. These mistakes are generally made by users who don't have full knowledge of simulation programs. On the other hand, due to the presupposition of building occupation schedule, air change rate and indoor equipment in predesign stage of a new building, there could be some errors in the simulation results (Yılmaz, 2010).

Simulation programs that are not actual but virtual experiments have been developed to anticipate/predict the future implication of one's current action. A key feature of intelligent behavior simulation based approach predicts models are analytical, empirical-based and numerical simulations. Simulation control provides many advantages such as; (Mahdavi, 2013)

- Effectively inform control decision making,
- The variety and sophistication of control variables can be extended,
- Simply change the configuration of building by making sure that control logic up-to-date,
- Virtual sensors,
  - ✓ Unlimited sensor locations,
  - ✓ Unlimited sensor types (glare, radiant asymmetry, cost, etc.),
- Aggregate indicators (PMV, PPD),
- Flexibility in face of layout system configuration.

On the other hand, there are some specific problems with simulations such as; human factor and weather forecast.

Human factor: Occupancy, actual usage of the building has not a static schedule, it changes on a daily basis. It is not useful to keep track of human behavior, occupancy for each thermal zone and match it with the actual occupancy. As a result, the input of occupancy schedule cannot represent the actual usage of the building to be simulated (Maile, Fischer, & Bazjanac, 2007).

Weather forecast: Cooling and heating loss are calculated according to assumptions. In order to perform the heat loss and gain calculations, the description of weather data should be defined precisely. Weather data which is not a static input do not allow having 100% correct results in simulation programs (Maile, Fischer, & Bazjanac, 2007).

Comparison of architectural design alternatives is the major benefit of the energy performance simulation programs. They are alternatives to the existing building and are validated for both thermal comfort and energy usage of the building. Simulation results are rarely found accurate for the prediction of absolute energy values. Many validation tests are performed to validate building energy simulation tools relative to each other. BESTEST (Building Energy Simulation Test) is one of the validation test which is developed and conducted by IEA (International Energy Agency). It is also possible to conduct validation test comparing actual measurements from test buildings. Absolute values differences are the results of the internal load assumptions such as dynamic occupant usage and so on. In order to have more accurate results, energy simulation models should be calibrated with actual measurements (Maile, Fischer, & Bazjanac, 2007).

According to Mahdavi (2013) further progress such as; simulation model calibration, building monitoring, microclimatic forecasting, occupancy modelling and dynamic model to achieve more accurate results from simulation programs are needed.

Simulation model calibration: In order to achieve accurate simulation models; calibration, verification and validation should be done. First of all, created base model should be calibrated to match area being studied. After then, to ensure that, this model works as expected based on the input, it should be verified. When the model has been verified, validation of the model should be done by comparing the model results with the data obtained from the case study.

Building monitoring: In order to collect data and useful information for achieving building energy performance from the case study area, building monitoring could be a technique by using a set of devices such as cameras, data loggers and sensors.

Microclimatic forecasting: Even if it is possible to obtain simulation results from study area location, some restrictions still exist for 100% accuracy of these results such as local wind direction, humidity and temperature alterations depending on the altitude.

Occupancy modeling: It is not always possible to obtain occupancy in a study area, so occupation pattern is an important factor in order to obtain more accurate simulation results.

Dynamic model actualization: It should be checked that if the model works under different sky conditions.

Simulation tools (for energy and lighting) have been extensively used in several studies to find optimum solutions for energy efficient buildings. For example, a study about the calculation of daylight levels has been conduted by Güvenkaya and Küçükdoğu (2009). They evaluated and applied the energy efficient design principles in the design of elementary schools by identifying envelope options using Radiance to calculate daylight levels. Ng, Wittkopf and Sun (2011) used EnergyPlus to simulate annual daylight levels at different measurement points in a small office building in Singapore. Ağırman (2013) used different simulation programs such as Radiance, DAYSIM and Ecotect and drawn a 3D Model Data with SketchUp for dwellings that she studied in order to find out the optimum solutions for side effects of thermal retrofitting in the field of daylighting. Ferreira, Soares and Rocha (2011) tried to find out the impacts of different control systems of lighting by using DAYSIM to compute the daylight autonomy and the levels of illuminance. Another study was about the potential impact of different PV shading devices on energy performance and daylight of office buildings (Khezri, 2012). He focused on external solar shading devices in Nordic Climate by analyzing five different control strategies using COMFEN, Ecotect and PVSyst computer programs in order to achieve quantitative data comperative analysis. Al-Dawoud (2006) investigated the impact of climate, glazing type and percentage from energy performance aspect for atriums and courtyards by using DOE2.1E simulation program. The importance of sustainable design for low energy consumption providing thermal comfort under warmer summer conditions has been studied by Holmes and Hacker (2007). In their research, the performance of a school building has been evaluated by using ENERGY2 simulation tool in their study.

Nowadays, accurate and efficient performance modelling and its simulation became inseparable part of the decision making period in order to design high performance building and retrofitting. Parallel to the process of improving performance modelling and programming, evaluating, applying and standardizing became crucial. Computer based simulation programs formulize the building in the field of energy, acoustic, visual and thermal comfort performances and provide to examine alternative results. It is possible to see if a building could meet or not the foreseen standards by the help of simulation programs.

2.4. Lighting Simulation Tools

Lighting designers and architects are quite interested with the use of Computer Aided Design Techniques for lighting attracts. Softwares provide accurate and physical valid lighting and daylighting design. They are applied to aid and design of varios new and unrealized buildings with little contextual restrains (Ng, Poh, Wei, & Nagakura, 2001). On the other hand, energy policy and saving estimation should not consider only the simulation results alone, but the field measurements should be taken into account also (Soori & Vishwas, 2013). Simulation tools used to evaluate the daylight and energy performance of control strategies were previously based on oversimplified settings and control strategies due to the limitations on available tools and techniques (Shen, Hu, & Patel, 2014). Some simulation tools recently used in studies were explained briefly.

Radiance is a suite of programs used by architects and engineers for the analysis and visualization of lighting in design. It was developed for Unix environment by the Building Technologies Program in the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory in Berkeley, California. Prediction of illumination, visual quality and appearance of design spaces evaluation of new lighting and daylighting tecnologies can be made by using Radiance. For lighting simulation, Radiance uses a hybrid approach of Monte Carlo and deterministic ray tracing techniques to compute radiance values such as the quantity of light passing through a specific point in a specific direction (Radsite, 2015).

The 3D model which is created either in Radiance or in CAD programs should include appropriate amount of details including surface materials chosen from the Material Editor to obtain proper photometric analysis.

DesignBuilder is a modular solution which was launched as the first Graphical User Interface to the EnergyPlus simulation engine. It comprises a core 3D modeller and 9 modules (Visualization, certification, simulation, daylighting, HVAC, cost, LEED, optimization and CFD) working together in order to provide energy use and consumption for buildings. It allows link to BIM solutions, analyze solar shading and test façade options. It has a advantage of modelling glazing systems including frame dividers and reveals in detail while electrochromic glazing, transparent insulation are also possible. Alike Radiance, DesignBuilder uses also CIE sky models. Beside Radiance, DesignBuilder uses also EnergyPlus simulations in order to determine the impact of daylight strategies on energy and carbon savings (DesignBuilder, 2012).

EnergyPlus has been developed by the support of US Energy Ministry and has a high calculation capacity. However, it does not have a developed user interface in real terms. It needs a professional use to manage program inputs and outputs as well as target-oriented usage. It should be considered that energy analysis works according to model's inputs and it is crucial to have complete and real inputs in order to achieve accurate and confidential results. Preparing a building for energy simulation involves many steps such as building geometry, environmental and energy parameters investigation, measurements and records (Yılmaz, 2010).

Ecotect provides to couple 3D modelling interface with solar, thermal, lighting, acoustic and cost analysis functions. Its export facilities is able to make the final design validation by interfacing with many analysis tools such as Radiance and EnergyPlus. Energy performance of buildings, thermal simulations, solar radiation, daylight levels and shadow diagrams can be simulated and analyzed (EERE, 2015).

Integrating into Ecotect Analysis or exporting the model to Radiance, this program can generate daylighting analysis. It needs the 3D models as simple as possible such as a massing model with defined zones for daylighting analysis. Ecotect Analysis together with Green Building studio allow producing data for energy analysis, water usage and cost evaluation, thermal performance, solar radiation, daylighting, shadows and reflections. On the other hand, it is possible to calculate electric lighting as footcandle levels by BRE daylight calculation or by Radiance exports (Ecotect, 2012).

Velux Daylight Visualizer developed by LUXION in collaboration with the VELUX group provides rendering and computer based lighting simulations. Models can be either created by Daylight Visualizer or imported from a compatible program such as

SketchUp or AutoCAD. Luminance, illuminance, daylight factor and daylight animation are the simulation outputs. It is possible to import 3D models if they are only made of polygons. On the other hand, allowing only orthogonal shape modelling, application of the textures only for horizontal surfaces and not having undo function are the other restrictions of the program (Velux, 2012).

Relux is a lighting planning software for architects, designers and electrical engineers where the calculations and simulations are carried out by the radiosity method. Simulation are complying with the standards EN 12464 for interior rooms and outdoor projects, EN 1838 for emergency lighting and CIE for daylight. Proof of energy consumption for rooms, zones, storeys, properties are made according to the EN15193 and DIN18599. Simulation results can be exported as DXF and DWG for scenes, HDR for simulations, XLS for lists, AVI, JPEG and BMP for films (Relux, 2012).

DIALux is a complete software developed by DIAL GmbH provides to make light planning by allowing the use of latest luminaire data of the world's manufacturers via online menu. Energy evaluation, colored light scenes with LED or other color changing luminaires and planning whole buildings including outdoor spaces are possible. It gives the street light calculation according to American Standard IESNA RP-08-00 and it is possiple to switch between the European standard CIE 140/EN 13201. In this study, DIALux 4.12 version has been conducted in order to evaluate illuminance and uniformity values in the selected parts of the case building (DIALux, 2015). On the other hand, being a userfriendly program, DIALux has some restrictions that can be viewed as disadvantages. One of them is that DIALux is not able to calculate the energy consumption for selected specific hour periods. In this study, all the calculations were done manually. Another negative side is that, DIALux is not capable to make the models in every form in detail. It means that, shading devices were modeled as rectangular prismatic form, differently as in real case.

Both of DIALux and RELUX calculate electric light, daylight and energy performance of the electric light. They are free of charge but not opens sources. However, Relux licences for programs subject to a charge, for special applications such as; ReluxVivaldi, ReluxEnergy CH, ReluxCAD and ReluxTunnel (Relux, 2012).

2.5. Selected Studies about Daylighting Simulation Tools

There are various types of daylighting design tools used by practitioners providing qualitative and quantitative information. These tools involve: (IEA, 2000)

- Physical models,
- Simple tools (formulae, tables, nomograms, diagrams, typology, computer tools etc.),
- Computer based tools, simulation programs (images, visual comfort calculations etc.).

A study was carried in order to explore the impact of ceiling geometry and louver paramaters on the performance of daylighting by using Radiance simulation program and physical model experiments (Freewan, Shao and Riffat, 2008). The illuminance level and its distribution uniformity have been investigated as performance indicators for daylighting performance in a subtropical climate region. Physical model experiments and Radiance simulations have been compared. As a result, it was seen that the performance of the the louvers could be improved by differing the ceiling geometry. Ng, Wittkopf and Sun (2011) compared the impact of glazing type on daylighting performance for a small office building facing to West located in Singapore. Another study by Kazanasmaz (2013) is about the estimation of daylight illuminance and classification of its effectiveness with a movable blind system. The software tool used in this study was DIALux. The field measurements in a real case validated the simulation model. So, daylight calculations in terms of different alternatives of slat angles in the movable blind systems were done by using this simulation model. Greenup and Edmonds (2004) studied on the effect of micro-light guiding shade which is a device that acts both shade the façade from direct sunlight and distribute daylight into deep into the buildings. It performs the dual purposes of shading and redirecting the light. Its effectiveness, efficiency, implementation, cost and construction issues were performed by experiments and by simulation tools. Radiance is the simulation tool which was used to compare the results obtained from experiments. It was also powerful in finding the optimal configuration of the panels in various situations.

CHAPTER 3

THE PROCEDURE

3.1. Description of Sample Rooms in the Case Building

In this study, an educational building which requires a high level of daylighting performance, because of being used all day long, became the case building. A university building complex, Department of Mechanical Engineering Building in Izmir Institute of Technology was evaluated in terms of energy efficient lighting criteria. The selection criteria about this building are mentioned as below.

The first criterion is based on the variety in orientation and the types of their function. There are several rooms facing to different directions. These rooms vary according to their sizes and the purpose of their use. The second criterion is about the shading device types which vary due to their design and material and fixed on all façades. The last one is about its daylighting performance. This is considered as insufficient according to the previous research conducted by Kazanasmaz et al. in 2011.

Figure 3.1 Location of the case building, view from Google Earth

This case building showed in the Figure 3.1 is located on the southern part of the IYTE campus and has 38°32' N latitude and 26°64' longitude. It is constituted of two floors over the ground and a basement and has an approximately 6676 m^2 of area of usage. The building is planned around an introverted courtyard containing classrooms, laboratories on an educational wing and has a storey height of 3.30-3.60 m. Classrooms are facing Southeast and Southwest while laboratories are located on the extraverted part of the wing and facing Northeast and Northwest. Office rooms and lecture hall are located on the administrative wing having a storey height of 2.60 m and facing Southwest and Northwest. Figure 3.2 and 3.3 present the Southeast façade of this building and its ground floor plan. The physical and geometrical properties of the sample rooms (Table 3.1) and the layout and technical properties of the artificial lighting system were obtained from the architectural and electrical/lighting system drawings and field observation. By utilizing such drawings and obtaining visual data by observation, several sample rooms were selected.

Figure 3.2 View from main entrance (Southeast façade) of the building

In order to evaluate the daylight performance of the building, six different rooms having different functions, sizes and façade configurations are selected from all four directions. The sample rooms were located on the ground floor as displayed and marked with blue in Figure 3.3 were designated with codes, namely Part A, B, C, D, E and F. They involved classrooms, a lecture hall, a laboratory and office rooms which were given the geometrical description in Table 3.1 and explained in detail below. Each part has consisted of single volume space and can only receive sunlight from one way.

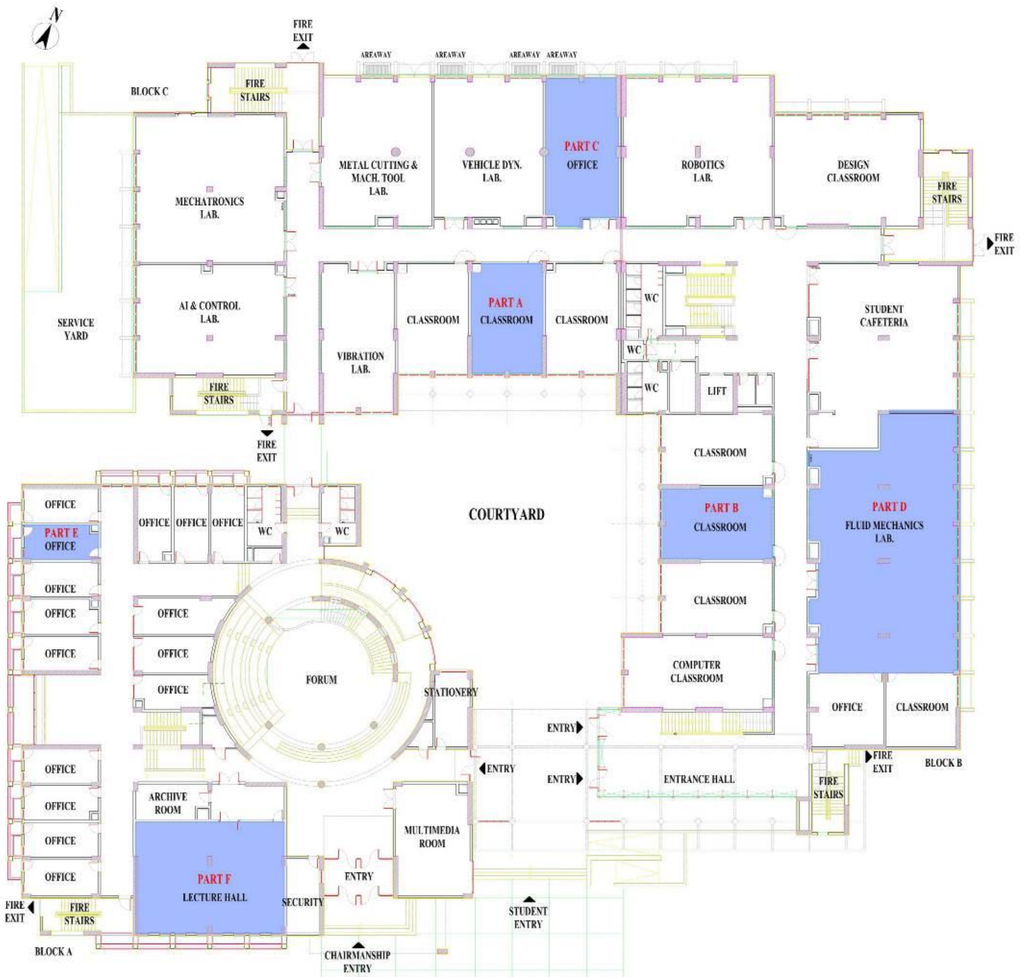


Figure 3.3 General layout of the building and studied parts in blue

Table 3.1 Geometrical description for the case building

DESCRIPTION		Part A	Part B	Part C	Part D	Part E	Part F
ORIENTATION		Southeast	Southwest	Northwest	Northeast	Southwest	Southeast
ROOM	No.	Z55	Z48	Z35	Z64	Z17	Z06
	Type	Class	Class	Office	Lab	Office	Lecture Hall
	Lighting Row No. & Total Lighting No.	3 & 9	3 & 9	6 & 18	3&30 - 3&24	3 & 3	4 & 24
	Illuminance Measured		X		X		
	Width, m	6.40	6.40	6.50	22.90	3.10	13.00
	Depth, m	9.80	9.80	12.40	12.10	6.60	9.85
	Height, m	3.60	3.60	3.30	3.30	2.60	3.40
	Floor Area (m^2)	61.13	62.83	80.36	268.82	19.70	128.19
WINDOW	Width, m	2.90	2.90	2.90	2.90	0.95	0.95 & 1.40
	Height, m	2.55	2.55	1.80	1.80	2.50	2.35
	Height from Floor, m	1.05	1.05	1.05	1.05	0.10	1.05
	Pieces	2	2	2	7	2	7 & 1
	Total Glazed Area (m^2)	14.80	14.80	10.44	36.54	4.75	18.92
	Window-to-Wall Ratio (WWR %)	63	63	49	48	59	43

Figure 3.4 Views from Part A

Part A (Figure 3.4) is a Southeast-facing classroom and located at the education wing looking to the courtyard. It has a 6.40m width and 9.80m depth with a storey height of 3.60m. This part does not have any shading devices or cantilevers on the façade. Thus, the curtains are the only sun blocker. Windows are located on a single façade and Window-to-Floor Ratio (WFR) has been defined as 24%. In this part, there are only tables and arm chairs as furnishing.

Figure 3.5 Views from Part B

Part B (Figure 3.5) is another classroom facing Southwest and looking to the courtyard. It has a width of 6.40m and a depth of 9.80m with a storey height of 3.60m. This part also does not have any shading device or cantilever on the façade. Thus, the curtains are the only sun blockers. Windows are located on a single façade and WFR has been defined as 24%. In this part, there are white color wooden surface tables and chairs as furnishing.


Figure 3.6 Views from Part C

Part C (Figure 3.6) is an office room shared by four research assistants of the department. It is a Northwest-facing room and located on the outer perimeter of the building. It has a width of 6.50m and a depth of 12.40m with a storey height of 3.30m. This part has horizontal overhangs with dimensions of 1.00m and 0.30m and vertical cantilevers with dimensions of 1.25m, 1.20m and 0.40m on the façade in order to control direct sunlight penetrating. However, these extensions cause the insufficient daylighting instead of controlling. Windows are located on a single façade and WFR is 13%. Chairs, desks and many cupboards in different sizes are the furnishings of this place.


Figure 3.7 Views from Part D

Part D (Figure 3.7) is a laboratory facing Northeast and located on the outer perimeter of the building. It has a width of 22.90m and a depth of 12.10m with a storey height of 3.30m. There are horizontal shading overhangs with dimensions of 1.00m and 0.30m and vertical cantilevers with dimensions of 1.25m, 1.20m and 0.40m on the façade to block daylight. Windows are located on a single façade and WFR is 14%.

High test benches located in the middle of the laboratory by the long side, block the daylight entering the deep of the laboratory.

Figure 3.8 Views from Part E

Part E (Figure 3.8) is an academic staff facing Southwest and and located on the outer perimeter of the building. It has a width of 3.10m and a depth of 6.60m with a storey height of 2.60m. There is a balcony with a depth of 1.20m and fixed horizontal shading devices. Windows are located on a single façade and WFR is 24%.

Figure 3.9 Views from Part F

Part F (Figure 3.9) is a Southeast-facing lecture hall and located on the main entrance-façade of the building. It has a width of 13.00m and a depth of 9.85m with a storey height of 3.40m. This part, similar to Part E, has its own balcony in front with a 1.20m depth and fixed horizontal shading devices in order to control direct sunlight penetrating. Windows are located on a single façade and WFR has been defined as 15%.

3.2. Field Measurements

The rules and recommendations by CIBSE Code (1994) were used to determine the number of measurement points and their locations. In order to evaluate the current daylighting performance of the selected parts, daylight illuminance measurements were taken from Part B and Part D at reference points as showed in Figure 3.11 and Figure 3.12. A digital illuminance-meter and a luminance-meter (Figure 3.10 (a) and (b)) were used to obtain vaues of illuminance and luminance. A digital illuminance meter with detachable receptor head was used where the units are given in Lux [lx] or foot candles [fcd]. The measuring ranger are 0,01 – 299,900 lx and 0,001 – 29,990 fcd. User calibration function could be set the correction function (CCF) ranging from 0.500 to 2.000 with accuracy 2% ±1 digit of value displayed. A luminance meter having small diameter measurements (0.4mm) with SLR (single lens reflex) was used. Measure dark surfaces range starts at 0.001 cd/m^2. The instrument has three settings: instantaneous luminance, peak luminance and luminance ratio and categorized in the upper range of DIN quality class B (Konica Minolta, 2015).

(a) (b)

Figure 3.10 Illuminance meter (a) and luminance meter (b)

(Source: Konica Minolta Instrument Catalogue)

All the measurements were carried out on December 4th, 2014. The sky condition was partly-cloudy. The measurement time was 2:00 PM for Part B and 2:30 PM for Part D.

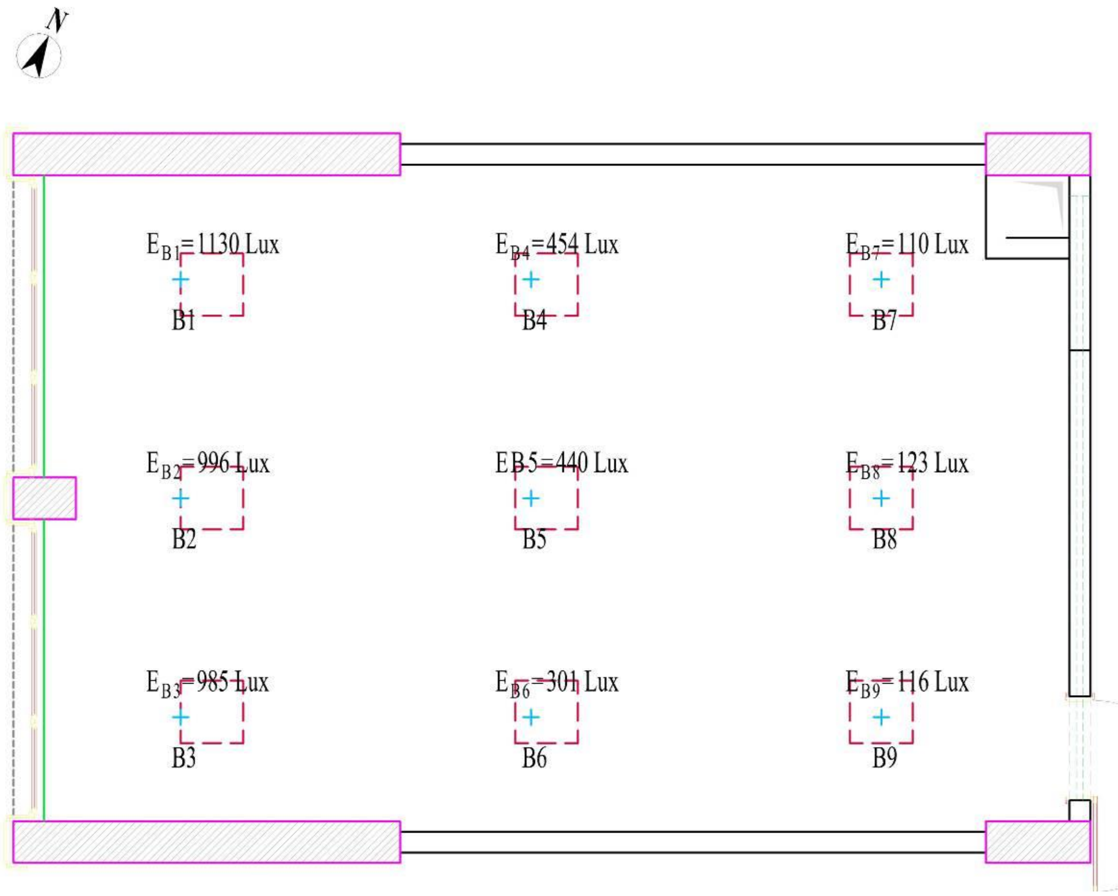


Figure 3.11 Illuminance measurement points' layout for Part B

The constant height for each reading was 0.75m from the floor level. The measurements were used to validate the simulation model. As the surface materials and façade configurations of Part B and Part D are similar to the other rooms, field survey was conducted in only these places.

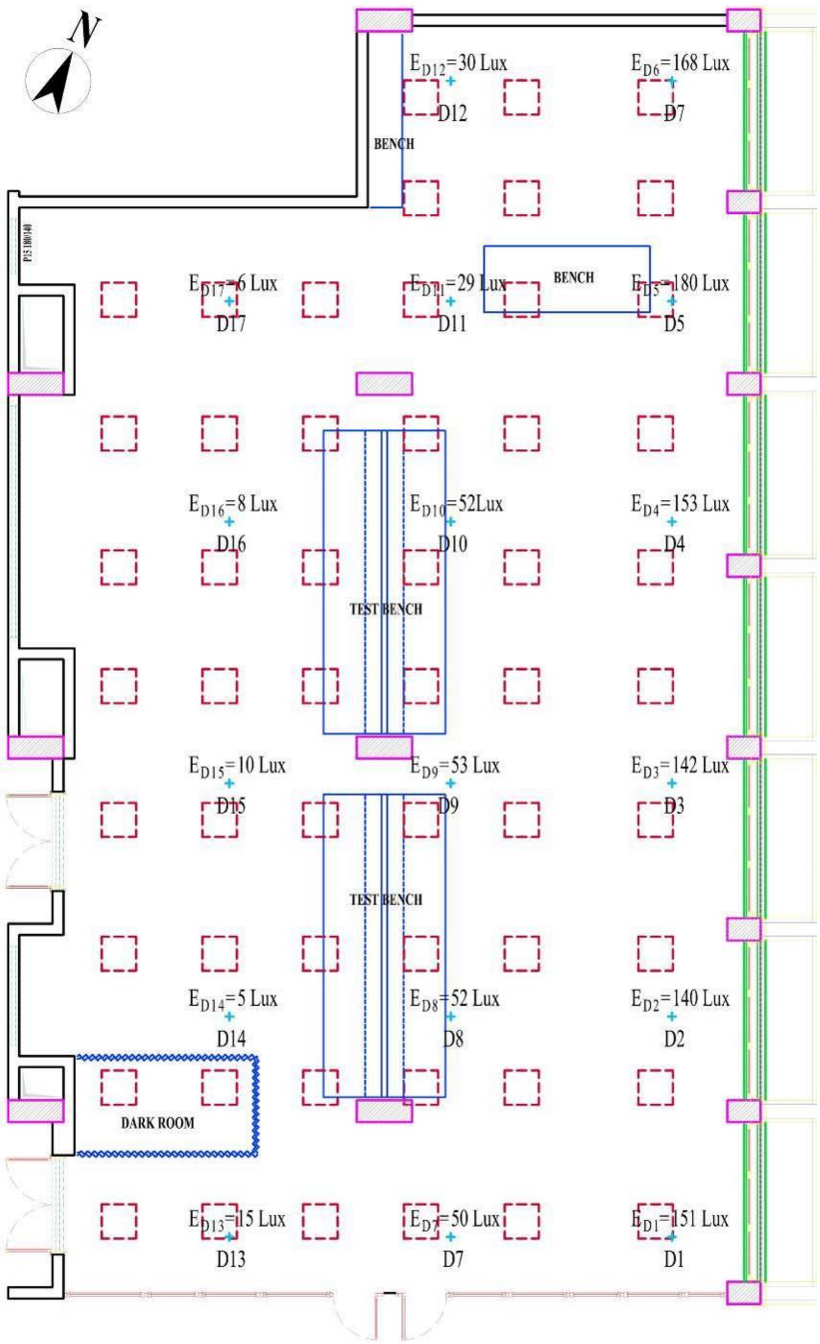


Figure 3.12 Layout of Part D with illuminance measurement points

By the help of luminance meter and illuminance meter, optical properties of the glazing (transmittance) and surface materials (reflectance) for walls, floor and tables were determined. Regarding to CIBSE standards, required illuminance values for classrooms in educational buildings should be 300-500 lx and for laboratories this should be 500-750 lx (CIBSE, 1994). Luminance and illuminance at specific points on surfaces were measured. Reflectance and transmittance were calculated according to the formula (1-3) below (Fontoynont, 2013). Table 3.2 displays the reflectance of surface materials and transmittance of glazing.

$$L = E x \rho / \pi \quad (1)$$

L: Luminance [cd/m^2]

E : Illuminance [lx]

ρ : Reflectance of the surface material

$$\tau_{nn} = L_{in}/L_{out} \quad (2)$$

L_{in} : the luminance of an object observed behind the glazing

L_{out} : the luminance of the same object without glazing

τ_{nn} : the normal-normal transmittance of a clear glazing

$$\tau_{nn} = E_{in}/E_{out} \quad (3)$$

E_{in} : the vertical illuminance behind the glazing

E_{out} : the vertical illuminance without glazing

($E_{outside}$= 3951 lx)

Table 3.2 Reflectance of surface materials and transmittance of glazing for Part A-F

Reflectance of Surface Materials			
ρ	**Wall**	**Floor**	**Table**
	68%	25%	55%

Transmittance of Glazing	
$\tau_{nn} = E_{in}/E_{out}$	$\tau_{nn} = L_{in}/L_{out}$
1848 lx / 6065 lx = 30%	54,95 cd/m^2 / 130 cd/m^2 = 42%

Transmittance of glazing is accepted as (30+42)/2= 36%

3.3. Simulation Models in DIALux

Simulations were employed for winter/summer solstices and equinoxes in DIALux. It calculated both daylight and artificial light illuminance in each selected room of the educational building. These analyses involved calculations at 9:00 AM, 12:00 PM and 3:00 PM. The geometrical and optical properties of these rooms were the inputs as observed and calculated in the field survey. The validation of the simulation model was due to the comparison of the actual daylight illuminance with the base case model outputs. The model involved the location (latitude and longitude) of the site and the orientation of each room customly. DIALux calculated the sun position according to this information and the date as well. The azimuth and altitude angles determine the sun position according to location and date. Table 1 presents these angles which were obtained from an online sunpath diagram calculation tool for the exact location in İYTE, Urla, Turkey (http://www.sunearthtools.com/dp/tools/pos_sun.php).

Table 3.3 Sun angles for the selected location

	Azimuth /Altitude		
	09:00	**12:00**	**15:00**
December 21 (gmt+2)	115.710	147.780	192.520
	-5.450	20.980	27.200
March 21 (gmt+2)	95.960	131.150	195.720
	7.810	40.090	50.920
June 21 (gmt+2)	85.770	127.450	243.890
	34.370	68.130	63.200
September 21 (gmt+2)	107.910	153.900	221.490
	22.340	49.370	44.190

DIALux is a lighting simulation tool which is used to predict electric lighting performance and to design the layout of luminaires with the necessary illuminance and power load. It calculates the illuminance on working plane and at specific points. It also displays the luminance on specific points in lighting analysis. This tool may also calculates daylight illuminance similarly. Thus, exact location (latitude and longitude) may be set and the orientation of the space can be fixed. It calculates daylight illuminance with the integration of sky models such as clear, overcast and partially overcast skies. These are in accordance with CIE 110-1994 “Spatial Distributions of Various Reference Skies”. Calculations are performed according to DIN 5034 and CIE publication 110. DIALux involves the use of actual electric lighting fixtures from the market. DIALux applies radiosity as the simulation engine.

Consequently, as daylighting and artificial lighting calculations might be collectively evaluated by DIALux, this tool was used in this thesis. Energy efficient design criteria such as environmental factors, building skin, glazing selection, shading device, passive climatization, daylighting and artificial lighting, building form and orientation determine the sustainability of the building. So, DIALux displays the ability to calculate the daylight illuminance with external obstructions and artificial lighting illuminance with electrical energy consumption as well. So, shading devices, lightings and glazings of the case building were analyzed and alternative retrofit solutions were proposed in terms of energy efficient lighting criteria by using DIALux simulation tool. Parameters below were considered in order to retrofit the case building:

- Fenestration (dimensions, glazings’ type, color and transmission value),
- Shading device,
- Surface color,
- Lighting fixture layout and type.

Various design alternatives were produced and scenario resulted in;

- Illuminance,
- Uniformity

were compared according to standards and design recommendations.

3.4. Definition of Input and Output Parameters

Selected and grouped rooms according to the criteria mentioned above were evaluated in terms of daylighting performance. For this, their illuminance and uniformity were specified, daylighting performance were determined and the amount of the space that can benefit from daylight was studied. Artifical lighting was identified and analyzed according to the actual lighting luminaires.

3.4.1. Fenestration

Many different studies have been conducted to investigate the role of fenestration/windows on building energy consumption. For example, Ghisi and Tinker (2005) studied on optimum window areas (window to wall ratio) in a 10-storey office building in order to obtain optimum lighting energy usage for various room sizes and window orientations by using energy simulation programs. Optimum window area provided the lowest energy consumption for artificial lighting and cooling solar heat gained through fenestration. Another study conducted by Ko (2009) was about the improvement of the energy performance of office buildings depending on fenestration. He used simulation programs for different climate zones to define the best combination of fenestration parameters: window area, visual transmittance, heat transfer coefficient and solar heat gain coefficient in order to optimize daylighting and energy savings.

Susorova et al. (2013) mentioned that fenestration paramaters such as;

- Window-to-wall ratio,
- Window orientation,
- Width-to-depth ratio

may decrease the energy consumption (up to 14% overall savings) by using an optimum geometry in hot climatic regions. Shallow rooms with medium-sized windows generally perform properly for all orientations while deep rooms with medium-sized windows generally perform the best in cold climates. Properly designed fenestration due to its geometry and combination with shading may minimize the energy consumption of the building.

Boubekri (2004) mentioned that, recommended window to floor area ratio for daylighting must not be less than 14% according to German DIN 5034-4 standard. In the spaces having more than 8m depth, it is not possible to obtain ideal values for an optimum daylighting.

While providing a good daylighting, considerable energy savings could be achieved. However, natural light is not “free” for using in the building. It means that, large glazings may result in a great amount of heat loss in winter and heat gain in summer and may also cause visual discomfort. These issues should be solved properly in early design stage. For instance, double glazing or high effective thermal insulation glasses might be used (DfEE, 1999).

So, fenestration is one of the important input factors in constructing retrofit scenarios in this study. The window area will assumed to be stable and unchanged in retrofit scenarios, since the ratio of window area to floor area is within the recommended range. However, the transmittance of glazing and the colour of fenestration will be the input variables. Since it is considered that they might easily and practically be changed in a retrofitting construction in this building.

3.4.2. Surface Color

Lopez-Besora (2014) mentioned that the proper use of color in spaces provides reduction in energy consumption in lighting. Surface color has different effect on the perception of space in terms of dimension, lightness and user's mood.

It is proposed to use lighter color for the main surfaces if the space is to appear light. Floor is one of the important reflecting surfaces in a building and should have a light color. In order to obtain proper overall lightings, it is important to use relatively high surface reflectances. For instance, wall finish reflectance should not ensure less than 0.6 with ceiling finish reflectance not less than 0.7 and floor reflectance should be as high as practicable. In order to minimize confusing reflections and glare glossy finishes to ceilings and walls should be avoided (DfEE, 1999).

3.4.3. Shading Device

The main purpose of a shading device is to protect the building transparent envelope from solar radiation and to prevent overheating by blocking undesired energy flow into the building. Solar shading devices has an important effect on reducing annual energy requests of the systems (Bellia, Falco and Minichiello, 2013).

Shading and light redirecting devices can be classified into either static or movable. A lightshelf, an overhang or a laser cut panel are the types of static devices. On the orher hand, venetian blinds, roller blinds or curtains are the movable device types (Reinhart, Mardaljevic, & Rogers, 2013).

There are many researches conducted about shading device effects on energy consumption. One of them is made by Tzempelikos and Athienitis (2001) in order to evaluate shading device characteristics, shading control and glazing area on cooling and lighting loads. A building located in Montreal has been selected as case study and an exterior roller blade has been considered as shading device.

Figure 3.13 Views of shading devices (from Part E)

Figure 3.14 Views of shading devices (from Part E and F)

Another study conducted by Bellia, Falco and Minichiello (2013) to analyze the influence of shading devices on the energy requirement of an office building in Italy by using a simulation tool. They evaluated the energy demand of the lighting, heating and cooling systems and energy savings related to use of shading devices. Thus, in this thesis, shading device is another factor that affects the daylight illuminance and uniformity inside the building. By changing the optical properties of shading devices, they might act as light guiding systems, such as light shelves, to balance the light distribution on the horizontal workplane. They transmit daylight to the deeper areas in rooms. They will consequently be involved in retrofit scenarios. Shading device examples from case building are given in Figure 3.13 and 3.14.

Maestre et al. (2015) studied on the influence of the selected polar positions for shading device calculations in building energy performance simulations. They analyzed different overhang and side fin typologies and orientations, location lattitudes in their study. They used several types of shading devices made up of an overhang and two side fins. Overhangs were as wide as the window and a length equal to 100%, 75% or 25% of its height, while side fins were as high as the window and a depth equal to 100%, 75% or 25% of its width by considering different latitudes.

It is important to select the design and dimension of the shading devices because of being an integral part of the fenestration system design for the balance between many requirements such as daylighting, solar gains and letting the view to improve human performance. On the other hand, aesthetics and integration with building structure is another crucial issue in shading device selection (Freewan, 2014). Moreover, it should be tested that the shading devices do not block the outdoor views.

3.4.4. Lighting Fixture

There are many different parameters affecting the choice of lamps such as; luminous efficacy, total light output (wattage), color rendering, color appearance, size, lifetime, need for control gear, starting characteristics and cost. Besides, luminous efficiency and light distribution, appearance, ease of maintanence are the important subjects in choosing lamps and luminaires (DfEE, 1999).

Figure 3.15 Luminaires in the building

Lamps and luminaires should be cleaned regularly in order to eliminate deterioration of the light output performance. So, it is important to regard maintenance when selecting the lighting equipment. In a school building, an electric lighting equipment should be cleaned at least once a year. On the other hand, it is crucial to minimize the number of different lamp types to install improper/incorrect lamp. Another issue is properly distribution of light. It means that, walls and ceiling should ideally receive light both directly from lumaires and by inter-reflection (DfEE, 1999). Lighting fixture examples from case building are given in Figure 3.15.

3.4.5. Illuminance

Illuminance (E) is the total luminous flux incident on a surface per unit area and is the indicator which is related to brightness while directly reflects the intensity of the light and its unit is Lux (lx). Different surface color and reflectance may cause different illuminance level. In theory it is possible to reduce energy consumption in lighting if the illuminance distribution in space level could be adjusted and distributed uniformly (Hsieh, 2012; IEA, 2010). Similarly, daylight illuminance is the amount of light intensity penetrating inside through glazed surface (Kazanasmaz and Firat, 2013).

According to the use of building interiors, British Draft Development DD 73 Standard determines that (Boubekri, 2004; Kazanasmaz et al., 2011):

Recommended Illuminance values are:

Classrom & Office : 300-500 lx

Laboratory : 500-750 lx

3.4.6. Uniformity

Uniformity is another important output of this study. It is a measure of balance of daylight inside and provides to understand the distribution of light intensity throughout the horizontal/working area (Kazanasmaz and Firat, 2013). Uniformity values for daylit interiors should satisfy the equations below (4,5) according to DIN 5034 (Licht, 2006);

$$U_1=E_{min}/E_{avg}>0.50 \quad (4)$$

$$U_2=E_{min}/E_{max}>0.67 \quad (5)$$

3.4.7. Electrical Energy Consumption and Luminous Efficacy

Educational buildings have no exception in an efficient use of energy in lighting. It means that, carbon dioxide emissions and running cost of each lighting installation should be minimized. Energy efficiency in electric lighting is directly linked with proper selection of lighting equipment and with controlling the lighting. It is crucial to select lamps with an high efficacy. Those lamps derive high levels of light for the energy they consume (DfEE, 1999). Luminous efficacy is defined as the "quotient of the luminous flux emitted by the power consumed by the light source". Its unit is lm/Watt (IEA, 2010).

CEN standard EN15193 specifies the metering and calculation methodology to be conducted for the evaluation of energy consumption for lightings in the buildings. It introduces a Lighting Energy Numeric Indicator (LENI) for certification purposes. This standard can be both applied for the design of new and existing buildings to be retrofitted. On the other hand, EN15193 makes available a benchmarking system for various types of building in order to rank the energy needs for lighting and provides guidance with notional limits derived from reference standards. According to benchmark values and lighting design criteria (Table G.1 in appendices) given in EN15193-2007, Annex F Table 1, LENI values should be 27 $kWh/a.m^2$ - 34.9 $kWh/a.m^2$ for education buildings according to basic fulfillment of requirements. On the hand, laboratories needs greater illuminance values (500-750 lx) than classrooms and office rooms (300-500 lx). For this reason, LENI values could be proposed as 41.8 $kWh/a.m^2$ - 51.9 $kWh/a.m^2$ for laboratories according to comprehensive fulfillment requirements (EN15193-2007).

Energy consumption has been calculated for each single three hour periods for characteristic days of the year; winter/summer solstices and equinoxes:

- 9:00 AM - 12:00 PM
- 12:00 PM - 3:00 PM
- 3:00 PM - 6:00 PM

Results are in the units of:

- Wh
- kWh/a
- LENI: Lighting Energy Numeric Indicator [$kWh/a.m^2$]

Assumption: Winter/summer solstices and equinoxes results cover 75 days four each. Thus, annual energy consumption corresponds 300 days.

3.5. Scenario Input Parameter Values

The objective here was to identify design alternatives of that would improve the daylighting performance and reduce the electric energy consumption. Illuminance and uniformity values are the indicators of visual performance. The insufficient amount of daylight during a certain time would determine the need for supplementary electric lighting. By utilizing the appropriate lighting fixture type and layout, energy consumed by the system would also be reduced. The working hours in this educational buildings was from 9:00 AM to 6:00 PM. The selected options for input parameters in constructing scenarios were described below.

3.5.1. Fenestration (FC, FT)

Two alternatives for fenestration color and four alternatives for fenestration transmittance were determined (Table 3.4) for retrofit simulations. FC_0 represents the base case (that means the original color of fenestration is dark green); FC_1 denotes the light color. T_0 is the base case that is the transmittance of glazing measured in the field; FT_1 displays the high transmittance, 90%; FT_2 represents the medium transmittance, 70%; FT_3 is the low transmittance, 50%.

Table 3.4 Values for fenestration color and fenestration transmittance

Fenestration Color FC (%)	**FC_0**		**FC_1**	
	80		90	
Fenestration Transmittance FT (%)	**FT_0**	**FT_1**	**FT_2**	**FT_3**
	36	90	70	50

3.5.2. Surface Color (SC)

Two alternatives for surface color including only wall color were determined (Table 3.5) for retrofit simulations. SC_0 represents the base case (that means the surface reflectance of the original wall color of wall is 68%); SC_1 is 80%.

Table 3.5 Values for surface color

Surface Color SC (%)	**SC_0**	**SC_1**
	68	80

3.5.3. Shading Device (SD)

In this study, apart from base case (S0), seven retrofit scenarios (S1…S7) have been conducted by using shading devices (light shelf, horizontal and vertical shading devices) in order to find optimum solutions to satisfy visual comfort and lighting energy efficiency. A light shelf, horizontal and vertical blinds were applied on the upper and lower division of the windows by proposing a wide range of slat angle combinations. Their locations, distances and numbers are proposed for all parts as in Table 3.6. Alternatives for shading devices were determined according to the slat positions and slat angles. The steps of scenario applications are explained in detail in section 3.6.

It is also important to make the selection of shading devices by considering their productibility and cost effectivitiy according to the presence in the market. Today, it is possible to find various types of the shading device with different materials and dimensions. However, shading devices with width of 15, 20, 25 and 30 cm are the most commonly used ones in standards (IEA, 2000; Schüco, 2015). For this study, shading devices with a regular width of 25 cm were selected in order to increase outdoor visual contact.

Table 3.6 Shading devices' locations, distances and numbers proposed for all parts

DESCRIPTION				Part A	Part B	Part C	Part D	Part E	Part F
ORIENTATION				Southeast	Southwest	Northwest	Northeast	Southwest	Southeast
SHADING DEVICES	Base Case (Solstice/Equinox)		**S0**						
	Light Shelf (LS) Location			2.20	2.20	2.05	2.05	1.80	2.20
			S1	LS					
	Horizantal Shading Device u: upper l: lower	Distance S2&S3		30 cm					
		Numbers	**S2**	u:4 LS l:2	u:4 LS l:2	u:2 LS l:2	u:2 LS l:2	u:2 LS l:5	u:3 LS l:3
		Numbers	**S3**	u:4 l:3	u:4 l:3	u:2 l:3	u:2 l:3	u:2 l:6	u:3 l:4
		Distance S4		20 cm					
		Numbers	**S4**	u:7 l:6	u:7 l:6	u:4 l:5	u:4 l:5	u:4 l:9	u:6 l:6
	Vertical Shading Device u: upper l: lower	Distance S5&S6		40 cm					
		Numbers	**S5**	u:7 LS l:7	u:7 LS l:7	u:7 LS l:7	u:7 LS l:7	u:2 LS l:2	u:2 LS l:2 u:3 LS l:3
		Numbers	**S6**	u:7 l:7	u:7 l:7	u:7 l:7	u:7 l:7	u:2 l:2	u:2 l:2 u:3 l:3
		Distance S7		20-23 cm					
		Numbers	**S7**	u:12 l:12	u:12 l:12	u:12 l:12	u:12 l:12	u:4 l:4	u:4 l:4 u:6 l:6

3.5.3.1. Light Shelf (LS)

A metal light shelf (Figure 3.16) has been proposed for each single window in all parts for retrofit scenarios S1, S2 and S5. S0 represents the base case. S1 denotes the first scenario including only the application of the light shelf. The rho value of its upper surface was determined as 90% with mirror effect in order to have further daylight reflection to the ceiling of the room. The rho values of other surfaces were 30% without mirror effect to prevent glare. Geometrical properties and location heights for the proposed light shelves are given in Table 3.7. Horizontal and vertical shading device locations are arranged according to light shelf position as upper and lower.

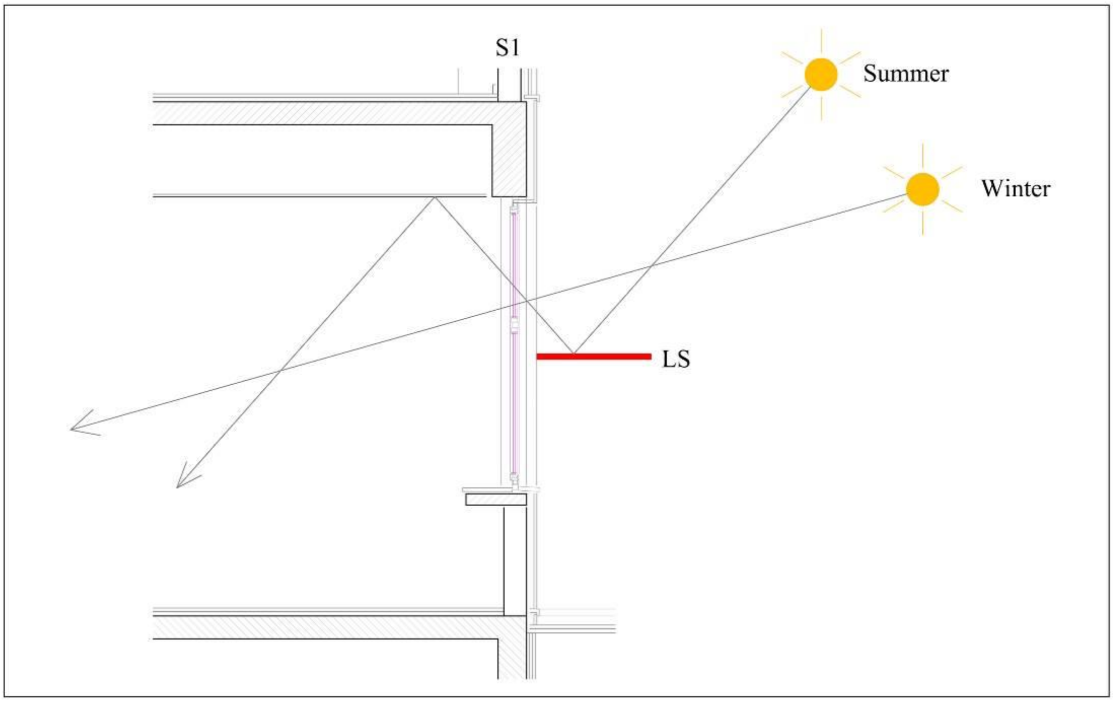


Figure 3.16 Light shelf representation for the case building
(Drawn by the Author)

In the market, exterior light shelf dimensions vary between 40 cm and 180 cm (Alcoa, 2015). For this study, 100 cm width was chosen as an optimum dimension after many simulation result evaluations. Height of the light shelf was basically decided according to the similar studies conducted (IEA, 2000; Alcoa, 2015). In order to maintain outdoor visual contact and prevent glare, the height of the light shelf was selected above eye level, 2.20m. However, it was seen that the light shelf wasn't so effective comparing to horizontal and vertical shading devices scenarios for the case building.

Table 3.7 Geometrical properties of a light shelf proposed for all parts

Parts	Room Height (m)	Window Height (m)	Light Shelf		
			Location (m)	Window Width (m)	Depth (m)
Part A	3.60	2.55	2.20	2.90	1.00
Part B	3.60	2.55	2.20	2.90	1.00
Part C	3.30	1.80	2.05	2.90	1.00
Part D	3.30	1.80	2.05	2.90	1.00
Part E	2.60	2.50	1.80	0.95	1.00
Part F	3.40	2.35	2.20	0.95 / 1.40	1.00

3.5.3.2. Horizontal Shading Devices (HSD)

Horizontal shading devices have been proposed for each single window in retrofit scenarios S2, S3 and S4 (Figure 3.17) of all parts. S2 is the second scenario including the installation of both the light shelf and horizontal slats. S3 and S4 are the variations of S2. The rho value of its upper surface is determined as 90% with mirror effect in order to have further daylight reflection to the ceiling of the room. The rho values of other surfaces are 30% without mirror effect to prevent glare. In this study, dimensions of an horizontal shading device are proposed by 0.25x0.05xwindow width (upper or lower) m. Slats are movable from 0° to 90° with 15° intervals where 0° is accepted as open and 90° as closed. Upper and lower slats are moving independently from each other. Distance between slats and their numbers for related scenarios are given in Table 3.6.

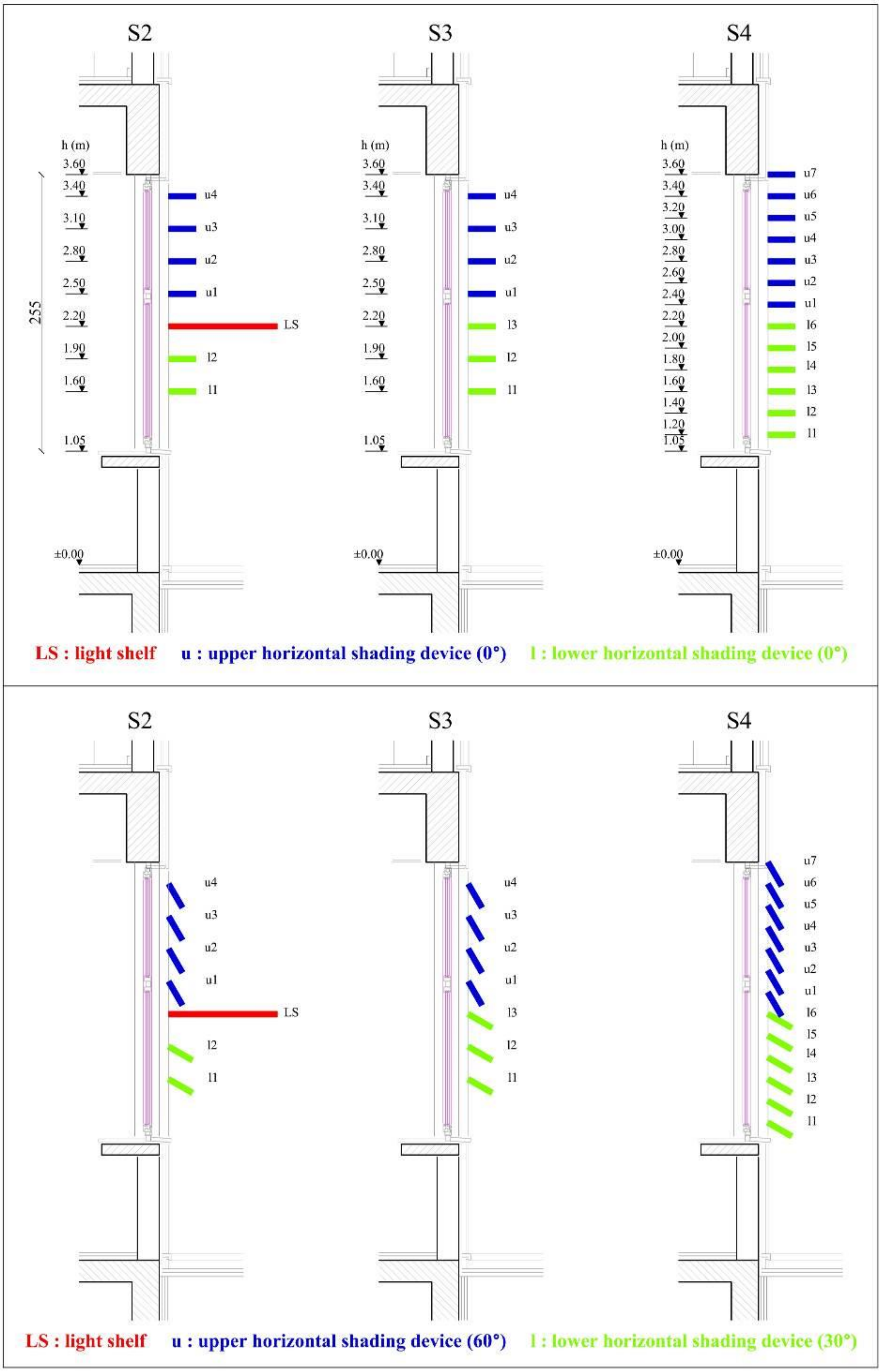


Figure 3.17 Horizontal shading devices' representation

(Drawn by the Author)

3.5.3.3. Vertical Shading Devices (VSD)

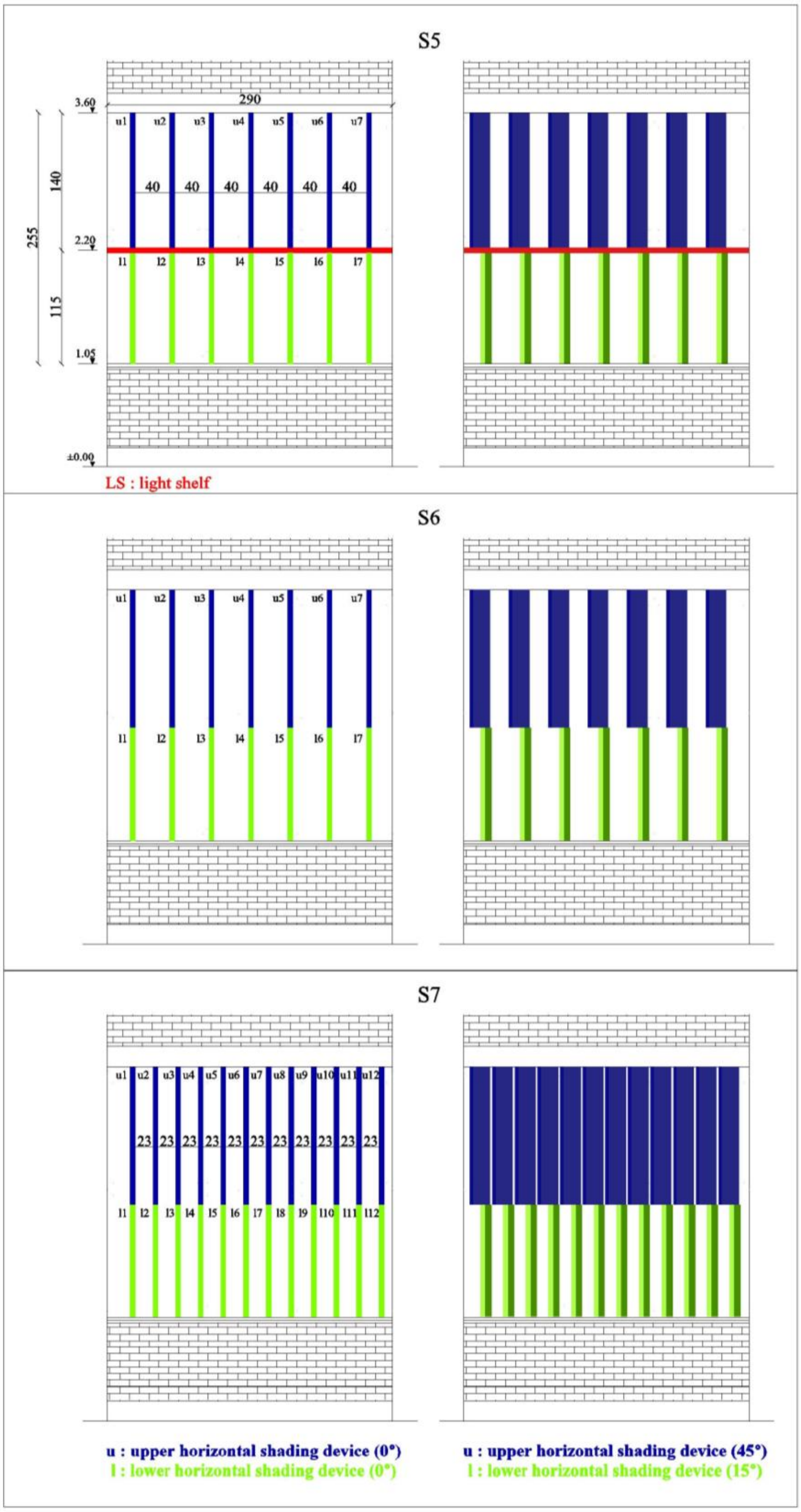


Figure 3.18 Vertical shading devices' representation

(Drawn by the Author)

Vertical shading devices have been proposed for each single window in retrofit scenarios S5, S6 and S7 (Figure 3.18) of all parts. S5 is the fifth scenario including the installation of both the light shelf and vertical slats. S6 and S7 are the variations of S5. The rho value of surfaces is determined as 30% without mirror to prevent glare. In this study, dimensions of a vertical shading device are proposed by 0.25x0.05xwindow height m. Slats are movable from 0° to 90° with 15° intervals where 0° is accepted as open and 90° as closed. Upper and lower slats are moving independently from each other. Distance between slats and their numbers for related scenarios are given in Table 3.6.

3.5.4. Lighting Fixture (LL, LT)

Lighting fixture layout (LL) is defined according to the number of luminaire rows (n) which are switched on. LL_0 means that lamps are not working and LL_1 is the one working row of luminaires that was close to the rear zone. LL_2 identifies two working rows of luminaires. The alternatives increase in number according to the number of luminaire rows.

Electric lighting plan layout of Part B has been given as an example in Figure 3.19. There exist three rows including three pieces of lighting fixture on each. Row numbering has been made according to the rows near to the window side. First row is the three fixtures on the window side, second row is the other three fixtures in the middle and the third row is the last three fixtures located near to the door.

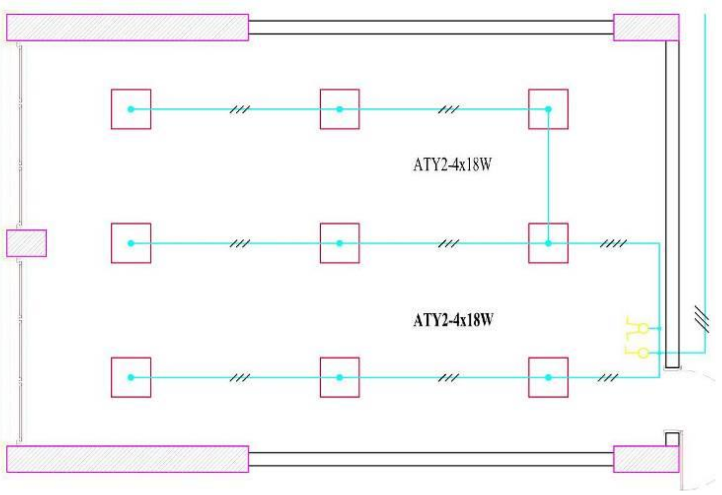


Figure 3.19 Lighting Plan of Part B

Two alternatives for ligting fixture types (LT) were determined for retrofit simulations that their specifications are explained on the Table 3.8.

Table 3.8 Lighting fixture type alternatives and their specifications

Fluorescent (4x18W)	**Specification**	**LED**
70 W	**Power**	41 W
3834 lm	**Luminous Flux**	3400 lm
80	**Color Rendering Index**	>80
15,000 hours	**Lifetime**	50,000 hours
3000-4000 K	**Color Temperature**	3000-4000 K
Yes	**Toxic Mercure**	No
	Energy Savings	Approx. 40%

The luminaire used in this building (Figure 3.20) is a recessed luminaire for 4x18 W fluorescent lamps. They are located at intervals of 120 or 180 cm on the suspended ceiling. It has a luminous flux of 3834 lm and consumes 70 W (Table 3.8).

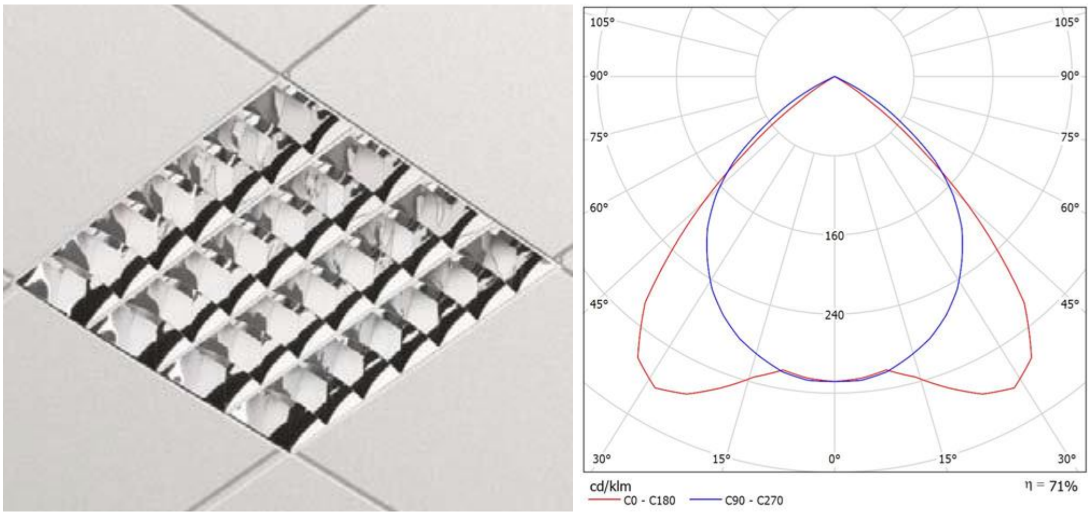


Figure 3.20 A luminaire with fluorescent lamps 4x18 W

(<u>Source:</u> Philips Product Catalog Indoor Luminaires)

A LED panel (Figure 3.21) with a similar luminous flux has been selected in order to reduce energy consumption in retrofitting scenarios. In this study, LED luminaires are used to replace the existing fluorescent lamps. It has a luminous flux of

3400 lm and consumes 41 W (Table 3.8). This resulted approximately 40% of energy saving.

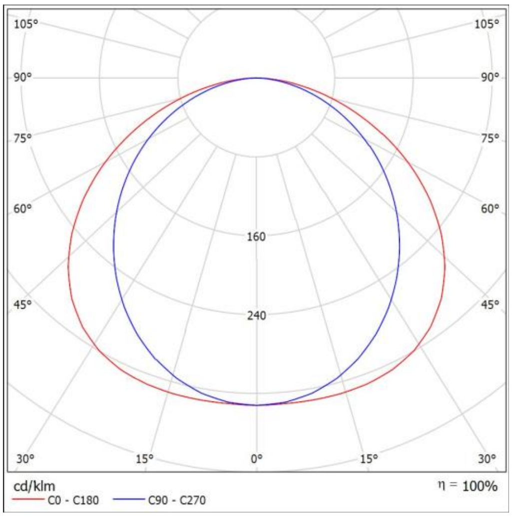


Figure 3.21 A luminaire with LEDs W60L60 LED 830

(<u>Source:</u> Philips Product Catalog Indoor Luminaires)

3.6. Scenario Application Steps

The case building does not provide a proper daylight performance for its occupants. The base case scenario and seven scenarios were applied in order to retrofit the building. First, the base case was simulated and evaluated for the winter/summer solstices and equinoxes: December 21st/June 21st and March 21st/September 21st. Second, a total of seven daylighting and energy efficiency improvement scenarios have been simulated only for the day of December 21st using lighting calculation tool-DIALux. All the simulations are calculated under open sky conditions. The reason to select this day was due to the lowest sun angles which allow daylight nearby the deepest zone of the room. Third, one scenario including HSD which resulted in the optimum illuminance and uniformity values; and another one including VSD were determined among retrofitting scenarios. Fourth, these two optimum scenarios were assigned as S8 and S9 respectively. They involved LED lighting fixtures which replaced the existing fluorescent lighting fixtures. So, it was possible to test their energy efficiency and to compare the results in terms of illuminance and uniformity values. DIALux calculated the annual lighting energy consumption of the optimum two scenarios (with flourescent lighting fixtures) and re-proposed ones, S8 and S9, for the winter solstice. The outcome for the comparison of energy efficiency for the fluorescent and LED lighting has been obtained.

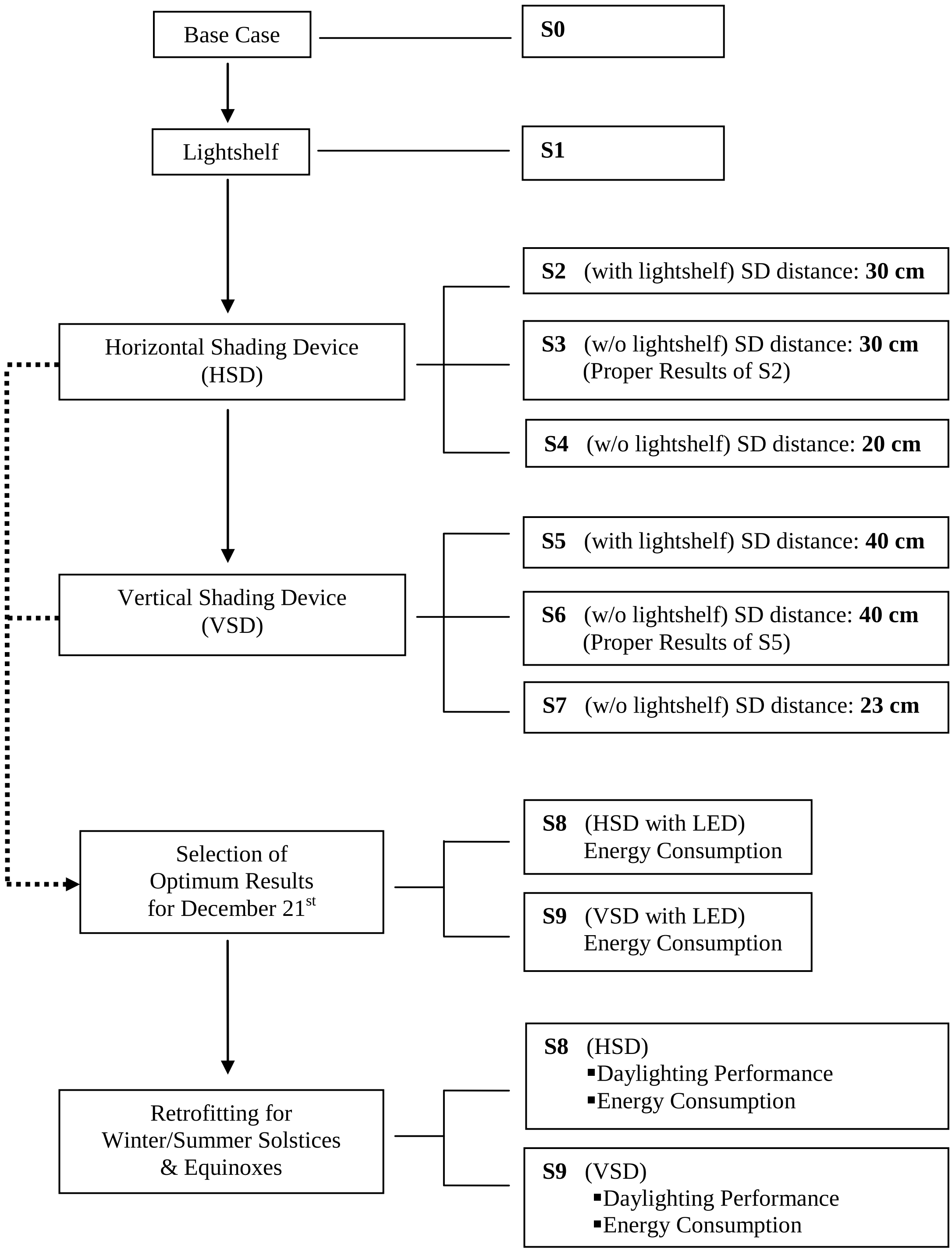


Figure 3.22 Flowchart for scenario application steps

Fifth, the simulation generated the outputs of the optimum case for HSD (S8) and the optimum case for VSD (S9) with fluorescent lighting fixtures for the equinoxes and the summer solstice (March 21^{st}/September 21^{st} and June 21^{st}) over again. Sixth, results were evaluated. The models representing unbalanced daylight distribution were retrofitted additionally by means of installing the vertical and horizontal slats and of modifying the slat angles. Finally, the latest retrofitted results for the solstices and equinoxes determined the improved scenarios containing the optimum shading device type, slat angle, lighting fixture layout and type. Their annual energy consumption for all seasons having optimum conditions were calculated for fluorescent and LED lighting fixtures. Scenario application steps explained above are summarised and given as a flowchart in Figure 3.22. Their details including assigned parameters for the scenarios, day and time, outputs are explained under three parts by using flowcharts (Figure 3.23, 3.24 and 3.25).

Base Case Scenario (S0): The case rooms (i.e. Parts) were modelled according to existing façade configuration by using the base case parameters. Reference points were assigned to evaluate simulation results. In base case scenario, simulations were run at 9:00 AM, 12:00 PM and 3:00 PM for the winter/summer solstices and equinoxes (December 21^{st}/June21^{st} and March 21^{st}/September 21^{st}). The measures for the daylight performance were illuminance (E_{avg}, E_{min}, E_{max}) and the uniformity ($U1=E_{min}/E_{avg}$; $U2=E_{min}/E_{max}$) while lighting fixtures were switched off. Results were evaluated in terms of the required/recommended daylight conditions. In any case of the occurance of inadequate daylight conditions, retrofit scenarios (S1-S7) were applied respectively. Flowchart for the base case scenario is given in Figure 3.23.

Scenarios S1-S7: The actual façade configurations of all parts were assumed to be removed. It means that, all existing horizontal and vertical overhangs, cantilevers, balconies were excluded from the simulation models. Models contained proposed shading devices on the flat surface of the façade. Table 3.6 displays the location of shading devices, the distances between slats and their numbers proposed for all parts. Retrofit values of FT, FC, SC, LS, SD, LL and LT were assigned. Simulations run for December 21^{st}, at 9:00 AM, 12:00 PM, 3:00 PM. FC, SC and LT were kept the same in all scenarios. FT, SD (u&l angles) and LL were the varying parameters.

For S1, a single light shelf was only installed on the façade of each part.

For S2, horizontal shading devices (HSD) became the design variant with a light shelf. Simulation was run initially for 0° of slat angle for upper and lower slats. As mentioned previously, slats are movable from 0° to 90° with 15° intervals, where 0° is accepted as “open” and 90° as “closed”. Upper and lower slats are moving independently from each other. Lighting fixtures were selected as “off” and shading device angles’ as open for the first simulation model. Results evalautions and simulations were proceeded until the proper results were obtained by using variable parameters.

For S3, appropriate values of FTs were selected according to the findings of S2. Lightshelf was eliminated and a movable horizontal slat was located on its place. It was assigned in the lower type of HSD. Simulation was conducted to observe the effect of lightshelf.

For S4, HSDs were only used and all simulations were run as it was for S2 similarly.

For S5, VSDs were installed with a light shelf on the façade. The simulations followed the similar process as explained previously.

For S6, appropriate values of FTs were selected according to the findings of S5. Lightshelf was removed; and simulation was conducted to obtain the effect of lightshelf.

For S7, VSDs were only used and the simulations followed the similar process as explained previously. In any case of the occurance of inadequate daylight conditions, the simulation was run once again until satisfying the required values.

Annual energy consumptions, (corresponding 300 days/9 hours) were calculated according to the day of December 21st, including parameters for fluorescent and LED luminaires of S8 and S9. Figure 3.24 presents this process using a flowchart.

Retrofit Studies: Final retrofit solutions were proposed for S8 and S9 in winter/summer solstices and equinoxes. In any case of obtaining unsuccessful values of illuminance and uniformity, additional horizontal and vertical slats were installed to satisfy uniformity and to avoid direct sunlight.

Annual energy consumptions were calculated according to winter/summer solstices and equinoxes’ parameters (LL numbers) for fluorescent and LED luminaires of S8 and S9. Winter/summer solstices and equinoxes (W/S S&E) results cover 75 days four each (corresponding 300 days/9 hours). Flowchart for retrofit studies for S8 & S9 in all tropics is given in Figure 3.25.

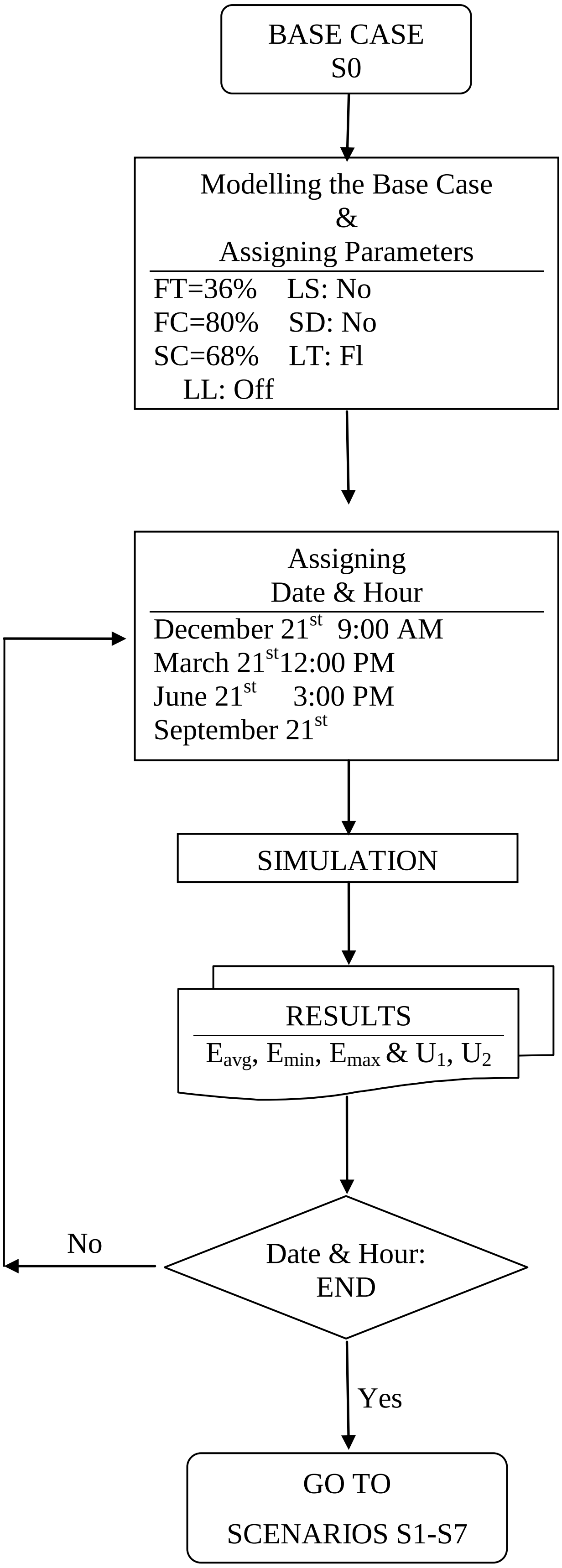
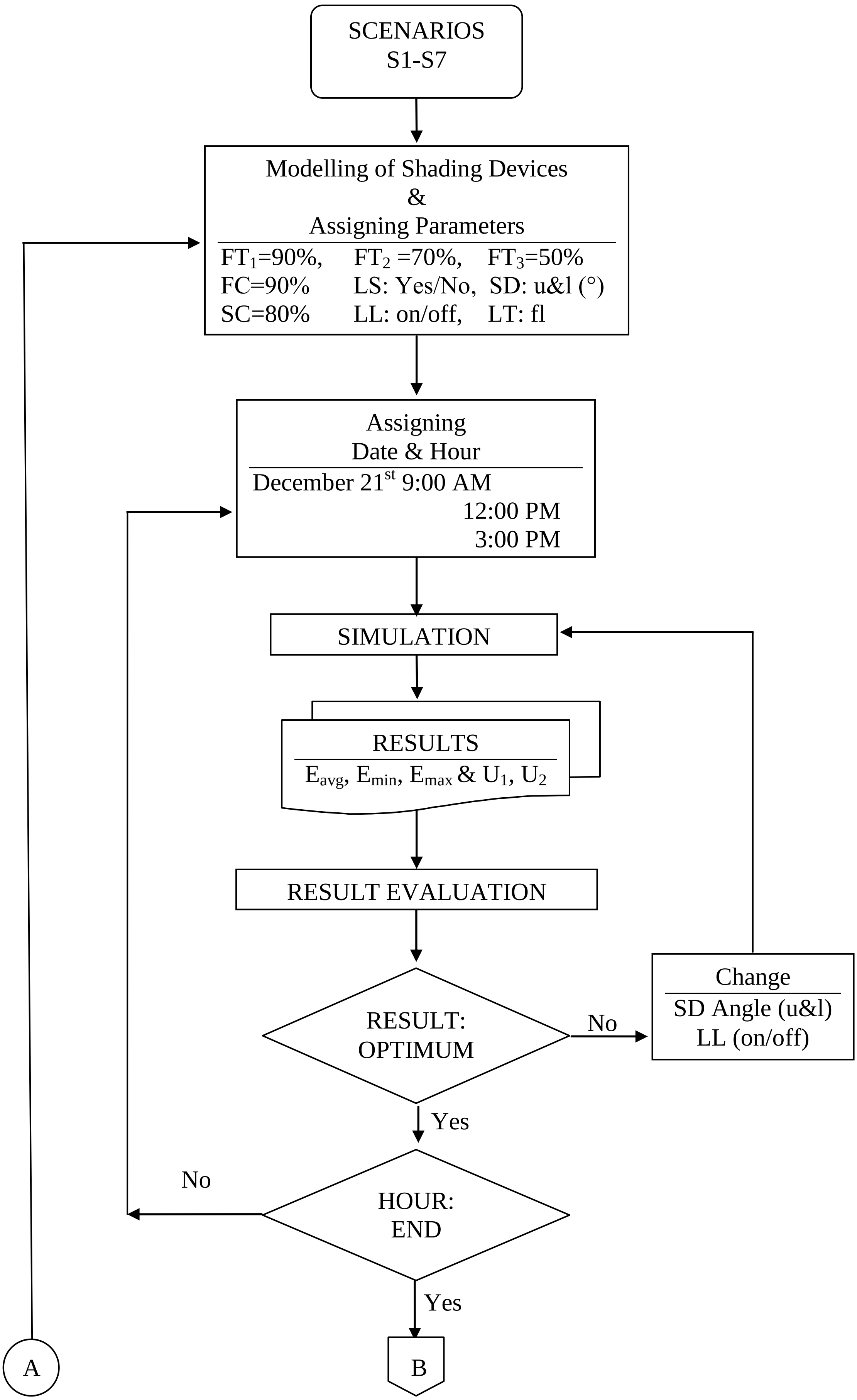


Figure 3.23 Flowchart for base case


SCENARIOS
S1-S7
Modelling of Shading Devices
&
Assigning Parameters
FT1=90%, FT2 =70%, FT3=50%
FC=90% LS: Yes/No, SD: u&l (°)
SC=80% LL: on/off, LT: fl
Assigning
Date & Hour
December 21st 9:00 AM
12:00 PM
3:00 PM
SIMULATION
RESULTS
Eavg, Emin, Emax & U1, U2
RESULT EVALUATION
RESULT:
OPTIMUM
No
Change
SD Angle (u&l)
LL (on/off)
Yes
No
HOUR:
END
Yes
A
B

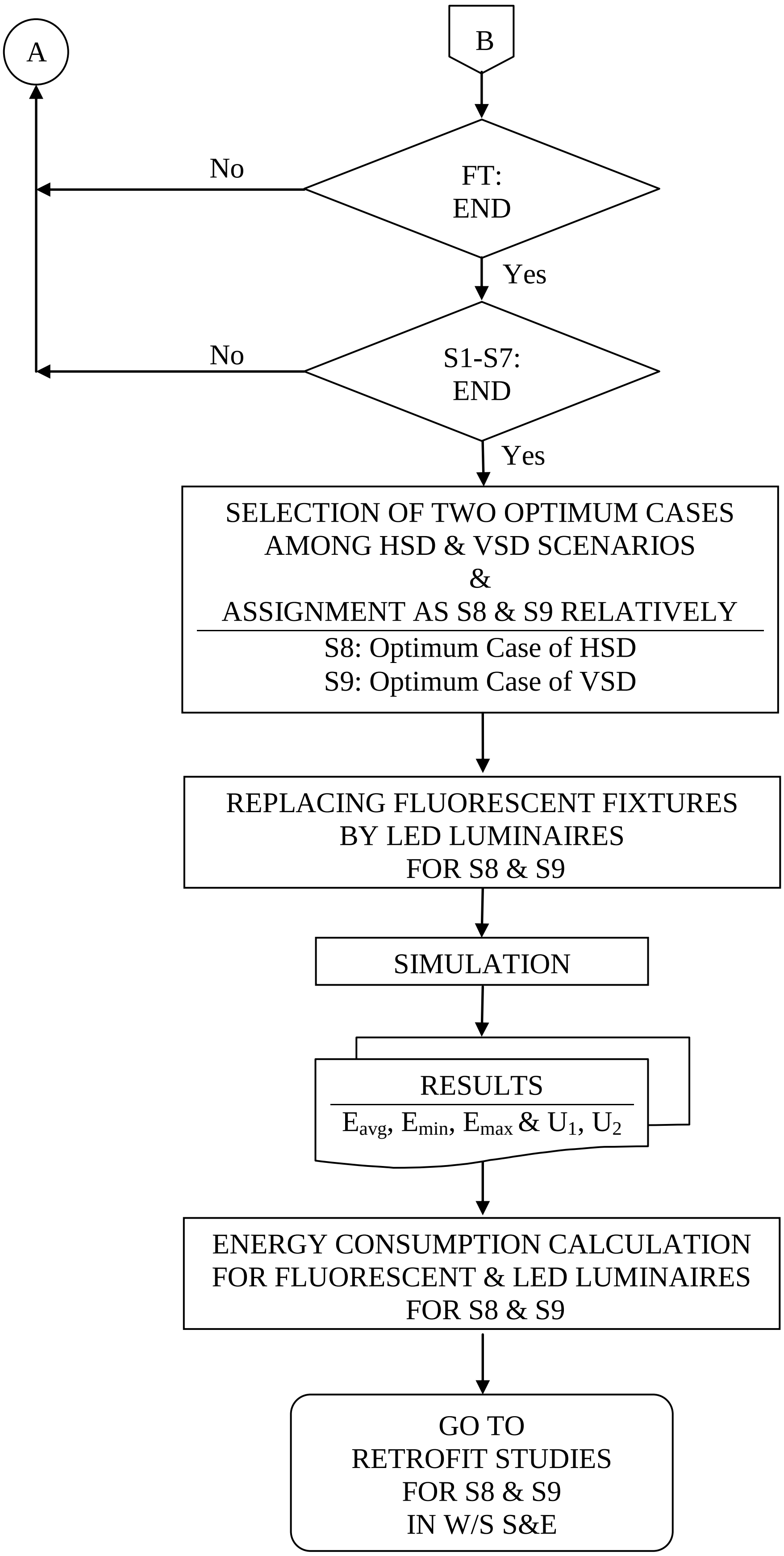


Figure 3.24 Flowchart for scenarios S1-S7

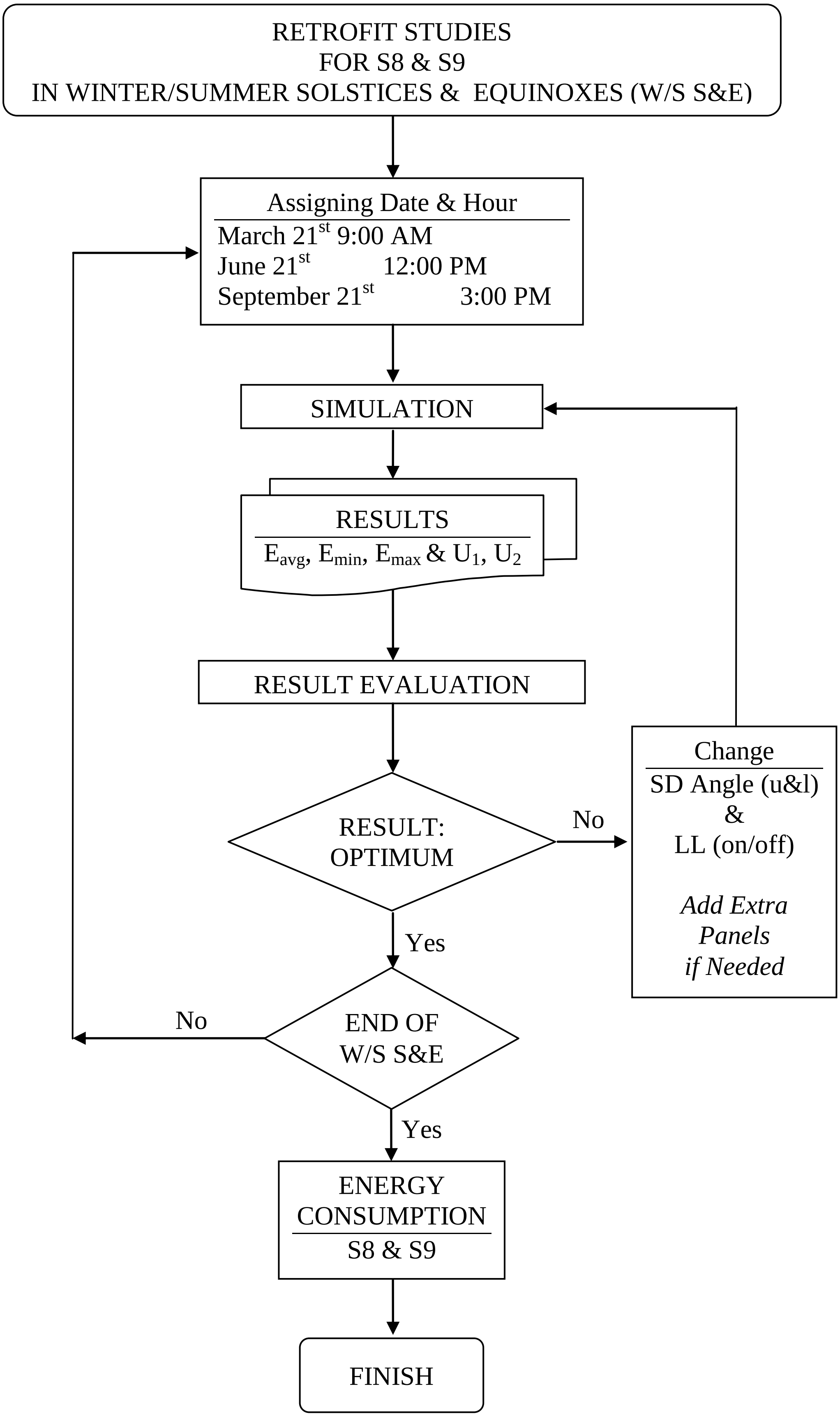


Figure 3.25 Flowchart of retrofit studies for scenarios S8 & S9

CHAPTER 4

RESEARCH FINDINGS

4.1. Field Measurements and Validation of the Simulation Model

The objective of conducting these field measurements was to determine the actual daylight performance and to validate the base case scenario by comparing the output values, namely, illuminance and uniformity. Measurements were conducted on December 4th, 2014, at 2:00 PM for Part B and 2:30 PM for Part D under intermediate (partly cloudy) sky conditions. Figure 4.1 displays the comparison of measured and simulated daylight illuminance in Part B. It was observed that there was an unbalanced daylight distribution in this classroom. Its uniformity (almost 0.1-0.2) was very low and the illuminance at approx. half of the measurement points was below the recommendations for a classroom. On the other hand, the area close to the windows was very bright when compared to the rear area. Thus, it was necessary to propose a shading system to achieve a uniform daylight distribution.

In order to validate the measured findings with the simulated ones, the relative error (RE) was calculated (6). It ranged from 4.5% to 36.8%. Although their distribution lines were parallel, there was observed deviations at only two points, at which the RE's were 36.8% and 34.3%, respectively (Figure 4.1).

$$RE = ((E_M - E_S)/E_M)\% \quad (6)$$

RE: Relative error

E_M: Measured daylight illuminance

E_S: Simulated daylight illuminance

Figure 4.2 presents the comparison of measured and simulated daylight illuminance by using a scatter plot diagram for Part B. This is necessary to validate the DIALux model. The coefficient of determination (R^2) and the lineer regression equation were calculated by using Excel. R^2 value was 97% which showed the high accuracy of the model. In other words, this is an indicator for approx. 97 percent chance of prediction power of the measured values by using the simulated values. Consequently, the simulation outputs fit the field measurements very well. Specifically, the measured illuminance was greater than the simulated ones.

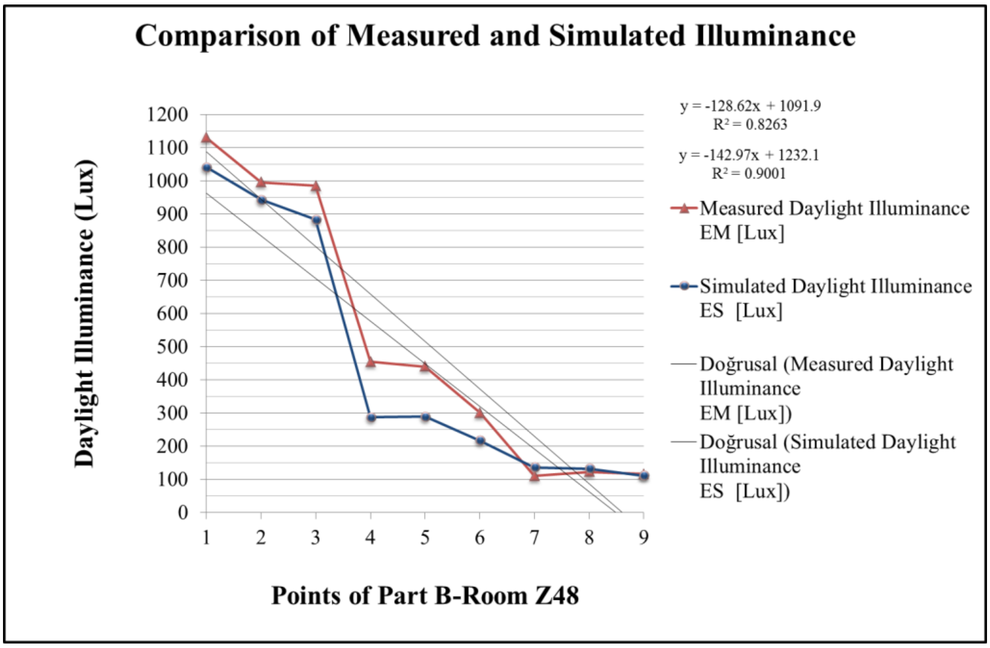


Figure 4.1 Comparison of measured and simulated daylight illuminance for Part B

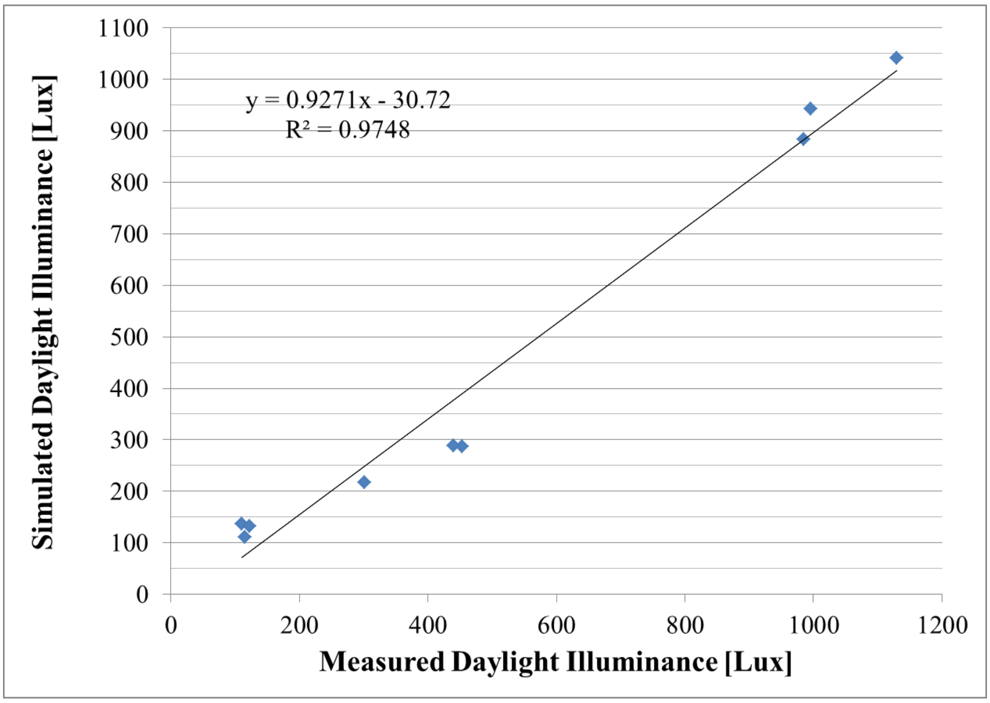


Figure 4.2 Scatter plot diagram displaying daylight illuminance for Part B

Figure 4.3 displaying the comparison of measured and simulated daylight illuminance for Part D shows that uniformity (almost 0.06-0.13) in this laboratory was very low according to the recommendations. Measured illuminance values ranged from 6 to 180 lx while simulated ones ranged from 10 to 172 lx. Illuminance values were quite insufficient while comparing the recommended values (500-750 lx) for a laboratory. This part needs to be retrofitted in order to obtain visual comfort conditions.

Although the lines were parallel to each other, several deviations occur at some measurement points. The sky models used by this simulation tool and the surface reflectance of actual surfaces might cause such deviations. In general, measured illuminance was lower than the simulated ones except at some points.

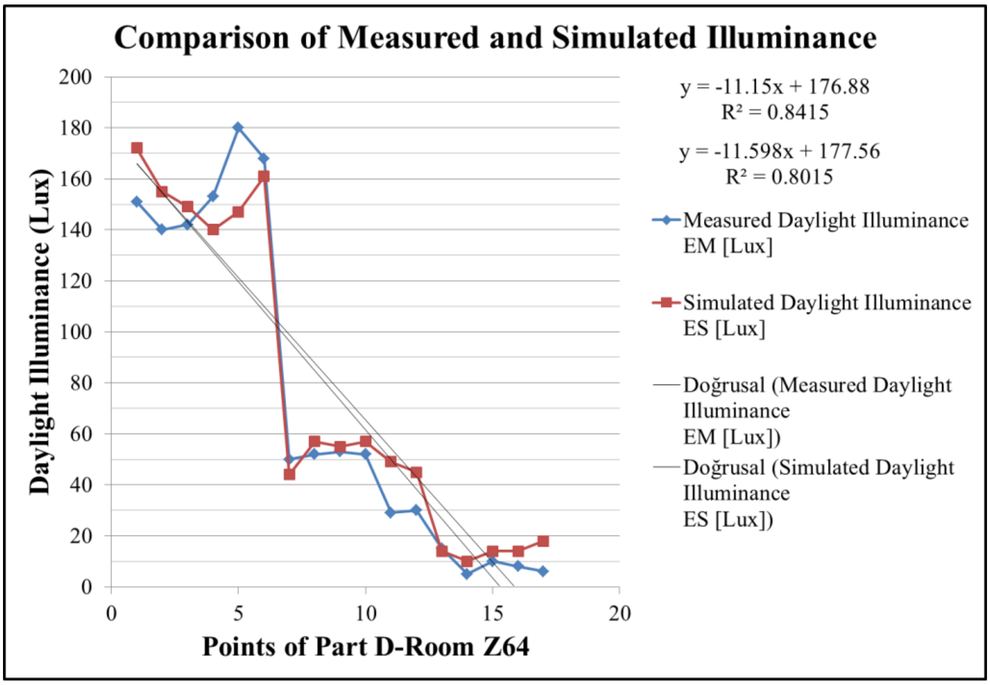


Figure 4.3 Comparison of measured and simulated daylight illuminance for Part D

The relative error ranged from 3.8% to 69%, was calculated by using the formula (6) at all measurement points except two of them. It was assumed that their very low values caused such bias. So, they were excluded. Illuminance values at other points were very close to each other. Their coefficient of determination and lineer regression equation were calculated similarly. The R^2 value was 96% and their lineer regression line was displayed in Figure 4.4. This showed a strong relation between the measured and simulated outputs. This means that it is possible to predict the measured values with approx. 96 percent chance by knowing the simulated values. As a result of this confidence, the physical and optical attributes of materials were used identically in simulating the other rooms in this study.

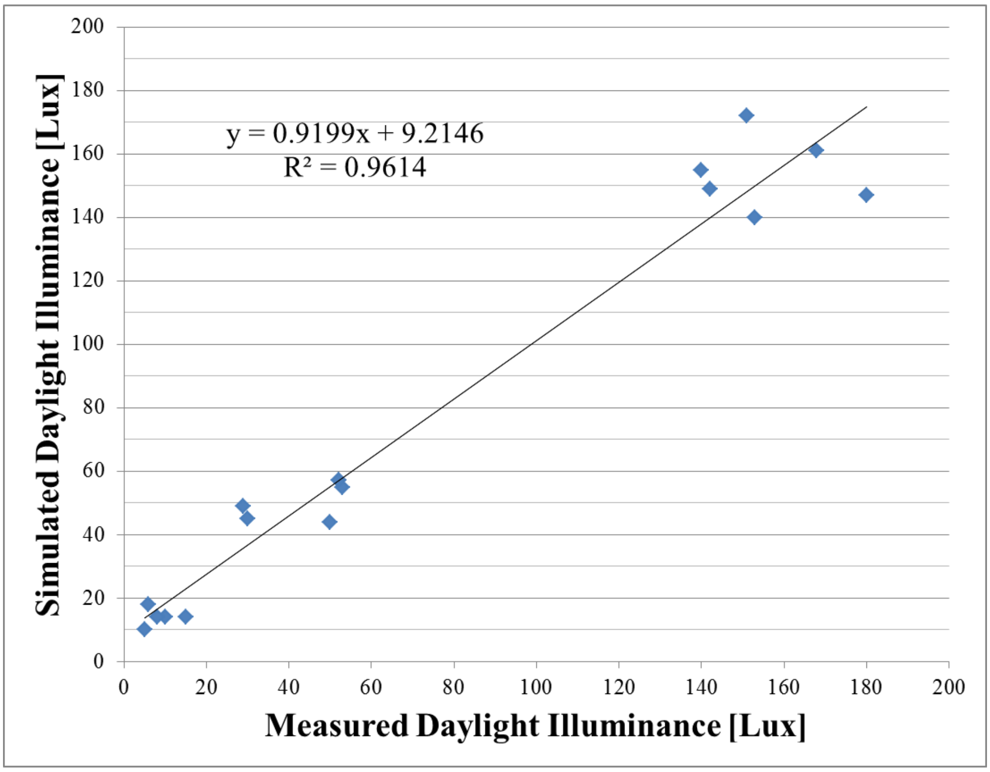


Figure 4.4 Comparison of measured and simulated daylight illuminance for Part D

4.2. Scenario Studies

In this study, an educational building, Department of Mechanical Engineering in Izmir Institute of Technology has become the case building. In order to evaluate and daylight and artificial lighting as an integrated system, six different rooms has been selected from this building complex. These rooms defined as parts have different orientations, functions, dimensions and façade configurations.

Various parameters such as fenestration transmittance, fenestration color, surface color, lighting layout, lighting types, light shelves and shading devices have been used in order to retrofit the daylighting that affecting visual comfort conditions and artificial lighting that affecting energy consumption. Scenarios (S1-S7) were generated according to input parameters; fenestration transmittance (FT1: 90%, FT2: 70%, FT3: 50%), light shelf, location and angle of horizontal and vertical shading devices, lighting fixture layout and types.

Retrofit studies were conducted for winter/summer solstices and equinoxes under clear sky conditions. On the purpose of specify the illuminance, 9:00 AM, 12:00 PM and 3:00 PM that corresponding to the working hours has been selected for simulations. DIALux 4.12 has been used as a simulation tool.

Scenario application steps have been studied for each part by following the steps below:

- Base case scenario - S0 (Figure 3.22),
- Scenario S1-S7 (Figure 3.23),
- Retrofit studies S8-S9 (Figure 3.24).

For each part, more than 250 simulations were run. As a result, more than 1500 simulation results in total have been evalauted in order to obtain proper solutions for daylighting and energy consumption for all parts.

Part A has been explained in detail in section 4.2.1. Other part results' (B, C, D, E and F) has been summarized in the following sections.

In the appendices, all the scenario results, except Part A, for daylighting and energy consumption calculations were given as tables and images for all parts. Part A scenario results including images and tables were given in section 4.2.1

4.2.1 Daylighting and Energy Consumption Results for Part A

Part A is the first part that is evaluated in this study. It is a classroom (recommended illuminance value was 300-500 lx) located on the ground floor facing with Southeast façade. Base case has been simulated for W/S S&E according to the paramaters defined in the Table 4.1. Average illuminance values have been found out as 3033 lx, 4635 lx, 801 lx and 3336 lx respectively on December 21st, March 21st, June 21st and September 21st at 12:00 PM. Uniformity values (E_{min}/E_{avg}) has been found out as 0.13, 0.07, 0.32 and 0.10 respectively on December 21st, March 21st, June 21st and September 21st at 12:00 PM.

When the classroom was examined from Figures 4.5, 4.6 and 4.7, it was seen that there was an unbalanced daylight distribution during the day due to the direct sunlight inside the room. Consequently, visual comfort conditions have been negatively affected. Figure 4.5 displays the outdoor and indoor perspectives for the base case scenario in the winter solstice. This day resembles the worst scenario, since, the sun angles have the lowest incident values. The direct sunlight can reach at the rear wall during the morning hours, as shown in Figure 4.5. The sun patch occurs similarly in the middle of the room at noon. Figure 4.6 presents the distribution of daylight in false color rendering in solstices and equinoxes. These perspectives are informative to show the excessive amount of bright areas in this classroom. Daylight illuminance exceeds approx. 1000 lx in most of the time during the day. Even in summer time, disturbing bright area is almost one third of the whole floor area during the morning and at noon. The darkest region in this room received a very low level of daylight in the afternoon annually. Their value was below 200 lx. The similar situation happened only in the morning on June 21st. The illuminance maps in Figure 4.7 show the distribution horizontally. The day of December 21st is distinguished from the others; since the variation of daylight illuminance during the day is very high. While the illuminance of the half of the floor area is above 1000 lx and very bright at noon, the illuminance of the other half was below 200 lx in the afternoon.

Curtains seem to be the only solution and indispensable for such existing situations in the classroom to prevent direct sunlight. They have been used generally in the actual case. But it causes the use of all artificial lighting system of the classroom during the day. For this reason, retrofit scenarios has been improved as mentioned in section 3.6 to provide energy efficiency, to satisfy the required illuminance and uniformity values by taking advantage of daylight while protecting from direct sunlight.

Tables 4.2-4.6 show all retrofit scenario results including illuminance and uniformity. Results are given in the morning-noon-afternoon hours according to the proper selection of slat angles and lighting fixture layouts for each fenestration transmittance values.

Table 4.1 Part A-Base case results (S0 for W/S S&E)

Base Case Results (Results taken from DIALux)

Part A - Southeast Façade (north is directed 26° to east)
(Room Z55 : h=3.60 m, Area= 61.13 m²)

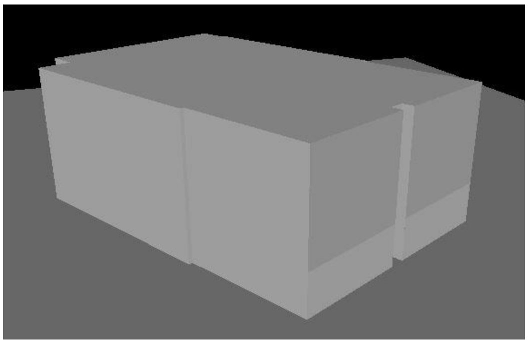
FT: Fenestration Transmittance
FC: Fenestration Color = 80%
SC: Surface Color = 68%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

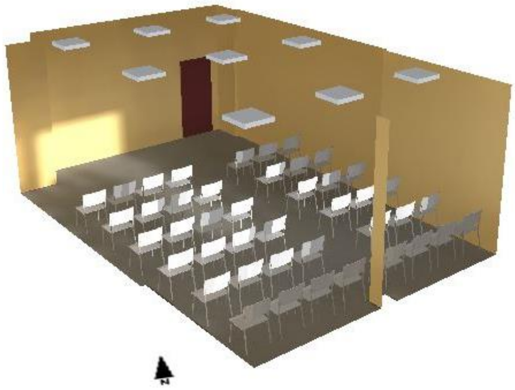
Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	ILLUMINANCE (Lux) E_{min}	ILLUMINANCE (Lux) E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	UNIFORMITY U_2 E_{min}/E_{max}
Winter Solstice : December 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	1304	307	2008	0.24	0.15
					0	FL	**12 PM**	3033	408	6937	0.13	0.06
					0	FL	**3 PM**	627	146	2358	0.23	0.06
Equinox : March 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	2656	325	7658	0.12	0.04
					0	FL	**12 PM**	4635	336	13234	0.07	0.03
					0	FL	**3 PM**	530	173	1238	0.33	0.14
Summer Solstice : June 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	1355	199	8029	0.15	0.02
					0	FL	**12 PM**	801	255	1709	0.32	0.15
					0	FL	**3 PM**	494	160	1023	0.32	0.16
Equinox : September 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	1746	259	5099	0.15	0.05
					0	FL	**12 PM**	3336	335	12525	0.10	0.03
					0	FL	**3 PM**	700	225	1659	0.32	0.13

Outdoor & indoor perspective views for S0 in *Winter Solstice : December 21 st*
Part A - Southeast Façade (north is directed 26° to east)

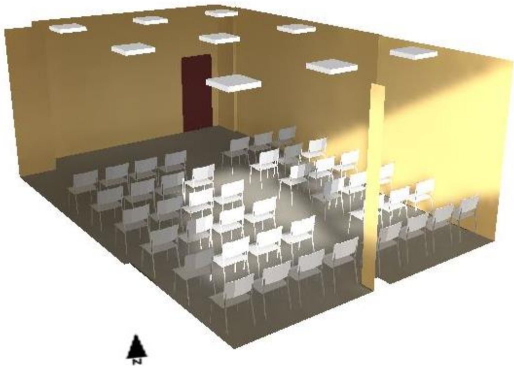
Outdoor Perspective	**Indoor Perspective**

9:00 AM

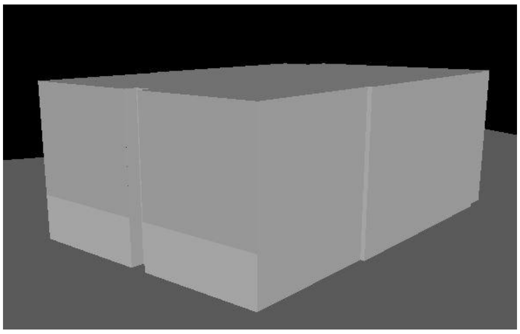




12:00 PM



3:00 PM



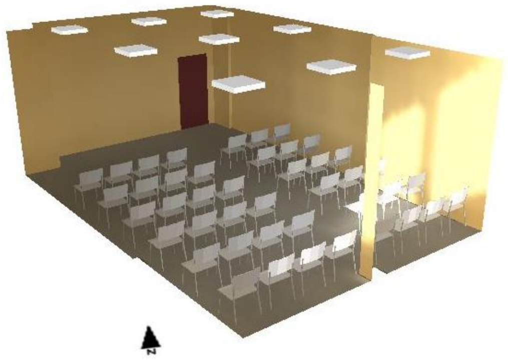


Figure 4.5 Part A-Outdoor & indoor perspective views for S0

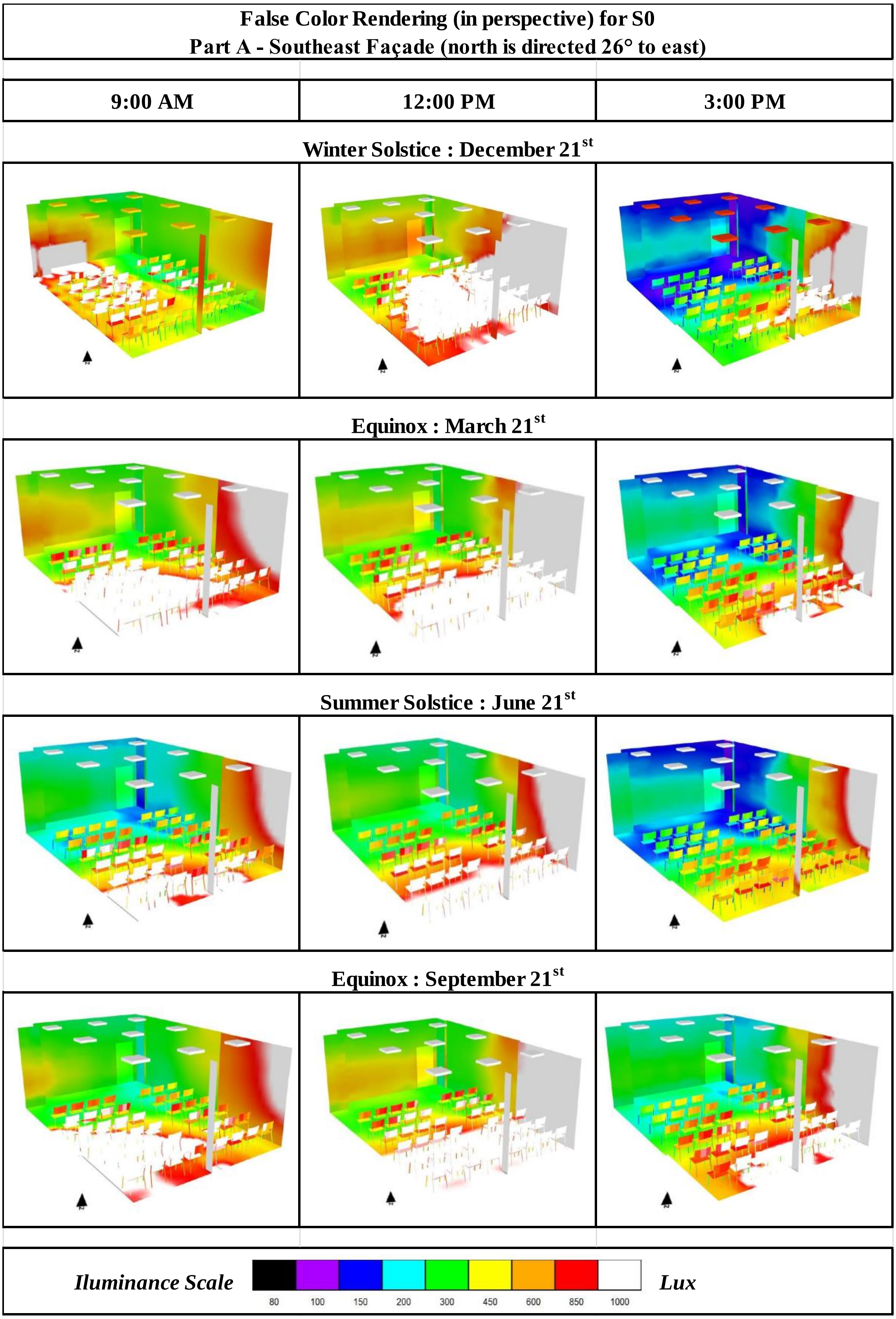


Figure 4.6 Part A-False Color Rendering (in perspective) for S0

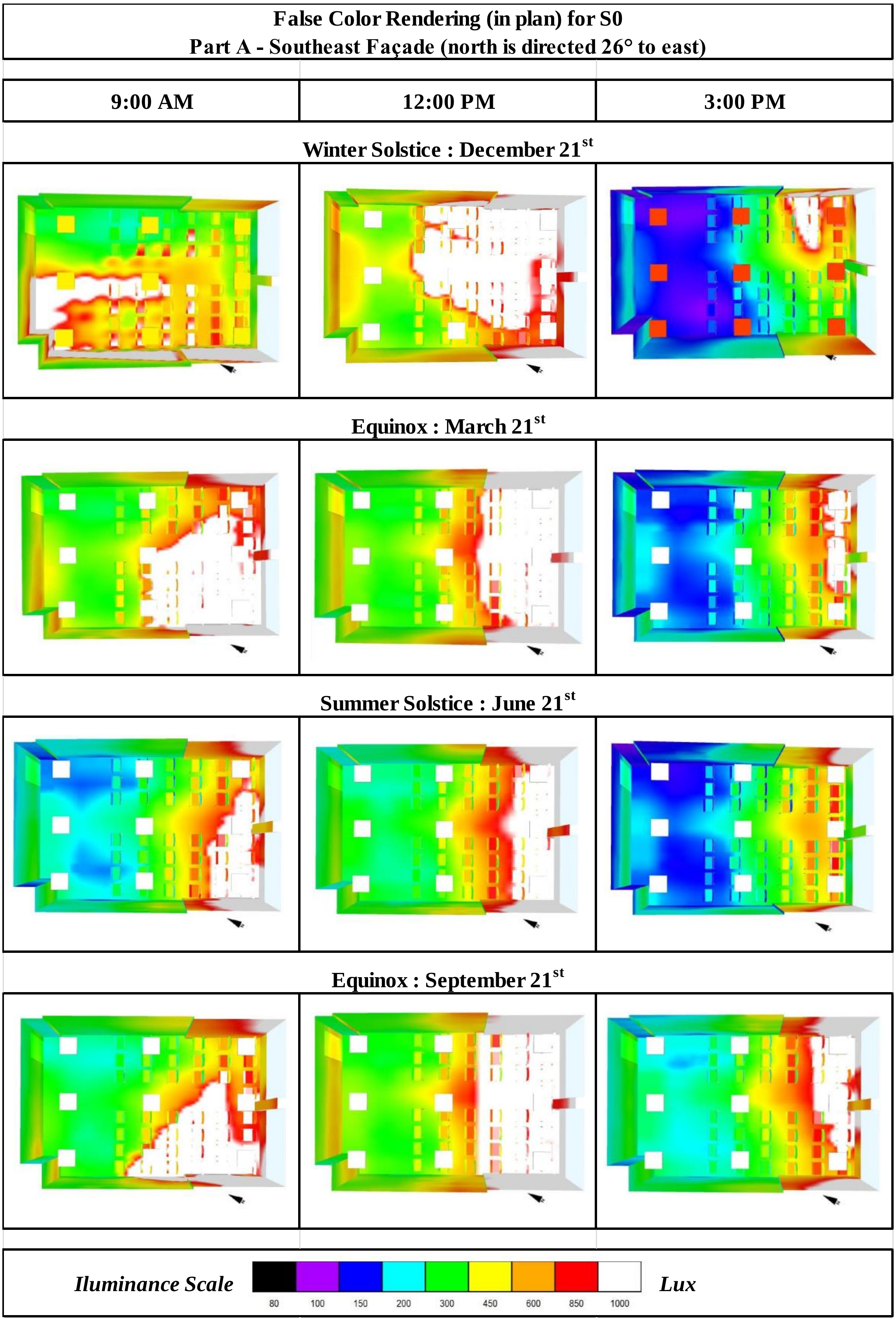


Figure 4.7 Part A-False Color Rendering (in plan) for S0

Table 4.2 Part A-Retrofit scenarios (S1)

Retrofit Scenarios (Results taken from DIALux for December 21st)												
Part A - Southeast Façade (north is directed 26° to east) (Room Z55 : h=3.60 m, Area= 61.13 m^2)												
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row** (on) **LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode**												
Scenario	**FT**	**Light Shelf**	**SD**		**LL**	**LT**	**Hour**	**ILLUMINANCE (Lux)**			**UNIFORMITY**	
			Type	**Angle**	**n**			E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S1	FT_1 90%	Yes	No	No	0	FL	**9 AM**	3169	1038	5433	0.33	0.19
					0	FL	**12 PM**	8334	1310	18101	0.16	0.07
					0	FL	**3 PM**	1727	479	6456	0.28	0.07
	FT_2 70%	Yes	No	No	0	FL	**9 AM**	2463	807	4221	0.33	0.19
					0	FL	**12 PM**	6480	1022	14067	0.16	0.07
					0	FL	**3 PM**	1340	374	5014	0.28	0.07
	FT_3 50%	Yes	No	No	0	FL	**9 AM**	1758	579	3015	0.33	0.19
					0	FL	**12 PM**	4627	739	10041	0.16	0.07
					1	FL	**3 PM**	1106	486	3594	0.44	0.14

Findings of Scenario-S1 including the installation of a light shelf only are presented in Table 4.2. Light shelf on this location couldn't prevent the penetration of direct sunlight during the day. Changing the fenestration transmittance remained incapable of decreasing illuminance, so the transmittance displayed no effect on improving the visual comfort. Even when the fenestration transmittance value was 50%, the sun patches were monitored in some zones. In the other zones of this room, illuminance varied approximately from 500 lx to 4600 lx. A single row of lighting fixture only was switched on to achieve a high level of illuminance up to 500 lx in front of the white board.

Table 4.3 Part A-Retrofit scenarios (S2-S3)

Part A - Southeast Façade (north is directed 26° to east)
(Room Z55 : h=3.60 m, Area= 61.13 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical** **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
LT: Lighting Fixture Type; **FL: Fluorescent** **LED: Light Emitting Diode**

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
SD u=4 l=2	FT_1 90%	Yes	SD_2 h	u=90° l=90°	0	FL	**9 AM**	1479	297	3838	0.20	0.08
				u=90° l=90°	0	FL	**12 PM**	926	403	1975	0.44	0.20
distance 30 cm				u=90° l=90°	1	FL	**3 PM**	1023	298	5027	0.29	0.06
	FT_2 70%	Yes	SD_2 h	u=30° l=90°	0	FL	**9 AM**	1330	344	3225	0.26	0.11
S2				u=90° l=90°	0	FL	**12 PM**	717	312	1527	0.44	0.20
Light Shelf				u=45° l=45°	1	FL	**3 PM**	531	305	875	0.57	0.35
location 220 cm	FT_3 50%	Yes	SD_2 h	u=15° l=45°	0	FL	**9 AM**	1037	307	2391	0.30	0.13
width 290 cm				u=90° l=90°	1	FL	**12 PM**	661	391	1101	0.59	0.36
length 100 cm				u=30° l=45°	1	FL	**3 PM**	459	261	698	0.57	0.37
SD u=4 l=3	FT_1 90%	No	SD_3 h	u=° l=°		FL	**9 AM**					
				u=° l=°		FL	**12 PM**					
distance 30 cm				u=° l=°		FL	**3 PM**					
	FT_2 70%	No	SD_3 h	u=° l=°		FL	**9 AM**					
S3				u=° l=°		FL	**12 PM**					
				u=° l=°		FL	**3 PM**					
	FT_3 50%	No	SD_3 h	u=15° l=45°	0	FL	**9 AM**	1020	294	2383	0.29	0.12
				u=90° l=90°	1	FL	**12 PM**	572	335	906	0.59	0.37
				u=60° l=45°	2	FL	**3 PM**	529	416	626	0.79	0.67

As a result of scenario-S2, with the application of a light shelf and HSD whose slat distances were 30 cm, uniformity varied from 0.11 to 0.59 (Table 4.3). Sun patch was prevented; but, illuminance reached up to 5000 lx near the windows. When the fenestration transmittance was, 50% (FT3), uniformity and illuminance were obtained satisfactorily when a single row of lighting fixture turned on at noon and in the afternoon hours. Illuminance and uniformity varied between the range of 261-1100 lx and 0.36-0.59 respectively. To obtain these results, all the slat angles were set to 90° at noon, while the upper and lower slat angles were set to 30° and 45° respectively in the afternoon. Most of the adequate findings of scenario-S2 were obtained in the FT3 condition.

Lightshelf was eliminated and a movable horizontal slat was located on its place in scenario-S3 to compare their effect on daylight performance.

In scenario S3 (Table 4.3), simulations were conducted only using S2-FT3 parameters while removing the light shelf and replacing an HSD to obtain better results for visual comfort. At this time, unlike the conditions and parameters of S2-FT3, upper slat angles were 60° and two rows of lighting fixtures worked on to increase insufficent illuminance in the afternoon. The required minimum illuminance became, 400 lx. Results obtained in S3-FT3 were much better than the ones in S2-FT3, but excessive amount of daylight was still observed near the windows.

Scenario-S4 (Table 4.4) containing HSD whose slat distances were 20 cm, the number of slats were increased. They allowed the penetration of sunlight and daylight in a controlled manner, thus the uniformity ranged between 0.46-0.89. This led to a comfortable visual environment. For all fenestration transmittance values (FT1, FT2 and FT3) daylight illuminance were close to each other and approximately proper for recommended values (300-500 lx). However, an illuminance of 276 lx was obtained near the white board despite the working of one more lighting fixture in the morning in S4-FT3. Results, in general, were found to be better when compared to S4-FT2 results in terms of uniformity. So, S4-FT1 was proposed as the most appropriate solution among the HSD scenarios. In S4-FT1, in the morning hours upper and lower slat angles were 0° and 75° respectively and there was no need for using the artificial lighting. At noon, all the slat angles were 75° and two rows of lighting fixtures turned on. In the afternoon, upper and lower slat angles were 15° and 60° respectively and two rows of lighting fixtures turned on.

Table 4.4 Part A-Retrofit scenarios (S4)

Part A - Southeast Façade (north is directed 26° to east)
(Room Z55 : h=3.60 m, Area= 61.13 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
SD u=7 l=6 distance 20 cm **S4**	FT_1 90%	No	SD_4 h	u=0° l=75°	0	FL	**9 AM**	507	366	656	0.72	0.56
				u=75° l=75°	2	FL	**12 PM**	480	377	596	0.79	0.63
				u=15° l=60°	2	FL	**3 PM**	532	471	616	0.89	0.76
	FT_2 70%	No	SD_4 h	u=0° l=45°	0	FL	**9 AM**	448	309	594	0.69	0.52
				u=75° l=60°	2	FL	**12 PM**	480	379	591	0.79	0.64
				u=30° l=30°	2	FL	**3 PM**	505	437	602	0.87	0.73
	FT_3 50%	No	SD_4 h	u=15° l=15°	1	FL	**9 AM**	445	276	599	0.62	0.46
				u=60° l=45°	2	FL	**12 PM**	525	468	627	0.89	0.75
				u=30° l=30°	2	FL	**3 PM**	450	329	574	0.73	0.57

Scenario S5, including the application of a light shelf and VSD whose slat distances were 40 cm, resulted to a range of uniformity of 0.04-0.85 (Table 4.5). Thus, the uniformity was below the expected values. However, S5-FT3 was the best solution among these. Illuminance and unifority values were 355-7731 lx and 0.04-0.74 respectively. Lightshelf was eliminated in Scenario-S6 to observe its effect on daylighting.

In scenario S6 (Table 4.5), simulations were conducted only for S5-FT3 parameters by removing light shelf in order to search for better daylighting results. In S6-FT3 proper results couldn't be achieved. Illuminance and unifority values were 266-7957 lx and 0.04-0.78 respectively.

Table 4.5 Part A-Retrofit scenarios (S5-S6)

Part A - Southeast Façade (north is directed 26° to east)
(Room Z55 : h=3.60 m, Area= 61.13 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S5 **SD u=7 l=7** distance 40 cm	FT_1 90%	Yes	SD_5 v	u=90° l=90°	0	FL	**9 AM**	918	374	2899	0.41	0.13
				u=90° l=90°	0	FL	**12 PM**	2382	508	13933	0.21	0.04
				u=90° l=90°	1	FL	**3 PM**	495	289	724	0.58	0.40
Light Shelf location 220 cm width 290 cm length 100 cm	FT_2 70%	Yes	SD_5 v	u=90° l=90°	0	FL	**9 AM**	712	290	2255	0.41	0.13
				u=90° l=90°	0	FL	**12 PM**	1852	400	10831	0.22	0.04
				u=90° l=90°	2	FL	**3 PM**	568	485	664	0.85	0.73
	FT_3 50%	Yes	SD_5 v	u=45° l=90°	0	FL	**9 AM**	561	255	1660	0.45	0.15
				u=90° l=90°	0	FL	**12 PM**	1320	286	7731	0.22	0.04
				u=90° l=90°	2	FL	**3 PM**	495	365	611	0.74	0.60
S6 **SD u=7 l=7** distance 40 cm	FT_1 90%	No	SD_6 v	u=° l=°		FL	**9 AM**					
				u=° l=°		FL	**12 PM**					
				u=° l=°		FL	**3 PM**					
	FT_2 70%	No	SD_6 v	u=° l=°		FL	**9 AM**					
				u=° l=°		FL	**12 PM**					
				u=° l=°		FL	**3 PM**					
	FT_3 50%	No	SD_6 v	u=45° l=90°	0	FL	**9 AM**	596	266	1673	0.45	0.16
				u=90° l=90°	0	FL	**12 PM**	1422	303	7957	0.21	0.04
				u=90° l=90°	2	FL	**3 PM**	518	403	616	0.78	0.65

Table 4.6 Part A-Retrofit scenarios (S7)

Part A - Southeast Façade (north is directed 26° to east) (Room Z55 : h=3.60 m, Area= 61.13 m^2)												
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row** (on) **LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode**												
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux)**			**UNIFORMITY**	
								E_{avg}	**E_{min}**	**E_{max}**	**U_1 E_{min}/E_{avg}**	**U_2 E_{min}/E_{max}**
SD u=12 l=12 distance 23 cm **S7**	FT_1 90%	No	SD_7 v	u=30° l=45°	1	FL	**9 AM**	487	330	637	0.68	0.52
				u=75° l=75°	2	FL	**12 PM**	466	294	609	0.63	0.48
				u=75° l=75°	3	FL	**3 PM**	545	468	655	0.86	0.71
	FT_2 70%	No	SD_7 v	u=30° l=30°	1	FL	**9 AM**	460	285	608	0.62	0.47
				u=60° l=75°	1	FL	**12 PM**	438	256	591	0.58	0.43
				u=75° l=60°	2	FL	**3 PM**	486	284	586	0.58	0.49
	FT_3 50%	No	SD_7 v	u=45° l=30°	2	FL	**9 AM**	486	340	618	0.70	0.55
				u=45° l=75°	1	FL	**12 PM**	515	309	753	0.60	0.41
				u=75° l=75°	3	FL	**3 PM**	504	436	589	0.86	0.74

In scenario S7 (Table 4.6) with VSD whose slat distances were 23 cm, the number of slats were increased unlike S6. Sunlight and daylight were controlled easily. ;so, uniformity was between 0.41 and 0.86. A high level of uniformity was obtained. S7-FT3 was proposed as the proper selection among the VSD scenarios. In S7-FT3, upper and lower slat angles were 45° and 30° respectively and two rows of lighting fixture turned on in the morning. At noon, upper and lower slat angles were 45° and 75° respectively and a single row of lighting fixture turned on. In the afternoon, upper and lower slat angles were 75° and three rows of lighting fixture turned on. In the proper scenarios of vertical shading devices (S7-FT3), uniformity values were found to be low and single row of lighting fixture worked on at noon.

A total of two accurate scenarios (one including HSD:S4-FT1 and one including VSD:S7-FT3) were selected and simulated using the same parameters. But the fluorescent fixtures were replaced to LED lighting fixtures at this time to compare the visual comfort conditions and their energy consumption (Table 4.7 and 4.8). The former, now named as S8 and the latter was S9.

According to simulation results (Table 4.7), scenarios conducted by using LED lighting fixtures resulted in higher values in terms of uniformity. For instance, at noon, HSD uniformity was increased from 0.79 (S4-FT1) to 0.92 (S8) and in the morning of VSD uniformity was increased from 0.70 (S7-FT1) to 0.82 (S9).

Table 4.8 presents the comparison of energy consumption of retrofit scenarios among the most accurate ones (S4-FT1, S8-FT1, S7-FT3 and S9-FT3) on December 21^{st}. The outputs were kWh/a and LENI (kWh/a.m^2). As the power intensity of the fluorescent and LED lighting fixtures were 70 W and 41 W respectively, the LED one consumes approx. 41% of less energy than the fluorescent one.

The LENI values of HSD and VSD scenarios (with fluorescent) were 12.4 and 18.6 kWh/a.m^2 respectively. S4 including HSD results in less energy consumption (756 kWh/a) annually than S7 including VSD (1134 kWh/a). Almost two third of the floor area required illumination artificially. This situation was assumed to be constant throughout the year. So, the calculation based on multiplying the total amount of energy consumed for one day (December 21^{st}) by the total number of working days (300 days).

Simulations were repeated for the proper selection of the HSD and VSD scenarios by using the same parameters of December 21^{st} for summer solstice and equinoxes; June 21^{st}, March 21^{st} and September 21^{st} respectively (Table 4.9 and 4.11). Retrofitting studies were conducted until visual comfort conditions were achieved for the improper results. For this part, facing Southeast façade, fixed panels were placed to prevent direct sunlight in solstices and equinoxes. For HSD, fixed panels with the height of window were placed on the two sides of window (Table 4.10, Figure 4.8-4.10). For VSD, fixed panels with the height of window were placed on the two sides and one panel on the top of the window with the same width (Table 4.12, Figure 4.11-4.13).

When comparing daylighting results for Part A, selected optimum horizontal shading device scenario (S4-FT1) could be proposed instead of vertical shading device scenario (S7-FT3) in achieving optimum visual comfort paramaters indoor.

Table 4.7 Part A-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of illuminance & uniformity

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Illuminance & Uniformity (Results taken from DIALux for December 21st)

Part A - Southeast Façade (north is directed 26° to east) (Room Z55 : h=3.60 m, Area= 61.13 m²)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S4	FT_1 90%	No	SD_4 h	u=0° l=75°	0	FL	**9 AM**	507	366	656	0.72	0.56
				u=75° l=75°	2	FL	**12 PM**	480	377	596	0.79	0.63
				u=15° l=60°	2	FL	**3 PM**	532	471	616	0.89	0.76
S8	FT_1 90%	No	SD_4 h	u=0° l=75°	0	LED	**9 AM**	507	366	656	0.72	0.56
				u=75° l=75°	2	LED	**12 PM**	416	382	456	0.92	0.84
				u=15° l=60°	2	LED	**3 PM**	470	433	519	0.92	0.83
S7	FT_3 50%	No	SD_7 v	u=45° l=30°	2	FL	**9 AM**	486	340	618	0.70	0.55
				u=45° l=75°	1	FL	**12 PM**	515	309	753	0.60	0.41
				u=75° l=75°	3	FL	**3 PM**	504	436	589	0.86	0.74
S9	FT_3 50%	No	SD_7 v	u=45° l=30°	2	LED	**9 AM**	424	347	481	0.82	0.72
				u=45° l=75°	1	LED	**12 PM**	484	311	754	0.64	0.41
				u=75° l=75°	3	LED	**3 PM**	410	361	451	0.88	0.80

Table 4.8 Part A-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of energy consumption

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Energy Consumption (Results taken from DIALux for December 21st)

Part A - Southeast Façade (north is directed 26° to east) (Room Z55 : h=3.60 m, Area= 61.13 m^2)

FT: Fenestration Transmittance
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent Luminous Flux: 3834 lm; Power=70 W
LED : Light Emitting Diode Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2)

Scenario	FT	SD Type	SD Angle	LL n	LT	Hour	ENERGY CONSUMPTION Time h	Floor Area %	Energy Wh	kWh/a a:300 d	LENI
S4	FT_1 90%	SD_4 h	u=0° l=75°	0	FL	**9 AM**	3	0	0	756.0	12.4
			u=75° l=75°	2	FL	**12 PM**	3	66.6	1260		
			u=15° l=60°	2	FL	**3 PM**	3	66.6	1260		
S8	FT_1 90%	SD_4 h	u=0° l=75°	0	LED	**9 AM**	3	0	0	442.8	7.2
			u=75° l=75°	2	LED	**12 PM**	3	66.6	738		
			u=15° l=60°	2	LED	**3 PM**	3	66.6	738		
S7	FT_3 50%	SD_7 v	u=45° l=30°	2	FL	**9 AM**	3	66.6	1260	1134.0	18.6
			u=45° l=75°	1	FL	**12 PM**	3	33.3	630		
			u=75° l=75°	3	FL	**3 PM**	3	100	1890		
S9	FT_3 50%	SD_7 v	u=45° l=30°	2	LED	**9 AM**	3	66.6	738	664.2	10.9
			u=45° l=75°	1	LED	**12 PM**	3	33.3	369		
			u=75° l=75°	3	LED	**3 PM**	3	100	1107		

Table 4.9 Part A-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the horizontal shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Horizontal Shading Devices (S4-FT1) (Results taken from DIALux)

Part A - Southeast Façade (north is directed 26° to east) (Room Z55 : h=3.60 m, Area= 61.13 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=75°	0	507	366	656	0.72	0.56
	March 21st			626	292	1091	0.47	0.27
	June 21st			400	184	705	0.46	0.26
	September 21st			481	229	840	0.48	0.27
12 PM	December 21st	u=75° l=75°	2	480	377	596	0.79	0.63
	March 21st			435	310	573	0.71	0.54
	June 21st			361	169	541	0.47	0.31
	September 21st			444	327	579	0.74	0.56
3 PM	December 21st	u=15° l=60°	2	532	471	616	0.89	0.76
	March 21st			598	532	664	0.89	0.80
	June 21st			544	508	634	0.93	0.80
	September 21st			674	555	810	0.82	0.68

Table 4.10 Part A-Retrofitting the results for the horizontal shading devices by using the fixed panels at W/S S&E

Retrofitting the Results for the Horizontal Shading Devices by Using the Fixed Panels at W/S S&E (S4-FT1) (Results taken from DIALux)

Part A - Southeast Façade (north is directed 26° to east) (Room Z55 : h=3.60 m, Area= 61.13 m^2)

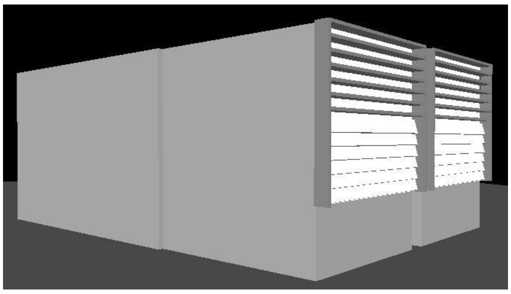
SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window

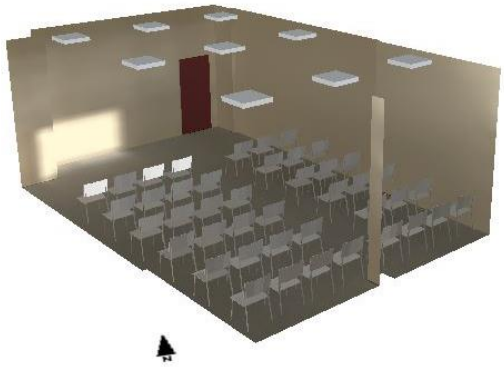
Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=75°	0	496	354	636	0.72	0.56
	March 21st	u=60° l=75°	2	513	459	605	0.89	0.76
	June 21st	u=0° l=90°	1	478	300	589	0.63	0.51
	September 21st	u=45° l=75°	2	504	442	597	0.88	0.74
12 PM	December 21st	u=75° l=75°	2	487	394	598	0.81	0.66
	March 21st			446	326	577	0.73	0.57
	June 21st	u=75° l=45°		547	500	657	0.91	0.76
	September 21st	u=75° l=75°		450	338	579	0.75	0.58
3 PM	December 21st	u=15° l=60°	2	507	439	602	0.87	0.63
	March 21st			566	520	642	0.92	0.81
	June 21st			508	438	612	0.86	0.72
	September 21st	u=45° l=90°		488	387	593	0.79	0.65

Outdoor & indoor perspective views for S8 in *Winter Solstice : December 21 st*
Part A - Southeast Façade (north is directed 26° to east)

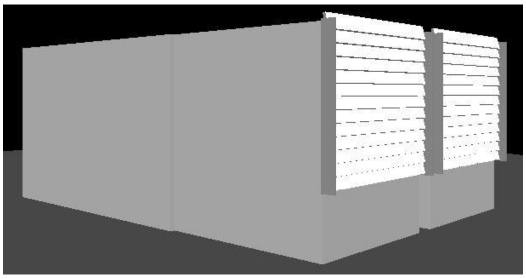
Outdoor Perspective	Indoor Perspective

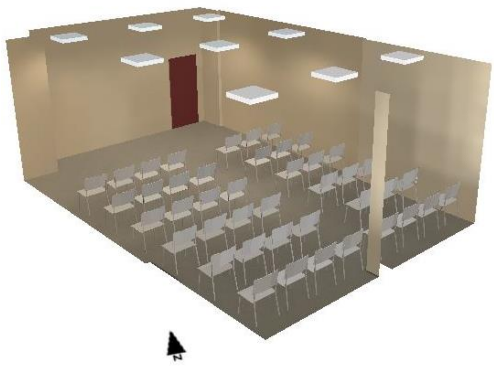
9:00 AM



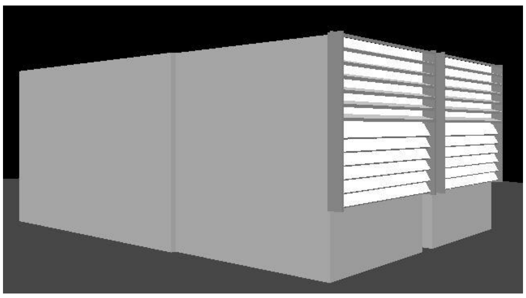


12:00 PM





3:00 PM



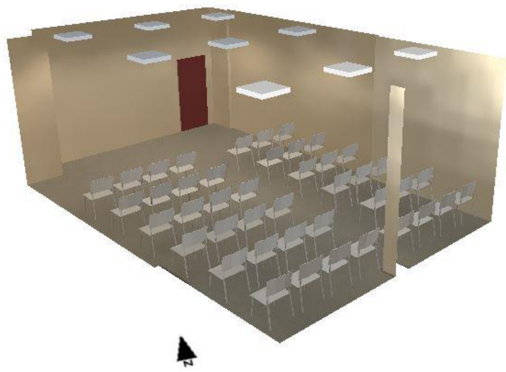


Figure 4.8 Part A-Outdoor & indoor perspective views for retrofitted S8

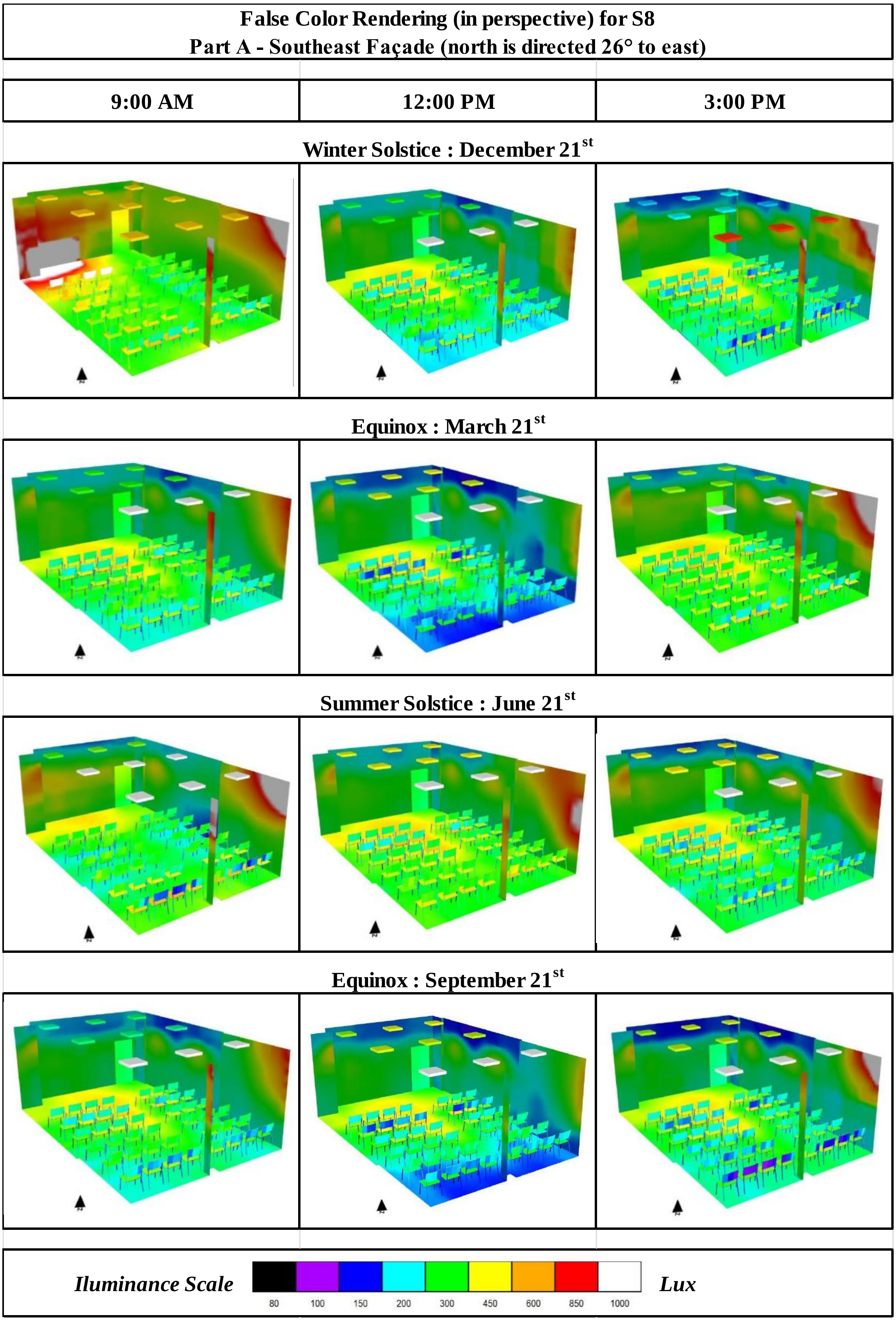


Figure 4.9 Part A-False color rendering (in perspective) for retrofitted S8

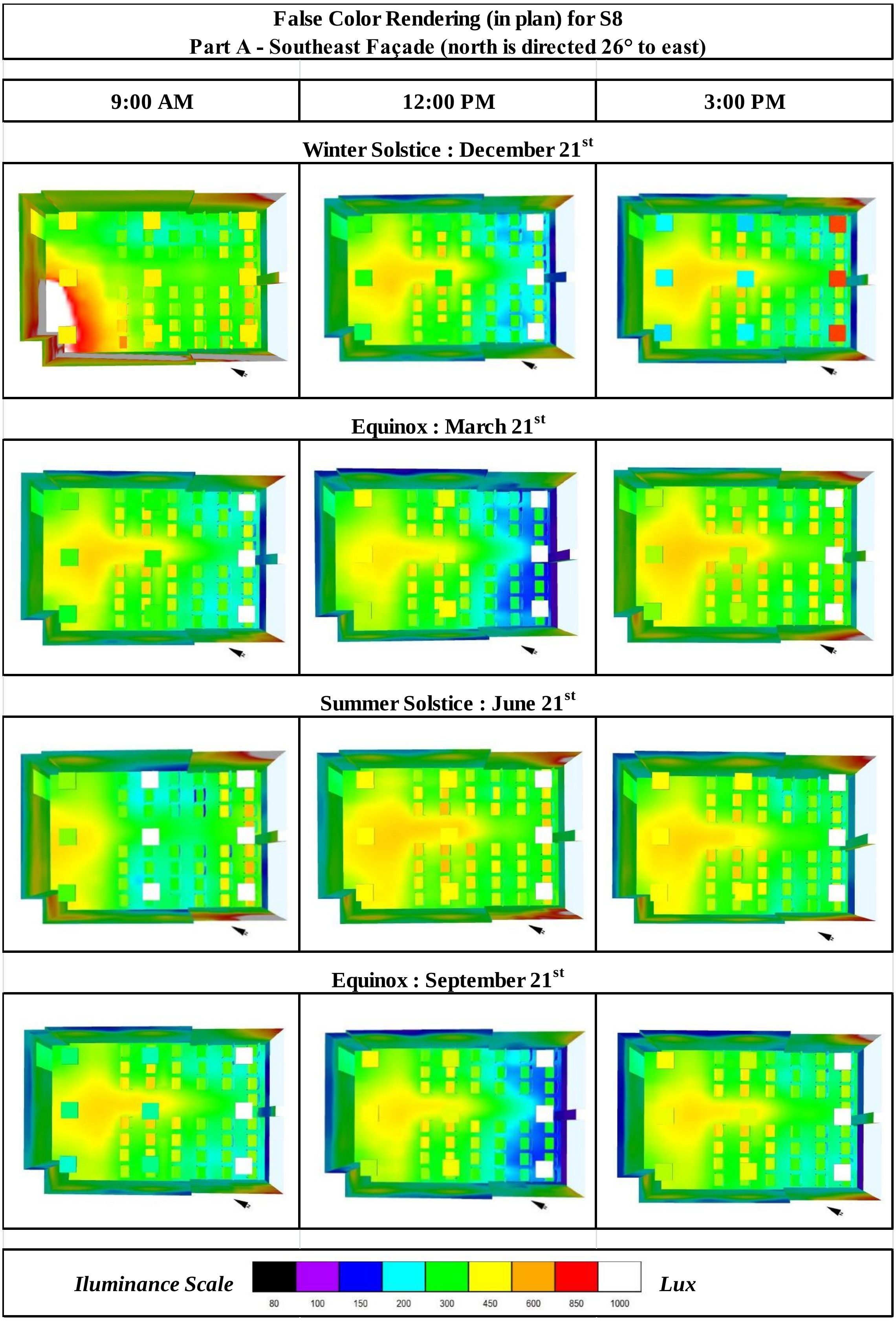


Figure 4.10 Part A-False color rendering (in plan) for retrofitted S8

Table 4.11 Part A-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the vertical shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Vertical Shading Devices (S7-FT3) (Results taken from DIALux)

Part A - Southeast Façade (north is directed 26° to east) (Room Z55 : h=3.60 m, Area= 61.13 m²)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=45° l=30°	2	486	340	618	0.70	0.55
	March 21st			1433	523	8330	0.37	0.06
	June 21st			496	405	600	0.82	0.68
	September 21st			503	387	611	0.77	0.63
12 PM	December 21st	u=45° l=75°	1	515	309	753	0.60	0.41
	March 21st			2372	289	17556	0.12	0.02
	June 21st			328	177	492	0.54	0.36
	September 21st			419	253	544	0.61	0.47
3 PM	December 21st	u=75° l=75°	3	504	436	589	0.86	0.74
	March 21st			487	423	576	0.83	0.73
	June 21st			482	432	576	0.90	0.75
	September 21st			518	456	601	0.88	0.76

Table 4.12 Part A-Retrofitting the results for the vertical shading devices by using the fixed panels at W/S S&E

Retrofitting the Results for the Vertical Shading Devices by Using the Fixed Panels at W/S S&E (S7-FT3) (Results taken from DIALux)								
Part A - Southeast Façade (north is directed 26° to east) (Room Z55 : h=3.60 m, Area= 61.13 m^2)								
SD: Shading Device (length=25cm); **Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row (on)** **Panel length: 25 cm** **Vertical; height: window height, location: head of each side of window** **Horizontal; width: window width, location: top of window**								
Hour	**W/S Solstices & Equinoxes**	**SD Angle**	**LL n**	**ILLUMINANCE (Lux)**			**UNIFORMITY**	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	**December 21st**	u=45° l=30°	2	448	303	586	0.68	0.52
	March 21st			524	438	611	0.84	0.72
	June 21st			463	322	579	0.70	0.56
	September 21st			460	318	584	0.69	0.55
12 PM	**December 21st**	u=60° l=60°	2	529	353	655	0.67	0.54
	March 21st			510	381	611	0.75	0.62
	June 21st	u=45° l=45°		500	396	593	0.79	0.67
	September 21st	u=60° l=45°		542	481	624	0.89	0.77
3 PM	**December 21st**	u=75° l=75°	3	482	416	576	0.86	0.72
	March 21st			469	403	567	0.86	0.71
	June 21st			462	397	562	0.86	0.71
	September 21st			488	427	580	0.88	0.74

Outdoor & indoor perspective views for S9 in *Winter Solstice : December 21 st*
Part A - Southeast Façade (north is directed 26° to east)

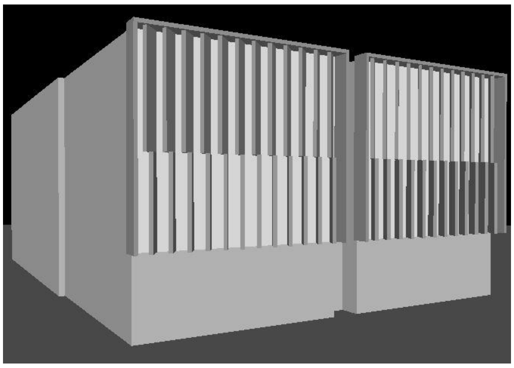
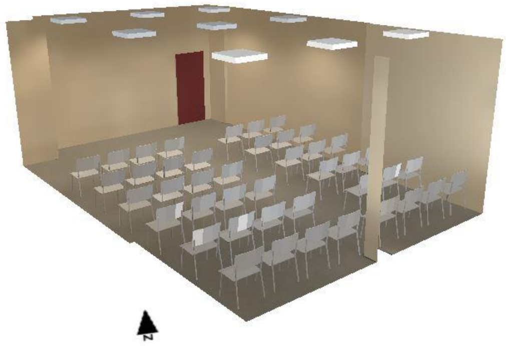
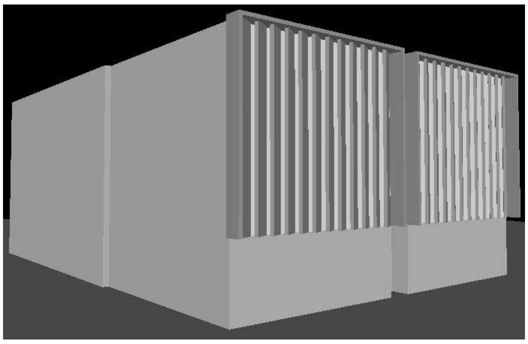
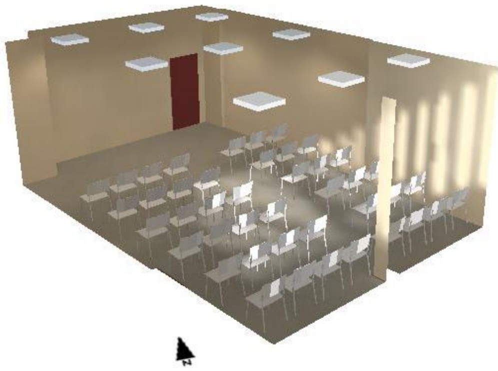
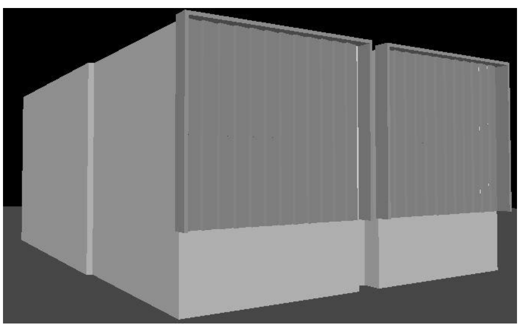
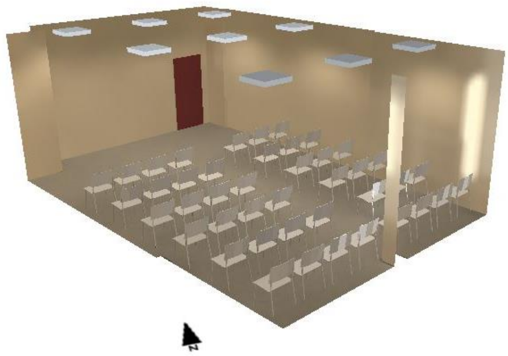
Outdoor Perspective	**Indoor Perspective**
9:00 AM	
	
12:00 PM	
	
3:00 PM	
	

Figure 4.11 Part A-Outdoor & indoor perspective views for retrofitted S9

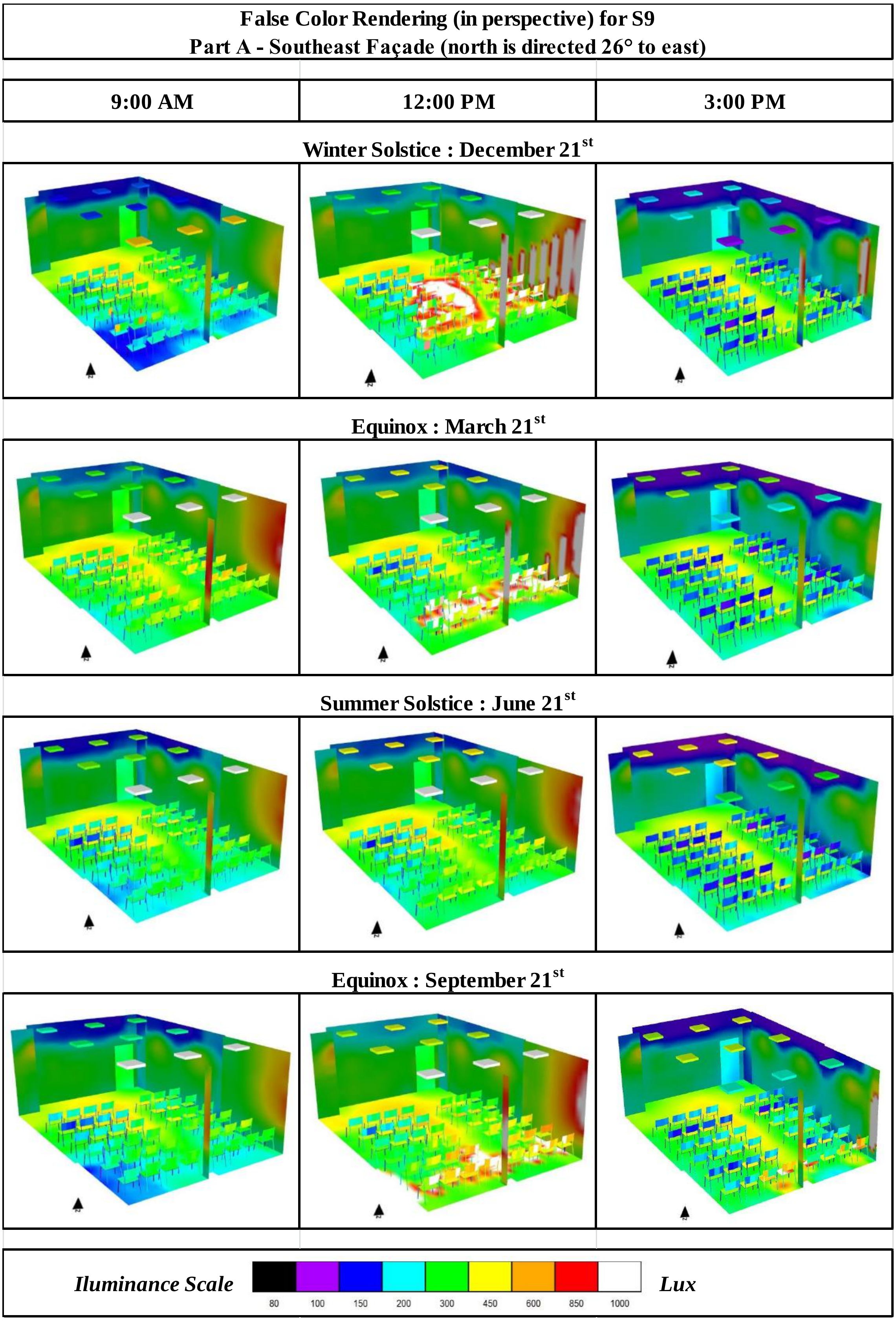


Figure 4.12 Part A-False color rendering (in perspective) for retrofitted S9

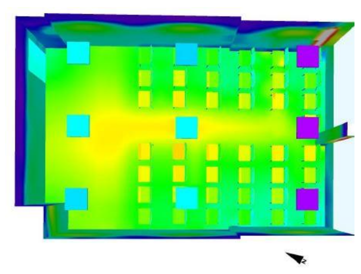
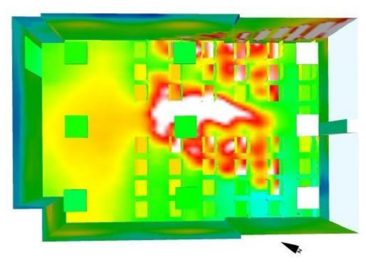
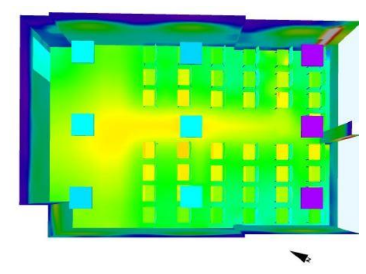
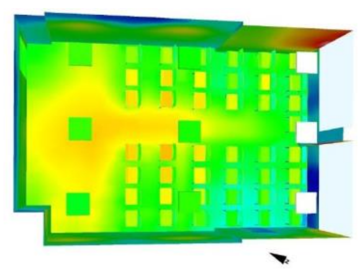
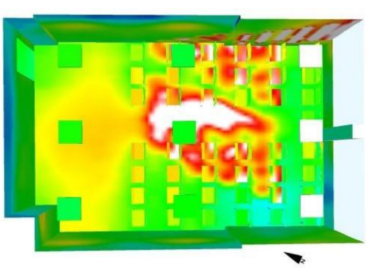
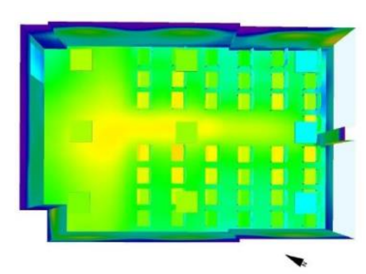
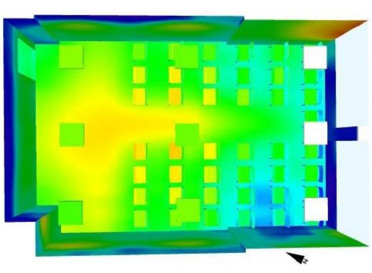
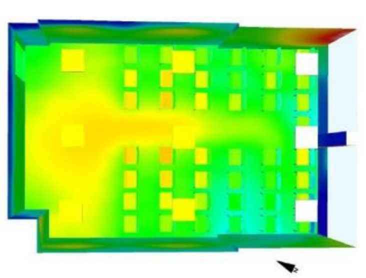
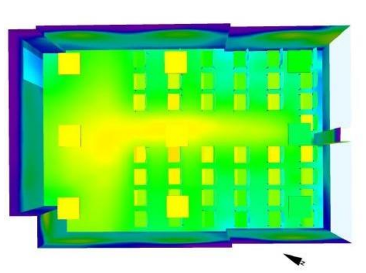
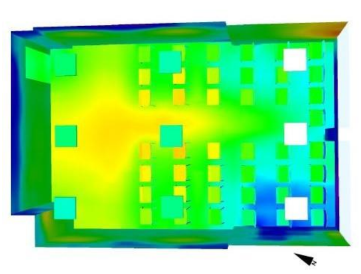
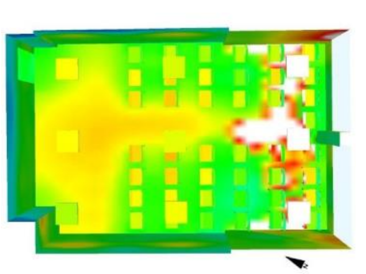
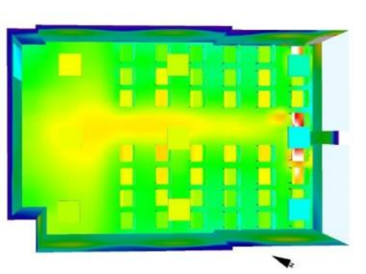
False Color Rendering (in plan) for S9 Part A - Southeast Façade (north is directed 26° to east)		
9:00 AM	**12:00 PM**	**3:00 PM**
Winter Solstice : December 21st		
		
Equinox : March 21st		
		
Summer Solstice : June 21st		
		
Equinox : September 21st		
		
Iluminance Scale 80 100 150 200 300 450 600 850 1000 ***Lux***		

Figure 4.13 Part A-False color rendering (in plan) for retrofitted S9

For annual energy consumption according to solstices and equinoxes calculation results were given in Table 4.13 and 4.14 for optimum HSD and VSD scenarios respectively.

When analyzed optimum horizontal shading scenario (S4-FT1) device energy consumption results, minimum LENI values were obtained as 3.6 kWh/a.m^2 for the day of December 21st. On the other hand, LENI reached to its maximum value, 4.6 kWh/a.m^2 in equinoxes. This is because of horizontal slats were open and less artificial lighting was needed during the winter solstice. In the morning hours on December 21st lighting didn't work.

In optimum vertical shading device scenario (S7-FT3), LENI value was found 5.4 kWh/a.m^2 in winter/summer solstices and equinoxes.

When used LEDs instead of fluorescent lighting fixtures, energy consumption decreased by 41%.

Accordingly, for Part A, energy consumption results for selected horizontal shading device scenario (S4-FT1) were found to be optimum comparing the selected vertical shading device scenario (S7-FT3).

Table 4.13 Part A-Comparison of lighting fixture type energy consumption for optimum results of the horizontal shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Horizontal Shading Devices

Part A - Southeast Façade (north is directed 26° to east) (Room Z55 : h=3.60 m, Area= 61.13 m^2)

SD: Shading Device; Type : horizontal; **upper: 7 lower: 6**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

W/S Solstices & Equinoxes	Hour	ENERGY CONSUMPTION								
		LL	Time h	Floor Area %	S4-FT1 with FL			S8 with LED		
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI
December 21st	9 AM	0	3	0	0	189.0	3.1	0	110.7	1.8
	12 PM	2	3	66.6	1260			738		
	3 PM	2	3	66.6	1260			738		
March 21st	9 AM	2	3	66.6	1260	283.5	4.6	738	166.1	2.7
	12 PM	2	3	66.6	1260			738		
	3 PM	2	3	66.6	1260			738		
June 21st	9 AM	1	3	33.3	630	236.3	3.9	369	138.4	2.3
	12 PM	2	3	66.6	1260			738		
	3 PM	2	3	66.6	1260			738		
September 21st	9 AM	2	3	66.6	1260	283.5	4.6	738	166.1	2.7
	12 PM	2	3	66.6	1260			738		
	3 PM	2	3	66.6	1260			738		
Annual Energy Consumption					**FL**	**992.3**	**16.2**	**LED**	**581.2**	**9.5**

Table 4.14 Part A-Comparison of lighting fixture type energy consumption for optimum results of the vertical shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Vertical Shading Devices

Part A - Southeast Façade (north is directed 26° to east)
(Room Z55 : h=3.60 m, Area= 61.13 m^2)

SD: Shading Device; **Type :** vertical;
upper: 12 **lower: 12**
LL: Lighting Fixture Layout; **n: Number of Lighting Row (on)**
LT: Lighting Fixture Type;
FL : Fluorescent; **Luminous Flux: 3834 lm; Power=70 W**
LED: Light Emitting Diode; **Luminous Flux: 3400 lm; Power=41 W**
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

W/S Solstices & Equinoxes	Hour	ENERGY CONSUMPTION								
		LL	Time h	Floor Area %	S7-FT3 with FL			S9 with LED		
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI
December 21st	9 AM	2	3	66.6	1260	330.8	5.4	738	193.7	3.2
	12 PM	2	3	66.6	1260			738		
	3 PM	3	3	100	1890			1107		
March 21st	9 AM	2	3	66.6	1260	330.8	5.4	738	193.7	3.2
	12 PM	2	3	66.6	1260			738		
	3 PM	3	3	100	1890			1107		
June 21st	9 AM	2	3	66.6	1260	330.8	5.4	738	193.7	3.2
	12 PM	2	3	66.6	1260			738		
	3 PM	3	3	100	1890			1107		
September 21st	9 AM	2	3	66.6	1260	330.8	5.4	738	193.7	3.2
	12 PM	2	3	66.6	1260			738		
	3 PM	3	3	100	1890			1107		
Annual Energy Consumption					**FL**	**1323.0**	**21.6**	**LED**	**774.9**	**12.7**

4.2.2 Daylighting Results for Part B

Part B is the second part that is evaluated in this study. It is a classroom (recommended illuminance value was 300-500 lx) located on the ground floor facing with Southwest façade. All the simulation steps were repeated similarly to Part A. In Appendix B, all the related tables and figures were given in the same sequence with Part A.

Base case average illuminance values have been found out as 1729 lx, 3682 lx, 881 lx and 4280 lx respectively on December 21st, March 21st, June 21st and September 21st at 3:00 PM. Uniformity values (E_{min}/E_{avg}) has been found out as 0.18, 0.11, 0.32 and 0.08 respectively on December 21st, March 21st, June 21st and September 21st at 3:00 PM (Table B.1).

When the classroom was examined from Figures B.1-B.3, it was seen that there was an unbalanced daylight distribution during the day like in Part A.

Retrofit scenarios (S1-S7) evaluated and it was observed that, proper daylighting results were obtained for HSD as S4-FT3 and for VSD as S7-FT3 for December 21st conditions. For winter/summer solstices and equinoxes daylighting results were retrofitted. Fixed panels were required due to the long width of the windows in order to block direct sunlight and sun patches. Table 4.15 and 4.16 showed the retrofit results for HSD and VSD in winter/summer solstices and equinoxes.

Table 4.15 Part B-Retrofitting the results for the horizontal shading devices by using the fixed panels at W/S S&E

Retrofitting the Results for the Horizontal Shading Devices by Using the Fixed Panels at W/S S&E (S4-FT3) (Results taken from DIALux)								
Part B - Southwest Façade (north is directed 26° to east) (Room Z48 : h=3.60 m, Area= 62.83 m^2)								
SD: Shading Device (length=25cm); LL: Lighting Fixture Layout; Panel length: 25 cm Vertical; height: window height,				Angle u: upper l: lower n: Number of Lighting Row (on) location: head of each side of window				
Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	476	433	551	0.91	0.78
	March 21st			509	456	580	0.89	0.79
	June 21st			503	454	576	0.90	0.79
	September 21st			495	449	569	0.91	0.79
12 PM	December 21st	u=0° l=0°	1	441	286	561	0.65	0.51
	March 21st	u=0° l=15°		420	289	507	0.69	0.57
	June 21st	u=0° l=0°	2	447	319	550	0.71	0.58
	September 21st			448	322	562	0.72	0.58
3 PM	December 21st	u=30° l=30°	2	481	448	542	0.93	0.83
	March 21st	u=30° l=75°		550	473	640	0.86	0.74
	June 21st	u=30° l=60°		511	454	559	0.89	0.81
	September 21st			565	474	667	0.84	0.71

Table 4.16 Part B-Retrofitting the results for the vertical shading devices by using the fixed panels at W/S S&E

Retrofitting the Results for the Vertical Shading Devices by Using the Fixed Panels at W/S S&E (S7-FT3) (Results taken from DIALux)								
Part B - Southwest Façade (north is directed 26° to east) (Room Z48 : h=3.60 m, Area= 62.83 m^2)								
SD: Shading Device (length=25cm); **Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row (on)** **Panel length: 25 cm** **Vertical; height: window height, location: head of each side of window** **Horizontal; width: window width, location: top of window**								
Hour	**W/S Solstices & Equinoxes**	**SD Angle**	**LL n**	**ILLUMINANCE (Lux)**			**UNIFORMITY**	
				E_{avg}	**E_{min}**	**E_{max}**	**U_1 E_{min}/E_{avg}**	**U_2 E_{min}/E_{max}**
9 AM	**December 21st**	u=0° l=0°	3	474	422	543	0.80	0.78
	March 21st			517	443	579	0.86	0.77
	June 21st			514	444	576	0.86	0.77
	September 21st			498	436	565	0.88	0.77
12 PM	**December 21st**	u=0° l=0°	2	503	450	578	0.89	0.78
	March 21st			550	482	616	0.88	0.78
	June 21st			488	402	578	0.82	0.70
	September 21st			482	392	570	0.81	0.69
3 PM	**December 21st**	u=0° l=60°	1	496	337	616	0.68	0.55
	March 21st	u=15° l=75°		497	369	655	0.74	0.56
	June 21st	u=0° l=75°		453	306	635	0.68	0.48
	September 21st	u=15° l=60°	2	573	505	645	0.88	0.78

4.2.3 Daylighting Results for Part C

Part C is the third part that is evaluated in this study. It is an office room (recommended illuminance value was 300-500 lx) located on the ground floor facing with Northwest façade. All the simulation steps were repeated similarly to Part A. In Appendix C, all the related tables and figures were given in the same sequence with Part A.

Base case average illuminance values have been found out as 58 lx, 109 lx, 140 lx and 89 lx respectively on December 21st, March 21st, June 21st and September 21st at 9:00 AM. Uniformity values (E_{min}/E_{avg}) has been found out as 0.23, 0.21, 0.18 and 0.21 respectively on December 21st, March 21st, June 21st and September 21st at 9:00 AM (Table C.1).

When the office room was examined from Figures C.1-C.3, it was seen that there was an unbalanced and insufficient daylight distribution during the day due to the improper design of horizontal overhangs and vertical cantilevers for this façade.

Retrofit scenarios (S1-S7) evaluated and it was observed that, in scenario S1 average illuminance values were proper but, maximum values are higher than 700 lx which was not recommended. So, proper daylighting results were obtained for HSD as S4-FT1 and for VSD as S7-FT2 for December 21st conditions. For winter/summer solstices and equinoxes daylighting results were retrofitted. Table 4.17 and 4.18 showed the retrofit results for HSD and VSD in winter/summer solstices and equinoxes.

Table 4.17 Part C-Retrofitting the results for the horizontal shading devices at W/S S&E

Retrofitting the Results for the Horizontal Shading Devices at W/S S&E (S4-FT1) (Results taken from DIALux)

Part C - Northwest Façade (north is directed 26° to east) (Room Z35 : h=3.30 m, Area= 80.36 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	426	293	596	0.69	0.49
	March 21st	u=45° l=45°		406	294	558	0.72	0.53
	June 21st	u=60° l=60°		398	284	545	0.71	0.52
	September 21st	u=45° l=30°		406	289	557	0.71	0.52
12 PM	December 21st	u=0° l=0°	3	466	353	667	0.76	0.53
	March 21st	u=60° l=60°		396	297	544	0.75	0.55
	June 21st	u=75° l=60°		401	299	559	0.75	0.54
	September 21st	u=45° l=60°		405	300	557	0.74	0.54
3 PM	December 21st	u=0° l=0°	3	444	333	628	0.75	0.53
	March 21st	u=60° l=60°		412	307	506	0.74	0.54
	June 21st	u=75° l=60°		422	316	586	0.75	0.54
	September 21st	u=60° l=60°		411	307	566	0.75	0.54

Table 4.18 Part C-Retrofitting the results for the vertical shading devices at W/S S&E

Retrofitting the Results for the Vertical Shading Devices at W/S S&E (S7-FT2) (Results taken from DIALux)

Part C - Northwest Façade (north is directed 26° to east) (Room Z35 : h=3.30 m, Area= 80.36 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row (on)**
<u>Panel</u> length: 25 cm
Vertical; height: window height, location: head of each side of window
Horizontal; width: window width, location: top of window

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21^{st}	u=0° l=0°	3	417	298	571	0.72	0.52
	March 21^{st}	u=60° l=0°		425	310	578	0.73	0.54
	June 21^{st}	u=75° l=30°		420	303	570	0.72	0.53
	September 21^{st}	u=60° l=0°		414	301	560	0.73	0.54
12 PM	December 21^{st}	u=0° l=0°	3	448	328	625	0.73	0.53
	March 21^{st}	u=60° l=45°		410	294	561	0.71	0.52
	June 21^{st}	u=75° l=45°		415	301	570	0.72	0.53
	September 21^{st}	u=60° l=45°		410	294	560	0.72	0.52
3 PM	December 21^{st}	u=0° l=0°	3	427	312	590	0.73	0.53
	March 21^{st}	u=60° l=45°		417	300	571	0.72	0.53
	June 21^{st}	u=75° l=60°		404	298	550	0.74	0.54
	September 21^{st}	u=60° l=45°		418	299	572	0.72	0.52

4.2.4 Daylighting Results for Part D

Part D is the fourth part that is evaluated in this study. It is a laboratory (recommended illuminance value was 500-750 lx) located on the ground floor facing with Northeast façade. All the simulation steps were repeated similarly to Part A. In Appendix D, all the related tables and figures were given in the same sequence with Part A.

Base case average illuminance values have been found out as 120 lx, 328 lx, 1353 lx and 508 lx respectively on December 21st, March 21st, June 21st and September 21st at 9:00 AM. Uniformity values (E_{min}/E_{avg}) has been found out as 0.18, 0.18, 0.06 and 0.11 respectively on December 21st, March 21st, June 21st and September 21st at 9:00 AM (Table D.1).

When the laboratory was examined from Figures D.1-D.3, it was seen that there was an unbalanced and insufficient daylight distribution during the day due to the improper design of horizontal overhangs and vertical cantilevers for this façade.

Retrofit scenarios (S1-S7) evaluated and it was observed that, in scenario S1 average illuminance values were proper but, maximum values are higher than 1500 lx which was not recommended. So, proper daylighting results were obtained for HSD as S4-FT1 and for VSD as S7-FT3 for December 21st conditions. For winter/summer solstices and equinoxes daylighting results were retrofitted. Table 4.19 and 4.20 showed the retrofit results for HSD and VSD in winter/summer solstices and equinoxes.

Table 4.19 Part D-Retrofitting the results for the horizontal shading devices at W/S S&E

Retrofitting the Results for the Horizontal Shading Devices by Using the Fixed Panels at W/S S&E (S4-FT1) (Results taken from DIALux)								
Part D - Southeast Façade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m²)								
SD: Shading Device (length=25cm); **LL: Lighting Fixture Layout;** **Panel length: 25 cm** **Vertical; height: window height,**			**Angle u: upper l: lower** **n: Number of Lighting Row** (on) **location: head of each side of window**					
Hour	**W/S Solstices & Equinoxes**	**SD Angle**	**LL n**	**ILLUMINANCE (Lux)**			**UNIFORMITY**	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	**December 21st**	u=0° l=0°	3	556	408	740	0.73	0.55
	March 21st	u=45° l=45°	3	620	447	757	0.72	0.59
	June 21st	u=45° l=60°	3	630	453	765	0.72	0.59
	September 21st	u=15° l=45°	3	636	443	776	0.70	0.57
12 PM	**December 21st**	u=0° l=0°	4	671	434	979	0.65	0.44
	March 21st	u=0° l=0°	3	618	457	834	0.74	0.55
	June 21st	u=0° l=60°	3	650	436	809	0.67	0.54
	September 21st	u=45° l=0°	3	617	444	797	0.72	0.59
3 PM	**December 21st**	u=0° l=0°	4	554	416	686	0.75	0.61
	March 21st			631	439	783	0.70	0.56
	June 21st			693	459	834	0.66	0.55
	September 21st			652	442	795	0.69	0.56

Table 4.20 Part D-Retrofitting the results for the vertical shading devices at W/S S&E

Retrofitting the Results for the Vertical Shading Devices at W/S S&E (S7-FT3) (Results taken from DIALux)

Part D - Southeast Façade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row (on)**
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window
Horizontal; width: window width, location: top of window

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	5	650	455	929	0.70	0.49
	March 21st		3	624	429	768	0.69	0.56
	June 21st	u=45° l=75°	4	682	467	930	0.69	0.50
	September 21st	u=45° l=75°	5	611	409	922	0.67	0.44
12 PM	December 21st	u=0° l=0°	4	589	374	874	0.63	0.43
	March 21st		4	614	415	830	0.68	0.50
	June 21st		3	632	438	780	0.69	0.56
	September 21st		3	551	415	709	0.75	0.59
3 PM	December 21st	u=0° l=0°	5	636	448	927	0.70	0.48
	March 21st		5	656	462	934	0.70	0.49
	June 21st		4	596	411	768	0.69	0.54
	September 21st		4	562	405	684	0.72	0.59

4.2.5 Daylighting Results for Part E

Part E is the fifth part that is evaluated in this study. It is an office room (recommended illuminance value was 300-500 lx) located on the ground floor facing with Southwest façade. All the simulation steps were repeated similarly to Part A. In Appendix E, all the related tables and figures were given in the same sequence with Part A.

Base case average illuminance values have been found out as 56 lx, 127 lx, 142 lx and 106 lx respectively on December 21st, March 21st, June 21st and September 21st at 9:00 AM. Uniformity values (E_{min}/E_{avg}) has been found out as 0.30, 0.31, 0.33 and 0.31 respectively on December 21st, March 21st, June 21st and September 21st at 9:00 AM (Table E.1).

When the office room was examined from Figures E.1-E.3, it was seen that there was an unbalanced and insufficient daylight distribution during the day due to the improper design of balconies and shading devices together for this façade.

Retrofit scenarios (S1-S7) evaluated and it was observed that, proper daylighting results were obtained for HSD as S4-FT3 and for VSD as S7-FT3 for December 21st conditions. For winter/summer solstices and equinoxes daylighting results were retrofitted. Table 4.21 and 4.22 showed the retrofit results for HSD and VSD in winter/summer solstices and equinoxes.

Table 4.21 Part E-Retrofitting the results for the horizontal shading devices at W/S S&E

Retrofitting the Results for the Horizontal Shading Devices at W/S S&E (S4-FT3) (Results taken from DIALux)

Part E - Southwest Façade (north is directed 26° to east) (Room Z17 : h=2.60 m, Area= 19.70 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=60° l=60°	3	492	450	522	0.91	0.86
	March 21st			510	455	536	0.89	0.85
	June 21st			506	455	533	0.90	0.85
	September 21st			497	450	525	0.91	0.86
12 PM	December 21st	u=30° l=30°	2	481	400	555	0.83	0.72
	March 21st	u=0° l=45°		433	320	523	0.74	0.61
	June 21st	u=30° l=30°		470	362	570	0.77	0.63
	September 21st	u=30° l=30°		466	362	561	0.78	0.65
3 PM	December 21st	u=30° l=30°	2	465	377	541	0.81	0.70
	March 21st	u=30° l=60°		459	368	537	0.80	0.68
	June 21st	u=30° l=60°		438	327	526	0.75	0.62
	September 21st	u=30° l=60°		471	382	547	0.81	0.70

Table 4.22 Part E-Retrofitting the results for the vertical shading devices at W/S S&E

Retrofitting the Results for the Vertical Shading Devices at W/S S&E (S7-FT3) (Results taken from DIALux)								
Part E - Southwest Façade (north is directed 26° to east) (Room Z17 : h=2.60 m, Area= 19.70 m^2)								
SD: Shading Device (length=25cm); Angle u: upper l: lower LL: Lighting Fixture Layout; n: Number of Lighting Row (on) Panel length: 25 cm Vertical; height: window height, location: head of each side of window Horizontal; width: window width, location: top of window								
Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	537	468	563	0.87	0.83
	March 21st	u=60° l=60°		515	457	539	0.89	0.85
	June 21st	u=60° l=60°		516	458	540	0.89	0.85
	September 21st	u=60° l=60°		506	453	531	0.89	0.85
12 PM	December 21st	u=45° l=0°	2	454	357	538	0.79	0.66
	March 21st	u=45° l=30°		460	365	543	0.79	0.67
	June 21st	u=45° l=0°		476	376	568	0.79	0.66
	September 21st	u=45° l=0°		469	371	559	0.79	0.66
3 PM	December 21st	u=0° l=15°	1	404	286	518	0.71	0.55
	March 21st	u=75° l=60°	2	471	349	565	0.74	0.62
	June 21st	u=60° l=60°	2	459	367	541	0.80	0.68
	September 21st	u=60° l=60°	2	463	363	544	0.78	0.67

4.2.6 Daylighting Results for Part F

Part F is the sixth part that is evaluated in this study. It is a lecture hall (recommended illuminance value was 300-500 lx) located on the ground floor facing with Southeast façade. All the simulation steps were repeated similarly to Part A. In Appendix E, all the related tables and figures were given in the same sequence with Part A.

Base case average illuminance values have been found out as 80 lx, 107 lx, 103 lx and 130 lx respectively on December 21st, March 21st, June 21st and September 21st at 3:00 PM. Uniformity values (E_{min}/E_{avg}) has been found out as 0.29, 0.27, 0.29 and 0.27 respectively on December 21st, March 21st, June 21st and September 21st at 3:00 PM (Table F.1).

When the lecture hall was examined from Figures F.1-F.3, it was seen that there was an unbalanced and insufficient daylight distribution during the day due to the improper design of balconies and shading devices together for this façade.

Retrofit scenarios (S1-S7) evaluated and it was observed that, proper daylighting results were obtained for HSD as S4-FT2 and for VSD as S7-FT3 for December 21st conditions. For winter/summer solstices and equinoxes daylighting results were retrofitted. Table 4.23 and 4.24 showed the retrofit results for HSD and VSD in winter/summer solstices and equinoxes.

Table 4.23 Part F-Retrofitting the results for the horizontal shading devices at W/S S&E

Retrofitting the Results for the Horizontal Shading Devices at W/S S&E (S4-FT2) (Results taken from DIALux)

Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	1	455	253	739	0.56	0.34
	March 21st	u=30° l=60°	2	568	318	866	0.56	0.37
	June 21st	u=0° l=0°	1	495	260	771	0.53	0.34
	September 21st			507	263	735	0.52	0.36
12 PM	December 21st	u=0° l=75°	1	489	295	813	0.60	0.36
	March 21st			486	280	813	0.58	0.34
	June 21st	u=45° l=75°	2	471	240	812	0.51	0.30
	September 21st	u=0° l=75°	1	483	277	802	0.57	0.35
3 PM	December 21st	u=0° l=0°	1	430	260	669	0.61	0.39
	March 21st			504	298	745	0.59	0.40
	June 21st			445	262	630	0.59	0.42
	September 21st	u=0° l=45°		469	267	737	0.57	0.36

Table 4.24 Part F-Retrofitting the results for the vertical shading devices at W/S S&E

Retrofitting the Results for the Vertical Shading Devices at W/S S&E (S7-FT3) (Results taken from DIALux)

Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row (on)**
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window
Horizontal; width: window width, location: top of window

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	21st December	u=30° l=45°	2	451	222	811	0.49	0.27
	21st March			492	284	829	0.58	0.34
	21st June			436	233	803	0.53	0.29
	21st September			442	231	801	0.52	0.29
12 PM	21st December	u=60° l=75°	2	469	236	876	0.50	0.27
	21st March			471	223	853	0.47	0.26
	21st June	u=30° l=75°		487	236	882	0.49	0.27
	21st September	u=90° l=90°	3	1749	342	16347	0.18	0.02
3 PM	21st December	u=0° l=0°	2	468	238	802	0.51	0.30
	21st March			524	283	824	0.54	0.34
	21st June			541	316	836	0.58	0.38
	21st September			597	344	853	0.58	0.40

4.3. Energy Consumption Results for all Parts

Summary of energy consumption graphics were prepared for winter/summer solstices and equinoxes for all Parts (Figure 4.14-4.17). These graphics cover base case (BC), selected optimum horizontal (HSD) and vertical shading device (VSD) scenarios' LENI results. LENI values were calculated and compared for fluorescent and LED ligting fixtures in kWh/p.m^2. "p" defines each solstice or equinox and refers to 75 days. As mentioned before, LEDs energy consumption is 40% less than fluorescent lighting fixture consumption. It was observed that BC energy consumption was in general higher than HSD and VSD in all parts.

For December 21st (Figure 4.14), it was understood that LENI values of HSD and VSD were close to each other in Part B and C. In Part A, D and F, HSD LENI values were found to be better (less) than VSDs. LENI values of VSD were obtained better (less) than HSDs only in Part E. Although Part B and E were both facing Southwest, optimum LENI results varied due to their fenestration specifications such as width, height and selected fenestration transmittance values; and due to the depth of the room. The depth of Part B was 9.80 m; while the depth of Part E was 6.60 m. So, the VSD resulted in a more energy efficient solution than the HSD did in the room which was shorter in depth. However, the position of the slat (horizontal versus vertical) did not show any impact on the energy consumption in the room which was longer in depth ($d > 9.00$ m). In addition, when compared to Part B and Part E, the LENI of the larger room is less than the LENI of the smaller room. It may be necessary to decrease the number of lighting fixtures in Part E. This situation was similar when there was a comparison between the LENI values of Part A and Part F. However, the HSD was the most energy efficient solution throughout the year, since their depths were identical.

As a summary, HSD and VSD LENI results were found close for Part B and C on December 21st, for Part C and E on June 21st (Figure 4.16), for Part B, C and E in equinoxes (Figure 4.15 and 4.17). On the other hand, it was figured out from the graphics that LENI results of VSD were only found to be optimum on June 21st (Figure 4.16) for Part B and in December 21st for Part (Figure 4.14) E. In general, the LENI values were at the least level on December 21st. All these figures (4.14 - 4.17) could be seen together in a single page in Appendix H.

It was concluded that HSD scenarios were found to be energy efficient solutions for Southeast and Southwest façades in relation to the geometric attributes (depth, width) of the room in this study. Annual energy consumption figures for each part were given in sections below. Their figures could be seen together in a single page in Appendix I.

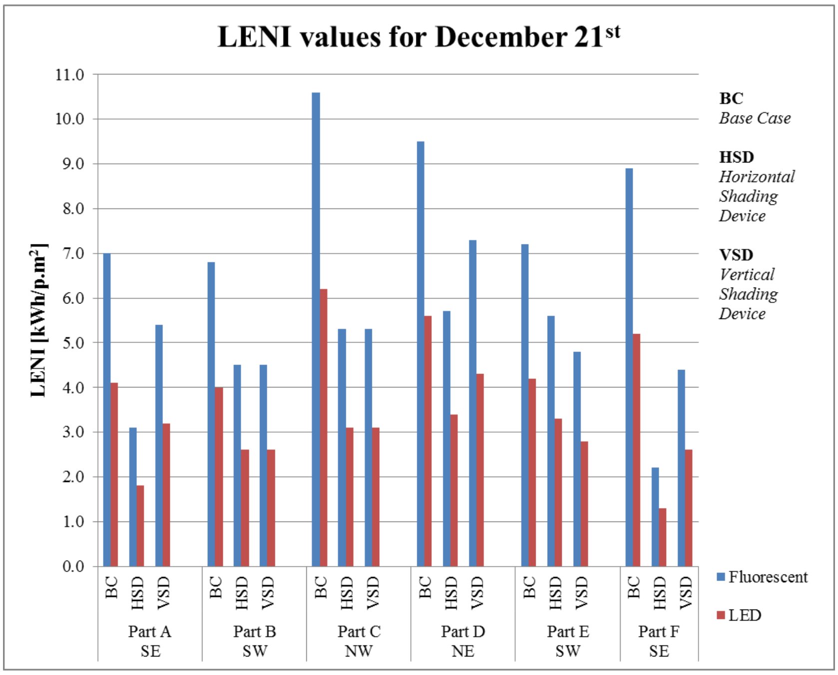


Figure 4.14 LENI Values of all parts for December 21st

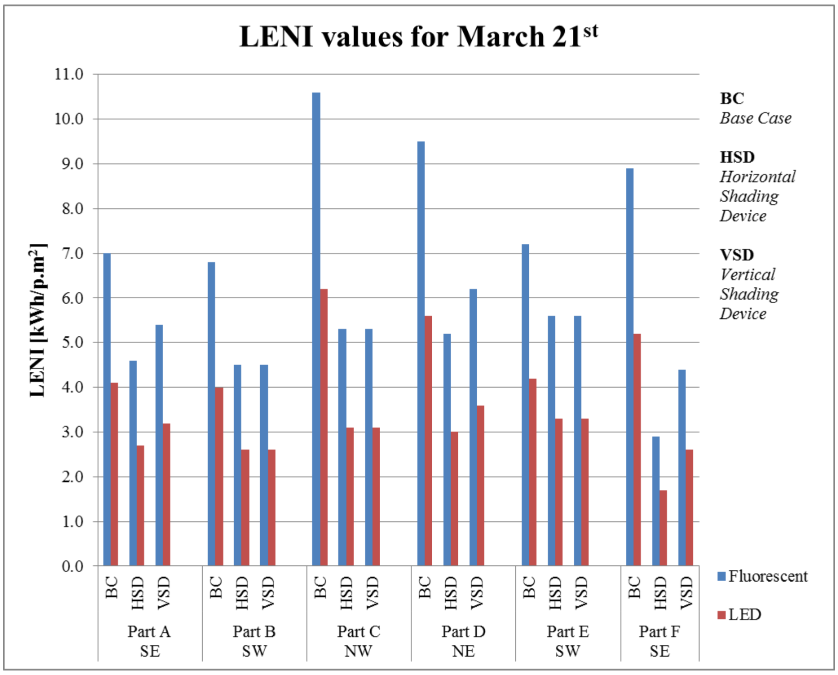


Figure 4.15 LENI Values of all parts for March 21st

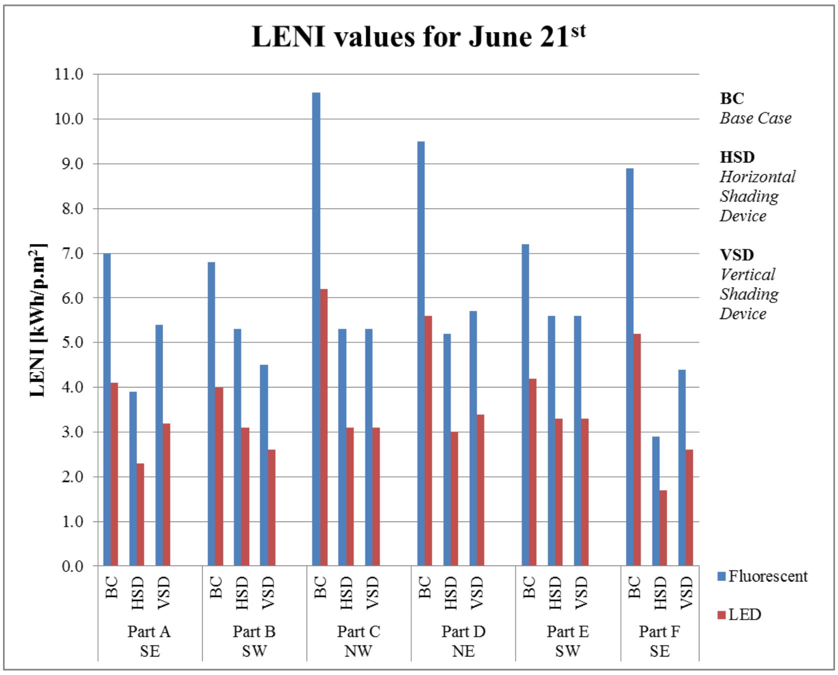


Figure 4.16 LENI Values of all parts for June 21st

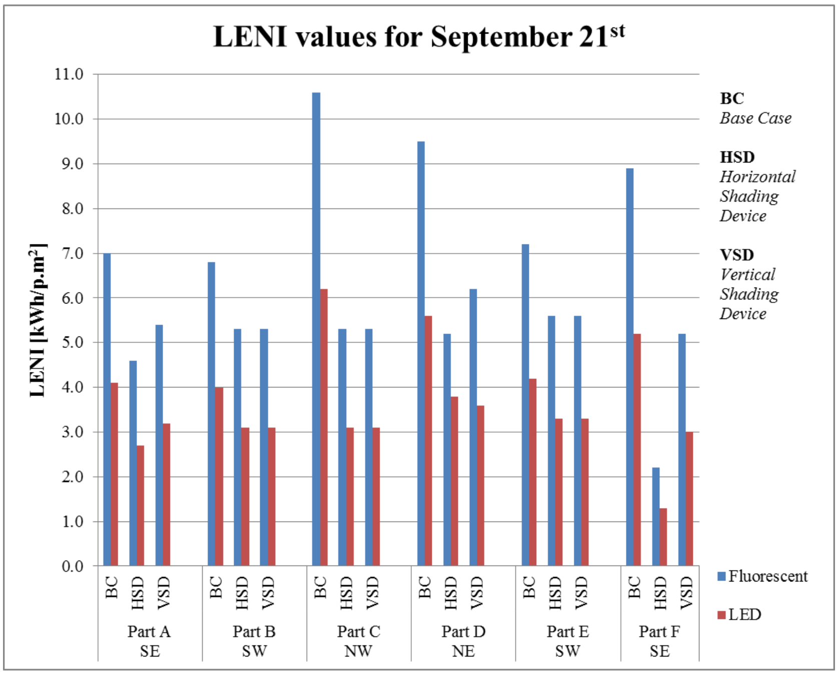


Figure 4.17 LENI Values of all parts for September 21st

4.3.1 Annual Energy Consumption for Part A

Summary of energy consumption results were given in Table 4.25. It was seen from table that the energy consumption for base case were 1701.0 kWh/a when all the lightings working on. Annual energy consumption results for selected optimum HSD (S4-FT1) and VSD (S7-FT3) scenarios were found 766.8 and 1150.2 kWh/a respectively when using December 21st parameters. After retrofitting for all solstices and equinoxes, energy consumption results were calculated as 992.3 kWh/a for HSD and 1323.0 kWh/a for VSD. Starting from this point of view, selected optimum HSD scenario's energy consumption result was found to be better than VSD results for winter/summer solstices and equinoxes. When comparing the selected optimum HSD energy consumption results with the base case, it was seen that 42% of saving could be achieved. Moreover, if the fluorescent lighting would be replaced by LEDs in optimum case of HSD, annual energy consumption decreased to 581.2 kWh/a. That means 66% saving could be obtained according to base case. Like that LENI values could be retrofitted from 27.8 to 9.5 kWh/a.m^2.

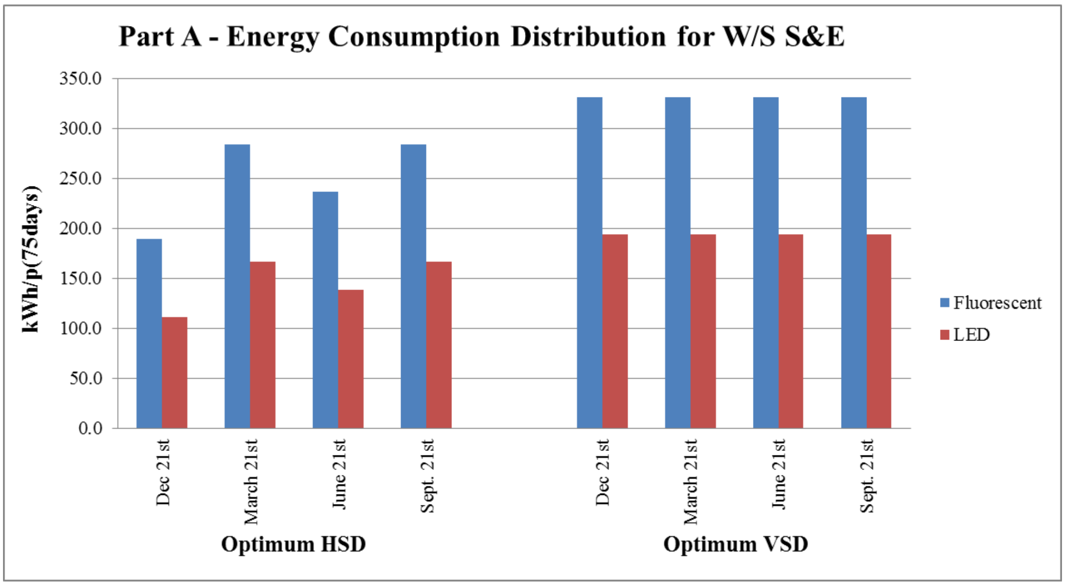


Figure 4.18 Part A-Energy Consumption Distribution of W/S S&E

From Figure 4.18, it was seen that energy consumption results were found as optimum in winter/summer solstices for selected optimum HSD.

Table 4.25 Part A-Summary of Energy Consumption

Summary of Energy Consumption

Part A - Southeast Façade (north is directed 26° to east)
(Room Z55 : h=3.60 m, Area= 61.13 m^2)

LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

DESCRIPTION		Hour	LL	FL kWh/a p: 75 d a: 300 d	FL LENI	LED kWh/a p: 75 d a: 300 d	LED LENI
Base Case (S0)		9 AM	3	1701.0	27.8	996.3	16.3
		12 PM	3				
		3 PM	3				
Optimum HSD&VSD for December 21st	S4-FT1	9 AM	0	766.8	12.5	432.0	7.1
		12 PM	2				
		3 PM	2				
	S7-FT3	9 AM	2	1150.2	18.8	648.0	10.6
		12 PM	1				
		3 PM	3				
Optimum HSD for Winter/Summer Solstices & Equinoxes	December 21st	9 AM	0	189.0	3.1	110.8	1.8
		12 PM	2				
		3 PM	2				
	March 21st	9 AM	2	283.5	4.6	166.1	2.7
		12 PM	2				
		3 PM	2				
	June 21st	9 AM	1	236.3	3.9	138.4	2.3
		12 PM	2				
		3 PM	2				
	September 21st	9 AM	2	283.5	4.6	166.1	2.7
		12 PM	2				
		3 PM	2				
	Annual Energy Consumption for Optimum HSD			992.3	16.2	581.2	9.5
Optimum VSD for Winter/Summer Solstices & Equinoxes	December 21st	9 AM	2	330.8	5.4	193.7	3.2
		12 PM	2				
		3 PM	3				
	March 21st	9 AM	2	330.8	5.4	193.7	3.2
		12 PM	2				
		3 PM	3				
	June 21st	9 AM	2	330.8	5.4	193.7	3.2
		12 PM	2				
		3 PM	3				
	September 21st	9 AM	2	330.8	5.4	193.7	3.2
		12 PM	2				
		3 PM	3				
	Annual Energy Consumption for Optimum VSD			1323.0	21.6	774.9	12.7

4.3.2 Annual Energy Consumption for Part B

Energy consumption results were summarized in Table 4.26. It was seen from table that the energy consumption for base case were 1701.0 kWh/a when all the lightings working on. Annual energy consumption results for selected optimum HSD (S4-FT3) and VSD (S7-FT3) scenarios were found 1150.2 and 1150.2 kWh/a respectively when using December 21st parameters. After retrofitting for all solstices and equinoxes, energy consumption results were calculated as 1228.5 kWh/a for HSD and 1181.3 kWh/a for VSD. It means that, selected optimum HSD and VSD scenario energy consumption results were found very close to each other. When comparing the selected optimum VSD energy consumption results with the base case, it was seen that 30% of saving could be achieved. Moreover, if the fluorescent lighting would be replaced by LEDs in optimum case of VSD, annual energy consumption decreased to 691.9 kWh/a. That means 59% saving could be obtained according to base case. Like that LENI values could be retrofitted from 27.1 to 11.0 kWh/a.m^2.

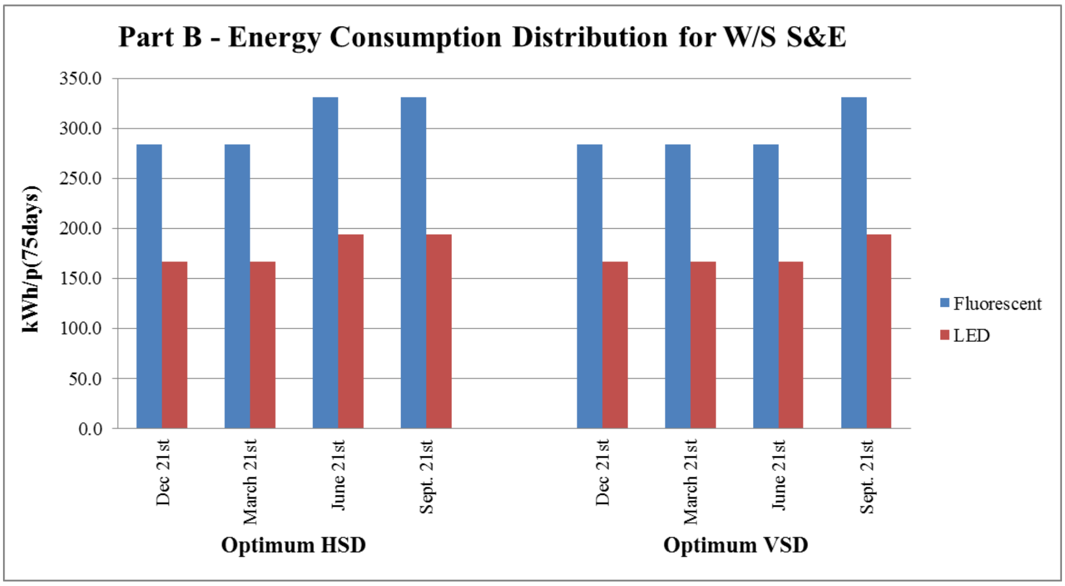


Figure 4.19 Part B-Energy Consumption Distribution of W/S S&E

From Figure 4.19, it was seen that energy consumption results were found as optimum in winter/summer solstices and March 21st for selected optimum VSD while HSD results were obtained optimum for December 21st and March 21st.

Table 4.26 Part B-Summary of Energy Consumption

<table>
<tr><th colspan="8">Summary of Energy Consumption</th></tr>
<tr><th colspan="8">Part B - Southwest Façade (north is directed 26° to east)
(Room Z48 : h=3.60 m, Area= 62.83 m^2)</th></tr>
<tr><td colspan="8">LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day</td></tr>
<tr><th colspan="2" rowspan="2">DESCRIPTION</th><th rowspan="2">Hour</th><th rowspan="2">LL</th><th colspan="2">FL</th><th colspan="2">LED</th></tr>
<tr><th>kWh/a
p: 75 d
a: 300 d</th><th>LENI</th><th>kWh/a
p: 75 d
a: 300 d</th><th>LENI</th></tr>
<tr><td colspan="2" rowspan="3">Base Case (S0)</td><td>9 AM</td><td>3</td><td rowspan="3">1701.0</td><td rowspan="3">27.1</td><td rowspan="3">996.3</td><td rowspan="3">15.9</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td rowspan="6">Optimum HSD&VSD for December 21st</td><td rowspan="3">S4-FT3</td><td>9 AM</td><td>3</td><td rowspan="3">1150.2</td><td rowspan="3">18.3</td><td rowspan="3">648.0</td><td rowspan="3">10.3</td></tr>
<tr><td>12 PM</td><td>1</td></tr>
<tr><td>3 PM</td><td>2</td></tr>
<tr><td rowspan="3">S7-FT3</td><td>9 AM</td><td>3</td><td rowspan="3">1150.2</td><td rowspan="3">18.3</td><td rowspan="3">648.0</td><td rowspan="3">10.3</td></tr>
<tr><td>12 PM</td><td>2</td></tr>
<tr><td>3 PM</td><td>1</td></tr>
<tr><td rowspan="13">Optimum HSD for Winter/Summer Solstices & Equinoxes</td><td rowspan="3">December 21st</td><td>9 AM</td><td>3</td><td rowspan="3">283.5</td><td rowspan="3">4.5</td><td rowspan="3">166.1</td><td rowspan="3">2.6</td></tr>
<tr><td>12 PM</td><td>1</td></tr>
<tr><td>3 PM</td><td>2</td></tr>
<tr><td rowspan="3">March 21st</td><td>9 AM</td><td>3</td><td rowspan="3">283.5</td><td rowspan="3">4.5</td><td rowspan="3">166.1</td><td rowspan="3">2.6</td></tr>
<tr><td>12 PM</td><td>1</td></tr>
<tr><td>3 PM</td><td>2</td></tr>
<tr><td rowspan="3">June 21st</td><td>9 AM</td><td>3</td><td rowspan="3">330.8</td><td rowspan="3">5.3</td><td rowspan="3">193.7</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>2</td></tr>
<tr><td>3 PM</td><td>2</td></tr>
<tr><td rowspan="3">September 21st</td><td>9 AM</td><td>3</td><td rowspan="3">330.8</td><td rowspan="3">5.3</td><td rowspan="3">193.7</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>2</td></tr>
<tr><td>3 PM</td><td>2</td></tr>
<tr><td colspan="3">Annual Energy Consumption for Optimum HSD</td><td>1228.5</td><td>19.6</td><td>719.6</td><td>11.5</td></tr>
<tr><td rowspan="13">Optimum VSD for Winter/Summer Solstices & Equinoxes</td><td rowspan="3">December 21st</td><td>9 AM</td><td>3</td><td rowspan="3">283.5</td><td rowspan="3">4.5</td><td rowspan="3">166.1</td><td rowspan="3">2.6</td></tr>
<tr><td>12 PM</td><td>2</td></tr>
<tr><td>3 PM</td><td>1</td></tr>
<tr><td rowspan="3">March 21st</td><td>9 AM</td><td>3</td><td rowspan="3">283.5</td><td rowspan="3">4.5</td><td rowspan="3">166.1</td><td rowspan="3">2.6</td></tr>
<tr><td>12 PM</td><td>2</td></tr>
<tr><td>3 PM</td><td>1</td></tr>
<tr><td rowspan="3">June 21st</td><td>9 AM</td><td>3</td><td rowspan="3">283.5</td><td rowspan="3">4.5</td><td rowspan="3">166.1</td><td rowspan="3">2.6</td></tr>
<tr><td>12 PM</td><td>2</td></tr>
<tr><td>3 PM</td><td>1</td></tr>
<tr><td rowspan="3">September 21st</td><td>9 AM</td><td>3</td><td rowspan="3">330.8</td><td rowspan="3">5.3</td><td rowspan="3">193.7</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>2</td></tr>
<tr><td>3 PM</td><td>2</td></tr>
<tr><td colspan="3">Annual Energy Consumption for Optimum VSD</td><td>1181.3</td><td>18.8</td><td>691.9</td><td>11.0</td></tr>
</table>

4.3.3 Annual Energy Consumption for Part C

Summary of energy consumption results were given in Table 4.27. It showed that the energy consumption for base case were 3402 kWh/a when all the lightings working on. Annual energy consumption results for selected optimum HSD (S4-FT1) and VSD (S7-FT2) scenarios were found 1701.0 and 1701.0 kWh/a respectively when using December 21st parameters. After retrofitting for all solstices and equinoxes, energy consumption results were found to be same; 1701.0 kWh/a for HSD and VSD. Thus, energy consumption results for December 21st didn't change after the retrofitting for winter/summer solstices and equinoxes. When comparing the selected optimum HSD and VSD energy consumption results with the base case, it was seen that 50% of saving could be achieved. Moreover, if the fluorescent lighting would be replaced by LEDs in optimum case of HSD and VSD, annual energy consumption decreased to 1701.0 kWh/a. That means 71% saving could be obtained according to base case. Like that LENI values could be retrofitted from 42.3 to 12.4 kWh/a.m^2.

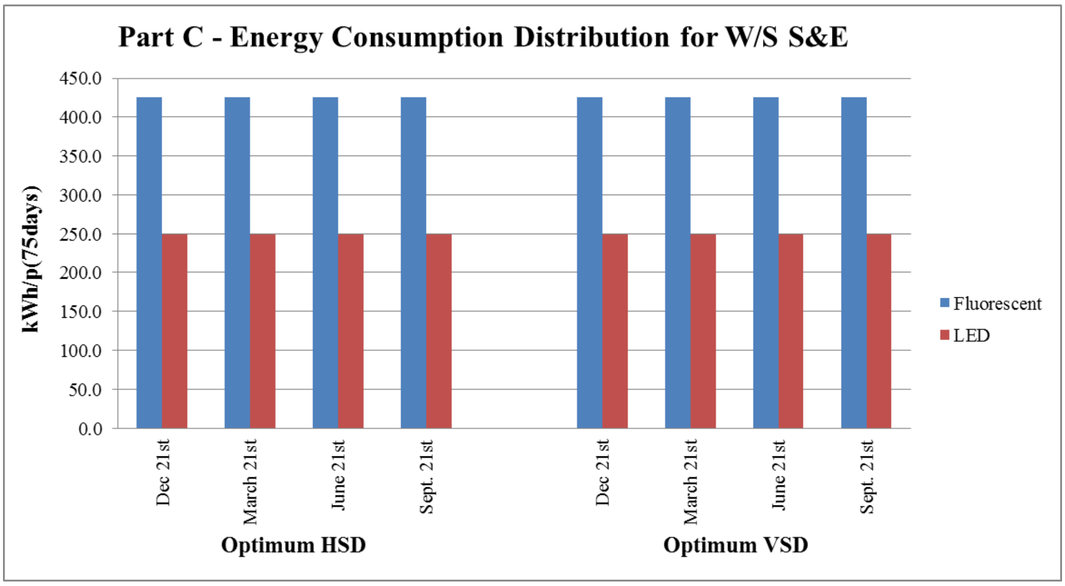


Figure 4.20 Part C-Energy Consumption Distribution of W/S S&E

From Figure 4.20, it was seen that energy consumption results were found as optimum in winter/summer solstices and equinoxes for selected optimum HSD and VSD both.

Table 4.27 Part C-Summary of Energy Consumption

<table>
<tr><th colspan="8">Summary of Energy Consumption</th></tr>
<tr><th colspan="8">Part C - Northwest Façade (north is directed 26° to east)
(Room Z35 : h=3.30 m, Area= 80.36 m²)</th></tr>
<tr><td colspan="8">LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m²) a: annual; p: period; d: day</td></tr>
<tr><th colspan="2" rowspan="2">DESCRIPTION</th><th rowspan="2">Hour</th><th rowspan="2">LL</th><th colspan="2">FL</th><th colspan="2">LED</th></tr>
<tr><th>kWh/a
p: 75 d
a: 300 d</th><th>LENI</th><th>kWh/a
p: 75 d
a: 300 d</th><th>LENI</th></tr>
<tr><td colspan="2" rowspan="3">Base Case (S0)</td><td>9 AM</td><td>6</td><td rowspan="3">3402.0</td><td rowspan="3">42.3</td><td rowspan="3">1992.6</td><td rowspan="3">24.8</td></tr>
<tr><td>12 PM</td><td>6</td></tr>
<tr><td>3 PM</td><td>6</td></tr>
<tr><td rowspan="6">Optimum HSD&VSD for December 21st</td><td rowspan="3">S4-FT1</td><td>9 AM</td><td>3</td><td rowspan="3">1701.0</td><td rowspan="3">21.2</td><td rowspan="3">996.3</td><td rowspan="3">12.4</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td rowspan="3">S7-FT2</td><td>9 AM</td><td>3</td><td rowspan="3">1701.0</td><td rowspan="3">21.2</td><td rowspan="3">996.3</td><td rowspan="3">12.4</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td rowspan="13">Optimum HSD for Winter/Summer Solstices & Equinoxes</td><td rowspan="3">December 21st</td><td>9 AM</td><td>3</td><td rowspan="3">425.3</td><td rowspan="3">5.3</td><td rowspan="3">249.1</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td rowspan="3">March 21st</td><td>9 AM</td><td>3</td><td rowspan="3">425.3</td><td rowspan="3">5.3</td><td rowspan="3">249.1</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td rowspan="3">June 21st</td><td>9 AM</td><td>3</td><td rowspan="3">425.3</td><td rowspan="3">5.3</td><td rowspan="3">249.1</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td rowspan="3">September 21st</td><td>9 AM</td><td>3</td><td rowspan="3">425.3</td><td rowspan="3">5.3</td><td rowspan="3">249.1</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td colspan="3">Annual Energy Consumption for Optimum HSD</td><td>1701.0</td><td>21.2</td><td>996.3</td><td>12.4</td></tr>
<tr><td rowspan="13">Optimum VSD for Winter/Summer Solstices & Equinoxes</td><td rowspan="3">December 21st</td><td>9 AM</td><td>3</td><td rowspan="3">425.3</td><td rowspan="3">5.3</td><td rowspan="3">249.1</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td rowspan="3">March 21st</td><td>9 AM</td><td>3</td><td rowspan="3">425.3</td><td rowspan="3">5.3</td><td rowspan="3">249.1</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td rowspan="3">June 21st</td><td>9 AM</td><td>3</td><td rowspan="3">425.3</td><td rowspan="3">5.3</td><td rowspan="3">249.1</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td rowspan="3">September 21st</td><td>9 AM</td><td>3</td><td rowspan="3">425.3</td><td rowspan="3">5.3</td><td rowspan="3">249.1</td><td rowspan="3">3.1</td></tr>
<tr><td>12 PM</td><td>3</td></tr>
<tr><td>3 PM</td><td>3</td></tr>
<tr><td colspan="3">Annual Energy Consumption for Optimum VSD</td><td>1701.0</td><td>21.2</td><td>996.3</td><td>12.4</td></tr>
</table>

4.3.4 Annual Energy Consumption for Part D

Energy consumption results were summarized in Table 4.28. It was seen from table that the energy consumption for base case were 10206.0 kWh/a when all the lightings working on. Annual energy consumption results for selected optimum HSD (S4-FT1) and VSD (S7-FT3) scenarios were found 6174.0 and 7938.0 kWh/a respectively when using December 21st parameters. After retrofitting for all solstices and equinoxes, energy consumption results were calculated as 5701.5 kWh/a for HSD and 6835.5 kWh/a for VSD. Starting from this point of view, selected optimum HSD scenario's energy consumption result was found to be better than VSD results for winter/summer solstices and equinoxes. When comparing the selected optimum HSD energy consumption results with the base case, it was seen that 44% of saving could be achieved. Moreover, if the fluorescent lighting would be replaced by LEDs in optimum case of HSD, annual energy consumption decreased to 3339.5 kWh/a. That means 67% saving could be obtained according to base case. Like that LENI values could be retrofitted from 38.0 to 12.4 kWh/a.m^2.

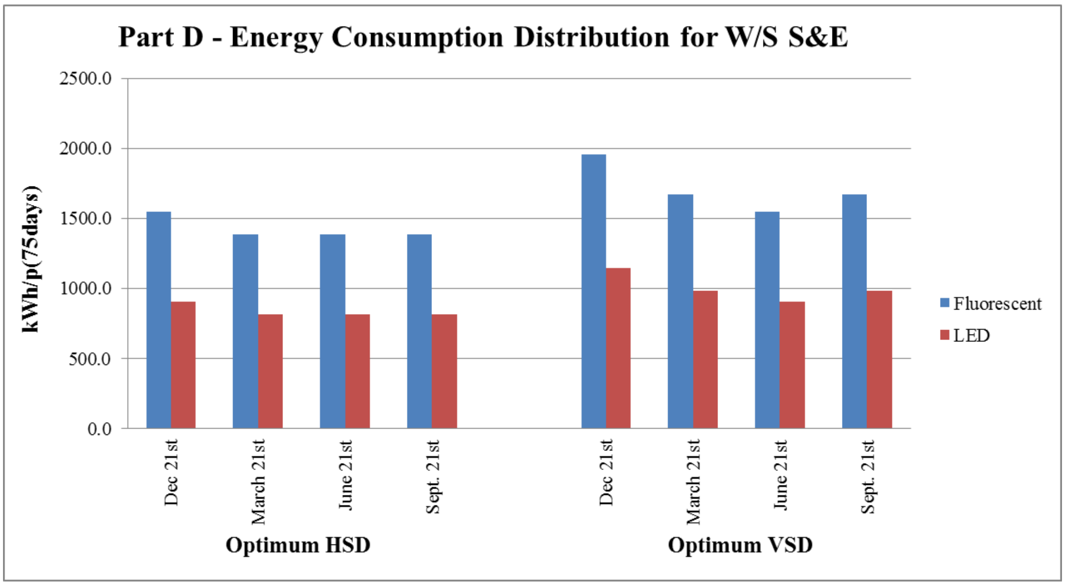


Figure 4.21 Part D-Energy Consumption Distribution of W/S S&E

From Figure 4.21, it was seen that energy consumption results were found as optimum for selected HSD in winter/summer solstices and equinoxes.

Table 4.28 Part D-Summary of Energy Consumption

Summary of Energy Consumption							
Part D - Northeast Facade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m^2)							
LL: Lighting Fixture Layout; n: Number of Lighting Row (on) LT: Lighting Fixture Type; FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day							
DESCRIPTION		Hour	LL	FL		LED	
				kWh/a p: 75 d a: 300 d	LENI	kWh/a p: 75 d a: 300 d	LENI
Base Case (S0)		9 AM 12 PM 3 PM	6 6 6	10206.0	38.0	5977.8	22.2
Optimum HSD&VSD for December 21st	S4-FT1	9 AM 12 PM 3 PM	3 4 4	6174.0	23.0	3616.0	13.5
	S7-FT3	9 AM 12 PM 3 PM	5 4 5	7938.0	29.5	4649.4	17.3
Optimum HSD for Winter/Summer Solstices & Equinoxes	December 21st	9 AM 12 PM 3 PM	3 4 4	1543.5	5.7	904.1	3.4
	March 21st	9 AM 12 PM 3 PM	3 3 4	1386.0	5.2	811.8	3.0
	June 21st	9 AM 12 PM 3 PM	3 3 4	1386.0	5.2	811.8	3.0
	September 21st	9 AM 12 PM 3 PM	3 3 4	1386.0	5.2	811.8	3.8
	Annual Energy Consumption for Optimum HSD			5701.5	21.2	3339.5	12.4
Optimum VSD for Winter/Summer Solstices & Equinoxes	December 21st	9 AM 12 PM 3 PM	5 4 5	1953.0	7.3	1143.9	4.3
	March 21st	9 AM 12 PM 3 PM	3 4 5	1669.5	6.2	977.9	3.6
	June 21st	9 AM 12 PM 3 PM	4 3 4	1543.5	5.7	904.1	3.4
	September 21st	9 AM 12 PM 3 PM	5 3 4	1669.5	6.2	977.9	3.6
	Annual Energy Consumption for Optimum VSD			6835.5	25.4	4003.7	14.9

4.3.5 Annual Energy Consumption for Part E

Energy consumption results were summarized in Table 4.29. It was seen from table that the energy consumption for base case were 567.0 kWh/a when all the lightings working on. Annual energy consumption results for selected optimum HSD (S4-FT3) and VSD (S7-FT3) scenarios were found 441.0 and 378.0 kWh/a respectively when using December 21st parameters. After retrofitting for all solstices and equinoxes, energy consumption results were calculated as 441.0 kWh/a for HSD and 425.3 kWh/a for VSD. It means that, selected optimum HSD and VSD scenario energy consumption results were found very close to each other. When comparing the selected optimum VSD energy consumption results with the base case, it was seen that 25% of saving could be achieved. Moreover, if the fluorescent lighting would be replaced by LEDs in optimum case of VSD, annual energy consumption decreased to 249.1 kWh/a. That means 56% saving could be obtained according to base case. Like that LENI values could be retrofitted from 28.8 to 12.6 kWh/a.m^2.

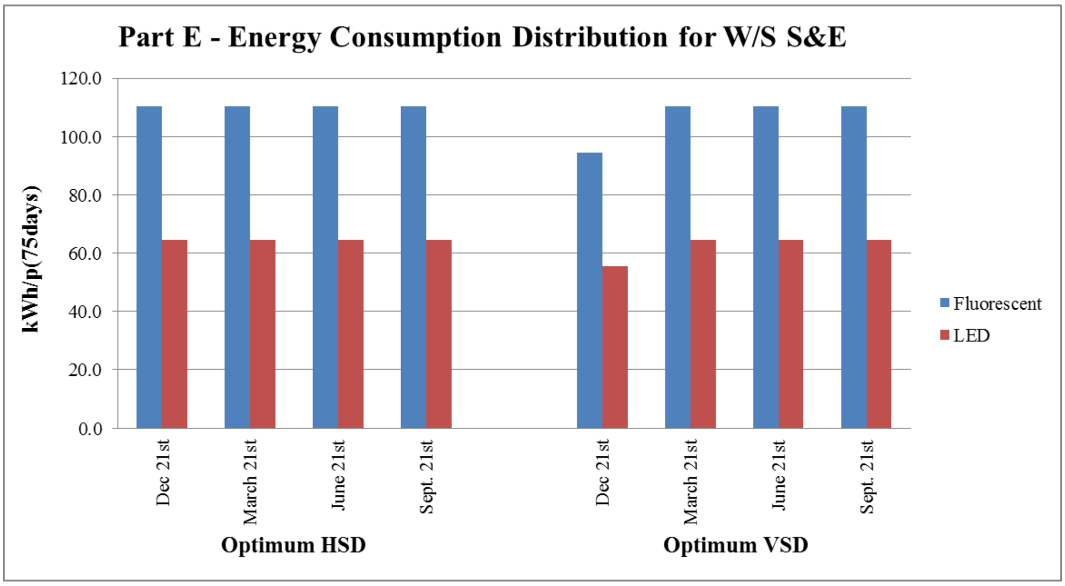


Figure 4.22 Part E-Energy Consumption Distribution of W/S S&E

From Figure 4.2, it was seen that energy consumption results were found as minimum in December 21st for selected optimum VSD.

Table 4.29 Part E-Summary of Energy Consumption

Summary of Energy Consumption

Part E - Southwest Façade (north is directed 26° to east)
(Room Z17 : h=2.60 m, Area= 19.70 m^2)

LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

DESCRIPTION		Hour	LL	FL kWh/a (p: 75 d, a: 300 d)	FL LENI	LED kWh/a (p: 75 d, a: 300 d)	LED LENI
Base Case (S0)		9 AM	3	567.0	28.8	332.1	16.9
		12 PM	3				
		3 PM	3				
Optimum HSD&VSD for December 21st	S4-FT3	9 AM	3	441.0	22.4	258.3	13.1
		12 PM	2				
		3 PM	2				
	S7-FT3	9 AM	3	378.0	19.2	221.4	11.2
		12 PM	2				
		3 PM	1				
Optimum HSD for Winter/Summer Solstices & Equinoxes	December 21st	9 AM	3	110.3	5.6	64.6	3.3
		12 PM	2				
		3 PM	2				
	March 21st	9 AM	3	110.3	5.6	64.6	3.3
		12 PM	2				
		3 PM	2				
	June 21st	9 AM	3	110.3	5.6	64.6	3.3
		12 PM	2				
		3 PM	2				
	September 21st	9 AM	3	110.3	5.6	64.6	3.3
		12 PM	2				
		3 PM	2				
	Annual Energy Consumption for Optimum HSD			441.0	22.4	258.3	13.1
Optimum VSD for Winter/Summer Solstices & Equinoxes	December 21st	9 AM	3	94.5	4.8	55.4	2.8
		12 PM	2				
		3 PM	1				
	March 21st	9 AM	3	110.3	5.6	64.6	3.3
		12 PM	2				
		3 PM	2				
	June 21st	9 AM	3	110.3	5.6	64.6	3.3
		12 PM	2				
		3 PM	2				
	September 21st	9 AM	3	110.3	5.6	64.6	3.3
		12 PM	2				
		3 PM	2				
	Annual Energy Consumption for Optimum VSD			425.3	21.6	249.1	12.6

4.3.6 Annual Energy Consumption for Part F

Summary of energy consumption results were given in Table 4.30. It was seen from table that the energy consumption for base case were 4536.0 kWh/a when all the lightings working on. Annual energy consumption results for selected optimum HSD (S4-FT2) and VSD (S7-FT3) scenarios were found 1134.0 and 2268.0 kWh/a respectively when using December 21st parameters. After retrofitting for all solstices and equinoxes, energy consumption results were calculated as 1323.0 kWh/a for HSD and 2362.5 kWh/a for VSD. Starting from this point of view, selected optimum HSD scenario's energy consumption result was found to be better than VSD results for winter/summer solstices and equinoxes. When comparing the selected optimum HSD energy consumption results with the base case, it was seen that 71% of saving could be achieved. Moreover, if the fluorescent lighting would be replaced by LEDs in optimum case of HSD, annual energy consumption decreased to 774.9 kWh/a. That means 83% saving could be obtained according to base case. Like that LENI values could be retrofitted from 35.4 to 6.0 kWh/a.m^2.

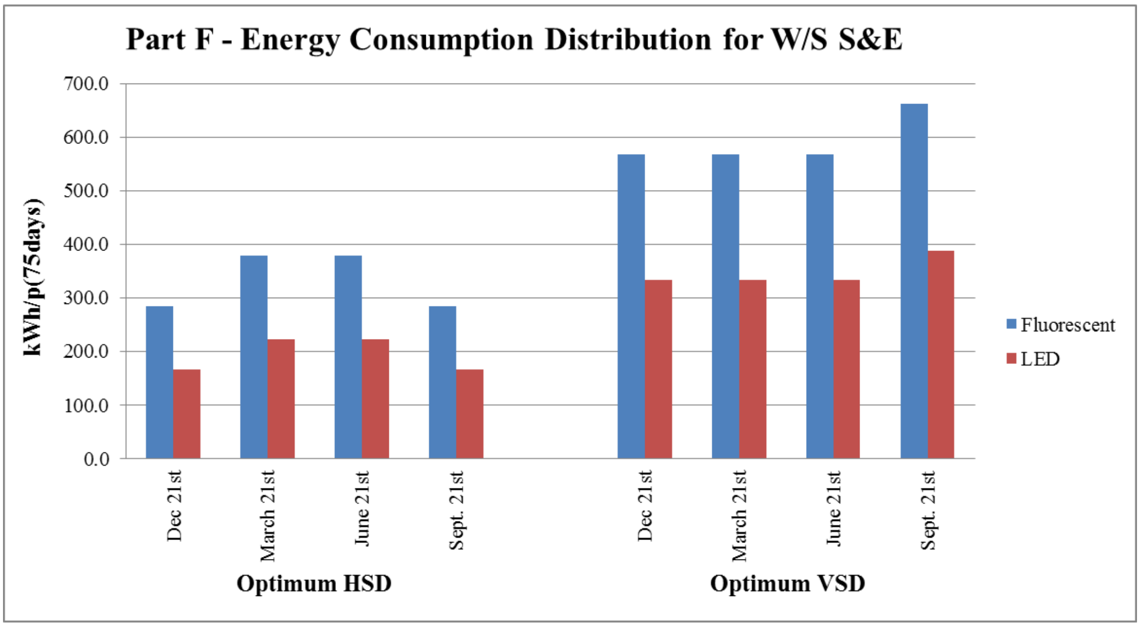


Figure 4.23 Part F-Energy Consumption Distribution of W/S S&E

From Figure 4.23, it was seen that energy consumption results were found as optimum in December 21st and September 21st for selected optimum HSD.

Table 4.30 Part F-Summary of Energy Consumption

Summary of Energy Consumption								
Part F - Southeast Façade (north is directed 26° to east) **(Room Z06 : h=3.40 m, Area= 128.19 m²)**								
LL: Lighting Fixture Layout; n: Number of Lighting Row (on) **LT: Lighting Fixture Type;** **FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W** **LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W** **LENI: Lighting Energy Numeric Indicator; kWh/(a.m²) a: annual; p: period; d: day**								
DESCRIPTION		**Hour**	**LL**	**FL**		**LED**		
				kWh/a p: 75 d a: 300 d	**LENI**	**kWh/a p: 75 d a: 300 d**	**LENI**	
Base Case (S0)		9 AM 12 PM 3 PM	4 4 4	4536.0	35.4	2656.8	20.7	
Optimum HSD&VSD for December 21st	**S4-FT2**	9 AM 12 PM 3 PM	1 1 1	1134.0	8.8	664.2	5.2	
	S7-FT3	9 AM 12 PM 3 PM	2 2 2	2268.0	17.7	1328.4	10.4	
Optimum HSD for Winter/Summer Solstices & Equinoxes	December 21st	9 AM 12 PM 3 PM	1 1 1	283.5	2.2	166.1	1.3	
	March 21st	9 AM 12 PM 3 PM	2 1 1	378.0	2.9	221.4	1.7	
	June 21st	9 AM 12 PM 3 PM	1 2 1	378.0	2.9	221.4	1.7	
	September 21st	9 AM 12 PM 3 PM	1 1 1	283.5	2.2	166.1	1.3	
	Annual Energy Consumption for Optimum HSD			1323.0	10.3	774.9	6.0	
Optimum VSD for Winter/Summer Solstices & Equinoxes	December 21st	9 AM 12 PM 3 PM	2 2 2	567.0	4.4	332.1	2.6	
	March 21st	9 AM 12 PM 3 PM	2 2 2	567.0	4.4	332.1	2.6	
	June 21st	9 AM 12 PM 3 PM	2 2 2	567.0	4.4	332.1	2.6	
	September 21st	9 AM 12 PM 3 PM	2 3 2	661.5	5.2	387.5	3.0	
	Annual Energy Consumption for Optimum VSD			2362.5	18.4	1383.8	10.8	

CHAPTER 5

A RETROFITTING MODEL FOR EDUCATIONAL BUILDINGS

In this chapter are presented the final outcomes of this study to lead to a retrofitting model for educational buildings in general. Although there are plenty of parameters affecting the energy efficiency of educational buildings in terms of lighting issues, here, the framework of the study led to involve a limited number of related parameters. However, key parameters were chosen to integrate both the daylighting and artificial lighting design approaches.

This model involves suggestions of what sort of retrofitting applications might be done to improve the lighting quality in educational buildings and to satisfy the lighting energy efficiency. Several treatments might be applied on the façade with the applications of appropriate solar shading devices. They are useful to balance the penetration of daylight and also to control the direct sunlight. They prevent undesired excessive solar gain throughout the year. The type of glazings might be changed in retrofitting applications. They are the key building components which control the passage of daylight through inside.

The surface color of the walls might be renewed in such applications also. This affects the reflectance of daylight inside the building. The layout of luminaires, their locations and their control might be considered jointly. Only the necessary number of luminaires should be switched on during the working hours. So, manual switches might be redesigned according to the layout of the luminaires, while replacing flourescent lamps by LEDs in retrofitting process. Utilizing such retrofitting model, one noteworthy outcome is figured out consequently. It is possible to decrease the amount of electricity use by taking simple precautions or modifications in existing educational buildings. This type of building is also a unique one since educational buildings involve rooms in different sizes and functions. Each room requires significant visual comfort conditions; their orientation and locations vary according to architectural design.

Required visual comfort parameters were taken into account while providing energy efficient solutions. For classrooms and office rooms illuminance values should be 300-500 lx while laboratories require 500-750 lx. For both, uniformity values should be 0.67 (E_{min}/E_{ave}) and 0.50 (E_{min}/E_{max}).

There are two rooms facing Southeast, Part A - classroom and Part F - lecture hall, having different façade organizations. Part A does not have any shading devices or cantilevers on its façade while Part F has its own balcony in front and fixed horizontal shading devices in order to control direct sunlight penetrating. WWR is 63% in Part A and 43% in Part F, WFR is 24% in Part A and 15% in Part F. After all scenario applications, horizontal shading device (HSD) scenario with 90% of fenestration transmittance (FT) were found to be the optimum one in terms of energy consumption results comparing the selected vertical shading device (VSD) scenario with 50% of FT for Part A where the LENI values could be retrofitted from 27.8 to 9.5 kWh/a.m^2. On the other hand, for Part F, HSD with 70% of FT were the optimum one comparing the selected VSD with 50% of FT where the LENI values could be retrofitted from 35.4 to 6.0 kWh/a.m^2. For both parts, HSD scenarios were the optimum solutions during the retrofitting process.

For Southwest orientation, there exist two rooms, Part B - classroom and Part E - office room, with different façade organizations. Part B, does not have any shading devices or cantilevers like in Part A on its façade; while Part E has its own balcony in front and fixed horizontal shading devices to control direct sunlight penetrating, similar to Part F. WWRs are close, 63% in Part B and 59% in Part E, WFRs are 24% in both Parts. After all scenario applications, for Part B and E, in both HSD and VSD scenarios, 50% of FT was found optimum in terms of energy consumption results. In both cases, LENI values could be retrofitted from 27.1 to 11.0 kWh/a.m^2 and from 28.8 to 12.6 kWh/a.m^2 for Part B and E respectively.

Part C - office room facing Northwest and Part D - laboratory facing Northeast have horizontal overhangs and vertical cantilevers on their façade to control direct sunlight penetrating. However, these extensions cause insufficient daylighting instead of controlling due to the orientation of the rooms. WWRs and WFRs are close in both Parts. WWRs are 49% and 48%; while WFRs are 13% and 14% in Part C and D respectively. To increase daylighting inside the laboratory, high test benches located in the middle by the longside should be reorganized to prevent the blockage. After all scenario applications, HSD scenario with 90% of FT and VSD scenario with 70% of FT were selected as optimum for Part C, where the LENI values could be retrofitted from

42.3 to 12.4 kWh/a.m^2 in both cases. On the other hand, for Part D, HSD with 90% of FT were found optimum comparing the selected VSD with 50% of FT where the LENI values could be retrofitted from 38.0 to 12.4 kWh/a.m^2.

As a result, it is seen that HSD scenarios are selected as optimum in order to obtain visual comfort conditions while providing energy efficient solutions in general. This provides to obtain entirety in façade design. Moreover, HSD has another advantage in providing visual contact with outdoor environment.

Consequently, visual comfort conditions were achieved in all parts for winter/summer solstices and equinoxes by making retrofit studies. Energy consumption results according to the daylighting results were calculated. Energy consumption results of base case (with fluorescent that is actually used in the building) were compared with optimum retrofit scenario (with LED). Results showed that (Figure 5.1), from 56% to 83% energy savings could be achived in all parts.

Orientation of Parts	Base Case FL	After Retrofitting FL	After Retrofitting LED	Saving %
Part A : *SE*	27.8	16.2	9.5	66
Part B : *SW*	27.1	18.8	11.0	59
Part C : *NW*	42.3	21.2	12.4	67
Part D : *NE*	38.0	21.2	12.4	67
Part E : *SW*	28.8	21.6	12.6	56
Part F : *SE*	35.4	10.3	6.0	83

Figure 5.1 Annual energy consumption results in LENI (kWh/a.m^2) and saving for parts

Observing the identical LENI values may present the evidence of the relation between the number of lighting fixtures working and the rooms' size. In general, the sum LENI values using fluorecent lamps for each room were within the limiting benchmark values (27 - 34.9 kWh/a.m^2) of energy efficient lighting design criteria defined in EN-15193-1. In addition, the contribution of LEDs in the energy consumption reached to a reduction of 40%.

CHAPTER 6

DISCUSSIONS AND CONCLUSIONS

This study aimed to figure out the optimum solutions of energy efficient lighting design using daylighting and artificial lighting parameters. These input parameters were the transmittance of glazing, type of shading device according to its slat position and angle, the type of lighting fixture and its layout. A total of nine scenarios were proposed by integrating the combination of these parameters on simulated models of six rooms in an educational building in İYTE. DIALux was run for many trials approx. 250 iterations to result in the optimum solutions for each room. The optimum solution satisfied, firstly, the required illuminance and uniformity; secondly, the minimum energy consumption. The main argument here was that the actual physical conditions (façade design and interior) of each room did not present any conscious design decision which had been taken for daylighting/artificial lighting and its efficient use.

Despite the studies conducted about visual comfort conditions of classrooms in relation to their daylight performance and shading devices, or about artificial light sources in education buildings; or about prediction of energy savings of artificial lighting use from daylighting, there still exist some deficiencies about integrated approach focusing on energy efficient natural and artificial lighting criteria together such as; fenestration properties, light shelves and shading devices, surface colors, lighting fixture type and layout.

The consideration in this study involved proposing retrofit scenarios for an appropriate use of daylight and artificial light as an integrated system to provide a reasonable reduction in electrical energy consumption.

According to the base case analysis by the simulation and observations of this building in the field survey, various problems in terms of lighting conditions were determined such as:

- Façade configurations including the type of shading devices were independent of room specifications such as orientation, function and size. For example, there are large overhangs facing North, which prevent the penetration of diffuse daylight to the interior. On the other hand, classrooms facing South do not have any shading devices located on their façade. This resulted in the penetration of excessive direct sunlight to the interior.

- Despite the Window-to-Wall Ratio was sufficient according to the standards (Li & Tsang, 2008), the room depth was more than the required values. This caused the insufficient amount of daylight in large rooms.
- The coated glazing which is used for thermal concerns (the transmittance of glazing was almost 36%) also minimizes the passage of daylight through the glass.

Discussions mentioned above depend on the architectural design decisions in terms of daylighting. All parameters affecting visual comfort conditions and energy efficiency should be properly determined in predesign stages. Simulation tools are useful to test these parameters until the optimum solutions obtained. In this way, visual comfort conditions and less energy consumption would be achieved without requiring retrofitting.

Discussions in detail about several findings may provide feedback information to researchers and professionals as mentioned below.

The evaluation of the energy consumption for periods was based on the LENI (Lighting Energy Numerical Indicator-kWh/p.m^2). Utilizing these values for all case rooms throughout the year, one discussion may be about the type of shading device and its relation to the orientation and room's geometrical attributes. Although Part E and Part B are two rooms facing Southwest (i.e. the same orientation), the installation of VSD in Part E was more energy efficient (4.8 kWh/p.m^2) than the use of HSD (5.5 kWh/p.m^2) in the same room on Dec 21st. Either the use of VSD or HDS did not make any difference in LENI values (5.5 kWh/p.m^2/flourescent) in the summer solstice and equinoxes. This condition is just the opposite when Part B was evaluated. The application of VSD in Part B was more efficient (4.5 kWh/p.m^2/flourescent) than the use of HSD (5.2 kWh/p.m^2/flourescent) in the same room on June 21st. Their use did not make any difference in the winter sostice (4.5 kWh/p.m^2/flourescent) and equinoxes (4.5 and 5.2 kWh/p.m^2/flourescent). The reason behind this situation is related with the sun angles and the depth of the room. In the winter season, when the sun angles are low, the use of VSD in the room with the least depth is the energy efficient solution. In the summer season, the use of VSD in the room with the highest depth is the energy efficient one. As a result, the expected results were obtained according to literature. The

HSDs has become the optimum solutions for Part A, Part D and Part F facing Southeast and Northeast. The VSDs have been the best options for Part B and Part E facing Southwest. Part C facing Northwest may involve either HSDs or VSDs and neither of them change the energy consumption among solstices and equinoxes. The energy consumption values have become constant throughout the year.

Annual energy consumption results according to the basic case for fluorescent in Parts A-F show that, LENI values were 27.8, 27.1, 42.3, 38.0, 28.8 and 35.3 kWh/a.m^2 respectively. On the other hand, annual energy consumption results according to the selected optimum shading device scenario for fluorescent in Parts A-F show that, LENI values were 16.2, 18.8, 21.2, 21.2, 21.6 and 10.3 kWh/a.m^2 respectively (Tables 4.25-30).

It is obvious that dimming profile for lighting control would significantly increase the energy performance while providing better visual comfort conditions in educational buildings (Barbhuiya and Barbhuiya, 2013).

Another discussion may base on the outside view which is obstructed by shading devices. The optimum scenarios lead to a high level of visual comfort conditions and a low level of energy consumption by positioning the slats with high angles (60° or 75°). This type of location blocks the view. In some classrooms, as the windows are situated behind the seating position, they are out of the students' visual field. They only affect the the instructor's vision. Such obstruction does not lead to any undesireable physical and visual conditions, although literature indicates the positive psychlogical effects of windows on learning performance. In this sense, HSDs may provide wider views than VSDs do, even if their slat angles are the same. So, it is obviously crucial to achieve visual comfort conditions and less energy consumption without ignoring the visual contact.

It is best to set the slat angles by the control of an automation system containing intelligent sensors which makes adjustments according the daylight illuminance. Flowcharts in this study where the applications steps for retrofitting scenarios were shown, would be an infrastructure for the future researches. Yet, this study aimed to provide feedback information about deficiencies in the actual case and optimum solutions to satisfy energy efficient lighting criteria. Such a preceding study was considered and its methodology was built to provide foreknowledge for such a system design.

This thesis, consequently, would made an important contribution for retrofitting of Mechanical Engineering Department in İzmir Institute of Technology in terms of visual comfort conditions and energy efficiency. Daylighting and energy consumption results obtained from the study would be helpful for making decisions of retrofitting.

For further studies, investment cost would be calculated in order to propose the retrofitting application phase. Many different parameters such as shading device’s design, structure and material, motor device, sensor, automation software, glazing and luminaire types etc. affect the total investment cost.

Approximately 70% of annual energy saving could be achieved after retrofitting according to this study. This saving is considered in the calculation of payback period for total investment. So, cost analysis results will be helpful for applying the retrofitting decision. More importantly, contributions for reducing the environmental pollution by bringing energy efficient solutions should not be disregarded while providing visual comfort conditions in the buildings.

Thus, this study will be an instructive one for new or retrofitted constructions by providing new information about energy efficient lighting performance. In this sense, it would be a guide for designers, architects and researchers.

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APPENDICES

APPENDIX A. VIEWS FROM THE CASE BUILDING

(a)

(b)

(c)

(d)

(e)

Figure A.1 Outdoor views (a-e) from the case building (photos by Göze Bayram)


(a) (b)


(c) (d)

(e)

Figure A.2 Interior views (a-e) from the case building (photos by Göze Bayram)

(a) (b) (c) (d) (e) (f) (g)

Figure A.3 Interior views (a-g) from case building (photos by Göze Bayram)

APPENDIX B. SIMULATION RESULTS FOR PART B

Table B.1 Part B-Base case results (S0 for W/S S&E)

Base Case Results (Results taken from DIALux)

Part B - Southwest Façade (north is directed 26° to east)

(Room Z48 : h=3.60 m, Area= 62.83 m²)

FT: Fenestration Transmittance
FC: Fenestration Color = 80%
SC: Surface Color = 68%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
Winter Solstice : December 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	139	48	282	0.34	0.17
					0	FL	**12 PM**	1087	173	6090	0.16	0.03
					0	FL	**3 PM**	1729	311	3341	0.18	0.09
Equinox : March 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	240	86	467	0.36	0.19
					0	FL	**12 PM**	588	183	1270	0.31	0.14
					0	FL	**3 PM**	3682	416	10028	0.11	0.04
Summer Solstice : June 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	235	89	447	0.38	0.2
					0	FL	**12 PM**	441	145	868	0.33	0.17
					0	FL	**3 PM**	881	280	1799	0.32	0.16
Equinox : September 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	187	70	359	0.37	0.19
					0	FL	**12 PM**	444	139	927	0.31	0.15
					0	FL	**3 PM**	4280	341	12127	0.08	0.03

Outdoor & indoor perspective views for S0 in *Winter Solstice : December 21st*
Part B - Southwest Façade (north is directed 26° to east)

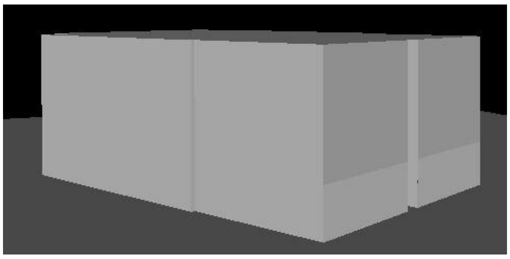
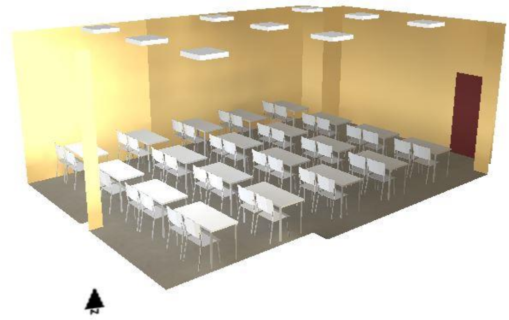
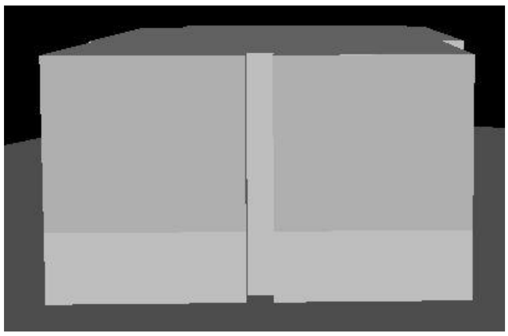
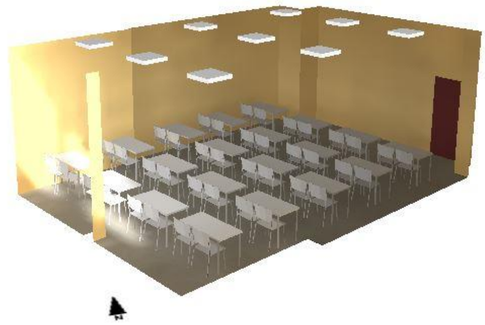
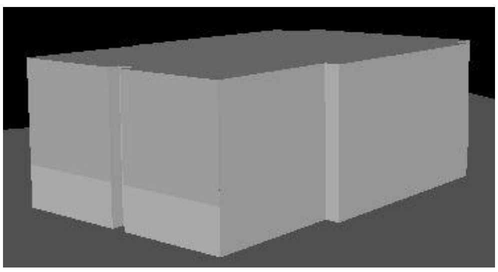
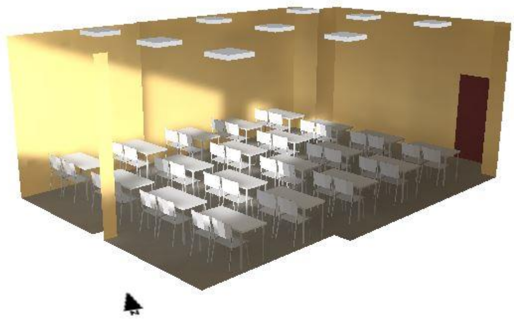
Outdoor Perspective	**Indoor Perspective**
9:00 AM	
	
12:00 PM	
	
3:00 PM	
	

Figure B.1 Part B-Outdoor & indoor perspective views for S0

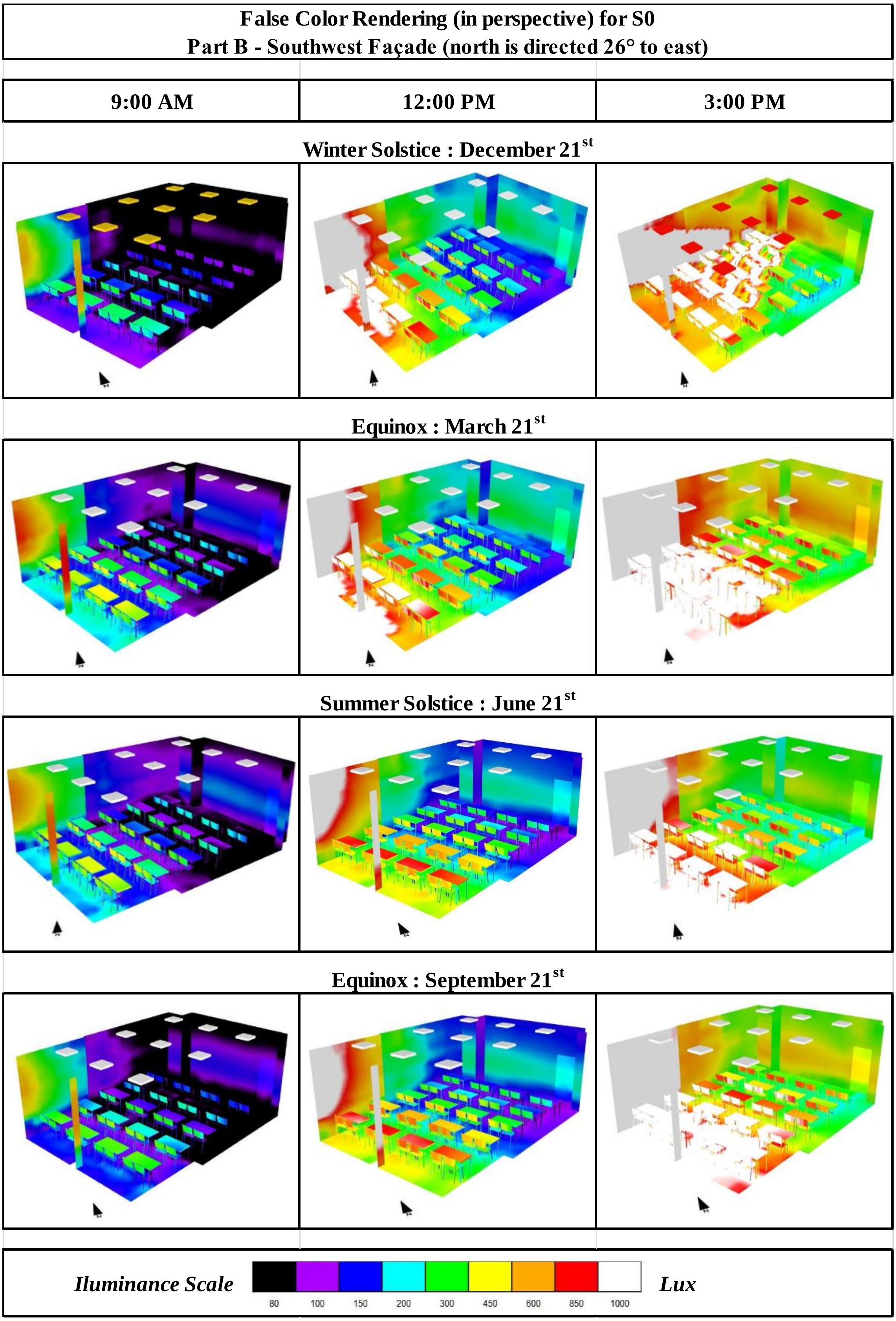


Figure B.2 Part B-False color rendering (in perspective) for S0

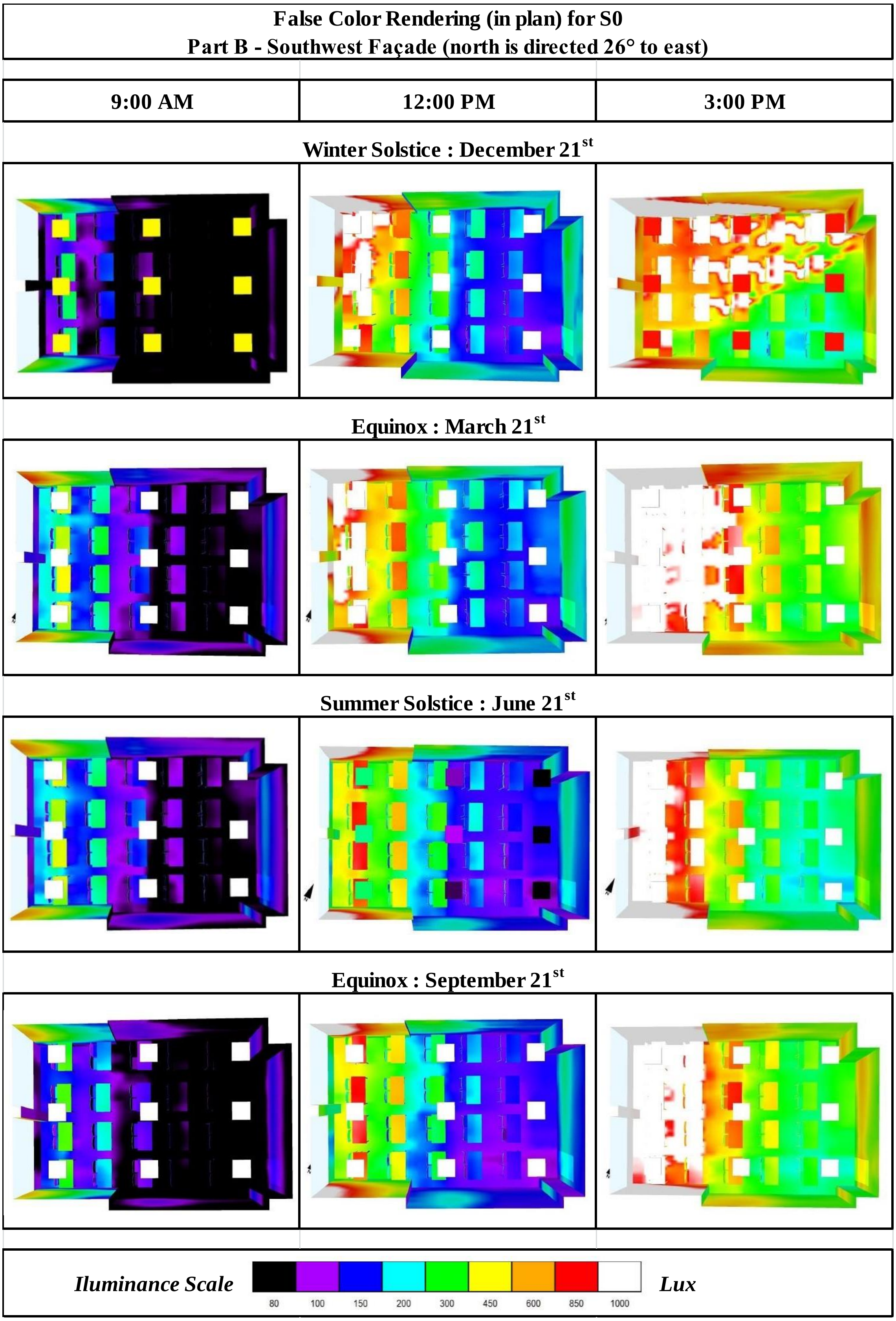


Figure B.3 Part B-False color rendering (in plan) for S0

Table B.2 Part B-Retrofit scenarios (S1-S7)

Retrofit Scenarios (Results taken from DIALux for December 21st)

Part B - Southwest Façade (north is directed 26° to east)

(Room Z48 : h=3.60 m, Area= 62.83 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S1	FT_1 90%	Yes	No	No	0	FL	9 AM	508	329	708	0.65	0.46
					0	FL	12 PM	3106	582	16948	0.19	0.03
					0	FL	3 PM	4878	1025	9002	0.21	0.11
	FT_2 70%	Yes	No	No	1	FL	9 AM	425	270	553	0.63	0.49
					0	FL	12 PM	2411	455	13165	0.19	0.03
					0	FL	3 PM	3786	796	6987	0.21	0.11
	FT_3 50%	Yes	No	No	2	FL	9 AM	481	420	559	0.87	0.75
					0	FL	12 PM	1723	333	9399	0.19	0.04
					0	FL	3 PM	3786	796	6987	0.21	0.11
SD u=4 l=2 distance 30 cm	FT_1 90%	Yes	SD_2 h	u=0° l=0°	1	FL	9 AM	508	329	708	0.65	0.46
				u=90° l=90°	1	FL	12 PM	607	355	1024	0.59	0.35
				u=90° l=90°	0	FL	3 PM	2895	322	6408	0.11	0.05
S2	FT_2 70%	Yes	SD_2 h	u=0° l=0°	2	FL	9 AM	443	327	538	0.74	0.61
				u=90° l=90°	1	FL	12 PM	502	291	798	0.58	0.36
				u=90° l=90°	0	FL	3 PM	2249	251	4974	0.11	0.05
Light Shelf location 220 cm width 290 cm length 100 cm	FT_3 50%	Yes	SD_2 h	u=0° l=0°	3	FL	9 AM	526	450	586	0.86	0.77
				u=90° l=90°	2	FL	12 PM	530	466	609	0.88	0.77
				u=90° l=90°	0	FL	3 PM	1604	180	3546	0.11	0.05

(cont. on next page)

Table B.2 (cont.)

Part B - Southwest Façade (north is directed 26° to east) (Room Z48 : h=3.60 m, Area= 62.83 m^2)												
FT: Fenestration Transmittance FC: Fenestration Color = 90% SC: Surface Color = 80% SD: Shading Device (length=25cm); Type h: horizontal v: vertical Angle u: upper l: lower LL: Lighting Fixture Layout; n: Number of Lighting Row (on) LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode												
Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
SD u=4 l=3 distance 30 cm **S3**	FT_1 90%	No	SD_3 h	u=° l=°		FL	**9 AM**					
				u=° l=°		FL	**12 PM**					
				u=° l=°		FL	**3 PM**					
	FT_2 70%	No	SD_3 h	u=° l=°		FL	**9 AM**					
				u=° l=°		FL	**12 PM**					
				u=° l=°		FL	**3 PM**					
	FT_3 50%	No	SD_3 h	u=0° l=0°	3	FL	**9 AM**	535	451	601	0.84	0.75
				u=90° l=90°	2	FL	**12 PM**	472	397	539	0.84	0.74
				u=90° l=90°	0	FL	**3 PM**	1548	154	3429	0.1	0.05
SD u=7 l=6 distance 20 cm **S4**	FT_1 90%	No	SD_4 h	u=0° l=0°	3	FL	**9 AM**	548	470	613	0.86	0.77
				u=0° l=60°	1	FL	**12 PM**	517	343	681	0.66	0.5
				u=30° l=60°	2	FL	**3 PM**	563	481	643	0.85	0.75
	FT_2 70%	No	SD_4 h	u=0° l=0°	3	FL	**9 AM**	516	453	586	0.88	0.77
				u=0° l=45°	1	FL	**12 PM**	477	313	617	0.66	0.51
				u=30° l=60°	2	FL	**3 PM**	499	460	550	0.92	0.84
	FT_3 50%	No	SD_4 h	u=0° l=0°	3	FL	**9 AM**	486	436	558	0.9	0.78
				u=0° l=15°	1	FL	**12 PM**	447	294	562	0.66	0.52
				u=30° l=30°	2	FL	**3 PM**	496	457	552	0.92	0.83

(cont. on next page)

Table B.2 (cont.)

Part B - Southwest Façade (north is directed 26° to east)
(Room Z48 : h=3.60 m, Area= 62.83 m²)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S5 SD u=7 l=7 distance 40 cm; Light Shelf location 220 cm width 290 cm length 100 cm	FT_1 90%	Yes	SD_5 v	u=0° l=0°	2	FL	**9 AM**	472	366	564	0.77	0.65
				u=90° l=90°	1	FL	**12 PM**	622	395	946	0.64	0.42
				u=90° l=90°	0	FL	**3 PM**	1305	390	5342	0.3	0.07
	FT_2 70%	Yes	SD_5 v	u=0° l=0°	2	FL	**9 AM**	429	299	528	0.7	0.57
				u=90° l=90°	1	FL	**12 PM**	514	322	732	0.63	0.44
				u=90° l=90°	0	FL	**3 PM**	1013	305	4155	0.3	0.07
	FT_3 50%	Yes	SD_5 v	u=0° l=0°	3	FL	**9 AM**	516	444	679	0.86	0.77
				u=30° l=60°	1	FL	**12 PM**	463	291	630	0.63	0.46
				u=90° l=90°	0	FL	**3 PM**	723	220	2970	0.3	0.07
S6 SD u=7 l=7 distance 40 cm	FT_1 90%	No	SD_6 v	u=° l=°		FL	**9 AM**					
				u=° l=°		FL	**12 PM**					
				u=° l=°		FL	**3 PM**					
	FT_2 70%	No	SD_6 v	u=° l=°		FL	**9 AM**					
				u=° l=°		FL	**12 PM**					
				u=° l=°		FL	**3 PM**					
	FT_3 50%	No	SD_6 v	u=0° l=0°	3	FL	**9 AM**	531	444	594	0.84	0.75
				u=30° l=60°	1	FL	**12 PM**	447	268	619	0.6	0.43
				u=90° l=90°	0	FL	**3 PM**	765	223	2981	0.29	0.07

(cont. on next page)

Table B.2 (cont.)

Part B - Southwest Façade (north is directed 26° to east) **(Room Z48 : h=3.60 m, Area= 62.83 m²)**												
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row** (on) **LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode**												
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux)**			**UNIFORMITY**	
								E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
SD u=12 l=12 distance 23 cm **S7**	FT_1 90%	No	SD_7 v	u=0° l=0°	3	FL	**9 AM**	553	461	630	0.83	0.73
				u=0° l=60°	1	FL	**12 PM**	459	309	605	0.67	0.51
				u=15° l=60°	0	FL	**3 PM**	960	259	5094	0.27	0.05
	FT_2 70%	No	SD_7 v	u=0° l=0°	3	FL	**9 AM**	520	445	580	0.86	0.77
				u=0° l=30°	1	FL	**12 PM**	450	286	618	0.64	0.46
				u=0° l=60°	0	FL	**3 PM**	909	290	4108	0.32	0.07
	FT_3 50%	No	SD_7 v	u=0° l=0°	3	FL	**9 AM**	488	429	552	0.88	0.78
				u=0° l=0°	2	FL	**12 PM**	538	481	606	0.89	0.79
				u=0° l=60°	1	FL	**3 PM**	785	340	3248	0.43	0.1

Table B.3 Part B-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of illuminance & uniformity

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Illuminance & Uniformity (Results taken from DIALux for December 21st)

Part B - Southwest Façade (north is directed 26° to east) (Room Z48 : h=3.60 m, Area= 62.83 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S4	FT_3 50%	No	SD_4 h	u=0° l=0°	3	FL	**9 AM**	486	436	558	0.9	0.78
				u=0° l=15°	1	FL	**12 PM**	447	294	562	0.66	0.52
				u=30° l=30°	2	FL	**3 PM**	496	457	552	0.92	0.83
S8	FT_3 50%	No	SD_4 h	u=0° l=0°	3	LED	**9 AM**	433	393	487	0.91	0.81
				u=0° l=15°	1	LED	**12 PM**	431	309	570	0.72	0.54
				u=30° l=30°	2	LED	**3 PM**	464	404	520	0.87	0.78
S7	FT_3 50%	No	SD_7 v	u=0° l=0°	3	FL	**9 AM**	488	429	552	0.88	0.78
				u=0° l=0°	2	FL	**12 PM**	538	481	606	0.89	0.79
				u=0° l=60°	1	FL	**3 PM**	785	340	3248	0.43	0.1
S9	FT_3 50%	No	SD_7 v	u=0° l=0°	3	LED	**9 AM**	435	386	481	0.89	0.8
				u=0° l=0°	2	LED	**12 PM**	506	426	607	0.84	0.7
				u=0° l=60°	1	LED	**3 PM**	769	357	3179	0.46	0.11

Table B.4 Part B-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of energy consumption

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Energy Consumption (Results taken from DIALux for December 21st)

Part B - Southwest Façade (north is directed 26° to east) (Room Z48 : h=3.60 m, Area= 62.83 m²)

FT: Fenestration Transmittance
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical** **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
LT: Lighting Fixture Type;
FL : Fluorescent **Luminous Flux: 3834 lm; Power=70 W**
LED : Light Emitting Diode **Luminous Flux: 3400 lm; Power=41 W**
LENI: Lighting Energy Numeric Indicator; kWh/(a.m²)

Scenario	FT	SD Type	SD Angle	LL n	LT	Hour	ENERGY CONSUMPTION Time h	Floor Area %	Energy Wh	kWh/a a:300 d	LENI
S4	FT_3 50%	SD_4 h	u=0° l=0°	3	FL	**9 AM**	3	100	1890	1134.0	18.0
			u=0° l=15°	1	FL	**12 PM**	3	33.3	630		
			u=30° l=30°	2	FL	**3 PM**	3	66.6	1260		
S8	FT_3 50%	SD_4 h	u=0° l=0°	3	LED	**9 AM**	3	100	1107	664.2	10.6
			u=0° l=15°	1	LED	**12 PM**	3	33.3	369		
			u=30° l=30°	2	LED	**3 PM**	3	66.6	738		
S7	FT_3 50%	SD_7 v	u=0° l=0°	3	FL	**9 AM**	3	100	1890	1134.0	18.0
			u=0° l=0°	2	FL	**12 PM**	3	66.6	1260		
			u=0° l=60°	1	FL	**3 PM**	3	33.3	630		
S9	FT_3 50%	SD_7 v	u=0° l=0°	3	LED	**9 AM**	3	100	1107	664.2	10.6
			u=0° l=0°	2	LED	**12 PM**	3	66.6	738		
			u=0° l=60°	1	LED	**3 PM**	3	33.3	369		

Table B.5 Part B-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the horizontal shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Horizontal Shading Devices (S4-FT3) (Results taken from DIALux)

Part B - Southwest Façade (north is directed 26° to east) (Room Z48 : h=3.60 m, Area= 62.83 m^2)

SD: Shading Device (length=25cm); **<u>Angle</u> u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	486	436	558	0.90	0.78
	March 21st			525	461	590	0.88	0.78
	June 21st			521	461	587	0.88	0.78
	September 21st			506	453	575	0.90	0.79
12 PM	December 21st	u=0° l=15°	1	447	294	562	0.66	0.52
	March 21st			454	315	553	0.69	0.57
	June 21st			344	247	482	0.72	0.51
	September 21st			345	243	479	0.70	0.51
3 PM	December 21st	u=30° l=30°	2	496	457	552	0.92	0.83
	March 21st			734	538	982	0.73	0.55
	June 21st			638	508	757	0.80	0.67
	September 21st			706	526	915	0.75	0.58

Table B.6 Part B-Retrofitting the results for the horizontal shading devices by using the fixed panels at W/S S&E

<table>
<tr><td colspan="10">Retrofitting the Results for the Horizontal Shading Devices
by Using the Fixed Panels at W/S S&E
(S4-FT3)
(Results taken from DIALux)</td></tr>
<tr><td colspan="10">Part B - Southwest Façade (north is directed 26° to east)
(Room Z48 : h=3.60 m, Area= 62.83 m²)</td></tr>
<tr><td colspan="10">SD: Shading Device (length=25cm); Angle u: upper l: lower
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window</td></tr>
<tr><th rowspan="2">Hour</th><th rowspan="2">W/S Solstices & Equinoxes</th><th rowspan="2">SD Angle</th><th rowspan="2">LL n</th><th colspan="3">ILLUMINANCE (Lux)</th><th colspan="2">UNIFORMITY</th></tr>
<tr><th>E_{avg}</th><th>E_{min}</th><th>E_{max}</th><th>U1 Emin/Eavg</th><th>U2 Emin/Emax</th></tr>
<tr><td rowspan="4">9 AM</td><td>December 21st</td><td rowspan="4">u=0° l=0°</td><td rowspan="4">3</td><td>476</td><td>433</td><td>551</td><td>0.91</td><td>0.78</td></tr>
<tr><td>March 21st</td><td>509</td><td>456</td><td>580</td><td>0.89</td><td>0.79</td></tr>
<tr><td>June 21st</td><td>503</td><td>454</td><td>576</td><td>0.90</td><td>0.79</td></tr>
<tr><td>September 21st</td><td>495</td><td>449</td><td>569</td><td>0.91</td><td>0.79</td></tr>
<tr><td rowspan="4">12 PM</td><td>December 21st</td><td>u=0° l=0°</td><td rowspan="2">1</td><td>441</td><td>286</td><td>561</td><td>0.65</td><td>0.51</td></tr>
<tr><td>March 21st</td><td>u=0° l=15°</td><td>420</td><td>289</td><td>507</td><td>0.69</td><td>0.57</td></tr>
<tr><td>June 21st</td><td rowspan="2">u=0° l=0°</td><td rowspan="2">2</td><td>447</td><td>319</td><td>550</td><td>0.71</td><td>0.58</td></tr>
<tr><td>September 21st</td><td>448</td><td>322</td><td>562</td><td>0.72</td><td>0.58</td></tr>
<tr><td rowspan="4">3 PM</td><td>December 21st</td><td>u=30° l=30°</td><td rowspan="4">2</td><td>481</td><td>448</td><td>542</td><td>0.93</td><td>0.83</td></tr>
<tr><td>March 21st</td><td>u=30° l=75°</td><td>550</td><td>473</td><td>640</td><td>0.86</td><td>0.74</td></tr>
<tr><td>June 21st</td><td rowspan="2">u=30° l=60°</td><td>511</td><td>454</td><td>559</td><td>0.89</td><td>0.81</td></tr>
<tr><td>September 21st</td><td>565</td><td>474</td><td>667</td><td>0.84</td><td>0.71</td></tr>
</table>

Outdoor & indoor perspective views for S8 in *Winter Solstice : December 21st*
Part - Southwest Façade (north is directed 26° to east)

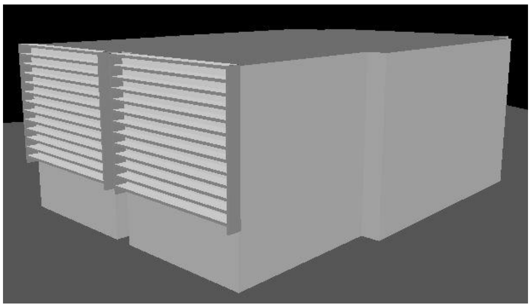
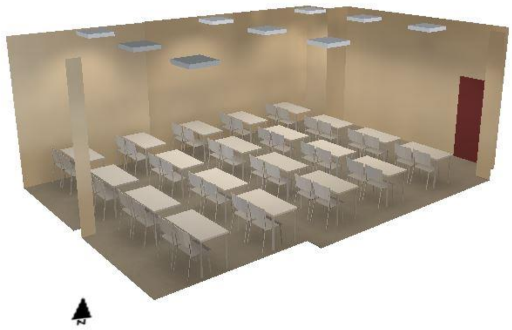
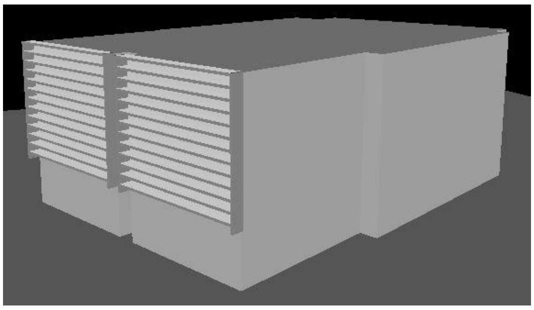
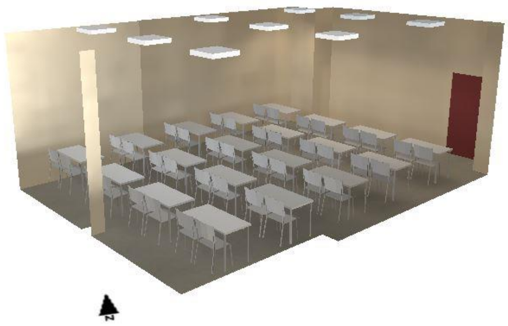
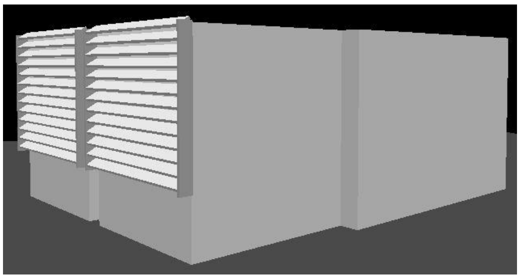
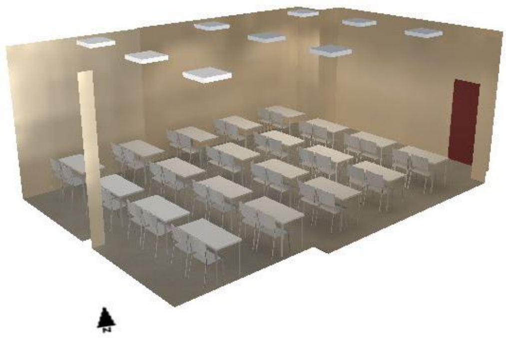
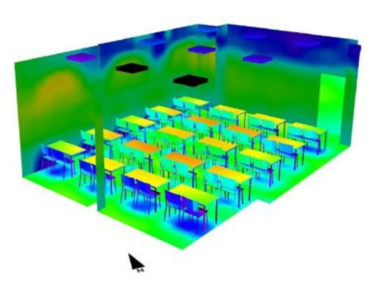
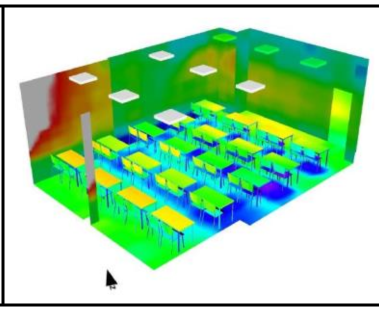
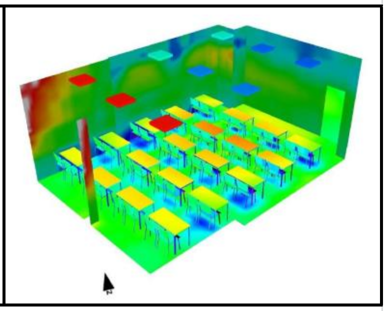
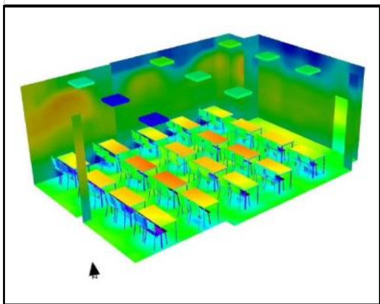
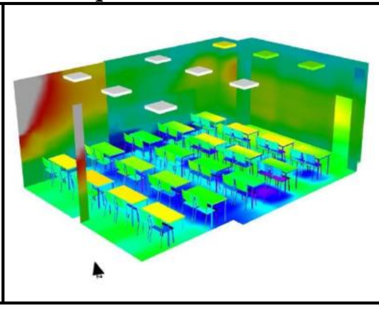
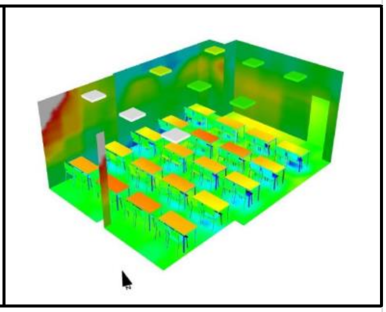
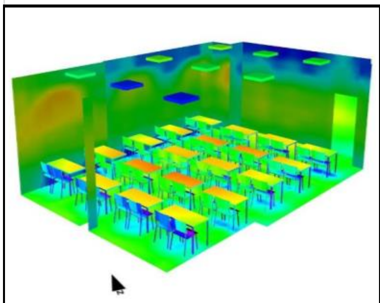
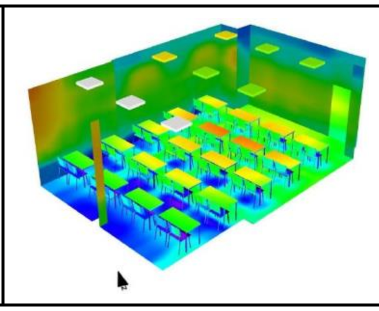
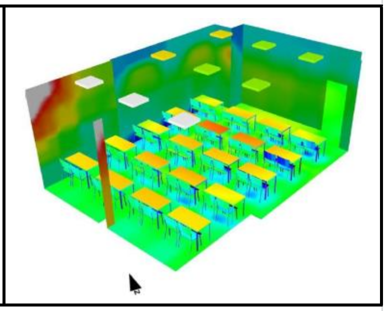
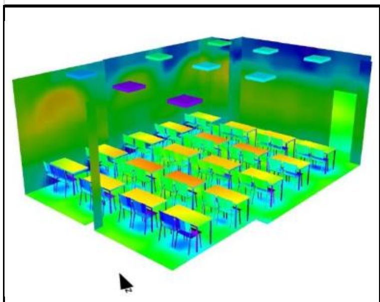
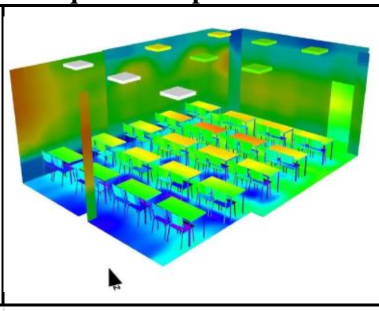
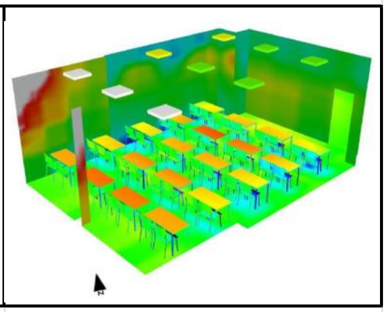
Outdoor Perspective	Indoor Perspective
9:00 AM	
	
12:00 PM	
	
3:00 PM	
	

Figure B.4 Part B-Outdoor & indoor perspective views for retrofitted S8

False Color Rendering (in perspective) for S8
Part B - Southwest Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM
Winter Solstice : December 21st		
		
Equinox : March 21st		
		
Summer Solstice : June 21st		
		
Equinox : September 21st		
		

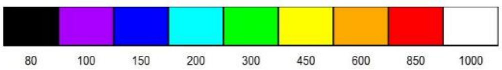
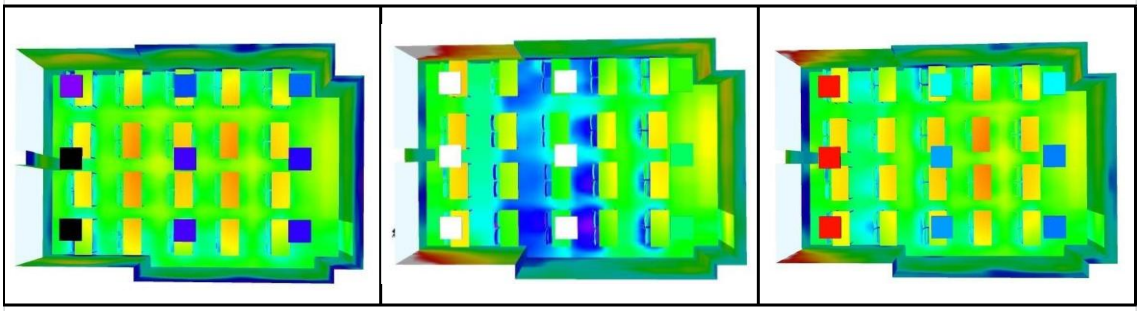
Iluminance Scale  *Lux*

Figure B.5 Part B-False color rendering (in perspective) for retrofitted S8

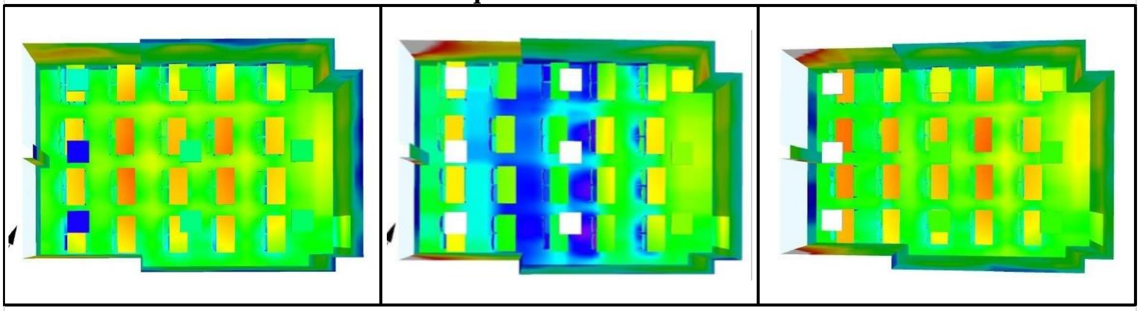
False Color Rendering (in plan) for S8
Part B - Southwest Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM

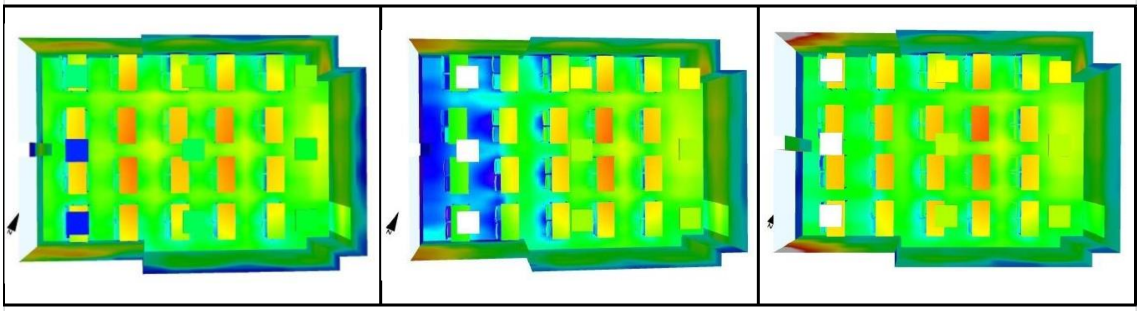
Winter Solstice : December 21st



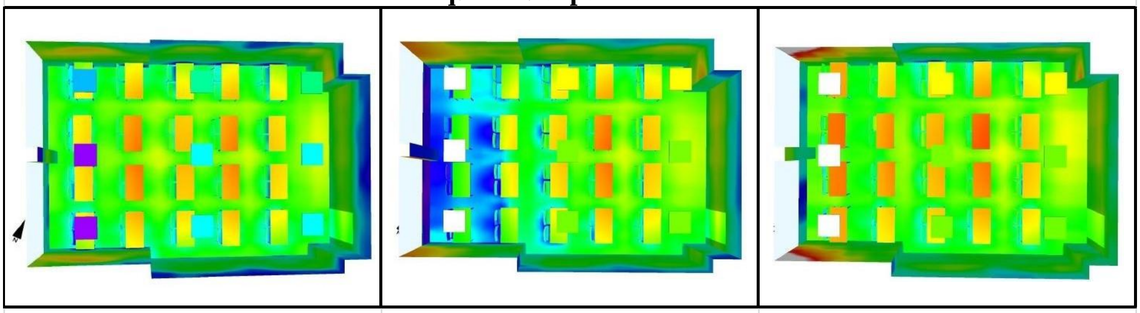
Equinox : March 21st



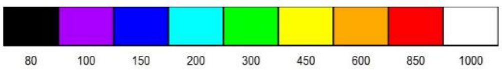
Summer Solstice : June 21st



Equinox : September 21st



Iluminance Scale



Lux

Figure B.6 Part B-False color rendering (in plan) for retrofitted S8

Table B.7 Part B-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the vertical shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Vertical Shading Devices (S7-FT3) (Results taken from DIALux)

Part B - Southwest Façade (north is directed 26° to east) (Room Z48 : h=3.60 m, Area= 62.83 m²)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	488	429	552	0.88	0.78
	March 21st			541	456	607	0.84	0.75
	June 21st			537	455	605	0.85	0.75
	September 21st			516	446	576	0.87	0.77
12 PM	December 21st	u=0° l=0°	2	538	481	606	0.89	0.79
	March 21st			607	503	722	0.83	0.70
	June 21st			540	482	611	0.89	0.79
	September 21st			533	481	604	0.90	0.80
3 PM	December 21st	u=0° l=60°	1	785	340	3248	0.43	0.10
	March 21st			769	601	1203	0.78	0.50
	June 21st			656	443	1039	0.68	0.43
	September 21st			666	449	1122	0.67	0.40

Table B.8 Part B-Retrofitting the results for the vertical shading devices by using the fixed panels at W/S S&E

Retrofitting the Results for the Vertical Shading Devices by Using the Fixed Panels at W/S S&E (S7-FT3) (Results taken from DIALux)

Part B - Southwest Façade (north is directed 26° to east) (Room Z48 : h=3.60 m, Area= 62.83 m^2)

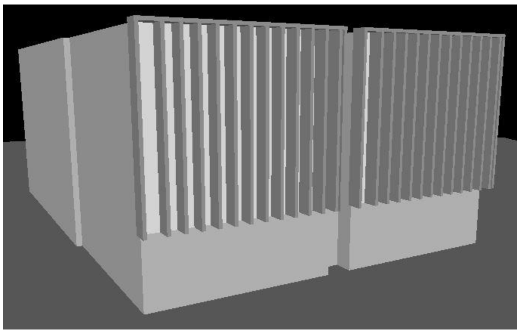
SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row (on)**
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window
Horizontal; width: window width, location: top of window

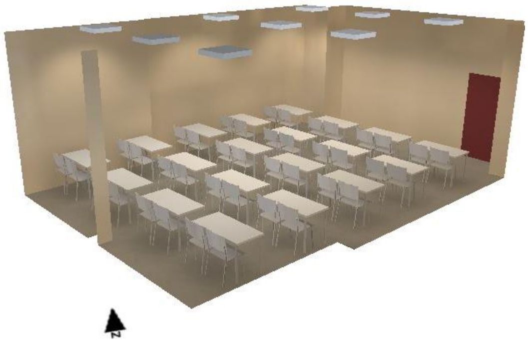
Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	474	422	543	0.80	0.78
	March 21st			517	443	579	0.86	0.77
	June 21st			514	444	576	0.86	0.77
	September 21st			498	436	565	0.88	0.77
12 PM	December 21st	u=0° l=0°	2	503	450	578	0.89	0.78
	March 21st			550	482	616	0.88	0.78
	June 21st			488	402	578	0.82	0.70
	September 21st			482	392	570	0.81	0.69
3 PM	December 21st	u=0° l=60°	1	496	337	616	0.68	0.55
	March 21st	u=15° l=75°		497	369	655	0.74	0.56
	June 21st	u=0° l=75°		453	306	635	0.68	0.48
	September 21st	u=15° l=60°	2	573	505	645	0.88	0.78

Outdoor & indoor perspective views for S9 in *Winter Solstice : December 21st*
Part B - Southwest Façade (north is directed 26° to east)

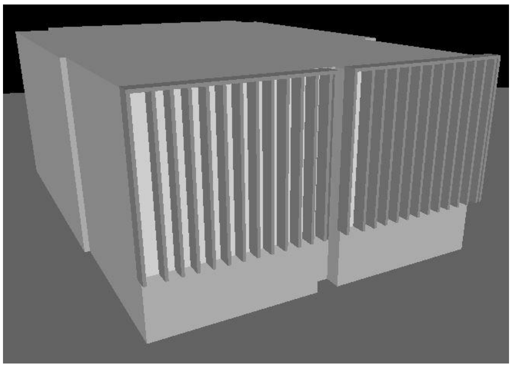
Outdoor Perspective	**Indoor Perspective**

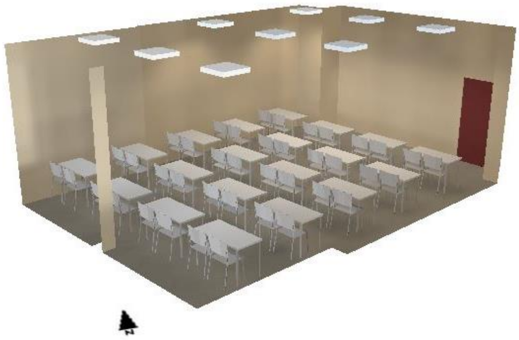
9:00 AM



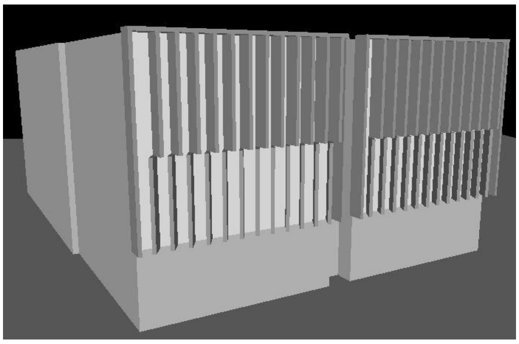


12:00 PM





3:00 PM



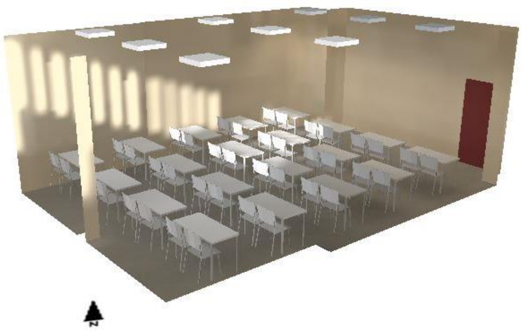


Figure B.7 Part B-Outdoor & indoor perspective views for retrofitted S9

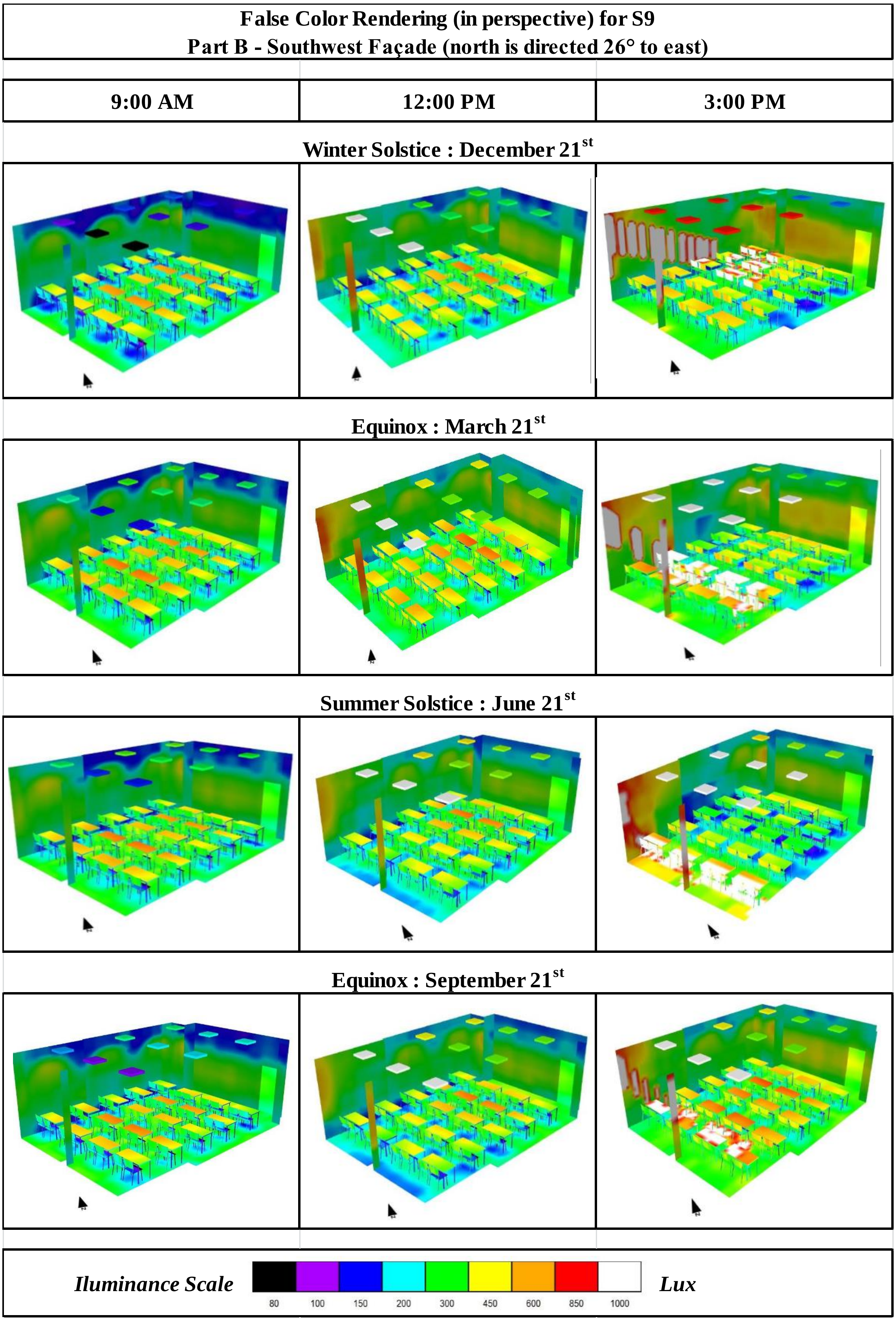
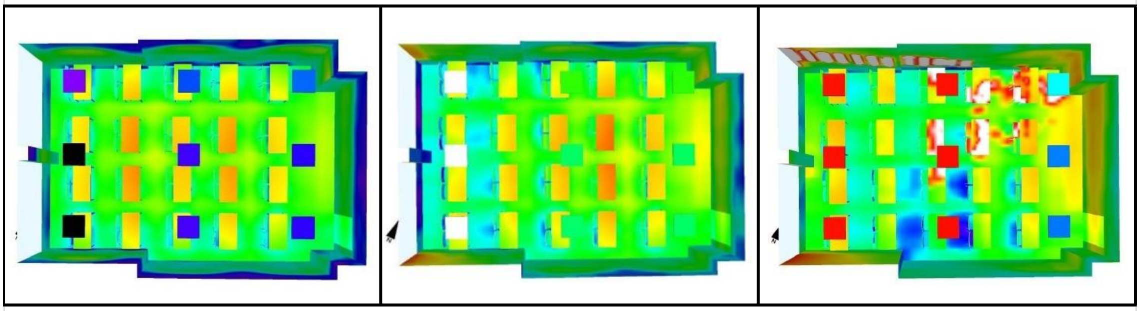


Figure B.8 Part B-False color rendering (in perspective) for retrofitted S9

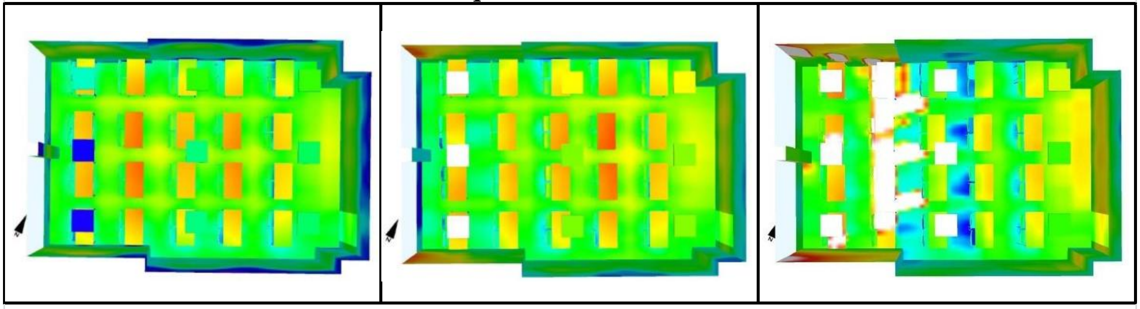
False Color Rendering (in plan) for S9
Part B - Southwest Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM

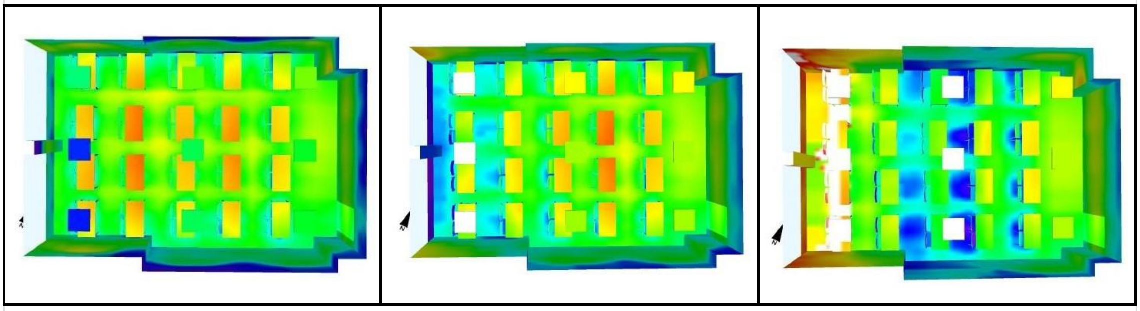
Winter Solstice : December 21st



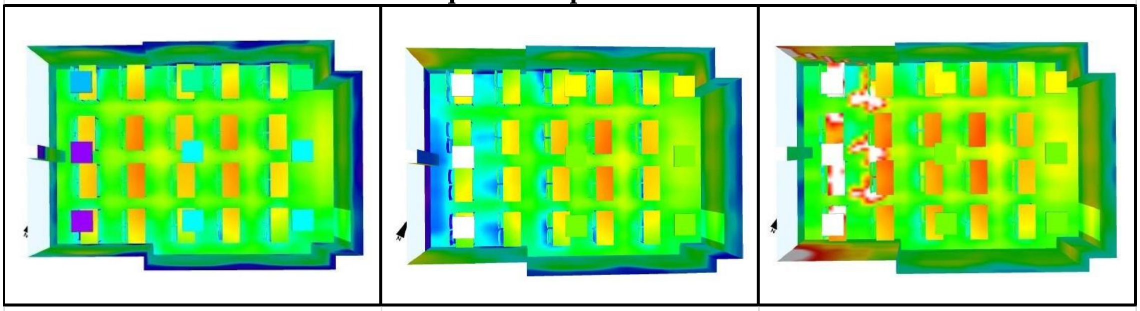
Equinox : March 21st

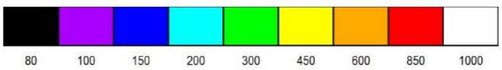


Summer Solstice : June 21st



Equinox : September 21st



Iluminance Scale 

Lux

Figure B.9 Part B-False color rendering (in plan) for retrofitted S9

Table B.9 Part B-Comparison of lighting fixture type energy consumption for optimum results of the horizontal shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Horizontal Shading Devices

Part B - Southwest Façade (north is directed 26° to east)
(Room Z48 : h=3.60 m, Area= 62.83 m^2)

SD: Shading Device; Type : horizontal;
upper: 7 lower: 6
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

W/S Solstices & Equinoxes	Hour	ENERGY CONSUMPTION								
		LL	Time h	Floor Area %	S4-FT3 with FL			S8 with LED		
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI
December 21st	9 AM	3	3	100	1890	283.5	4.5	1107	166.1	2.6
	12 PM	1	3	33.3	630			369		
	3 PM	2	3	66.6	1260			738		
March 21st	9 AM	3	3	100	1890	283.5	4.5	1107	166.1	2.6
	12 PM	1	3	33.3	630			369		
	3 PM	2	3	66.6	1260			738		
June 21st	9 AM	3	3	100	1890	330.8	5.3	1107	193.7	3.1
	12 PM	2	3	66.6	1260			738		
	3 PM	2	3	66.6	1260			738		
September 21st	9 AM	3	3	100	1890	330.8	5.3	1107	193.7	3.1
	12 PM	2	3	66.6	1260			738		
	3 PM	2	3	66.6	1260			738		
Annual Energy Consumption					**FL**	**1228.5**	**19.6**	**LED**	**719.6**	**11.5**

Table B.10 Part B-Comparison of lighting fixture type energy consumption for optimum results of the vertical shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Vertical Shading Devices

Part B - Southwest Façade (north is directed 26° to east)
(Room Z48 : h=3.60 m, Area= 62.83 m²)

SD: Shading Device; Type : vertical;
upper: 12 lower: 12
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m²) a: annual; p: period; d: day

W/S Solstices & Equinoxes	Hour	ENERGY CONSUMPTION								
		LL	Time h	Floor Area %	S7-FT3 with FL			S9 with LED		
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI
December 21st	9 AM	3	3		1890	283.5	4.5	1107	166.1	2.6
	12 PM	2	3		1260			738		
	3 PM	1	3		630			369		
March 21st	9 AM	3	3		1890	283.5	4.5	1107	166.1	2.6
	12 PM	2	3		1260			738		
	3 PM	1	3		630			369		
June 21st	9 AM	3	3		1890	283.5	4.5	1107	166.1	2.6
	12 PM	2	3		1260			738		
	3 PM	1	3		630			369		
September 21st	9 AM	3	3		1890	330.8	5.3	1107	193.7	3.1
	12 PM	2	3		1260			738		
	3 PM	2	3		1260			738		
Annual Energy Consumption					**FL**	**1181.3**	**18.8**	**LED**	**691.9**	**11.0**

APPENDIX C. SIMULATION RESULTS FOR PART C

Table C.1 Part C-Base case results (S0 for W/S S&E)

Base Case Results (Results taken from DIALux)

Part C - Northwest Façade (north is directed 26° to east)
(Room Z35 : h=3.30 m, Area= 80.36 m²)

FT: Fenestration Transmittance
FC: Fenestration Color = 80%
SC: Surface Color = 68%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
Winter Solstice : December 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	58	13	176	0.23	0.08
					0	FL	**12 PM**	103	23	301	0.22	0.08
					0	FL	**3 PM**	74	14	221	0.19	0.06
Equinox : March 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	109	23	338	0.21	0.07
					0	FL	**12 PM**	149	29	423	0.20	0.07
					0	FL	**3 PM**	161	26	474	0.16	0.06
Summer Solstice : June 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	140	25	438	0.18	0.06
					0	FL	**12 PM**	193	33	566	0.17	0.06
					0	FL	**3 PM**	236	36	714	0.15	0.05
Equinox : September 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	89	19	277	0.21	0.07
					0	FL	**12 PM**	147	29	422	0.2	0.07
					0	FL	**3 PM**	166	29	491	0.17	0.06

Outdoor & indoor perspective views for S0 in *Winter Solstice : December 21 st*
Part C - Northwest Façade (north is directed 26° to east)

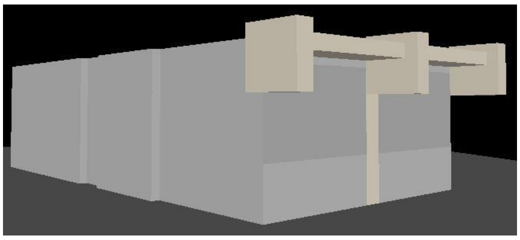
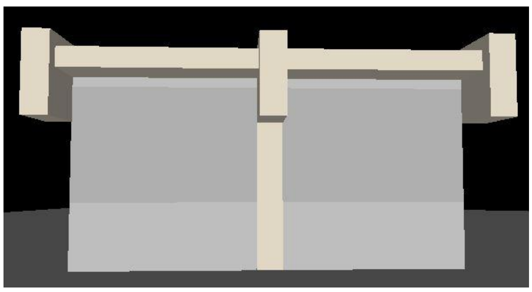
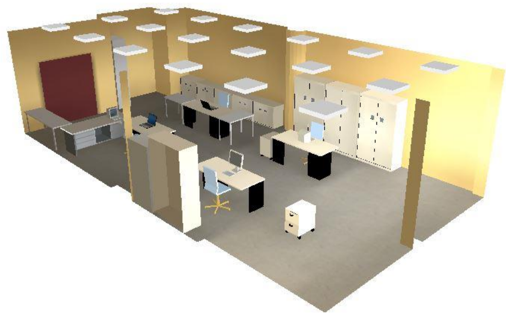
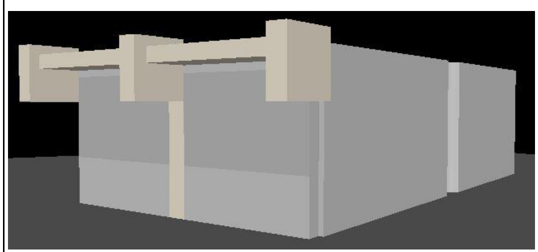
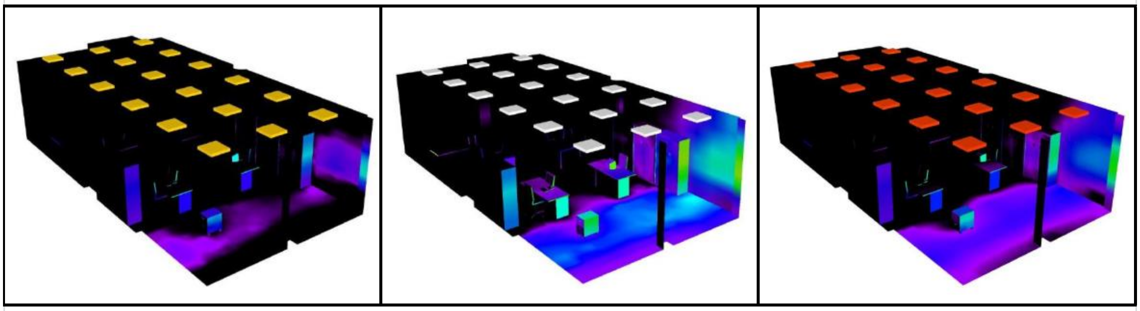
Outdoor Perspective	Indoor Perspective
9:00 AM	
	
12:00 PM	
	
3:00 PM	
	

Figure C.1 Part C-Outdoor & indoor perspective views for S0

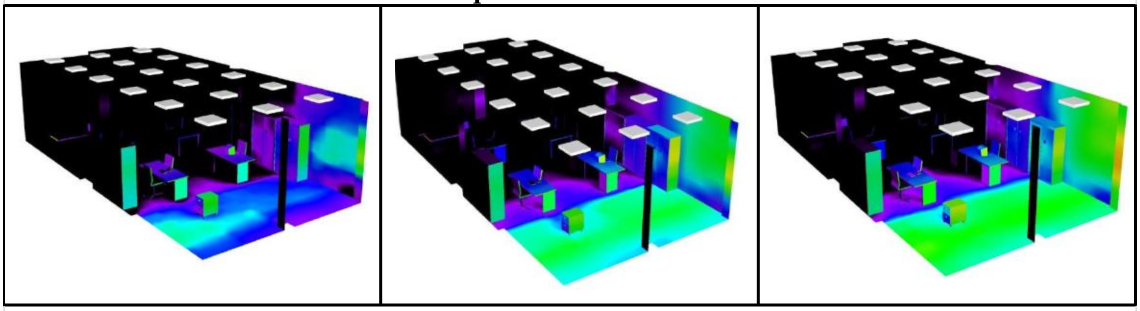
False Color Rendering (in perspective) for S0
Part C - Northwest Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM

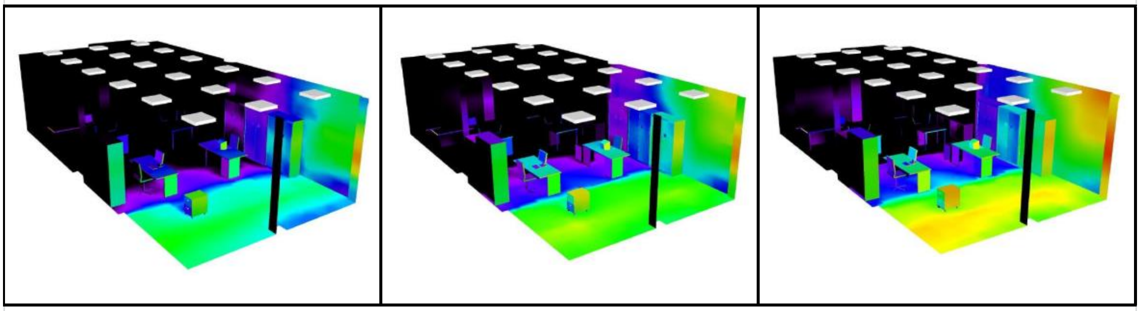
Winter Solstice : December 21st



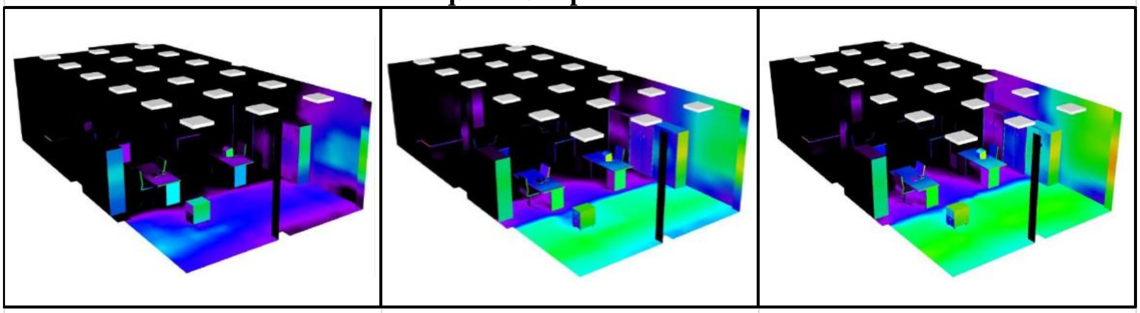
Equinox : March 21st



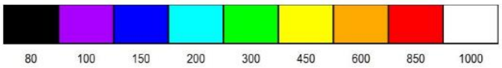
Summer Solstice : June 21st



Equinox : September 21st



Iluminance Scale



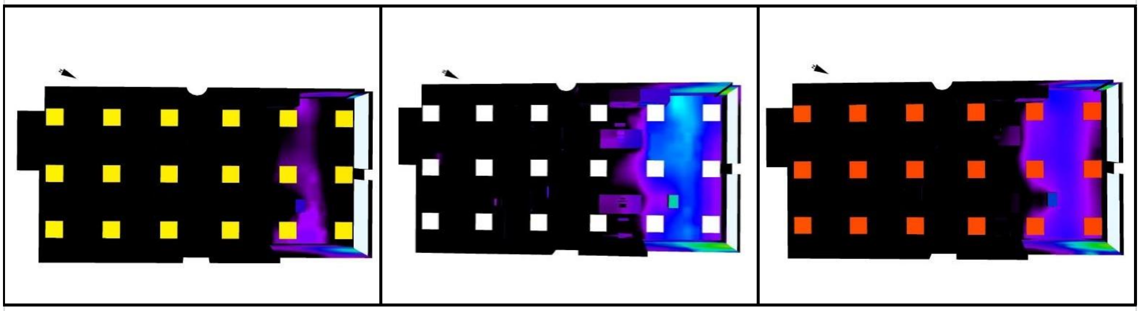
Lux

Figure C.2 Part C-False color rendering (in perspective) for S0

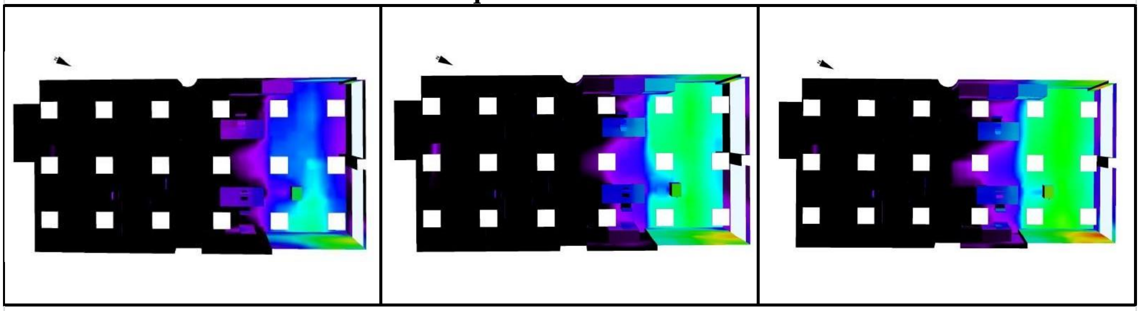
False Color Rendering (in plan) for S0
Part C - Northwest Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM

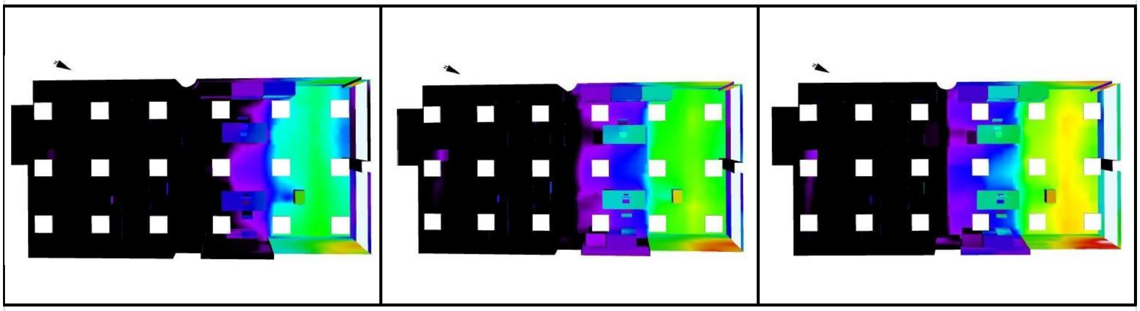
Winter Solstice : December 21st



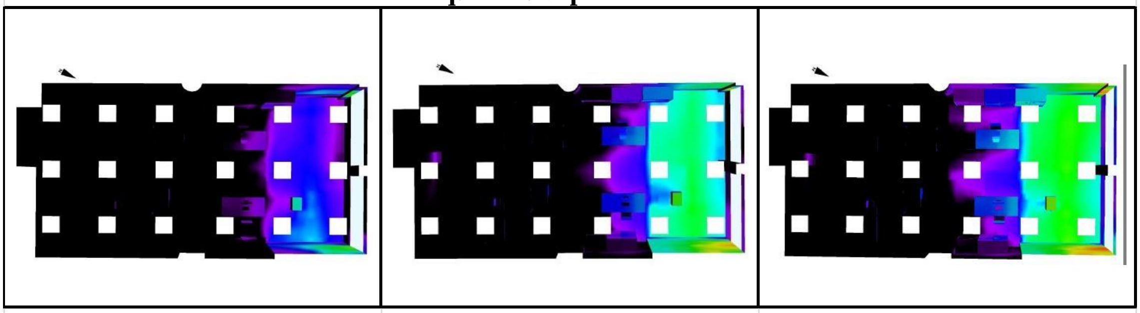
Equinox : March 21st



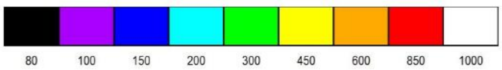
Summer Solstice : June 21st



Equinox : September 21st



Iluminance Scale



Lux

Figure C.3 Part C-False color rendering (in plan) for S0

Table C.2 Retrofit scenarios (S1-S7)

Retrofit Scenarios (Results taken from DIALux for December 21st)

Part C - Northwest Façade (north is directed 26° to east)

(Room Z35 : h=3.30 m, Area= 80.36 m²)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S1	FT_1 90%	Yes	No	No	3	FL	**9 AM**	517	358	735	0.69	0.49
					2	FL	**12 PM**	504	323	764	0.64	0.42
					2	FL	**3 PM**	451	278	646	0.62	0.43
	FT_2 70%	Yes	No	No	3	FL	**9 AM**	481	346	676	0.72	0.51
					2	FL	**12 PM**	443	280	597	0.63	0.47
					3	FL	**3 PM**	481	346	676	0.72	0.51
	FT_3 50%	Yes	No	No	3	FL	**9 AM**	444	325	617	0.73	0.53
					3	FL	**12 PM**	497	345	707	0.69	0.49
					3	FL	**3 PM**	471	337	660	0.72	0.51
SD u=2 l=2 distance 30 cm **S2** **Light Shelf** location 220 cm width 290 cm length 100 cm	FT_1 90%	Yes	SD_2 h	u=0⁰ l=0⁰	3	FL	**9 AM**	461	345	651	0.75	0.53
				u=0⁰ l=0⁰	2	FL	**12 PM**	409	275	588	0.67	0.47
				u=0⁰ l=0⁰	3	FL	**3 PM**	491	349	703	0.71	0.50
	FT_2 70%	Yes	SD_2 h	u=0⁰ l=0⁰	3	FL	**9 AM**	437	337	610	0.75	0.54
				u=0⁰ l=0⁰	3	FL	**12 PM**	484	348	694	0.72	0.50
				u=0⁰ l=0⁰	3	FL	**3 PM**	460	340	650	0.74	0.50
	FT_3 50%	Yes	SD_2 h	u=0⁰ l=0⁰	3	FL	**9 AM**	413	288	570	0.70	0.50
				u=0⁰ l=0⁰	3	FL	**12 PM**	444	334	627	0.75	0.53
				u=0⁰ l=0⁰	3	FL	**3 PM**	429	320	598	0.75	0.54

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Table C.2 (cont.)

Part C - Northwest Façade (north is directed 26° to east) (Room Z35 : h=3.30 m, Area= 80.36 m^2)												
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); Type h: horizontal v: vertical Angle u: upper l: lower **LL: Lighting Fixture Layout;** n: Number of Lighting Row (on) **LT: Lighting Fixture Type;** FL: Fluorescent LED: Light Emitting Diode												
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux) E_{avg}**	**E_{min}**	**E_{max}**	**UNIFORMITY U_1 E_{min}/E_{avg}**	**U_2 E_{min}/E_{max}**
SD u=2 l=3 distance 30 cm **S3**	FT_1 90%	No	SD_3 h			FL	**9 AM**					
						FL	**12 PM**					
						FL	**3 PM**					
	FT_2 70%	No	SD_3 h	$u=0^0$ $l=0^0$	3	FL	**9 AM**	446	335	629	0.75	0.53
				$u=0^0$ $l=0^0$	2	FL	**12 PM**	499	350	723	0.70	0.48
				$u=0^0$ $l=0^0$	3	FL	**3 PM**	469	340	670	0.72	0.51
	FT_3 50%	No	SD_3 h			FL	**9 AM**					
						FL	**12 PM**					
						FL	**3 PM**					
SD u=4 l=5 distance 20 cm **S4**	FT_1 90%	No	SD_4 h	$u=0^0$ $l=0^0$	3	FL	**9 AM**	426	293	596	0.69	0.49
				$u=0^0$ $l=0^0$	3	FL	**12 PM**	466	353	667	0.76	0.53
				$u=0^0$ $l=0^0$	3	FL	**3 PM**	444	333	628	0.75	0.53
	FT_2 70%	No	SD_4 h	$u=0^0$ $l=0^0$	4	FL	**9 AM**	508	338	740	0.66	0.46
				$u=0^0$ $l=0^0$	3	FL	**12 PM**	440	334	622	0.76	0.54
				$u=0^0$ $l=0^0$	3	FL	**3 PM**	424	316	592	0.75	0.53
	FT_3 50%	No	SD_4 h	$u=0^0$ $l=0^0$	4	FL	**9 AM**	492	325	712	0.66	0.46
				$u=0^0$ $l=0^0$	3	FL	**12 PM**	414	286	578	0.69	0.49
				$u=0^0$ $l=0^0$	3	FL	**3 PM**	404	270	558	0.67	0.49

(cont. on next page)

Table C.2 (cont.)

Part C - Northwest Façade (north is directed 26° to east) (Room Z35 : h=3.30 m, Area= 80.36 m^2)												
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row** (on) **LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode**												
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux) E_{avg}**	**E_{min}**	**E_{max}**	**UNIFORMITY U_1 E_{min}/E_{avg}**	**U_2 E_{min}/E_{max}**
SD u=7 l=7 distance 40 cm **S5** **Light Shelf** location 220 cm width 290 cm length 100 cm	FT_1 90%	Yes	SD_5 v	u=0^0 l=0^0	3	FL	**9 AM**	451	337	621	0.75	0.54
				u=0^0 l=0^0	3	FL	**12 PM**	506	358	710	0.71	0.50
				u=0^0 l=0^0	3	FL	**3 PM**	474	345	663	0.73	0.52
	FT_2 70%	Yes	SD_5 v	u=0^0 l=0^0	3	FL	**9 AM**	430	321	588	0.75	0.55
				u=0^0 l=0^0	3	FL	**12 PM**	470	345	655	0.73	0.53
				u=0^0 l=0^0	3	FL	**3 PM**	447	331	620	0.74	0.53
	FT_3 50%	Yes	SD_5 v	u=0^0 l=0^0	3	FL	**9 AM**	408	287	557	0.70	0.52
				u=0^0 l=0^0	3	FL	**12 PM**	436	325	602	0.75	0.54
				u=0^0 l=0^0	3	FL	**3 PM**	420	312	577	0.74	0.54
SD u=7 l=7 distance 40 cm **S6**	FT_1 90%	No	SD_6 v			FL	**9 AM**					
						FL	**12 PM**					
						FL	**3 PM**					
	FT_2 70%	No	SD_6 v	u=0^0 l=0^0	3	FL	**9 AM**	446	325	606	0.73	0.54
				u=0^0 l=0^0	3	FL	**12 PM**	496	347	685	0.70	0.51
				u=0^0 l=0^0	3	FL	**3 PM**	465	336	640	0.72	0.52
	FT_3 50%	No	SD_6 v			FL	**9 AM**					
						FL	**12 PM**					
						FL	**3 PM**					

(cont. on next page)

Table C.2 (cont.)

Part C - Northwest Façade (north is directed 26° to east) (Room Z35 : h=3.30 m, Area= 80.36 m^2)													
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical** **Angle u: upper l: lower** **LL: Lighting Fixture Layout;** **n: Number of Lighting Row** (on) **LT: Lighting Fixture Type;** **FL: Fluorescent** **LED: Light Emitting Diode**													
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux) E_{avg}**	**E_{min}**	**E_{max}**	**UNIFORMITY U_1 E_{min}/E_{avg}**	**U_2 E_{min}/E_{max}**
SD u=12 l=12 distance 23 cm **S7**	FT_1 90%	No	SD_7 v	u=0^0 l=0^0	3	FL	**9 AM**	434	319	599	0.73	0.53
				u=0^0 l=0^0	3	FL	**12 PM**	477	344	670	0.72	0.51
				u=0^0 l=0^0	3	FL	**3 PM**	448	325	625	0.73	0.52
	FT_2 70%	No	SD_7 v	u=0^0 l=0^0	3	FL	**9 AM**	417	298	571	0.72	0.52
				u=0^0 l=0^0	3	FL	**12 PM**	448	328	625	0.73	0.53
				u=0^0 l=0^0	3	FL	**3 PM**	427	312	590	0.73	0.53
	FT_3 50%	No	SD_7 v	u=0^0 l=0^0	4	FL	**9 AM**	497	323	715	0.65	0.45
				u=0^0 l=0^0	3	FL	**12 PM**	420	309	580	0.74	0.53
				u=0^0 l=0^0	3	FL	**3 PM**	406	295	556	0.73	0.53

Table C.3 Part C-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of illuminance & uniformity

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Illuminance & Uniformity (Results taken from DIALux for December 21st)

Part C - Northwest Façade (north is directed 26° to east) (Room Z35 : h=3.30 m, Area= 80.36 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S4	FT_1 90%	No	SD_4 h	u=0^0 l=0^0	3	FL	**9 AM**	426	293	596	0.69	0.49
				u=0^0 l=0^0	3	FL	**12 PM**	466	353	667	0.76	0.53
				u=0^0 l=0^0	3	FL	**3 PM**	444	333	628	0.75	0.53
S8	FT_1 90%	No	SD_4 h	u=0^0 l=0^0	3	LED	**9 AM**	361	271	468	0.75	0.58
				u=0^0 l=0^0	3	LED	**12 PM**	402	318	540	0.79	0.59
				u=0^0 l=0^0	3	LED	**3 PM**	379	299	499	0.79	0.60
S7	FT_2 70%	No	SD_7 v	u=0^0 l=0^0	3	FL	**9 AM**	417	298	571	0.72	0.52
				u=0^0 l=0^0	3	FL	**12 PM**	448	328	625	0.73	0.53
				u=0^0 l=0^0	3	FL	**3 PM**	427	312	590	0.73	0.53
S9	FT_2 70%	No	SD_7 v	u=0^0 l=0^0	3	LED	**9 AM**	351	264	442	0.75	0.60
				u=0^0 l=0^0	3	LED	**12 PM**	384	294	496	0.76	0.59
				u=0^0 l=0^0	3	LED	**3 PM**	362	277	461	0.77	0.60

Table C.4 Part C-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of energy consumption

Comparison of Selected Optimum Retrofit Scenarios
for Horizontal and Vertical Shading Devices
in terms of Energy Consumption
(Results taken from DIALux for December 21st)

Part C - Northwest Façade (north is directed 26° to east)
(Room Z35 : h=3.30 m, Area= 80.36 m^2)

FT: Fenestration Transmittance
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical** **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
LT: Lighting Fixture Type;
FL : Fluorescent **Luminous Flux: 3834 lm; Power=70 W**
LED : Light Emitting Diode **Luminous Flux: 3400 lm; Power=41 W**
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2)

Scenario	FT	SD Type	SD Angle	LL n	LT	Hour	ENERGY CONSUMPTION				
							Time h	Floor Area %	Energy Wh	kWh/a a:300 d	LENI
S4	FT_1 90%	SD_4 h	$u=0^0$ $l=0^0$	3	FL	**9 AM**	3	50	1890	1701.0	21.2
			$u=0^0$ $l=0^0$	3	FL	**12 PM**	3	50	1890		
			$u=0^0$ $l=0^0$	3	FL	**3 PM**	3	50	1890		
S8	FT_1 90%	SD_4 h	$u=0^0$ $l=0^0$	3	LED	**9 AM**	3	50	1107	996.3	12.4
			$u=0^0$ $l=0^0$	3	LED	**12 PM**	3	50	1107		
			$u=0^0$ $l=0^0$	3	LED	**3 PM**	3	50	1107		
S7	FT_2 70%	SD_7 v	$u=0^0$ $l=0^0$	3	FL	**9 AM**	3	50	1890	1701.0	21.2
			$u=0^0$ $l=0^0$	3	FL	**12 PM**	3	50	1890		
			$u=0^0$ $l=0^0$	3	FL	**3 PM**	3	50	1890		
S9	FT_2 70%	SD_7 v	$u=0^0$ $l=0^0$	3	LED	**9 AM**	3	50	1107	996.3	12.4
			$u=0^0$ $l=0^0$	3	LED	**12 PM**	3	50	1107		
			$u=0^0$ $l=0^0$	3	LED	**3 PM**	3	50	1107		

Table C.5 Part C-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the horizontal shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Horizontal Shading Devices (S4-FT1) (Results taken from DIALux)

Part C - Northwest Façade (north is directed 26° to east) (Room Z35 : h=3.30 m, Area= 80.36 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	426	293	596	0.69	0.49
	March 21st			473	352	679	0.74	0.52
	June 21st			506	359	771	0.68	0.47
	September 21st			455	344	648	0.76	0.53
12 PM	December 21st	u=0° l=0°	3	466	353	667	0.76	0.53
	March 21st			500	357	727	0.72	0.49
	June 21st			530	361	771	0.68	0.47
	September 21st			496	357	721	0.72	0.49
3 PM	December 21st	u=0° l=0°	3	444	333	628	0.75	0.53
	March 21st			533	365	780	0.68	0.47
	June 21st			600	375	891	0.63	0.42
	September 21st			526	363	766	0.69	0.47

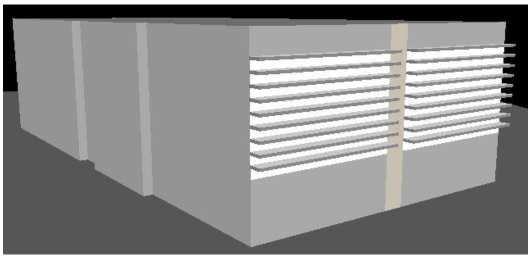
Table C.6 Part C-Retrofitting the results for the horizontal shading devices by using the fixed panels at W/S S&E

Retrofitting the Results for the Horizontal Shading Devices at W/S S&E (S4-FT1) (Results taken from DIALux)								
Part C - Northwest Façade (north is directed 26° to east) (Room Z35 : h=3.30 m, Area= 80.36 m^2)								
SD: Shading Device (length=25cm); LL: Lighting Fixture Layout; Panel length: 25 cm Vertical; height: window height,				Angle u: upper l: lower n: Number of Lighting Row (on) location: head of each side of window				
Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	426	293	596	0.69	0.49
	March 21st	u=45° l=45°		406	294	558	0.72	0.53
	June 21st	u=60° l=60°		398	284	545	0.71	0.52
	September 21st	u=45° l=30°		406	289	557	0.71	0.52
12 PM	December 21st	u=0° l=0°	3	466	353	667	0.76	0.53
	March 21st	u=60° l=60°		396	297	544	0.75	0.55
	June 21st	u=75° l=60°		401	299	559	0.75	0.54
	September 21st	u=45° l=60°		405	300	557	0.74	0.54
3 PM	December 21st	u=0° l=0°	3	444	333	628	0.75	0.53
	March 21st	u=60° l=60°		412	307	506	0.74	0.54
	June 21st	u=75° l=60°		422	316	586	0.75	0.54
	September 21st	u=60° l=60°		411	307	566	0.75	0.54

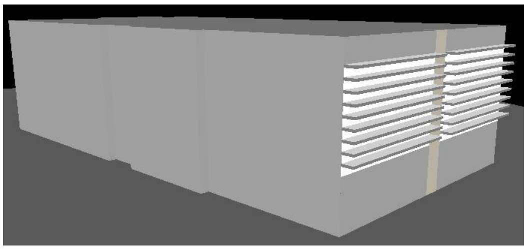
Outdoor & indoor perspective views for S8 in *Winter Solstice : December 21st*
Part C - Northwest Façade (north is directed 26° to east)

Outdoor Perspective	**Indoor Perspective**

9:00 AM



12:00 PM



3:00 PM

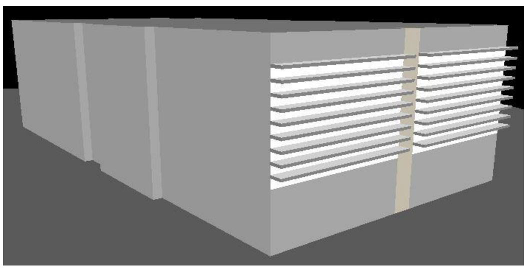


Figure C.4 Part C-Outdoor & indoor perspective views for retrofitted S8

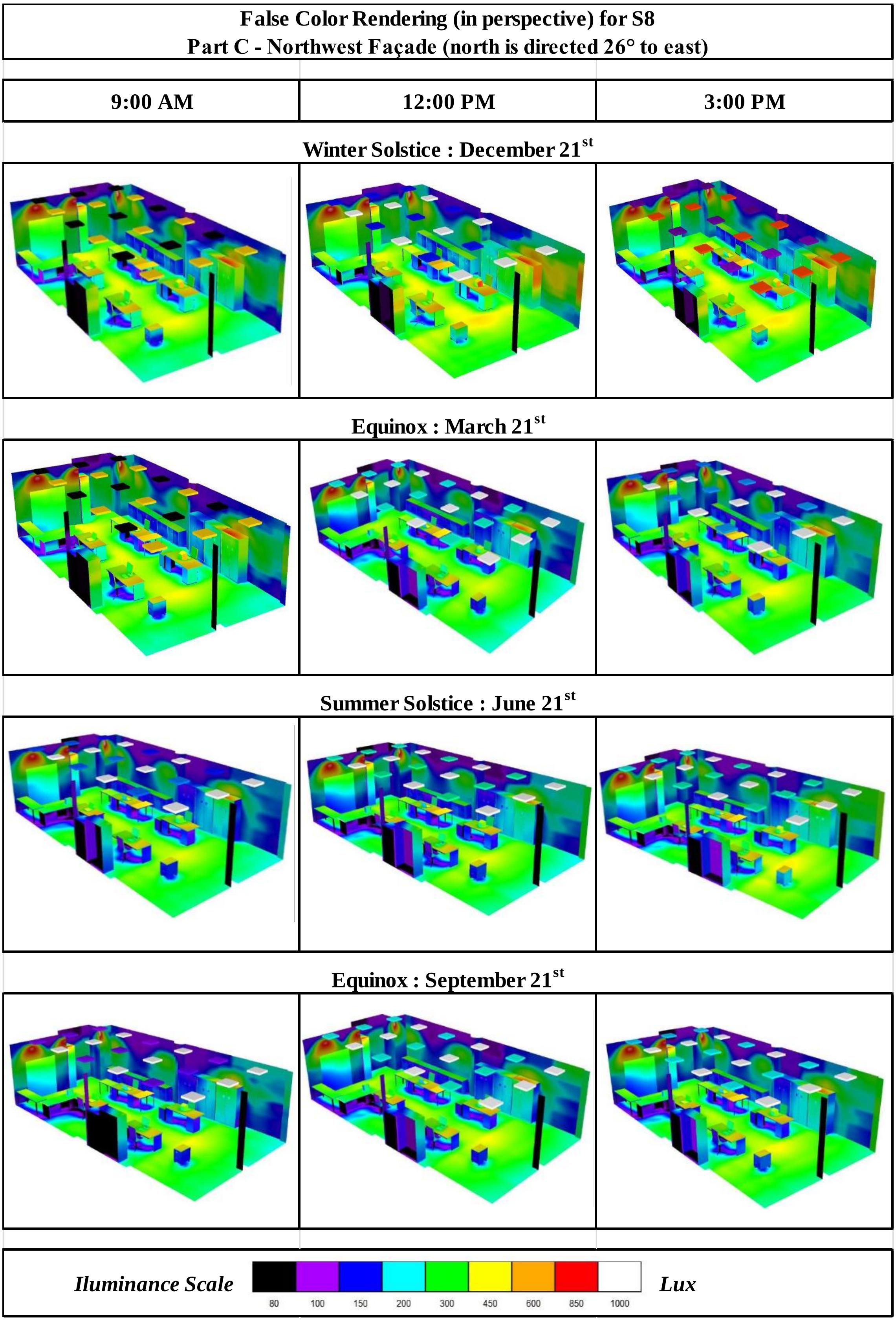
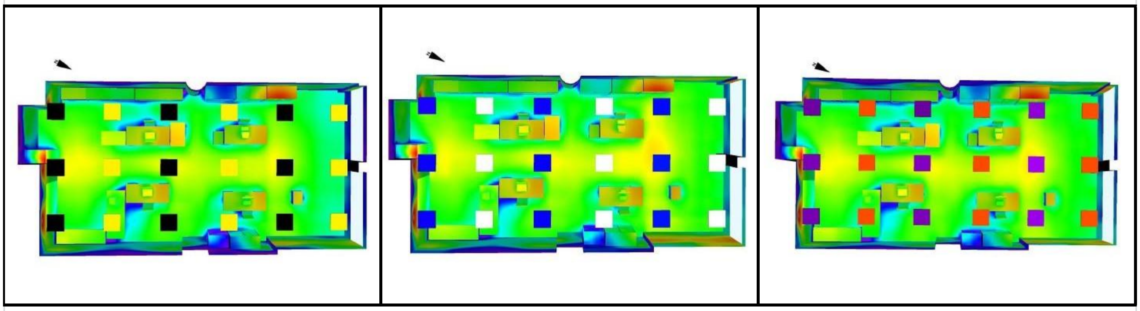


Figure C.5 Part C-False color rendering (in perspective) for retrofitted S8

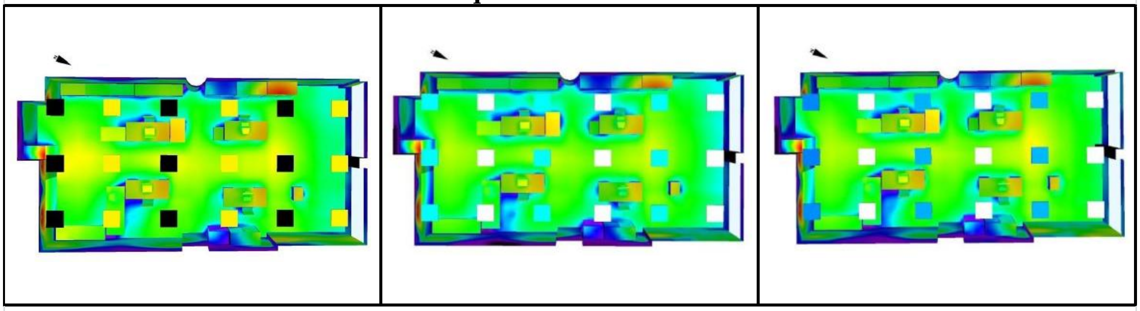
False Color Rendering (in plan) for S8
Part C - Northwest Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM

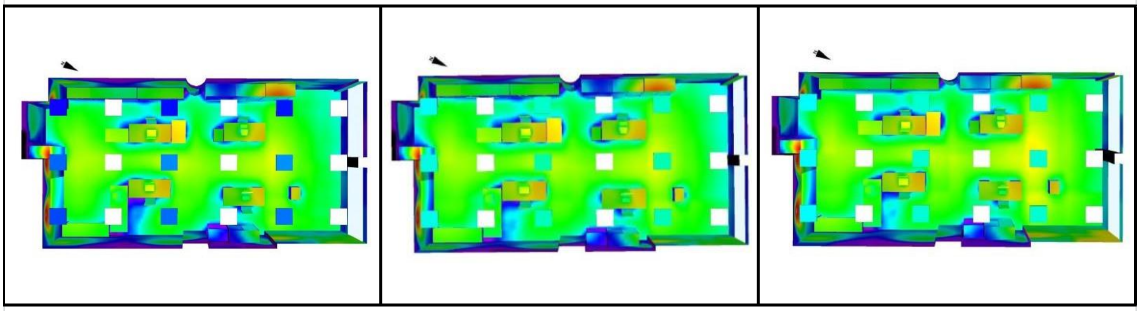
Winter Solstice : December 21st



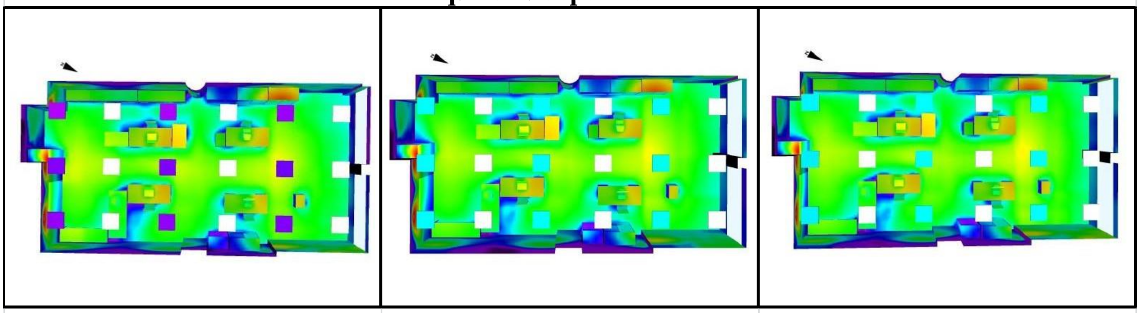
Equinox : March 21st



Summer Solstice : June 21st



Equinox : September 21st



Iluminance Scale	80	100	150	200	300	450	600	850	1000	*Lux*

Figure C.6 Part C-False color rendering (in plan) for retrofitted S8

Table C.7 Part C-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the vertical shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Vertical Shading Devices (S7-FT2) (Results taken from DIALux)

Part C - Northwest Façade (north is directed 26° to east) (Room Z35 : h=3.30 m, Area= 80.36 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	417	298	571	0.72	0.52
	March 21st			456	335	640	0.73	0.52
	June 21st			487	339	691	0.70	0.49
	September 21st			440	325	612	0.74	0.53
12 PM	December 21st	u=0° l=0°	3	448	328	625	0.73	0.53
	March 21st			488	339	697	0.69	0.49
	June 21st			531	345	769	0.65	0.45
	September 21st			483	338	688	0.70	0.49
3 PM	December 21st	u=0° l=0°	3	427	312	590	0.73	0.53
	March 21st			503	341	724	0.68	0.47
	June 21st			589	354	912	0.60	0.39
	September 21st			505	340	728	0.67	0.47

Table C.8 Part C-Retrofitting the results for the vertical shading devices by using the fixed panels at W/S S&E

Retrofitting the Results for the Vertical Shading Devices at W/S S&E (S7-FT2) (Results taken from DIALux)								
Part C - Northwest Façade (north is directed 26° to east) (Room Z35 : h=3.30 m, Area= 80.36 m^2)								
SD: Shading Device (length=25cm); **Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row (on)** **Panel length: 25 cm** **Vertical; height: window height, location: head of each side of window** **Horizontal; width: window width, location: top of window**								
Hour	**W/S Solstices & Equinoxes**	**SD Angle**	**LL n**	**ILLUMINANCE (Lux)**			**UNIFORMITY**	
				E_{avg}	**E_{min}**	**E_{max}**	**U_1 E_{min}/E_{avg}**	**U_2 E_{min}/E_{max}**
9 AM	**December 21st**	u=0° l=0°	3	417	298	571	0.72	0.52
	March 21st	u=60° l=0°		425	310	578	0.73	0.54
	June 21st	u=75° l=30°		420	303	570	0.72	0.53
	September 21st	u=60° l=0°		414	301	560	0.73	0.54
12 PM	**December 21st**	u=0° l=0°	3	448	328	625	0.73	0.53
	March 21st	u=60° l=45°		410	294	561	0.71	0.52
	June 21st	u=75° l=45°		415	301	570	0.72	0.53
	September 21st	u=60° l=45°		410	294	560	0.72	0.52
3 PM	**December 21st**	u=0° l=0°	3	427	312	590	0.73	0.53
	March 21st	u=60° l=45°		417	300	571	0.72	0.53
	June 21st	u=75° l=60°		404	298	550	0.74	0.54
	September 21st	u=60° l=45°		418	299	572	0.72	0.52

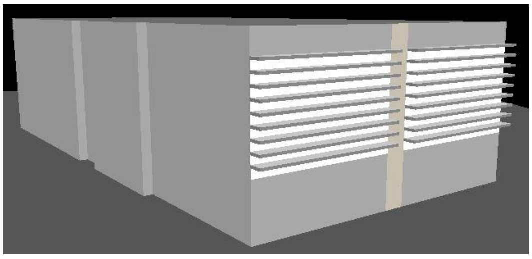
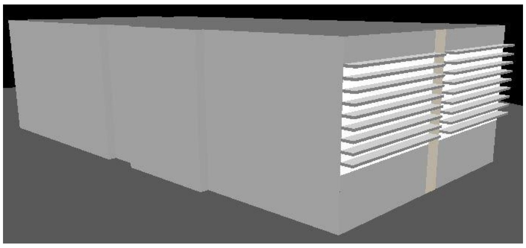
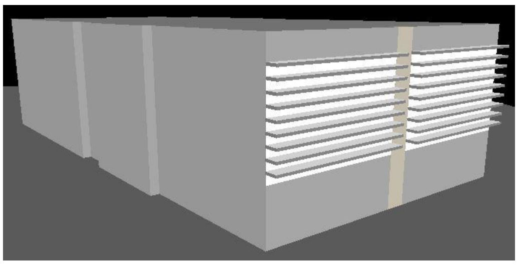
Outdoor & indoor perspective views for S9 in *Winter Solstice : December 21 st* Part C - Northwest Façade (north is directed 26° to east)	
Outdoor Perspective	**Indoor Perspective**
9:00 AM	
	
12:00 PM	
	
3:00 PM	
	

Figure C.7 Part C-Outdoor & indoor perspective views for retrofitted S9

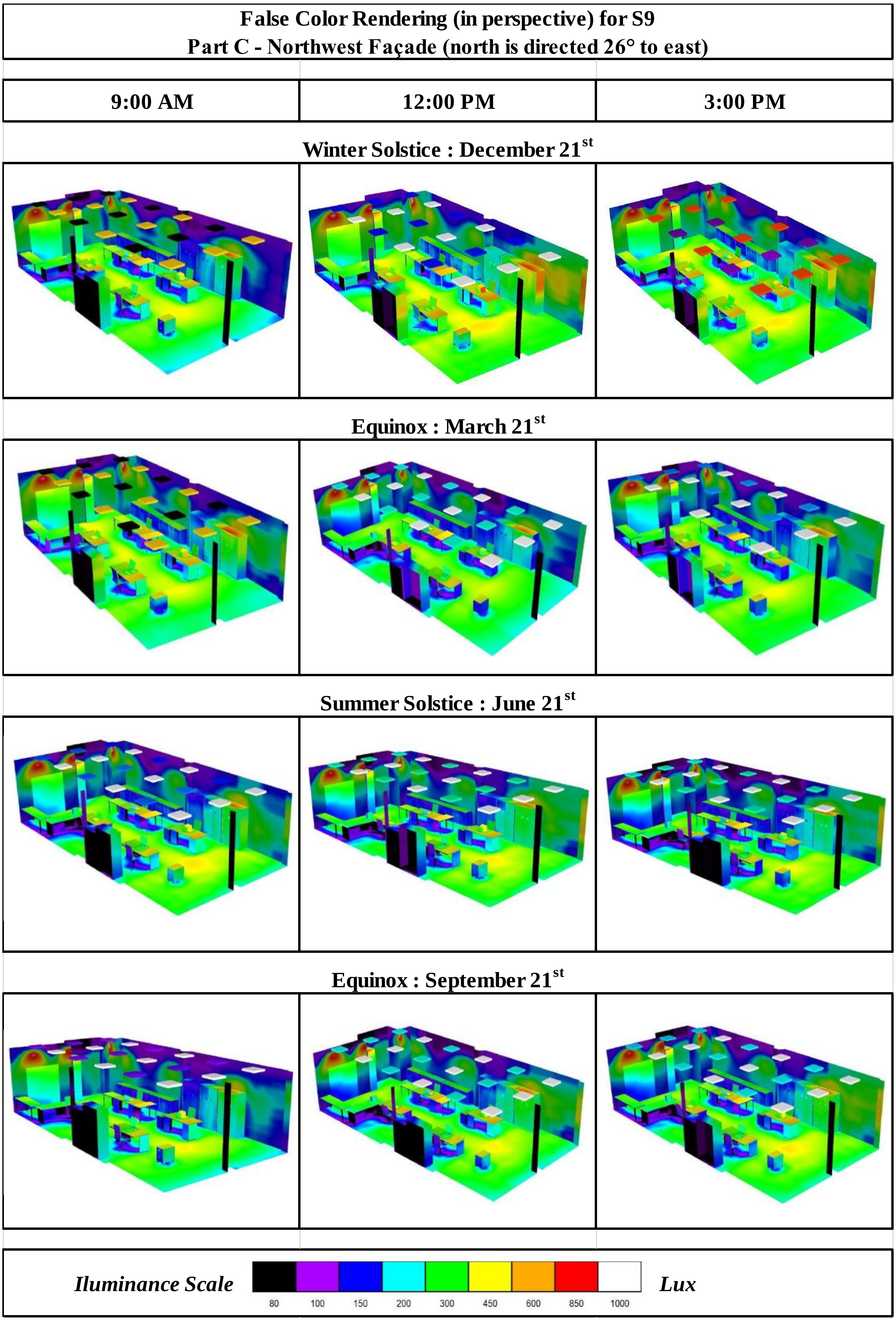
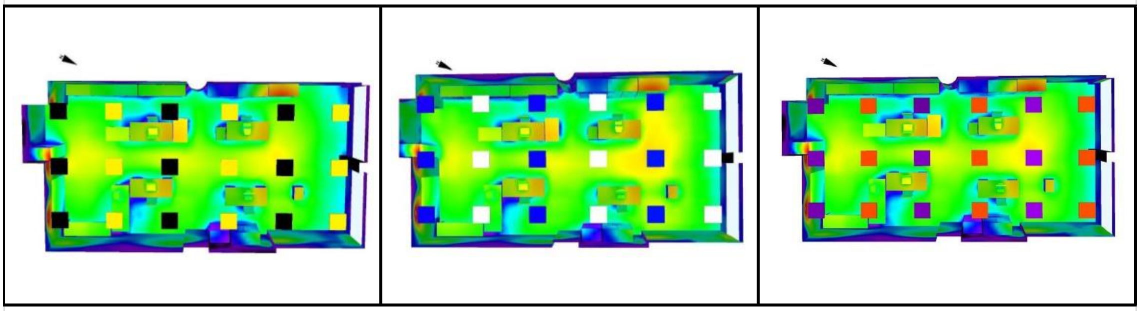


Figure C.8 Part C-False color rendering (in perspective) for retrofitted S9

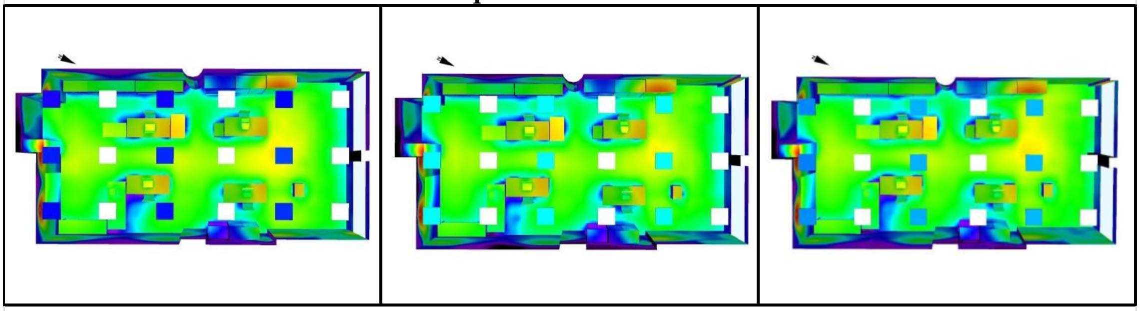
False Color Rendering (in plan) for S9
Part C - Northwest Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM

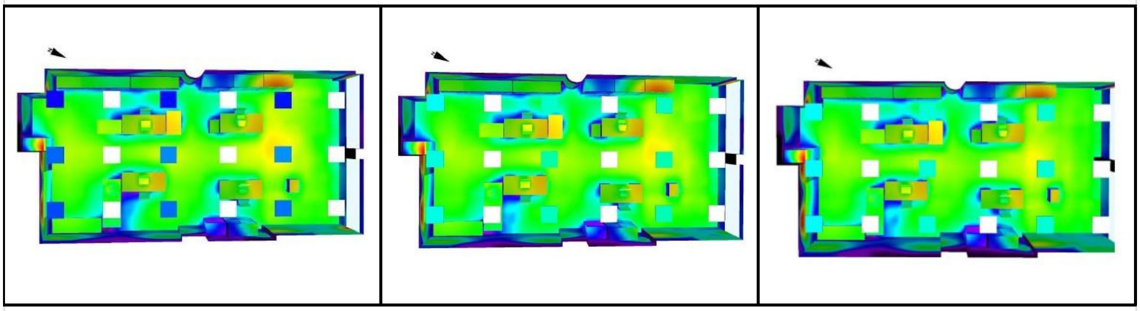
Winter Solstice : December 21st



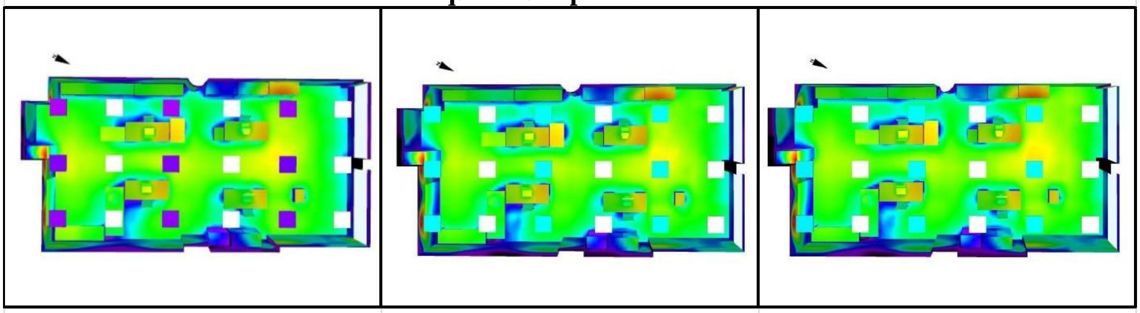
Equinox : March 21st



Summer Solstice : June 21st



Equinox : September 21st



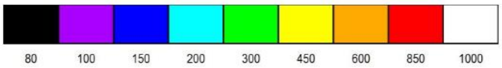
Iluminance Scale  ***Lux***

Figure C.9 Part C-False color rendering (in plan) for retrofitted S9

Table C.9 Part C-Comparison of lighting fixture type energy consumption for optimum results of the horizontal shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Horizontal Shading Devices

Part C - Northwest Façade (north is directed 26° to east)
(Room Z35 : h=3.30 m, Area= 80.36 m^2)

SD: Shading Device; Type : horizontal;
upper: 4 lower: 5
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

Solstices & Equinoxes	Hour	LL	Time h	Floor Area %	S4-FT1 with FL Energy Wh	S4-FT1 with FL kWh/a p: 75 d a: 300 d	S4-FT1 with FL LENI	S8 with LED Energy Wh	S8 with LED kWh/a p: 75 d a: 300 d	S8 with LED LENI
December 21st	9 AM	3	3	50	1890	425.3	5.3	1107	249.1	3.1
	12 PM	3	3	50	1890			1107		
	3 PM	3	3	50	1890			1107		
March 21st	9 AM	3	3	50	1890	425.3	5.3	1107	249.1	3.1
	12 PM	3	3	50	1890			1107		
	3 PM	3	3	50	1890			1107		
June 21st	9 AM	3	3	50	1890	425.3	5.3	1107	249.1	3.1
	12 PM	3	3	50	1890			1107		
	3 PM	3	3	50	1890			1107		
September 21st	9 AM	3	3	50	1890	425.3	5.3	1107	249.1	3.1
	12 PM	3	3	50	1890			1107		
	3 PM	3	3	50	1890			1107		
Annual Energy Consumption					**FL**	**1701.0**	**21.2**	**LED**	**996.3**	**12.4**

Table C.10 Part C-Comparison of lighting fixture type energy consumption for optimum results of the vertical shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Vertical Shading Devices

Part C - Northwest Façade (north is directed 26° to east)
(Room Z35 : h=3.30 m, Area= 80.36 m^2)

SD: Shading Device; Type : vertical;
upper: 12 lower: 12
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

Solstices & Equinoxes	Hour	ENERGY CONSUMPTION								
		LL	Time h	Floor Area %	S7-FT2 with FL			S9 with LED		
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI
December 21st	9 AM	3	3	50	1890			1107		
	12 PM	3	3	50	1890	425.3	5.3	1107	249.1	3.1
	3 PM	3	3	50	1890			1107		
March 21st	9 AM	3	3	50	1890			1107		
	12 PM	3	3	50	1890	425.3	5.3	1107	249.1	3.1
	3 PM	3	3	50	1890			1107		
June 21st	9 AM	3	3	50	1890			1107		
	12 PM	3	3	50	1890	425.3	5.3	1107	249.1	3.1
	3 PM	3	3	50	1890			1107		
September 21st	9 AM	3	3	50	1890			1107		
	12 PM	3	3	50	1890	425.3	5.3	1107	249.1	3.1
	3 PM	3	3	50	1890			1107		
Annual Energy Consumption					**FL**	**1701.0**	**21.2**	**LED**	**996.3**	**12.4**

APPENDIX D. SIMULATION RESULTS FOR PART D

Table D.1 Part D-Base case results (S0 for W/S S&E)

Base Case Results (Results taken from DIALux)

Part D - Northeast Façade (north is directed 26° to east)
(Room Z64 : h=3.3 m, Area= 268.82 m^2)

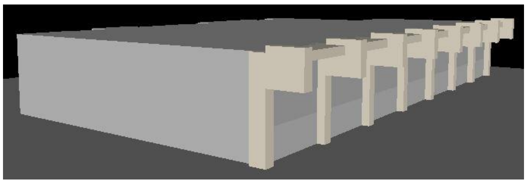
FT: Fenestration Transmittance
FC: Fenestration Color = 80%
SC: Surface Color = 68%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

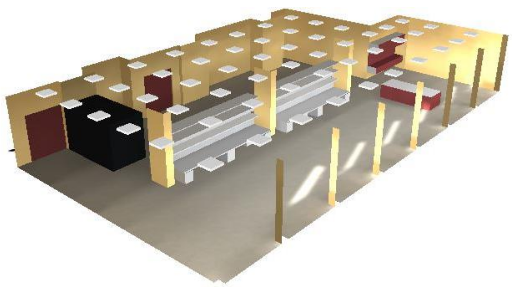
Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
Winter Solstice : December 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	120	22	280	0.18	0.08
					0	FL	**12 PM**	131	27	370	0.21	0.07
					0	FL	**3 PM**	76	16	234	0.21	0.07
Equinox : March 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	328	60	781	0.18	0.08
					0	FL	**12 PM**	231	46	602	0.2	0.08
					0	FL	**3 PM**	137	30	404	0.22	0.07
Summer Solstice : June 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	1353	84	7467	0.06	0.01
					0	FL	**12 PM**	338	61	807	0.18	0.08
					0	FL	**3 PM**	216	44	538	0.2	0.08
Equinox : September 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	508	57	3662	0.11	0.02
					0	FL	**12 PM**	264	50	641	0.19	0.08
					0	FL	**3 PM**	160	35	457	0.22	0.08

Outdoor & indoor perspective views for S0 in *Winter Solstice : December 21 st*
Part D - Northeast Façade (north is directed 26° to east)

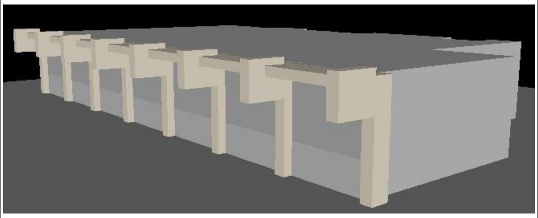
Outdoor Perspective	Indoor Perspective

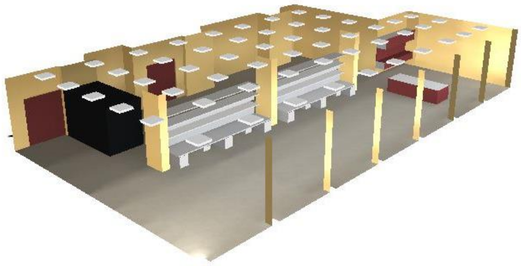
9:00 AM



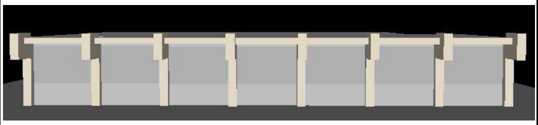


12:00 PM





3:00 PM



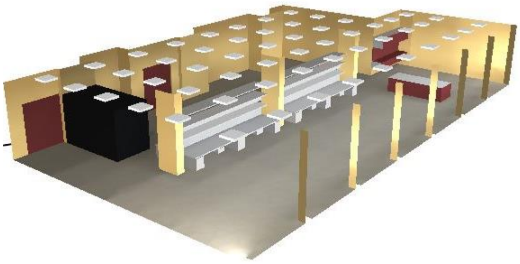


Figure D.1 Part D-Outdoor & indoor perspective views for S0

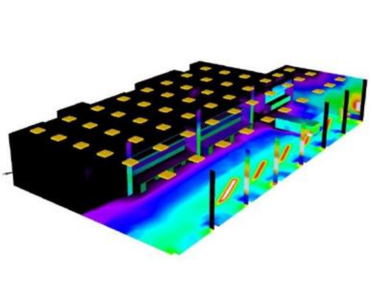
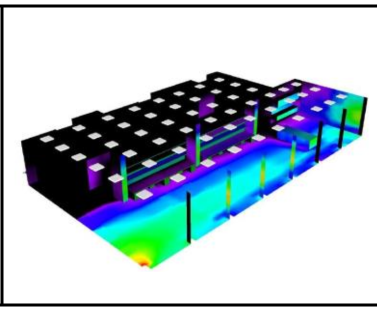
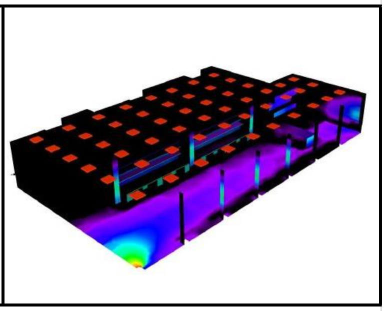
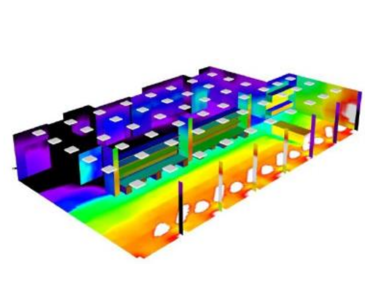
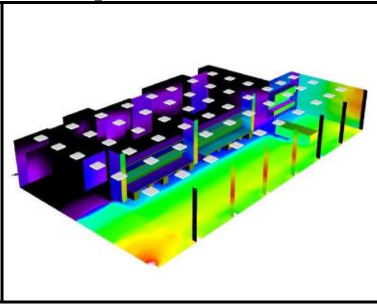
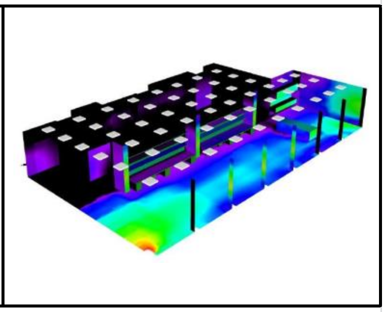
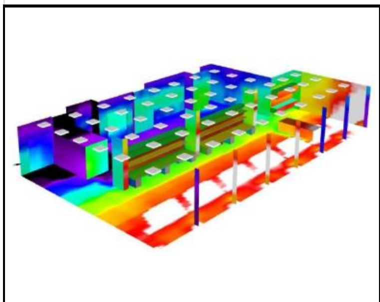
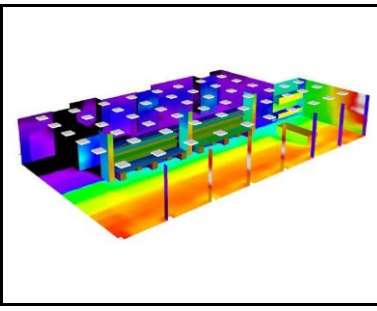
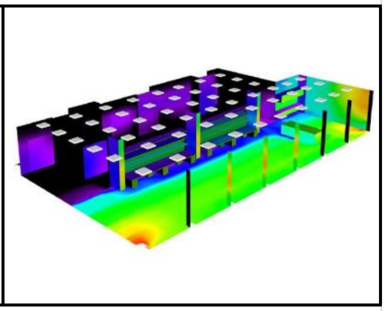
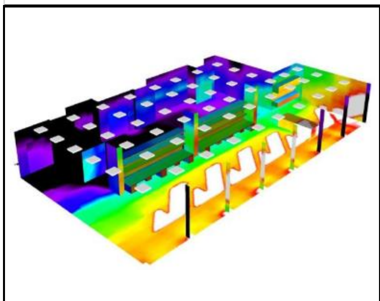
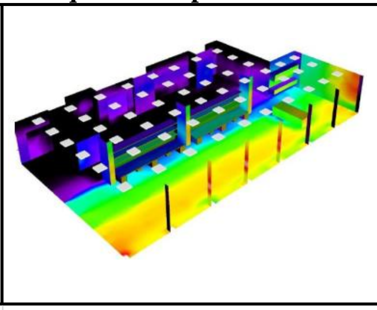
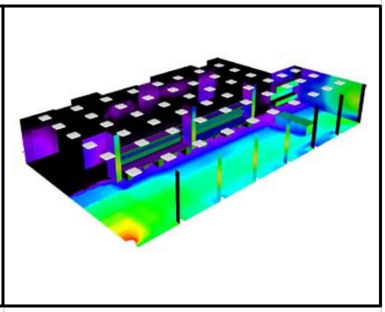
False Color Rendering (in perspective) for S0 Part D - Northeast Façade (north is directed 26° to east)		
9:00 AM	**12:00 PM**	**3:00 PM**
Winter Solstice : December 21st		
		
Equinox : March 21st		
		
Summer Solstice : June 21st		
		
Equinox : September 21st		
		
Iluminance Scale 80 100 150 200 300 450 600 850 1000 ***Lux***		

Figure D.2 Part D-False color rendering (in perspective) for S0

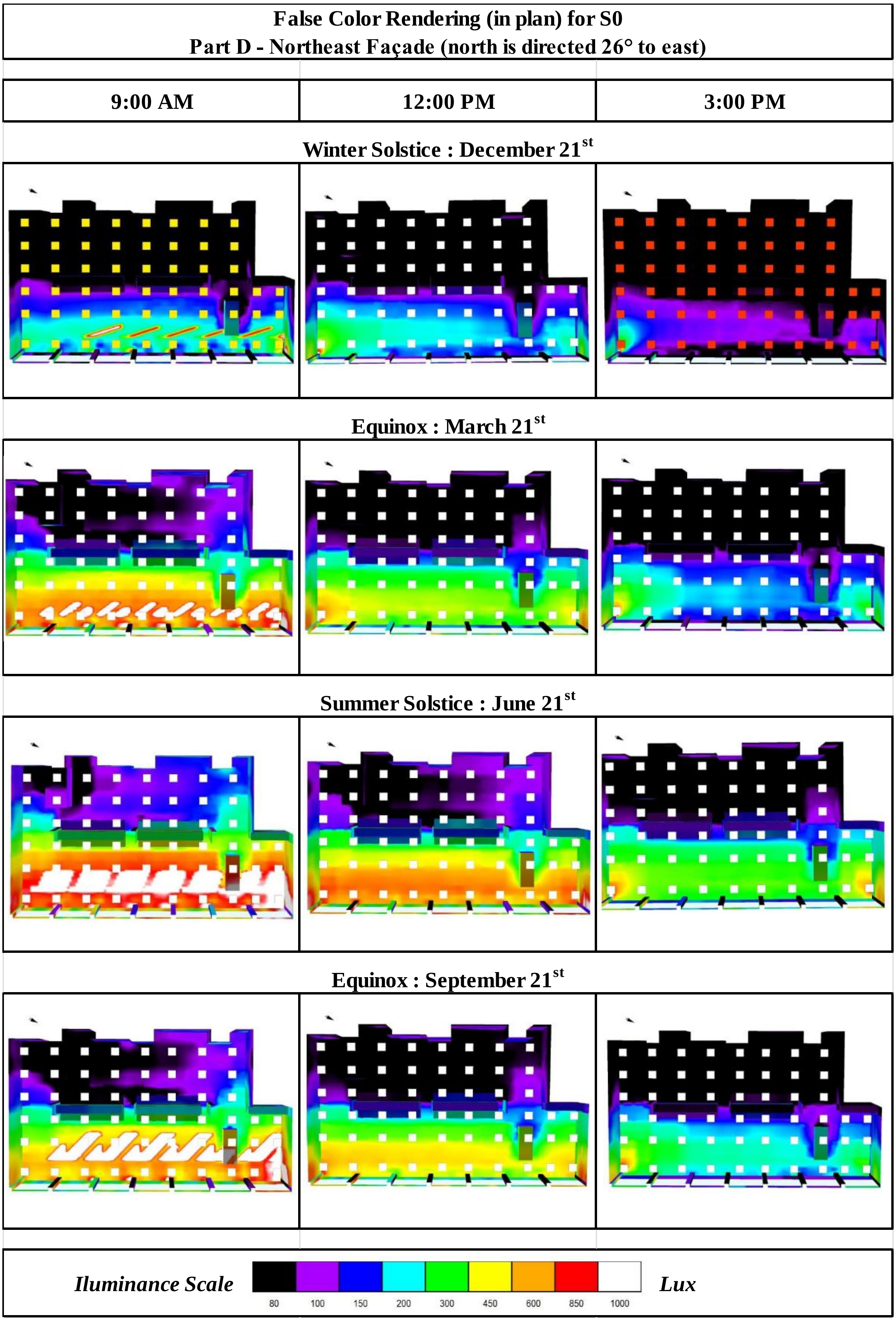


Figure D.3 Part D-False color rendering (in plan) for S0

Table D.2 Part D-Retrofit scenarios (S1-S7)

Retrofit Scenarios (Results taken from DIALux for December 21st)

Part D - Northeast Façade (north is directed 26° to east)

(Room Z64 : h=3.3 m, Area= 268.82 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S1	FT_1 90%	Yes	No	No	2	FL	**9 AM**	644	411	1517	0.64	0.27
					2	FL	**12 PM**	599	319	927	0.53	0.34
					3	FL	**3 PM**	572	398	704	0.70	0.57
	FT_2 70%	Yes	No	No	2	FL	**9 AM**	544	332	1179	0.61	0.28
					3	FL	**12 PM**	651	430	834	0.66	0.52
					4	FL	**3 PM**	624	427	812	0.68	0.53
	FT_3 50%	Yes	No	No	3	FL	**9 AM**	591	402	971	0.68	0.41
					3	FL	**12 PM**	564	401	699	0.71	0.57
					4	FL	**3 PM**	574	411	712	0.72	0.58
SD u=2 l=2 distance 30 cm **S2** **Light Shelf** location 220 cm width 290 cm length 100 cm	FT_1 90%	Yes	SD_2 h	u=0° l=0°	3	FL	**9 AM**	643	423	1009	0.66	0.42
				u=0° l=0°	3	FL	**12 PM**	607	429	765	0.71	0.56
				u=0° l=0°	4	FL	**3 PM**	599	378	841	0.63	0.45
	FT_2 70%	Yes	SD_2 h	u=0° l=0°	3	FL	**9 AM**	577	407	813	0.71	0.50
				u=0° l=0°	3	FL	**12 PM**	549	400	687	0.73	0.58
				u=0° l=0°	4	FL	**3 PM**	565	352	785	0.62	0.45
	FT_3 50%	Yes	SD_2 h	u=0° l=0°	4	FL	**9 AM**	614	412	861	0.67	0.48
				u=0° l=0°	4	FL	**12 PM**	595	416	718	0.70	0.58
				u=0° l=0°	4	FL	**3 PM**	641	455	932	0.71	0.49

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Table D.2 (cont.)

Part D - Northeast Façade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m^2)											
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row** (on) **LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode**											
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux)** E_{avg}	E_{min}	E_{max}	**UNIFORMITY** U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
SD u=2 l=3 distance 30 cm **S3**	FT_1 90%	No	SD_3 h	u=° l=°	0	FL	**9 AM**					
				u=° l=°	0	FL	**12 PM**					
				u=° l=°	0	FL	**3 PM**					
	FT_2 70%	No	SD_3 h	u=0° l=0°	3	FL	**9 AM**	612	412	930	0.67	0.44
				u=0° l=0°	3	FL	**12 PM**	571	412	724	0.72	0.57
				u=0° l=0°	4	FL	**3 PM**	578	359	817	0.62	0.44
	FT_3 50%	No	SD_3 h	u=° l=°	0	FL	**9 AM**					
				u=° l=°	0	FL	**12 PM**					
				u=° l=°	0	FL	**3 PM**					
SD u=4 l=5 distance 20 cm **S4**	FT_1 90%	No	SD_4 h	u=0° l=0°	3	FL	**9 AM**	556	408	740	0.73	0.55
				u=0° l=0°	4	FL	**12 PM**	671	434	979	0.65	0.44
				u=0° l=0°	4	FL	**3 PM**	554	416	686	0.75	0.61
	FT_2 70%	No	SD_4 h	u=0° l=0°	4	FL	**9 AM**	612	416	763	0.68	0.58
				u=0° l=0°	4	FL	**12 PM**	586	417	709	0.71	0.59
				u=0° l=0°	5	FL	**3 PM**	639	458	933	0.72	0.49
	FT_3 50%	No	SD_4 h	u=0° l=0°	4	FL	**9 AM**	568	404	703	0.71	0.58
				u=0° l=0°	5	FL	**12 PM**	656	473	940	0.72	0.50
				u=0° l=0°	5	FL	**3 PM**	616	435	925	0.71	0.47

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Table D.2 (cont.)

Part D - Northeast Façade (north is directed 26° to east)
(Room Z64 : h=3.3 m, Area= 268.82 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S5 SD u=7 l=7, distance 40 cm; Light Shelf location 220 cm, width 290 cm, length 100 cm	FT_1 90%	Yes	SD_5 v	u=0° l=0°	3	FL	**9 AM**	556	405	700	0.73	0.58
				u=0° l=0°	3	FL	**12 PM**	565	399	700	0.71	0.57
				u=0° l=0°	4	FL	**3 PM**	580	421	705	0.73	0.60
	FT_2 70%	Yes	SD_5 v	u=0° l=0°	4	FL	**9 AM**	616	371	910	0.60	0.41
				u=0° l=0°	4	FL	**12 PM**	623	364	916	0.58	0.40
				u=0° l=0°	4	FL	**3 PM**	551	410	676	0.74	0.61
	FT_3 50%	Yes	SD_5 v	u=0° l=0°	5	FL	**9 AM**	719	425	942	0.59	0.45
				u=0° l=0°	4	FL	**12 PM**	615	414	904	0.67	0.46
				u=0° l=0°	5	FL	**3 PM**	630	444	926	0.70	0.48
S6 SD u=7 l=7, distance 40 cm	FT_1 90%	No	SD_6 v	u=0° l=0°	3	FL	**9 AM**	577	413	734	0.72	0.56
				u=0° l=0°	3	FL	**12 PM**	604	419	757	0.69	0.55
				u=0° l=0°	7	FL	**3 PM**	604	425	783	0.70	0.54
	FT_2 70%	No	SD_6 v	u=° l=°	0	FL	**9 AM**					
				u=° l=°	0	FL	**12 PM**					
				u=° l=°	0	FL	**3 PM**					
	FT_3 50%	No	SD_6 v	u=° l=°	0	FL	**9 AM**					
				u=° l=°	0	FL	**12 PM**					
				u=° l=°	0	FL	**3 PM**					

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Table D.2 (cont.)

Part D - Northeast Façade (north is directed 26° to east)
(Room Z64 : h=3.3 m, Area= 268.82 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
SD u=12 l=12 distance 23 cm **S7**	FT_1 90%	No	SD_7 v	u=0° l=0°	4	FL	**9 AM**	658	418	936	0.64	0.45
				u=0° l=0°	4	FL	**12 PM**	664	423	934	0.64	0.45
				u=0° l=0°	4	FL	**3 PM**	552	399	679	0.72	0.59
	FT_2 70%	No	SD_7 v	u=0° l=0°	4	FL	**9 AM**	622	408	909	0.66	0.45
				u=0° l=0°	4	FL	**12 PM**	627	411	904	0.66	0.46
				u=0° l=0°	5	FL	**3 PM**	636	448	927	0.70	0.48
	FT_3 50%	No	SD_7 v	u=0° l=0°	5	FL	**9 AM**	650	455	929	0.70	0.49
				u=0° l=0°	4	FL	**12 PM**	589	374	874	0.63	0.43
				u=0° l=0°	5	FL	**3 PM**	636	448	927	0.70	0.48

Table D.3 Part D-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of illuminance & uniformity

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Illuminance & Uniformity (Results taken from DIALux for December 21st)

Part D - Northeast Façade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S4	FT_1 90%	No	SD_4 h	u=0° l=0°	3	FL	**9 AM**	556	408	740	0.73	0.55
				u=0° l=0°	4	FL	**12 PM**	671	434	979	0.65	0.44
				u=0° l=0°	4	FL	**3 PM**	554	416	686	0.75	0.61
S8	FT_1 90%	No	SD_4 h	u=0° l=0°	3	LED	**9 AM**	496	311	645	0.63	0.48
				u=0° l=0°	4	LED	**12 PM**	583	359	802	0.62	0.45
				u=0° l=0°	5	LED	**3 PM**	484	327	577	0.68	0.57
S7	FT_3 50%	No	SD_7 v	u=0° l=0°	5	FL	**9 AM**	650	455	929	0.70	0.49
				u=0° l=0°	4	FL	**12 PM**	589	374	874	0.63	0.43
				u=0° l=0°	5	FL	**3 PM**	636	448	927	0.70	0.48
S9	FT_3 50%	No	SD_7 v	u=0° l=0°	5	LED	**9 AM**	555	399	732	0.72	0.54
				u=0° l=0°	4	LED	**12 PM**	501	311	665	0.62	0.47
				u=0° l=0°	5	LED	**3 PM**	520	373	723	0.72	0.52

Table D.4 Part D-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of energy consumption

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Energy Consumption (Results taken from DIALux for December 21st)

Part D - Northeast Façade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m²)

FT: Fenestration Transmittance
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical** **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
LT: Lighting Fixture Type;
FL : Fluorescent **Luminous Flux: 3834 lm; Power=70 W**
LED : Light Emitting Diode **Luminous Flux: 3400 lm; Power=41 W**
LENI: Lighting Energy Numeric Indicator; kWh/(a.m²)

Scenario	FT	SD Type	SD Angle	LL n	LT	Hour	ENERGY CONSUMPTION Time h	Floor Area %	Energy Wh	kWh/a a:300 d	LENI
S4	FT_1 90%	SD_4 h	u=0° l=0°	3	FL	**9 AM**	3	48.1	5460	6174.0	23.0
			u=0° l=0°	4	FL	**12 PM**	3	66.7	7560		
			u=0° l=0°	4	FL	**3 PM**	3	66.7	7560		
S8	FT_1 90%	SD_4 h	u=0° l=0°	3	LED	**9 AM**	3	48.1	3198	3616.2	13.5
			u=0° l=0°	4	LED	**12 PM**	3	66.7	4428		
			u=0° l=0°	4	LED	**3 PM**	3	66.7	4428		
S7	FT_3 50%	SD_7 v	u=0° l=0°	5	FL	**9 AM**	3	81.5	9240	7938.0	29.5
			u=0° l=0°	4	FL	**12 PM**	3	70.4	7980		
			u=0° l=0°	5	FL	**3 PM**	3	81.5	9240		
S9	FT_3 50%	SD_7 v	u=0° l=0°	5	LED	**9 AM**	3	81.5	5412	4649.4	17.3
			u=0° l=0°	4	LED	**12 PM**	3	70.4	4674		
			u=0° l=0°	5	LED	**3 PM**	3	81.5	5412		

Table D.5 Part D-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the horizontal shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Horizontal Shading Devices (S4-FT1) (Results taken from DIALux)								
Part D - Southeast Façade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m²)								
SD: Shading Device (length=25cm); **LL: Lighting Fixture Layout;** **Angle u: upper l: lower** **n: Number of Lighting Row** (on)								
Hour	**W/S Solstices & Equinoxes**	**SD Angle**	**LL n**	**ILLUMINANCE (Lux)**			**UNIFORMITY**	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	**December 21st**	u=0° l=0°	3	556	408	740	0.73	0.55
	March 21st			937	509	1456	0.54	0.35
	June 21st			1158	579	1913	0.50	0.30
	September 21st			1073	500	9456	0.47	0.05
12 PM	**December 21st**	u=0° l=0°	4	671	434	979	0.65	0.44
	March 21st			761	466	1105	0.61	0.42
	June 21st			996	522	1371	0.52	0.38
	September 21st			806	472	1149	0.59	0.41
3 PM	**December 21st**	u=0° l=0°	4	554	416	686	0.75	0.61
	March 21st			631	439	783	0.70	0.56
	June 21st			693	459	834	0.66	0.55
	September 21st			652	442	795	0.69	0.56

Table D.6 Part D-Retrofitting the results for the horizontal shading devices by using the fixed panels at W/S S&E

Retrofitting the Results for the Horizontal Shading Devices by Using the Fixed Panels at W/S S&E (S4-FT1) (Results taken from DIALux)

Part D - Southeast Façade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m^2)

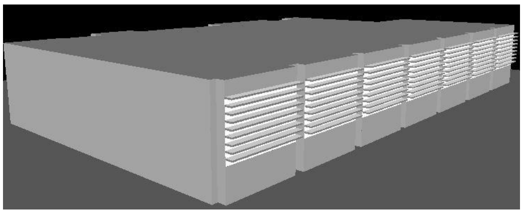
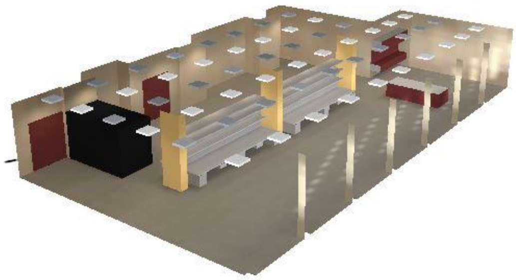
SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	556	408	740	0.73	0.55
	March 21st	u=45° l=45°	3	620	447	757	0.72	0.59
	June 21st	u=45° l=60°	3	630	453	765	0.72	0.59
	September 21st	u=15° l=45°	3	636	443	776	0.70	0.57
12 PM	December 21st	u=0° l=0°	4	671	434	979	0.65	0.44
	March 21st	u=0° l=0°	3	618	457	834	0.74	0.55
	June 21st	u=0° l=60°	3	650	436	809	0.67	0.54
	September 21st	u=45° l=0°	3	617	444	797	0.72	0.59
3 PM	December 21st	u=0° l=0°	4	554	416	686	0.75	0.61
	March 21st			631	439	783	0.70	0.56
	June 21st			693	459	834	0.66	0.55
	September 21st			652	442	795	0.69	0.56

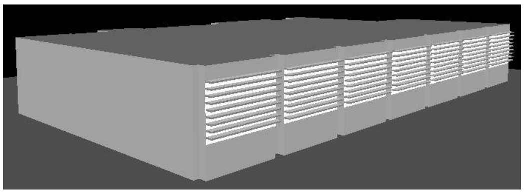
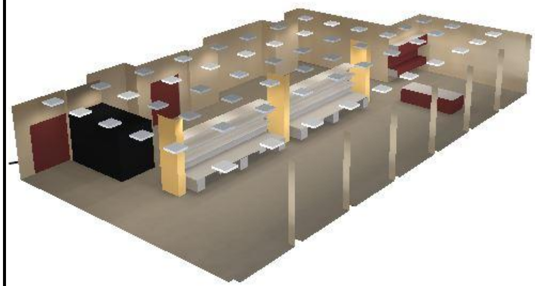
Outdoor & indoor perspective views for S8 in *Winter Solstice : December 21 st*
Part D - Northeast Façade (north is directed 26° to east)

Outdoor Perspective	Indoor Perspective

9:00 AM

12:00 PM

3:00 PM

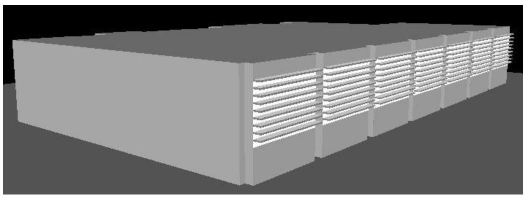
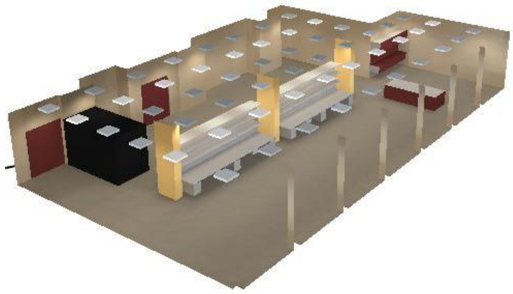



Figure D.4 Part D-Outdoor & indoor perspective views for retrofitted S8

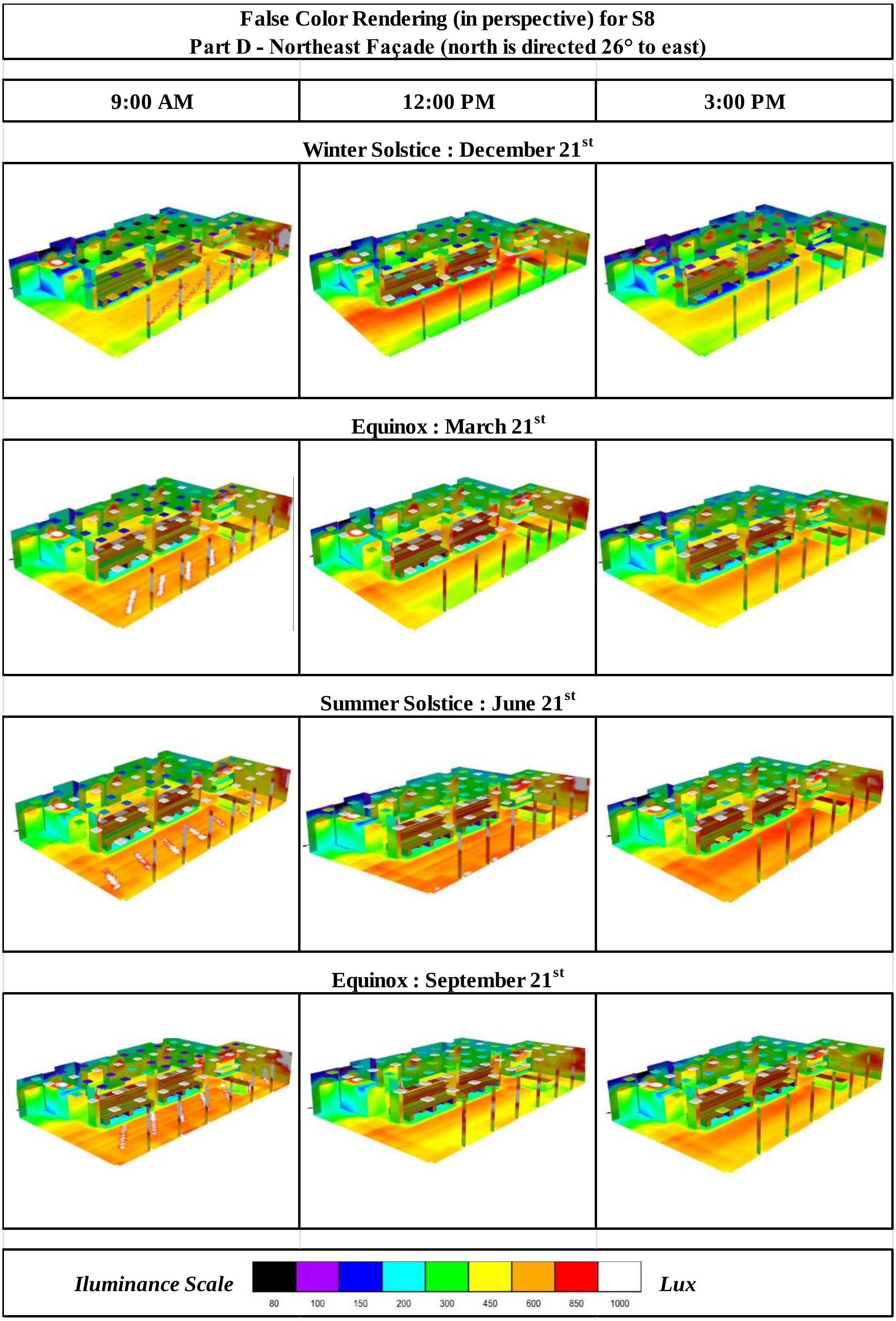


Figure D.5 Part D-False color rendering (in perspective) for retrofitted S8

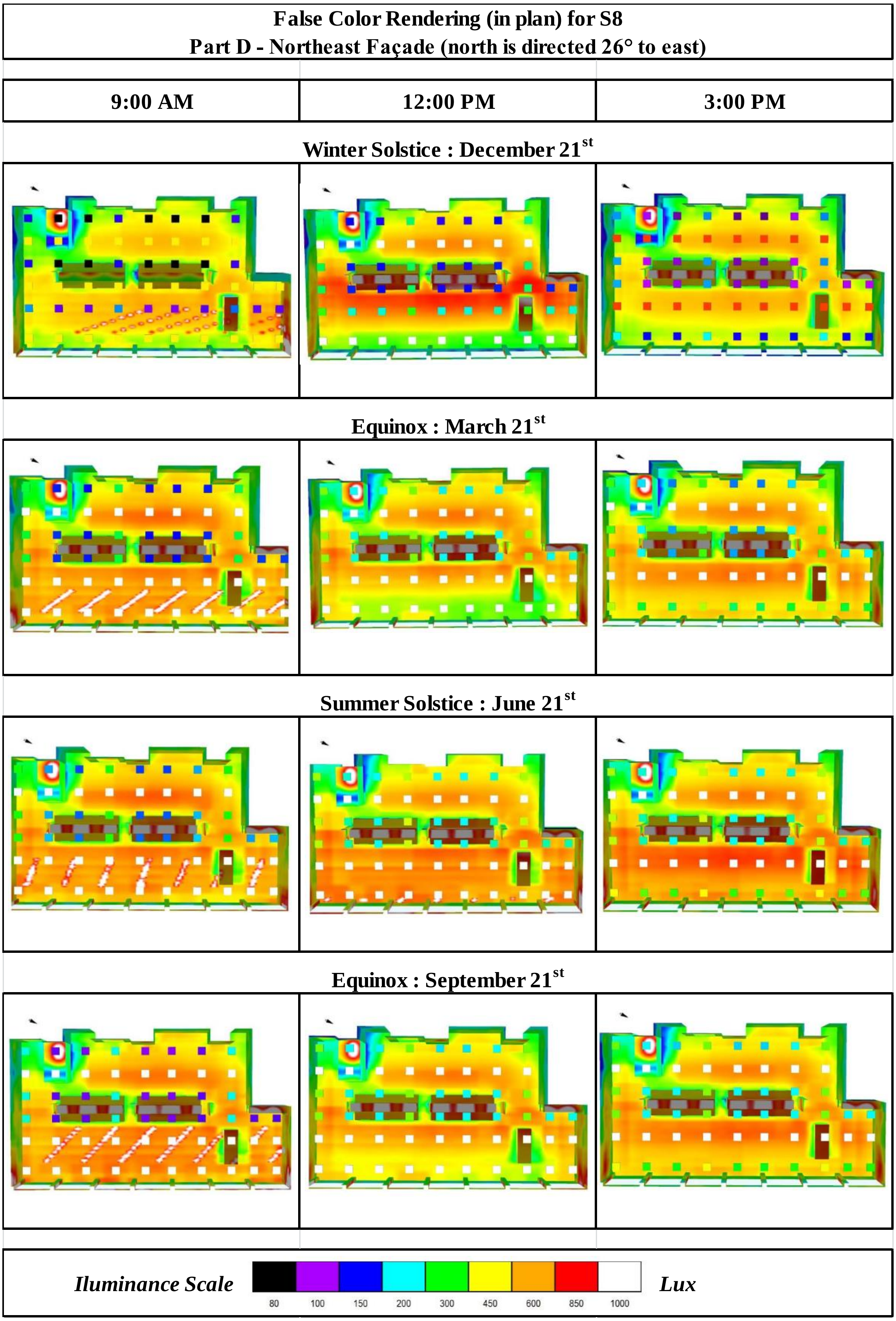


Figure D.6 Part D-False color rendering (in plan) for retrofitted S8

Table D.7 Part D-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the vertical shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Vertical Shading Devices (S7-FT3) (Results taken from DIALux)								
Part D - Southeast Façade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m^2)								
SD: Shading Device (length=25cm); LL: Lighting Fixture Layout; Angle u: upper l: lower; n: Number of Lighting Row (on)								
Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	5	650	455	929	0.70	0.49
	March 21st			828	571	1132	0.69	0.50
	June 21st			1820	701	11930	0.39	0.06
	September 21st			995	586	5503	0.59	0.11
12 PM	December 21st	u=0° l=0°	4	589	374	874	0.63	0.43
	March 21st			662	417	932	0.63	0.45
	June 21st			778	449	1055	0.58	0.43
	September 21st			695	424	960	0.61	0.44
3 PM	December 21st	u=0° l=0°	5	636	448	927	0.70	0.48
	March 21st			656	462	934	0.70	0.49
	June 21st			705	499	947	0.71	0.53
	September 21st			669	472	940	0.71	0.50

Table D.8 Part D-Retrofitting the results for the vertical shading devices by using the Fixed panels at W/S S&E

Retrofitting the Results for the Vertical Shading Devices at W/S S&E (S7-FT3) (Results taken from DIALux)								
Part D - Southeast Façade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m^2)								
SD: Shading Device (length=25cm); Angle u: upper l: lower LL: Lighting Fixture Layout; n: Number of Lighting Row (on) Panel length: 25 cm Vertical; height: window height, location: head of each side of window Horizontal; width: window width, location: top of window								
Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	5	650	455	929	0.70	0.49
	March 21st		3	624	429	768	0.69	0.56
	June 21st	u=45° l=75°	4	682	467	930	0.69	0.50
	September 21st	u=45° l=75°	5	611	409	922	0.67	0.44
12 PM	December 21st	u=0° l=0°	4	589	374	874	0.63	0.43
	March 21st		4	614	415	830	0.68	0.50
	June 21st		3	632	438	780	0.69	0.56
	September 21st		3	551	415	709	0.75	0.59
3 PM	December 21st	u=0° l=0°	5	636	448	927	0.70	0.48
	March 21st		5	656	462	934	0.70	0.49
	June 21st		4	596	411	768	0.69	0.54
	September 21st		4	562	405	684	0.72	0.59

Outdoor & indoor perspective views for S9 in *Winter Solstice : December 21 st*
Part D - Northeast Façade (north is directed 26° to east)

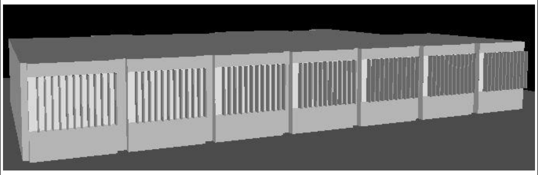
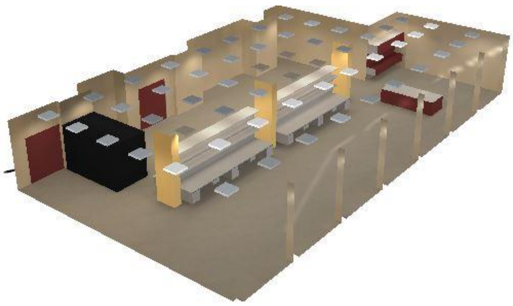
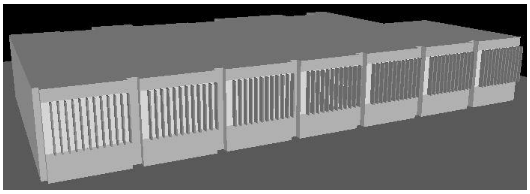
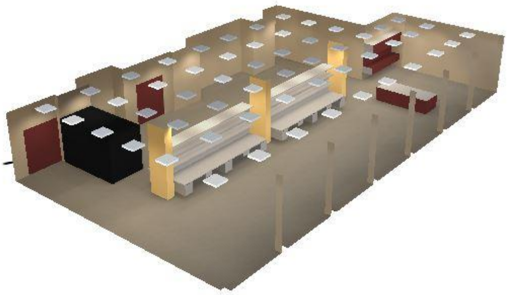
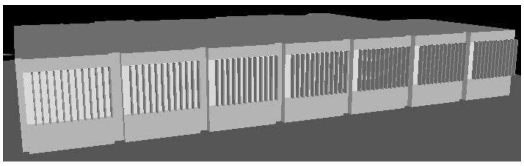
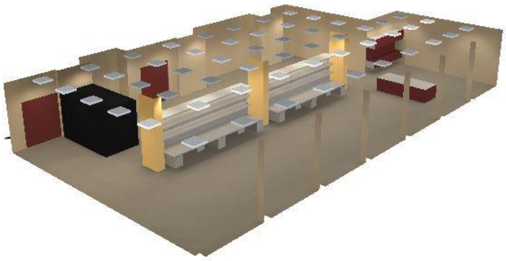
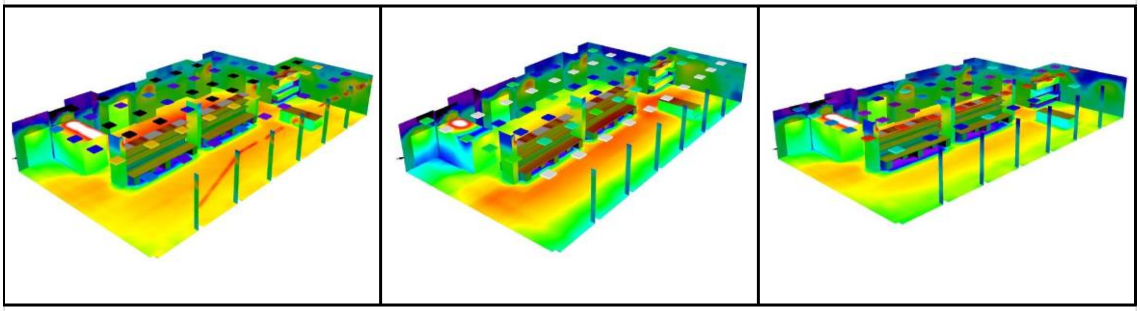
Outdoor Perspective	Indoor Perspective
9:00 AM	
	
12:00 PM	
	
3:00 PM	
	

Figure D.7 Part D-Outdoor & indoor perspective views for retrofitted S9

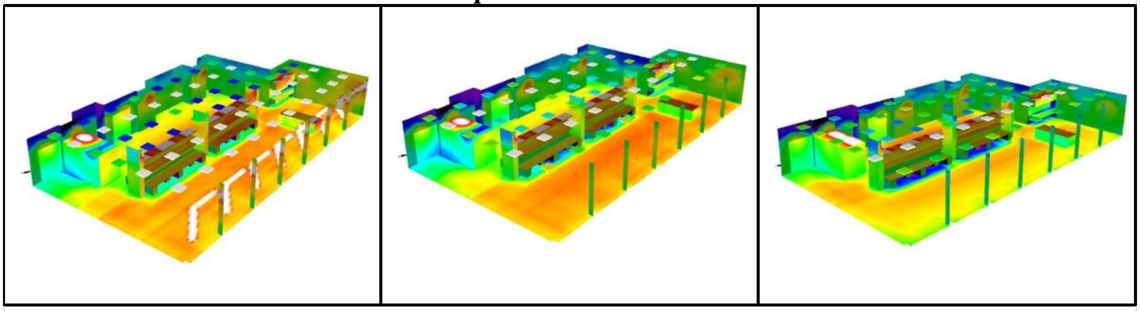
False Color Rendering (in perspective) for S9
Part D - Northeast Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM

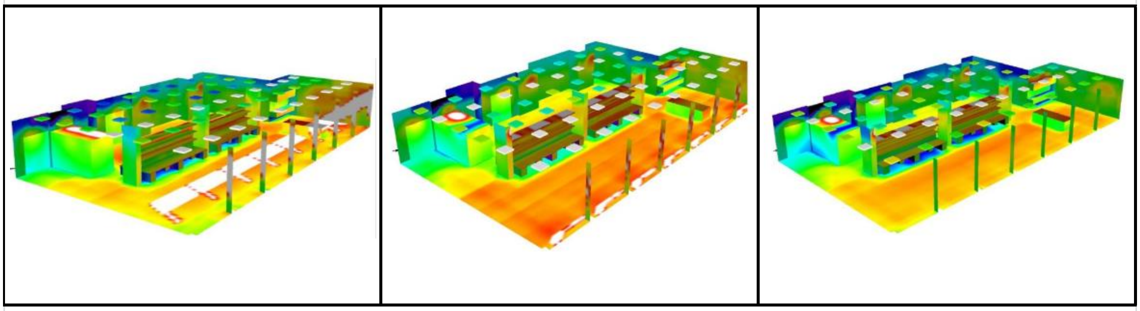
Winter Solstice : December 21st



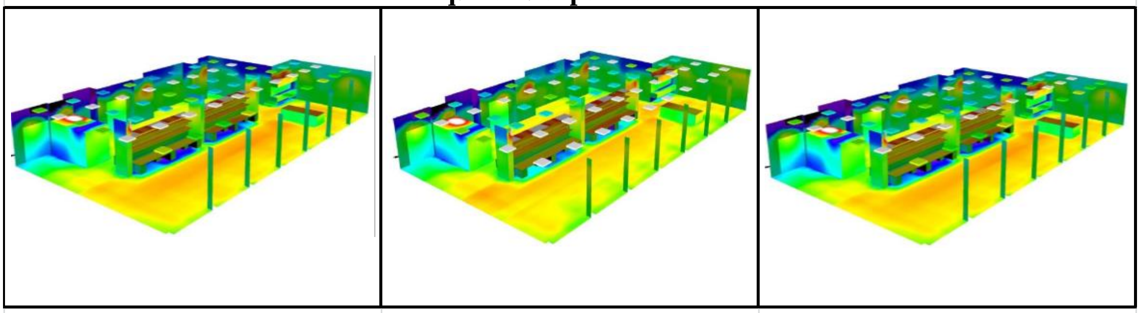
Equinox : March 21st



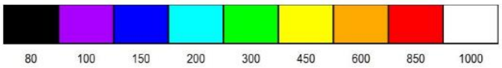
Summer Solstice : June 21st



Equinox : September 21st



Iluminance Scale



Lux

Figure D.8 Part D-False color rendering (in perspective) for retrofitted S9

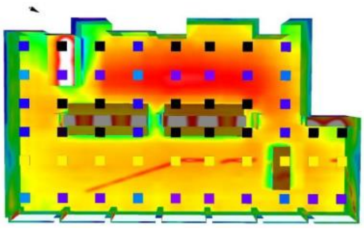
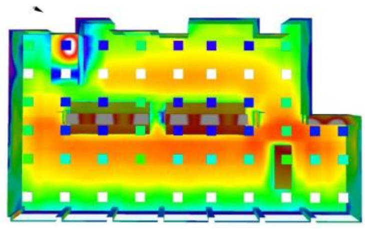
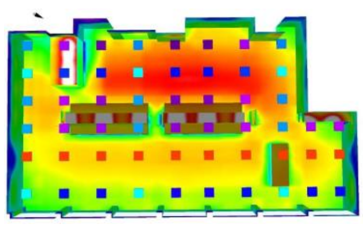
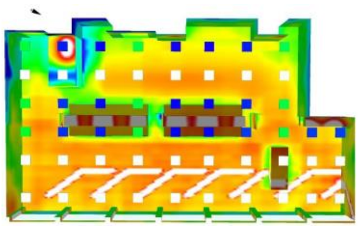
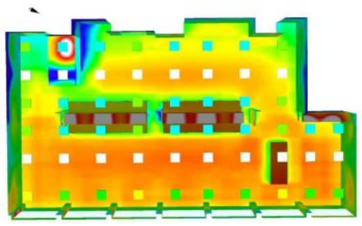
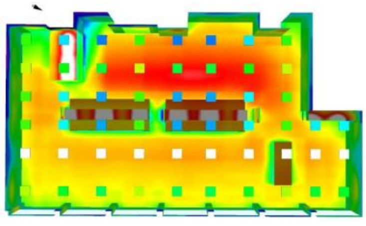
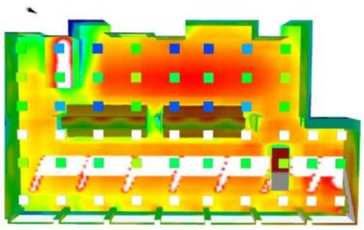
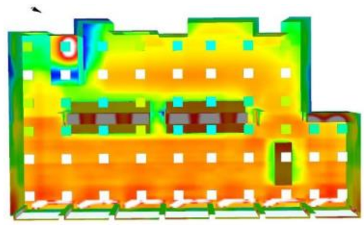
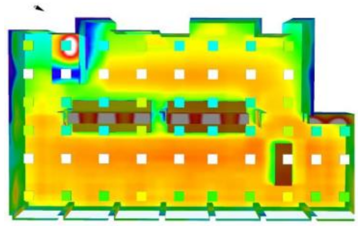
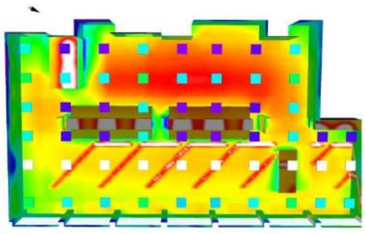
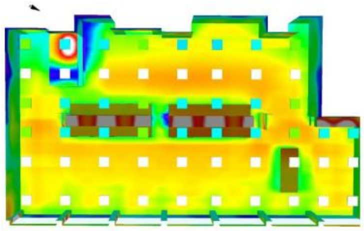
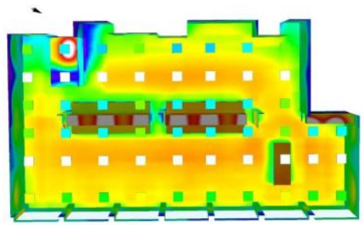
False Color Rendering (in plan) for S9 Part D - Northeast Façade (north is directed 26° to east)		
9:00 AM	**12:00 PM**	**3:00 PM**
Winter Solstice : December 21st		
		
Equinox : March 21st		
		
Summer Solstice : June 21st		
		
Equinox : September 21st		
		
Iluminance Scale  ***Lux***		

Figure D.9 Part D-False color rendering (in plan) for retrofitted S9

Table D.9 Part D-Comparison of lighting fixture type energy consumption for optimum results of the horizontal shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Horizontal Shading Devices										
Part D - Northeast Facade (north is directed 26° to east) (Room Z64 : h=3.3 m, Area= 268.82 m^2)										
SD: Shading Device; Type : horizontal; upper: 4 lower: 5 LL: Lighting Fixture Layout; n: Number of Lighting Row (on) LT: Lighting Fixture Type; FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day										
W/S Solstices & Equinoxes	Hour	ENERGY CONSUMPTION								
		LL	Time h	Floor Area %	S4-FT1 with FL			S8 with LED		
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI
December 21st	9 AM	3	3	48.1	5460	1543.5	5.7	3198	904.1	3.4
	12 PM	4	3	66.7	7560			4428		
	3 PM	4	3	66.7	7560			4428		
March 21st	9 AM	3	3	48.1	5460	1386.0	5.2	3198	811.8	3.0
	12 PM	3	3	48.1	5460			3198		
	3 PM	4	3	66.7	7560			4428		
June 21st	9 AM	3	3	48.1	5460	1386.0	5.2	3198	811.8	3.0
	12 PM	3	3	48.1	5460			3198		
	3 PM	4	3	66.7	7560			4428		
September 21st	9 AM	3	3	48.1	5460	1386.0	5.2	3198	811.8	3.0
	12 PM	3	3	48.1	5460			3198		
	3 PM	4	3	66.7	7560			4428		
Annual Energy Consumption					FL	5701.5	21.2	LED	3339.5	12.4

Table D.10 Part D-Comparison of lighting fixture type energy consumption for optimum results of the vertical shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Vertical Shading Devices

Part D - Northeast Facade (north is directed 26° to east)
(Room Z64 : h=3.3 m, Area= 268.82 m^2)

SD: Shading Device; Type : vertical;
upper: 12 lower: 12
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

W/S Solstices & Equinoxes	Hour	ENERGY CONSUMPTION								
		LL	Time h	Floor Area %	S7-FT3 with FL			S9 with LED		
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI
December 21st	9 AM	5	3	81.5	9240	1953.0	7.3	5412	1143.9	4.3
	12 PM	4	3	66.7	7560			4428		
	3 PM	5	3	81.5	9240			5412		
March 21st	9 AM	3	3	48.1	5460	1669.5	6.2	3198	977.9	3.6
	12 PM	4	3	66.7	7560			4428		
	3 PM	5	3	81.5	9240			5412		
June 21st	9 AM	4	3	66.7	7560	1543.5	5.7	4428	904.1	3.4
	12 PM	3	3	48.1	5460			3198		
	3 PM	4	3	66.7	7560			4428		
September 21st	9 AM	5	3	81.5	9240	1669.5	6.2	5412	977.9	3.6
	12 PM	3	3	48.1	5460			3198		
	3 PM	4	3	66.7	7560			4428		
Annual Energy Consumption					**FL**	**6835.5**	**25.4**	**LED**	**4003.7**	**14.9**

APPENDIX E. SIMULATION RESULTS FOR PART E

Table E.1 Part E-Base case results (S0 for W/S S&E)

Base Case Results (Results taken from DIALux)

Part E - Southwest Façade (north is directed 26° to east)
(Room Z17 : h=2.60 m, Area= 19.70 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 80%
SC: Surface Color = 68%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
Winter Solstice : December 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	56	17	103	0.3	0.16
					0	FL	**12 PM**	167	42	325	0.25	0.13
					0	FL	**3 PM**	145	40	263	0.28	0.15
Equinox : March 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	127	40	239	0.31	0.17
					0	FL	**12 PM**	196	56	349	0.29	0.16
					0	FL	**3 PM**	213	58	398	0.27	0.15
Summer Solstice : June 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	142	47	267	0.33	0.18
					0	FL	**12 PM**	173	50	308	0.29	0.16
					0	FL	**3 PM**	207	53	389	0.26	0.14
Equinox : September 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	106	32	203	0.31	0.16
					0	FL	**12 PM**	153	43	272	0.28	0.16
					0	FL	**3 PM**	209	56	399	0.27	0.14

Outdoor & indoor perspective views for S0 in *Winter Solstice : December 21st*
Part E - Southwest Façade (north is directed 26° to east)

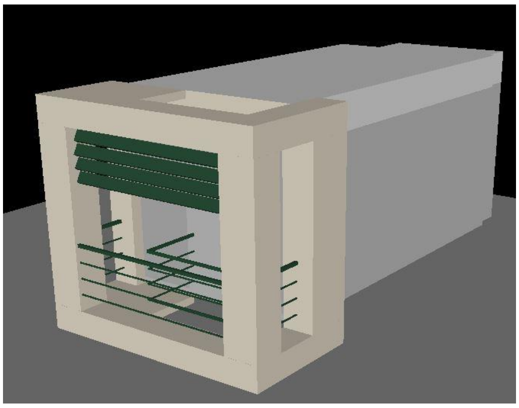
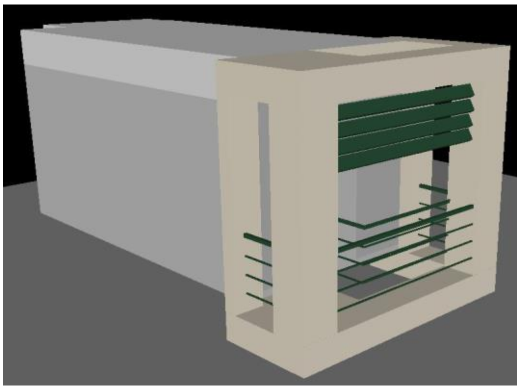
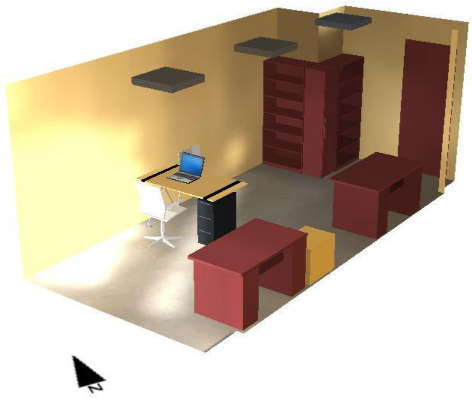
Outdoor Perspective	Indoor Perspective
9:00 AM	
	
12:00 PM	
	
3:00 PM	
	

Figure E.1 Part E-Outdoor & indoor perspective views for S0

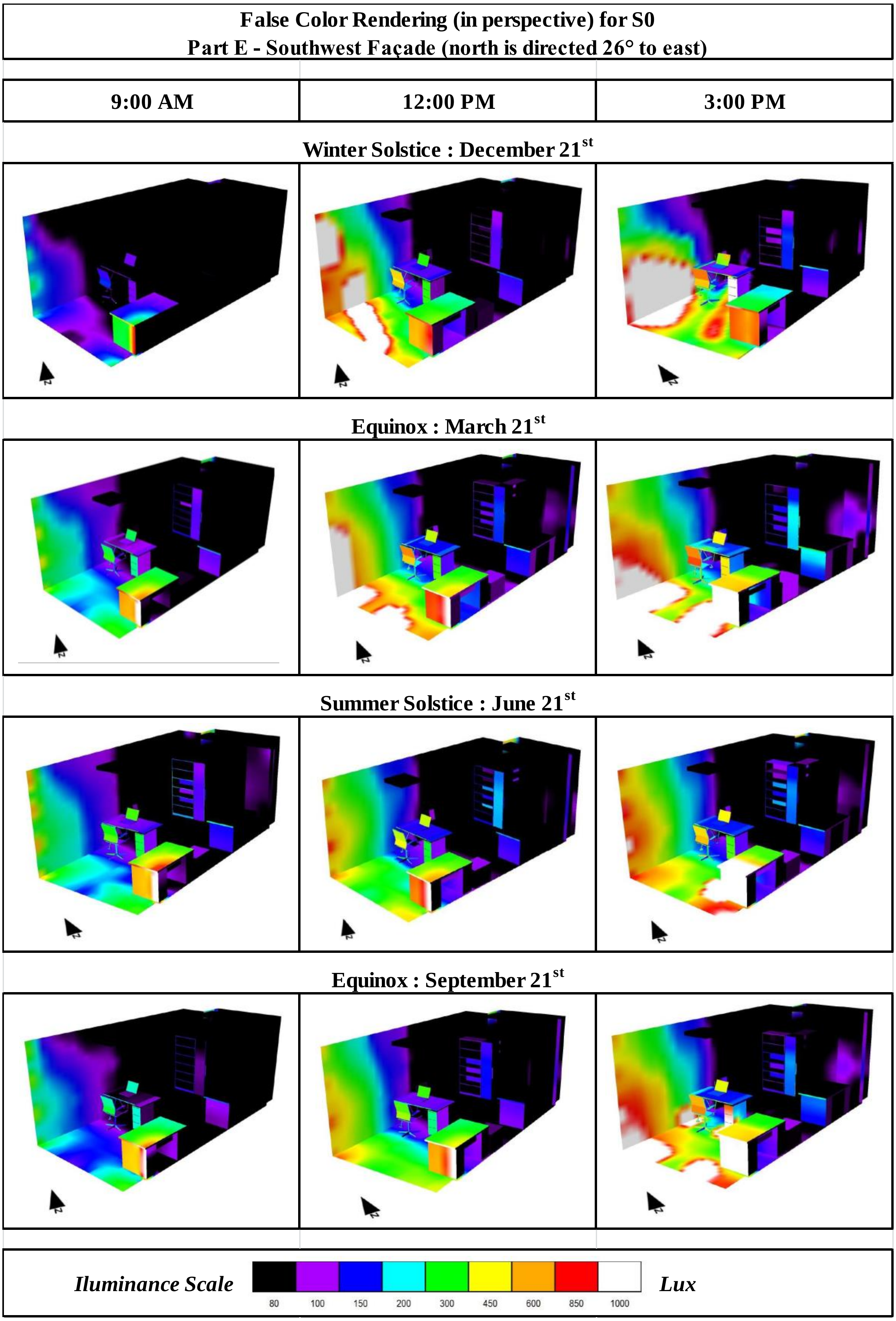
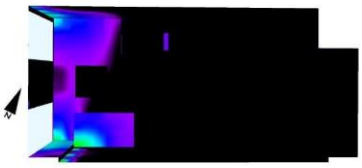
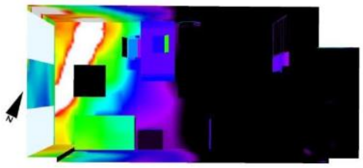
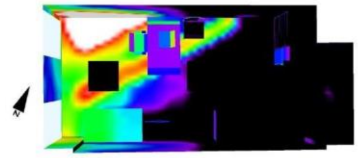
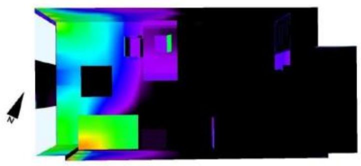
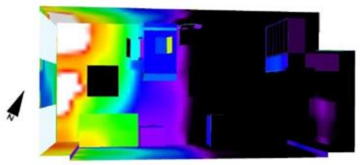
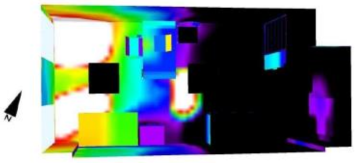
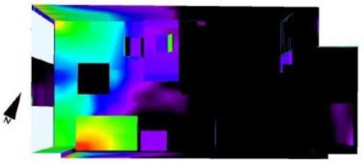
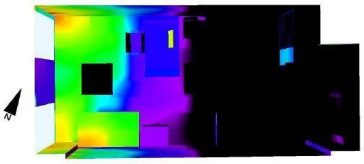
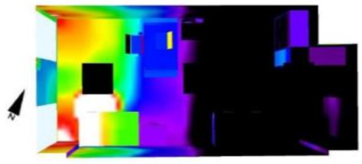
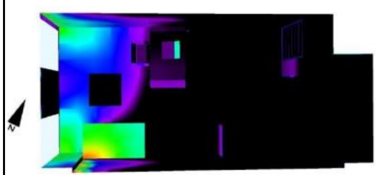
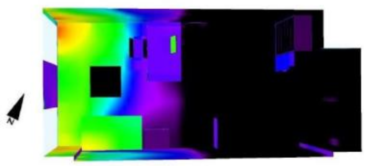
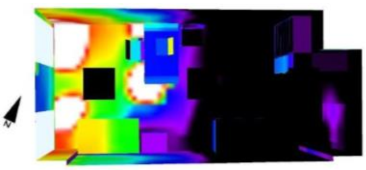


Figure E.2 Part E-False color rendering (in perspective) for S0

False Color Rendering (in plan) for S0
Part E - Southwest Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM
Winter Solstice : December 21st		
		
Equinox : March 21st		
		
Summer Solstice : June 21st		
		
Equinox : September 21st		
		

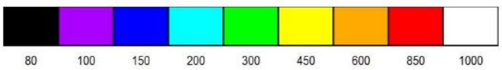
Iluminance Scale  ***Lux***

Figure E.3 Part E-False color rendering (in plan) for S0

Table E.2 Part E-Retrofit scenarios (S1-S7)

Retrofit Scenarios (Results taken from DIALux for December 21st)

Part E - Southwest Façade (north is directed 26° to east)

(Room Z17 : h=2.60 m, Area= 19.70 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S1	FT_1 90%	Yes	No	No	2	FL	**9 AM**	555	513	609	0.92	0.84
					0	FL	**12 PM**	1239	334	2357	0.27	0.14
					0	FL	**3 PM**	3115	483	6364	0.16	0.08
	FT_2 70%	Yes	No	No	2	FL	**9 AM**	495	415	568	0.84	0.73
					0	FL	**12 PM**	962	261	1827	0.27	0.14
					0	FL	**3 PM**	2417	372	4942	0.15	0.08
	FT_3 50%	Yes	No	No	2	FL	**9 AM**	436	320	528	0.73	0.61
					0	FL	**12 PM**	683	187	1299	0.27	0.14
					0	FL	**3 PM**	1724	267	3527	0.15	0.08
SD u=2 l=5 distance 30 cm	FT_1 90%	Yes	SD_2 h	u=0° l=0°	2	FL	**9 AM**	464	352	558	0.76	0.53
				u=90° l=90°	2	FL	**12 PM**	568	510	609	0.90	0.84
				u=90° l=90°	0	FL	**3 PM**	1215	140	4548	0.12	0.03
S2	FT_2 70%	Yes	SD_2 h	u=0° l=0°	2	FL	**9 AM**	426	293	530	0.69	0.55
				u=90° l=90°	2	FL	**12 PM**	507	420	570	0.83	0.74
				u=90° l=90°	0	FL	**3 PM**	944	109	3536	0.12	0.03
Light Shelf location 220 cm width 290 cm length 100 cm	FT_3 50%	Yes	SD_2 h	u=90° l=90°	3	FL	**9 AM**	508	456	535	0.90	0.85
				u=90° l=90°	2	FL	**12 PM**	449	329	536	0.73	0.61
				u=90° l=90°	0	FL	**3 PM**	675	79	2528	0.12	0.03

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Table E.2 (cont.)

Part E - Southwest Façade (north is directed 26° to east) (Room Z17 : h=2.60 m, Area= 19.70 m^2)												
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row** (on) **LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode**												
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux) E_{avg}**	**E_{min}**	**E_{max}**	**UNIFORMITY U_1 E_{min}/E_{avg}**	**U_2 E_{min}/E_{max}**
SD u=2 l=6 distance 30 cm **S3**	FT_1 90%	No	SD_3 h	u=0° l=0°	0	FL	**9 AM**					
				u=0° l=0°	0	FL	**12 PM**					
				u=0° l=0°	0	FL	**3 PM**					
	FT_2 70%	No	SD_3 h	u=0° l=0°	0	FL	**9 AM**					
				u=0° l=0°	0	FL	**12 PM**					
				u=0° l=0°	0	FL	**3 PM**					
	FT_3 50%	No	SD_3 h	u=90° l=90°	3	FL	**9 AM**	494	452	526	0.92	0.86
				u=60° l=60°	2	FL	**12 PM**	457	336	546	0.73	0.62
				u=90° l=60°	2	FL	**3 PM**	473	328	574	0.69	0.57
SD u=4 l=9 distance 20 cm **S4**	FT_1 90%	No	SD_4 h	u=0° l=75°	3	FL	**9 AM**	517	465	543	0.90	0.86
				u=45° l=60°	2	FL	**12 PM**	466	388	535	0.83	0.73
				u=45° l=60°	2	FL	**3 PM**	451	349	534	0.77	0.65
	FT_2 70%	No	SD_4 h	u=60° l=60°	3	FL	**9 AM**	499	452	526	0.91	0.86
				u=75° l=45°	2	FL	**12 PM**	431	320	524	0.74	0.61
				u=45° l=45°	2	FL	**3 PM**	455	362	534	0.79	0.68
	FT_3 50%	No	SD_4 h	u=60° l=60°	3	FL	**9 AM**	492	450	522	0.91	0.86
				u=30° l=30°	2	FL	**12 PM**	481	400	555	0.83	0.72
				u=30° l=30°	2	FL	**3 PM**	465	377	541	0.81	0.70

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Table E.2 (cont.)

Part E - Southwest Façade (north is directed 26° to east) (Room Z17 : h=2.60 m, Area= 19.70 m^2)												
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row** (on) **LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode**												
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux) E_{avg}**	**E_{min}**	**E_{max}**	**UNIFORMITY U_1 E_{min}/E_{avg}**	**U_2 E_{min}/E_{max}**
SD u=2 l=2 distance 40 cm **S5** **Light Shelf** location 220 cm width 290 cm length 100 cm	FT_1 90%	Yes	SD_5 v	u=0° l=0°	2	FL	**9 AM**	458	343	551	0.75	0.62
				u=90° l=90°	0	FL	**12 PM**	508	142	923	0.28	0.15
				u=90° l=90°	0	FL	**3 PM**	615	216	1014	0.35	0.21
	FT_2 70%	Yes	SD_5 v	u=0° l=0°	2	FL	**9 AM**	421	286	524	0.68	0.55
				u=90° l=90°	0	FL	**12 PM**	394	111	715	0.28	0.16
				u=90° l=90°	0	FL	**3 PM**	476	167	786	0.35	0.21
	FT_3 50%	Yes	SD_5 v	u=90° l=90°	3	FL	**9 AM**	536	464	558	0.87	0.83
				u=90° l=90°	2	FL	**12 PM**	571	508	606	0.89	0.84
				u=90° l=90°	1	FL	**3 PM**	444	327	569	0.74	0.58
SD u=2 l=2 distance 40 cm **S6**	FT_1 90%	No	SD_6 v	u=0° l=0°	0	FL	**9 AM**					
				u=0° l=0°	0	FL	**12 PM**					
				u=0° l=0°	0	FL	**3 PM**					
	FT_2 70%	No	SD_6 v	u=0° l=0°	0	FL	**9 AM**					
				u=0° l=0°	0	FL	**12 PM**					
				u=0° l=0°	0	FL	**3 PM**					
	FT_3 50%	No	SD_6 v	u=90° l=90°	3	FL	**9 AM**	541	464	570	0.86	0.82
				u=90° l=90°	2	FL	**12 PM**	587	512	634	0.87	0.81
				u=90° l=90°	1	FL	**3 PM**	490	356	664	0.73	0.54

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Table E.2 (cont.)

Part E - Southwest Façade (north is directed 26° to east) (Room Z17 : h=2.60 m, Area= 19.70 m^2)												
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row** (on) **LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode**												
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux)** E_{avg}	E_{min}	E_{max}	**UNIFORMITY** U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
SD u=4 l=4 distance 23 cm **S7**	FT_1 90%	No	SD_7 v	u=60° l=60°	3	FL	**9 AM**	519	459	540	0.88	0.85
				u=15° l=15°	1	FL	**12 PM**	420	286	548	0.68	0.52
				u=30° l=30°	1	FL	**3 PM**	447	303	566	0.68	0.73
	FT_2 70%	No	SD_7 v	u=60° l=60°	3	FL	**9 AM**	509	455	533	0.89	0.85
				u=45° l=30°	2	FL	**12 PM**	465	380	539	0.82	0.71
				u=15° l=30°	1	FL	**3 PM**	406	299	487	0.74	0.61
	FT_3 50%	No	SD_7 v	u=0° l=0°	3	FL	**9 AM**	537	468	563	0.87	0.83
				u=45° l=0°	2	FL	**12 PM**	454	357	538	0.79	0.66
				u=0° l=15°	1	FL	**3 PM**	404	286	518	0.71	0.55

Table E.3 Part E-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of illuminance & uniformity

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Illuminance & Uniformity (Results taken from DIALux for December 21st)

Part E - Southwest Façade (north is directed 26° to east) (Room Z17 : h=2.60 m, Area= 19.70 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S4	FT_3 50%	No	SD_4 h	u=60° l=60°	3	FL	**9 AM**	492	450	522	0.91	0.86
				u=30° l=30°	2	FL	**12 PM**	481	400	555	0.83	0.72
				u=30° l=30°	2	FL	**3 PM**	465	377	541	0.81	0.70
S8	FT3 50%	No	SD_4 h	u=60° l=60°	3	LED	**9 AM**	415	377	441	0.91	0.85
				u=30° l=30°	2	LED	**12 PM**	433	399	465	0.92	0.86
				u=30° l=30°	2	LED	**3 PM**	420	395	453	0.94	0.87
S7	FT_3 50%	No	SD_7 v	u=0° l=0°	3	FL	**9 AM**	537	468	563	0.87	0.83
				u=45° l=0°	2	FL	**12 PM**	454	357	538	0.79	0.66
				u=0° l=15°	1	FL	**3 PM**	404	286	518	0.71	0.55
S9	FT_3 50%	No	SD_7 v	u=0° l=0°	3	LED	**9 AM**	458	394	484	0.86	0.81
				u=45° l=0°	2	LED	**12 PM**	456	354	544	0.78	0.65
				u=0° l=15°	1	LED	**3 PM**	393	295	528	0.75	0.56

Table E.4 Part E-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of energy consumption

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Energy Consumption (Results taken from DIALux for December 21st)

Part E - Southwest Façade (north is directed 26° to east) (Room Z17 : h=2.60 m, Area= 19.70 m^2)

FT: Fenestration Transmittance
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical** **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
LT: Lighting Fixture Type;
FL : Fluorescent **Luminous Flux: 3834 lm; Power=70 W**
LED : Light Emitting Diode **Luminous Flux: 3400 lm; Power=41 W**
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2)

Scenario	FT	SD Type	SD Angle	LL n	LT	Hour	ENERGY CONSUMPTION Time h	Floor Area %	Energy Wh	kWh/a a:300 d	LENI
S4	FT_3 50%	SD_4 h	u=60° l=60°	3	FL	**9 AM**	3	100.0	630	441.0	22.4
			u=30° l=30°	2	FL	**12 PM**	3	66.7	420		
			u=30° l=30°	2	FL	**3 PM**	3	66.7	420		
S8	FT_3 50%	SD_4 h	u=60° l=60°	3	LED	**9 AM**	3	100.0	369	258.3	13.1
			u=30° l=30°	2	LED	**12 PM**	3	66.7	246		
			u=30° l=30°	2	LED	**3 PM**	3	66.7	246		
S7	FT_3 50%	SD_7 v	u=0° l=0°	3	FL	**9 AM**	3	100.0	630	378.0	19.2
			u=45° l=0°	2	FL	**12 PM**	3	66.7	420		
			u=0° l=15°	1	FL	**3 PM**	3	33.3	210		
S9	FT_3 50%	SD_7 v	u=0° l=0°	3	LED	**9 AM**	3	100.0	369	221.4	11.2
			u=45° l=0°	2	LED	**12 PM**	3	66.7	246		
			u=0° l=15°	1	LED	**3 PM**	3	33.3	123		

Table E.5 Part E-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the horizontal shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Horizontal Shading Devices (S4-FT3) (Results taken from DIALux)								
Part E - Southwest Façade (north is directed 26° to east) (Room Z17 : h=2.60 m, Area= 19.70 m²)								
SD: Shading Device (length=25cm); LL: Lighting Fixture Layout; Angle u: upper l: lower; n: Number of Lighting Row (on)								
Hour	**W/S Solstices & Equinoxes**	**SD Angle**	**LL n**	**ILLUMINANCE (Lux)**			**UNIFORMITY**	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	**December 21st**	u=60° l=60°	3	492	450	522	0.91	0.86
	March 21st			510	455	536	0.89	0.85
	June 21st			506	455	533	0.90	0.85
	September 21st			497	450	525	0.91	0.86
12 PM	**December 21st**	u=30° l=30°	2	481	400	555	0.83	0.72
	March 21st			545	502	611	0.92	0.82
	June 21st			470	362	570	0.77	0.63
	September 21st			466	362	561	0.78	0.65
3 PM	**December 21st**	u=30° l=30°	2	465	377	541	0.81	0.70
	March 21st			626	527	665	0.84	0.79
	June 21st			620	534	662	0.86	0.81
	September 21st			617	529	648	0.86	0.82

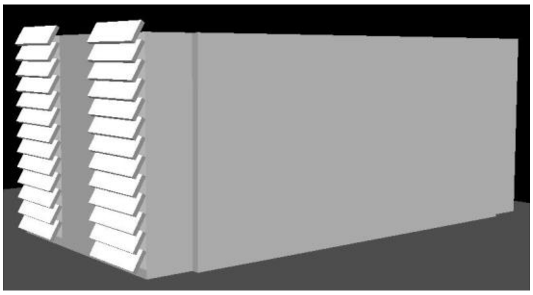
Table E.6 Part E-Retrofitting the results for the horizontal shading devices by using the fixed panels at W/S S&E

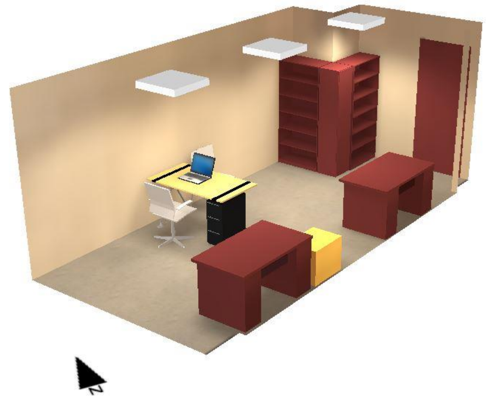
Retrofitting the Results for the Horizontal Shading Devices at W/S S&E (S4-FT3) (Results taken from DIALux)								
Part E - Southwest Façade (north is directed 26° to east) (Room Z17 : h=2.60 m, Area= 19.70 m^2)								
SD: Shading Device (length=25cm); LL: Lighting Fixture Layout; Panel length: 25 cm Vertical; height: window height,				Angle u: upper l: lower n: Number of Lighting Row (on) location: head of each side of window				
Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=60° l=60°	3	492	450	522	0.91	0.86
	March 21st			510	455	536	0.89	0.85
	June 21st			506	455	533	0.90	0.85
	September 21st			497	450	525	0.91	0.86
12 PM	December 21st	u=30° l=30°	2	481	400	555	0.83	0.72
	March 21st	u=0° l=45°		433	320	523	0.74	0.61
	June 21st	u=30° l=30°		470	362	570	0.77	0.63
	September 21st	u=30° l=30°		466	362	561	0.78	0.65
3 PM	December 21st	u=30° l=30°	2	465	377	541	0.81	0.70
	March 21st	u=30° l=60°		459	368	537	0.80	0.68
	June 21st	u=30° l=60°		438	327	526	0.75	0.62
	September 21st	u=30° l=60°		471	382	547	0.81	0.70

Outdoor & indoor perspective views for S8 in *Winter Solstice : December 21 [st]*
Part E - Southwest Façade (north is directed 26° to east)

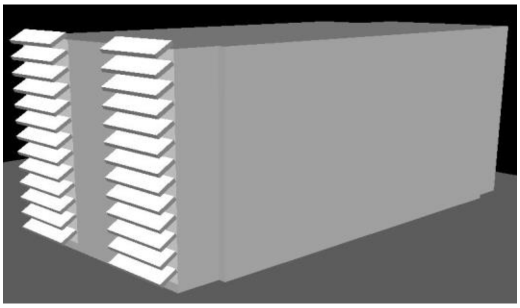
Outdoor Perspective	Indoor Perspective

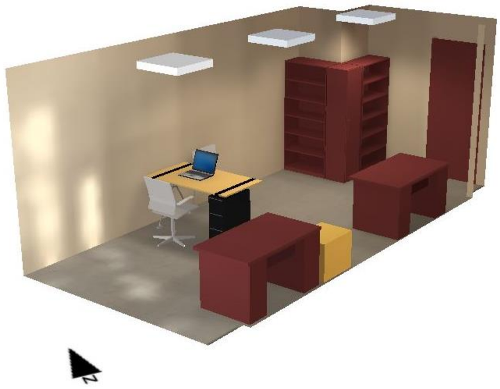
9:00 AM



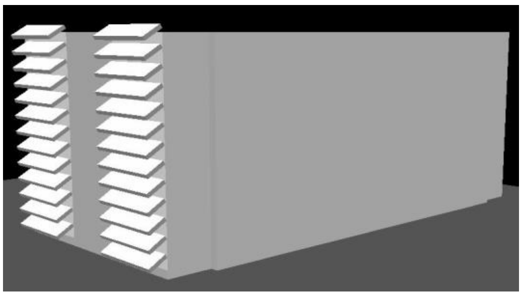


12:00 PM





3:00 PM



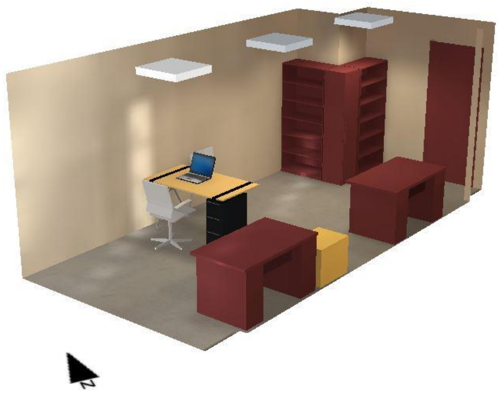


Figure E.4 Part E-Outdoor & indoor perspective views for retrofitted S8

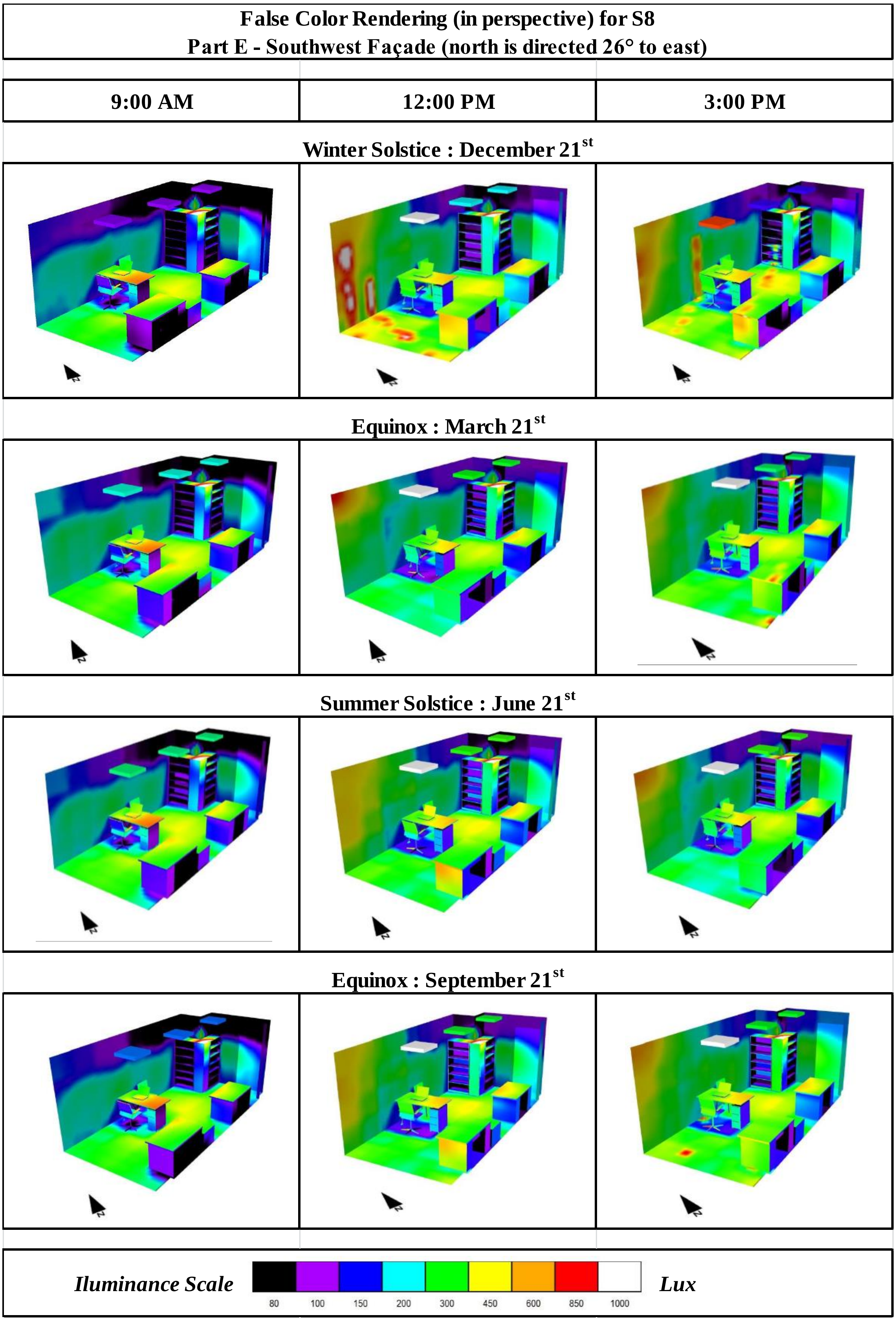


Figure E.5 Part E-False color rendering (in perspective) for retrofitted S8

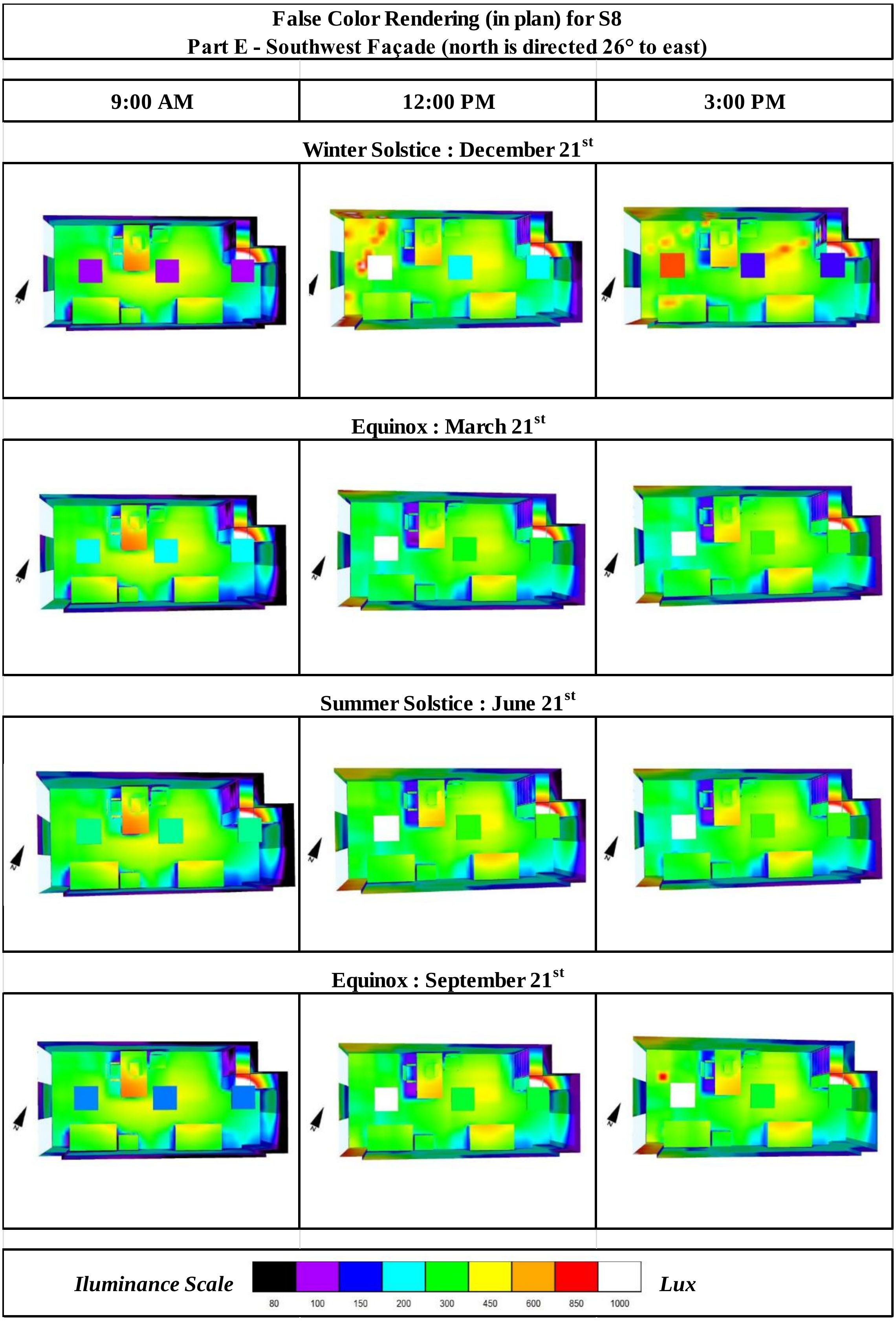


Figure E.6 Part E-False color rendering (in plan) for retrofitted S8

Table E.7 Part E-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the vertical shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Vertical Shading Devices (S7-FT3) (Results taken from DIALux)

Part E - Southwest Façade (north is directed 26° to east) (Room Z17 : h=2.60 m, Area= 19.70 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	3	537	468	563	0.87	0.83
	March 21st			588	487	645	0.83	0.76
	June 21st			585	488	638	0.84	0.77
	September 21st			561	477	602	0.85	0.79
12 PM	December 21st	u=45° l=0°	2	454	357	538	0.79	0.66
	March 21st			509	436	583	0.86	0.75
	June 21st			476	376	568	0.79	0.66
	September 21st			469	371	559	0.79	0.66
3 PM	December 21st	u=0° l=15°	1	404	286	518	0.71	0.55
	March 21st			739	505	1133	0.68	0.45
	June 21st			574	383	831	0.67	0.46
	September 21st			625	398	929	0.64	0.43

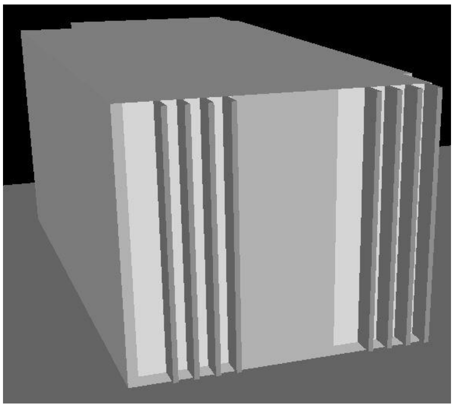
Table E.8 Part E-Retrofitting the results for the vertical shading devices by using the fixed panels at W/S S&E

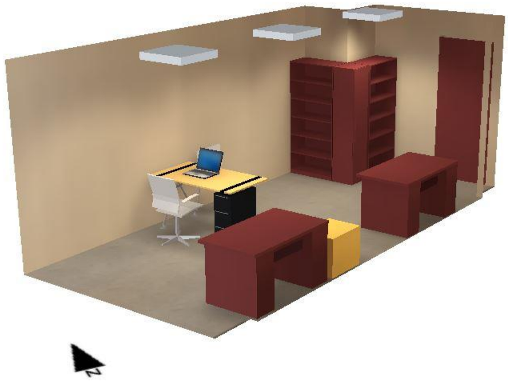
<table>
<tr><th colspan="9">Retrofitting the Results for the Vertical Shading Devices
at W/S S&E
(S7-FT3)
(Results taken from DIALux)</th></tr>
<tr><th colspan="9">Part E - Southwest Façade (north is directed 26° to east)
(Room Z17 : h=2.60 m, Area= 19.70 m²)</th></tr>
<tr><td colspan="9">SD: Shading Device (length=25cm); Angle u: upper l: lower
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window
Horizontal; width: window width, location: top of window</td></tr>
<tr><th rowspan="2">Hour</th><th rowspan="2">W/S Solstices & Equinoxes</th><th rowspan="2">SD Angle</th><th rowspan="2">LL n</th><th colspan="3">ILLUMINANCE (Lux)</th><th colspan="2">UNIFORMITY</th></tr>
<tr><th>E_{avg}</th><th>E_{min}</th><th>E_{max}</th><th>U_1 E_{min}/E_{avg}</th><th>U_2 E_{min}/E_{max}</th></tr>
<tr><td rowspan="4">9 AM</td><td>December 21st</td><td>u=0° l=0°</td><td rowspan="4">3</td><td>537</td><td>468</td><td>563</td><td>0.87</td><td>0.83</td></tr>
<tr><td>March 21st</td><td>u=60° l=60°</td><td>515</td><td>457</td><td>539</td><td>0.89</td><td>0.85</td></tr>
<tr><td>June 21st</td><td>u=60° l=60°</td><td>516</td><td>458</td><td>540</td><td>0.89</td><td>0.85</td></tr>
<tr><td>September 21st</td><td>u=60° l=60°</td><td>506</td><td>453</td><td>531</td><td>0.89</td><td>0.85</td></tr>
<tr><td rowspan="4">12 PM</td><td>December 21st</td><td>u=45° l=0°</td><td rowspan="4">2</td><td>454</td><td>357</td><td>538</td><td>0.79</td><td>0.66</td></tr>
<tr><td>March 21st</td><td>u=45° l=30°</td><td>460</td><td>365</td><td>543</td><td>0.79</td><td>0.67</td></tr>
<tr><td>June 21st</td><td>u=45° l=0°</td><td>476</td><td>376</td><td>568</td><td>0.79</td><td>0.66</td></tr>
<tr><td>September 21st</td><td>u=45° l=0°</td><td>469</td><td>371</td><td>559</td><td>0.79</td><td>0.66</td></tr>
<tr><td rowspan="4">3 PM</td><td>December 21st</td><td>u=0° l=15°</td><td>1</td><td>404</td><td>286</td><td>518</td><td>0.71</td><td>0.55</td></tr>
<tr><td>March 21st</td><td>u=75° l=60°</td><td>2</td><td>471</td><td>349</td><td>565</td><td>0.74</td><td>0.62</td></tr>
<tr><td>June 21st</td><td>u=60° l=60°</td><td>2</td><td>459</td><td>367</td><td>541</td><td>0.80</td><td>0.68</td></tr>
<tr><td>September 21st</td><td>u=60° l=60°</td><td>2</td><td>463</td><td>363</td><td>544</td><td>0.78</td><td>0.67</td></tr>
</table>

Outdoor & indoor perspective views for S9 in *Winter Solstice : December 21 st*
Part E - Southwest Façade (north is directed 26° to east)

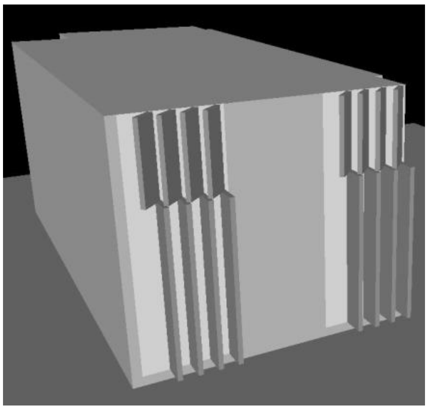
Outdoor Perspective	Indoor Perspective

9:00 AM

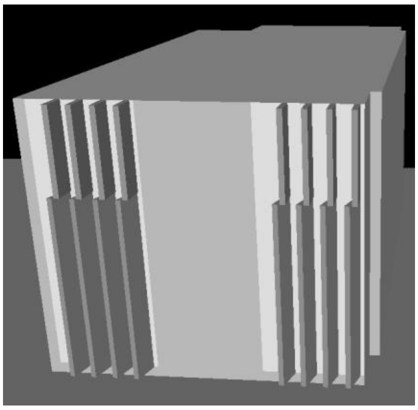




12:00 PM



3:00 PM



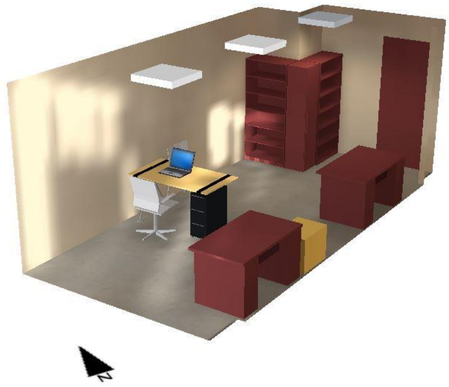


Figure E.7 Part E-Outdoor & indoor perspective views for retrofitted S9

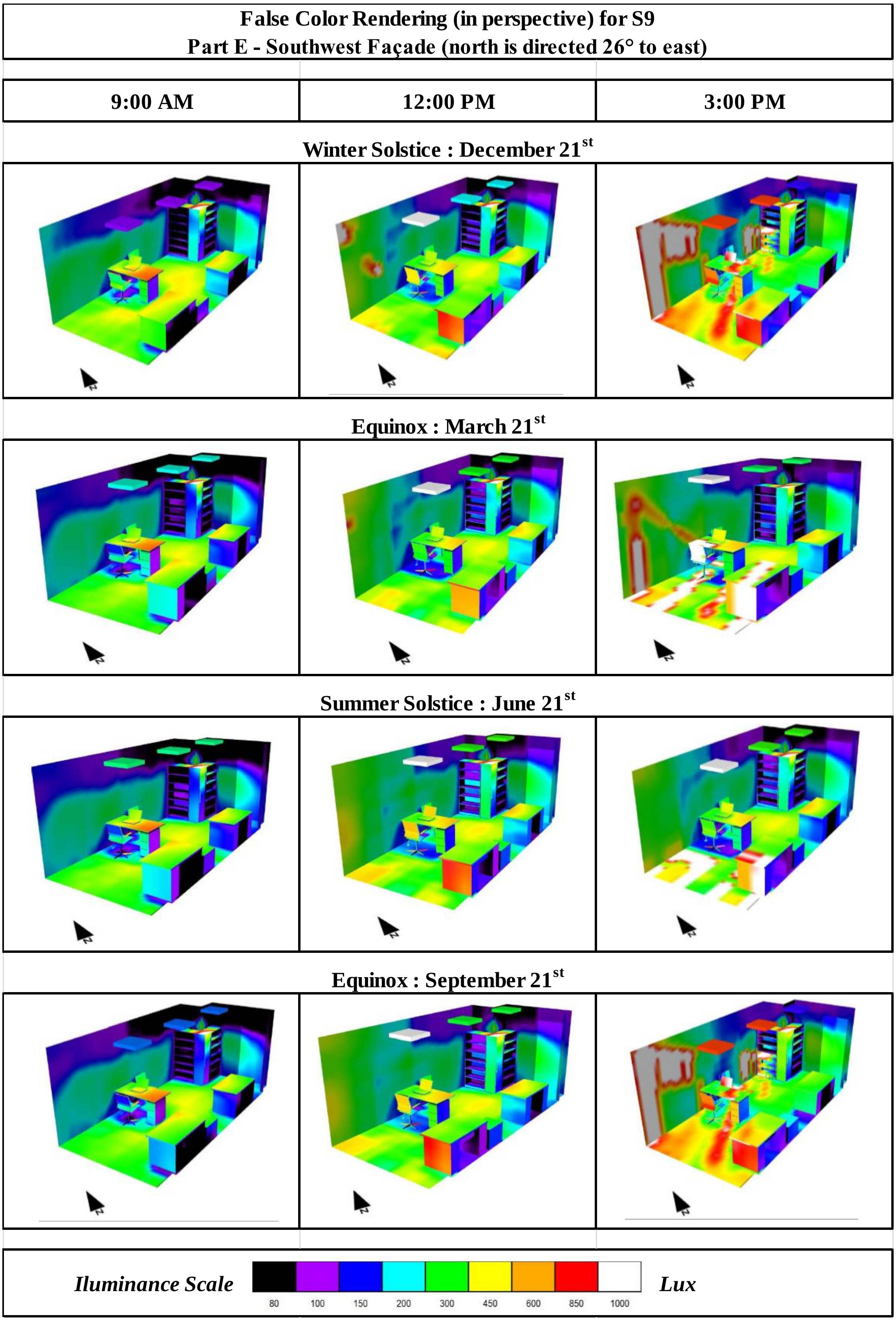


Figure E.8 Part E-False color rendering (in perspective) for retrofitted S9

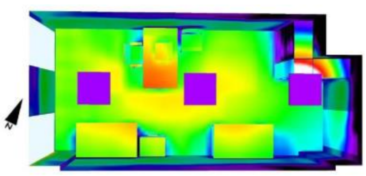
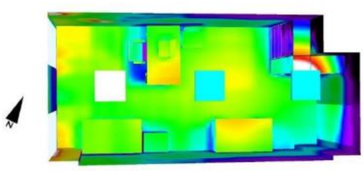
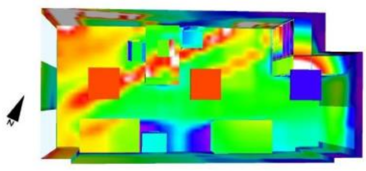
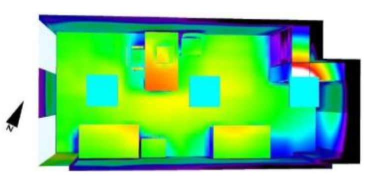
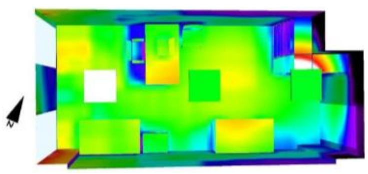
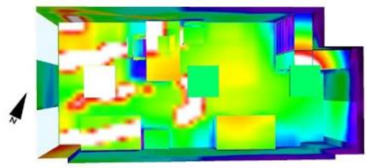
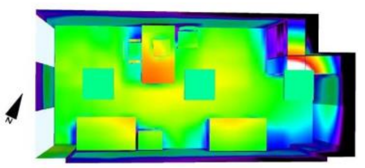
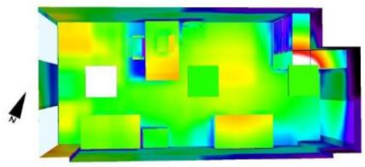
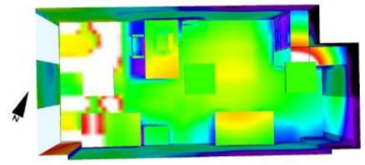
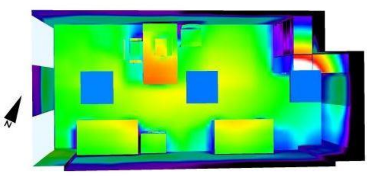
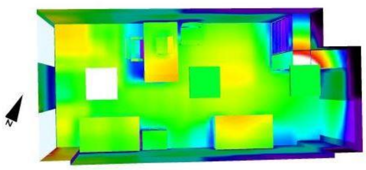
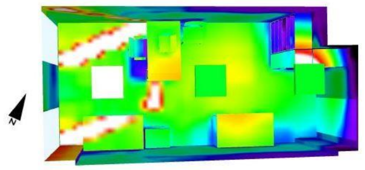
False Color Rendering (in plan) for S9 Part E - Southwest Façade (north is directed 26° to east)		
9:00 AM	**12:00 PM**	**3:00 PM**
Winter Solstice : December 21st		
		
Equinox : March 21st		
		
Summer Solstice : June 21st		
		
Equinox : September 21st		
		
Iluminance Scale	80 100 150 200 300 450 600 850 1000	***Lux***

Figure E.9 Part E-False color rendering (in plan) for retrofitted S9

Table E.9 Part E-Comparison of lighting fixture type energy consumption for optimum results of the horizontal shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Horizontal Shading Devices

Part E - Southwest Façade (north is directed 26° to east)
(Room Z17 : h=2.60 m, Area= 19.70 m^2)

SD: Shading Device; Type : horizontal;
upper: 4 lower: 9
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

W/S Solstices & Equinoxes	Hour	ENERGY CONSUMPTION								
		LL	Time h	Floor Area %	S4-FT1 with FL			S8 with LED		
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI
December 21st	9 AM	3	3	100	630	110.3	5.6	369	64.6	3.3
	12 PM	2	3	66.7	420			246		
	3 PM	2	3	66.7	420			246		
March 21st	9 AM	3	3	100	630	110.3	5.6	369	64.6	3.3
	12 PM	2	3	66.7	420			246		
	3 PM	2	3	66.7	420			246		
June 21st	9 AM	3	3	100	630	110.3	5.6	369	64.6	3.3
	12 PM	2	3	66.7	420			246		
	3 PM	2	3	66.7	420			246		
September 21st	9 AM	3	3	100	630	110.3	5.6	369	64.6	3.3
	12 PM	2	3	66.7	420			246		
	3 PM	2	3	66.7	420			246		
Annual Energy Consumption					**FL**	**441.0**	**22.4**	**LED**	**258.3**	**13.1**

Table E.10 Part E-Comparison of lighting fixture type energy consumption for optimum results of the vertical shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Vertical Shading Devices

Part E - Southwest Façade (north is directed 26° to east)
(Room Z17 : h=2.60 m, Area= 19.70 m^2)

SD: Shading Device; **Type :** vertical;
upper: 4 **lower: 4**
LL: Lighting Fixture Layout; **n: Number of Lighting Row (on)**
LT: Lighting Fixture Type;
FL : Fluorescent; **Luminous Flux: 3834 lm; Power=70 W**
LED: Light Emitting Diode; **Luminous Flux: 3400 lm; Power=41 W**
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

W/S Solstices & Equinoxes	Hour	ENERGY CONSUMPTION								
		LL	Time h	Floor Area %	S7-FT3 with FL			S9 with LED		
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI
December 21st	9 AM	3	3	100	630	94.5	4.8	369	55.4	2.8
	12 PM	2	3	66.7	420			246		
	3 PM	1	3	33.3	210			123		
March 21st	9 AM	3	3	100	630	110.3	5.6	369	64.6	3.3
	12 PM	2	3	66.7	420			246		
	3 PM	2	3	66.7	420			246		
June 21st	9 AM	3	3	100	630	110.3	5.6	369	64.6	3.3
	12 PM	2	3	66.7	420			246		
	3 PM	2	3	66.7	420			246		
September 21st	9 AM	3	3	100	630	110.3	5.6	369	64.6	3.3
	12 PM	2	3	66.7	420			246		
	3 PM	2	3	66.7	420			246		
Annual Energy Consumption					**FL**	**425.3**	**21.6**	**LED**	**249.1**	**12.6**

APPENDIX F. SIMULATION RESULTS FOR PART F

Table F.1 Part F-Base case results (S0 for W/S S&E)

Base Case Results (Results taken from DIALux)

Part F - Southeast Façade (north is directed 26° to east)
(Room Z06 : h=3.40 m, Area= 128.19 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 80%
SC: Surface Color = 68%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
Winter Solstice : December 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	317	38	1156	0.12	0.03
					0	FL	**12 PM**	393	56	4928	0.14	0.01
					0	FL	**3 PM**	80	23	220	0.29	0.11
Equinox : March 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	178	46	424	0.26	0.11
					0	FL	**12 PM**	195	52	472	0.26	0.11
					0	FL	**3 PM**	107	29	288	0.27	0.10
Summer Solstice : June 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	119	32	303	0.27	0.11
					0	FL	**12 PM**	148	42	354	0.29	0.12
					0	FL	**3 PM**	103	30	243	0.29	0.11
Equinox : September 21st												
S0	FT_0 36%	No	No	No	0	FL	**9 AM**	392	39	3235	0.10	0.01
					0	FL	**12 PM**	214	57	504	0.27	0.11
					0	FL	**3 PM**	130	35	339	0.27	0.10

Outdoor & indoor perspective views for S0 in *Winter Solstice : December 21 st*
Part F - Southeast Façade (north is directed 26° to east)

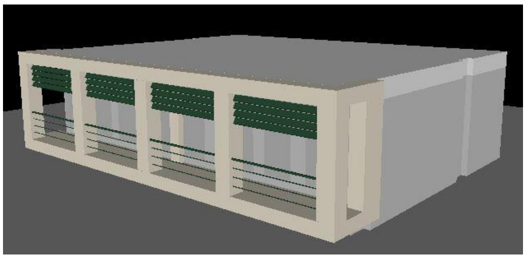
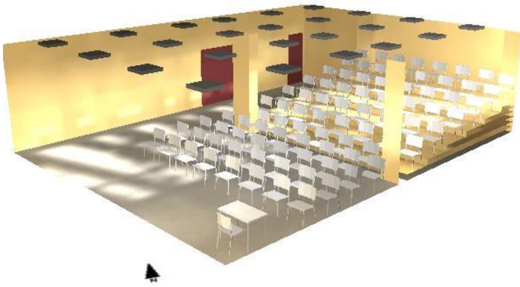
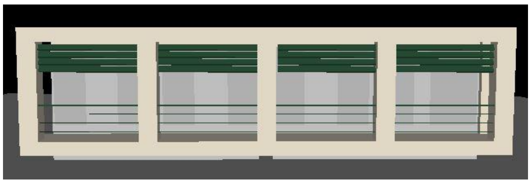
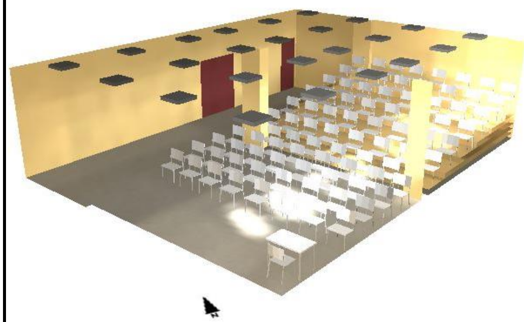
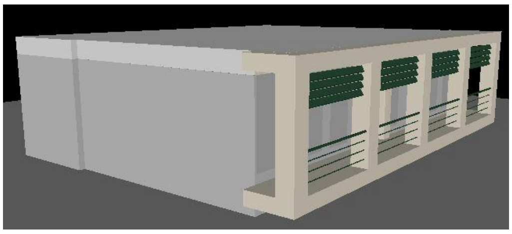
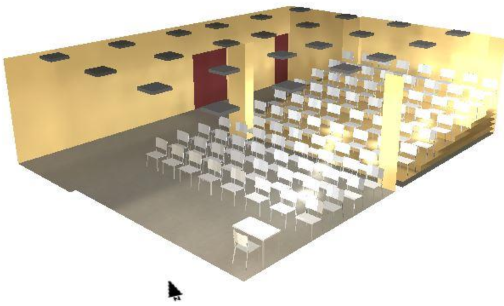
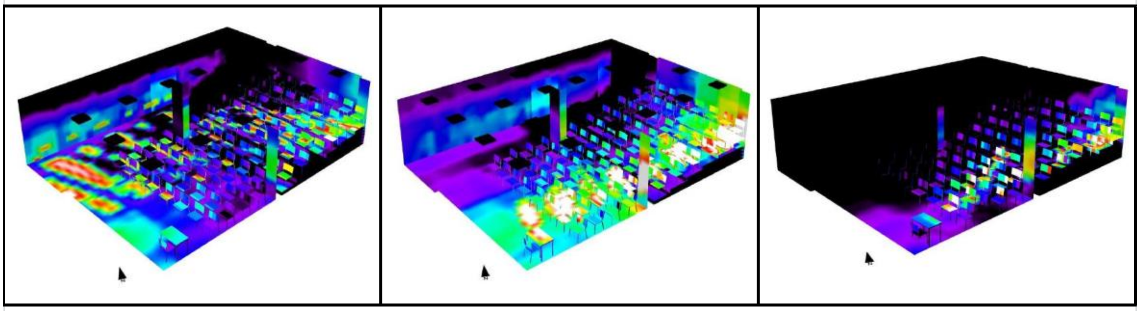
Outdoor Perspective	Indoor Perspective
9:00 AM	
	
12:00 PM	
	
3:00 PM	
	

Figure F.1 Part F-Outdoor & indoor perspective views for S0

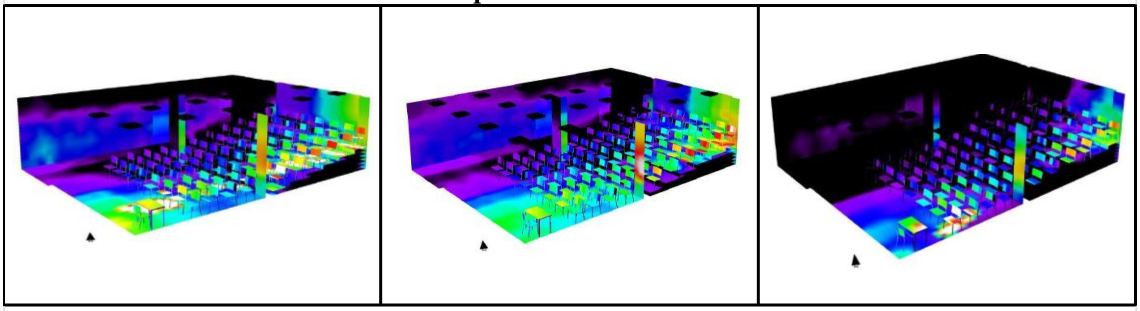
False Color Rendering (in perspective) for S0
Part F - Southeast Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM

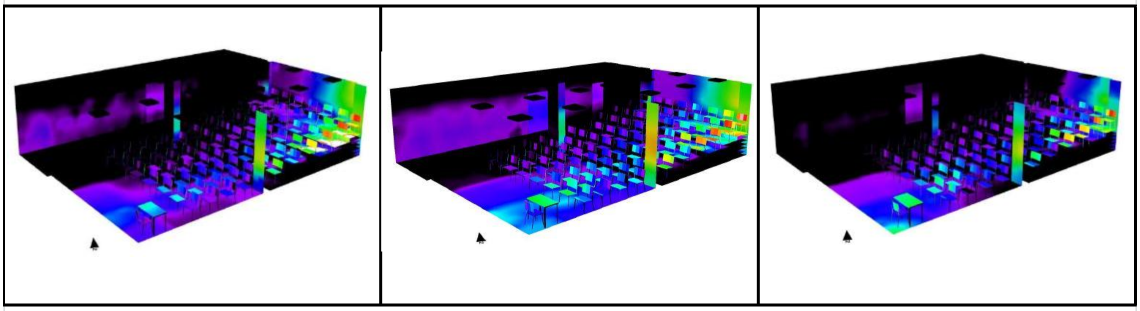
Winter Solstice : December 21st



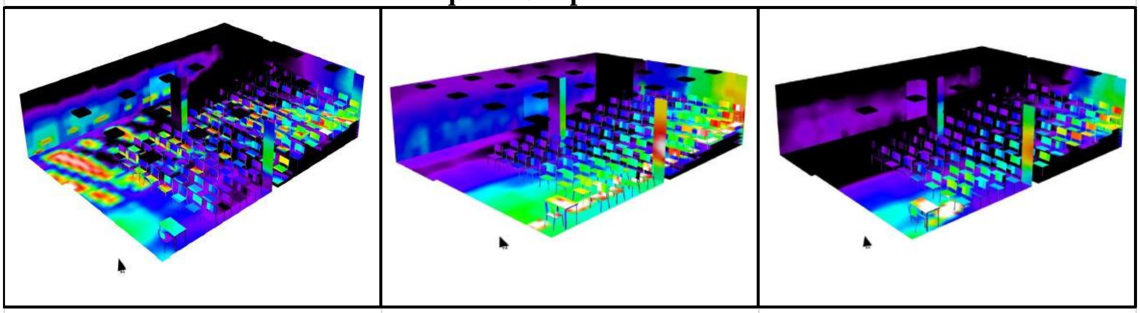
Equinox : March 21st



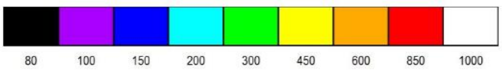
Summer Solstice : June 21st



Equinox : September 21st



Iluminance Scale



Lux

Figure F.2 Part F-False color rendering (in perspective) for S0

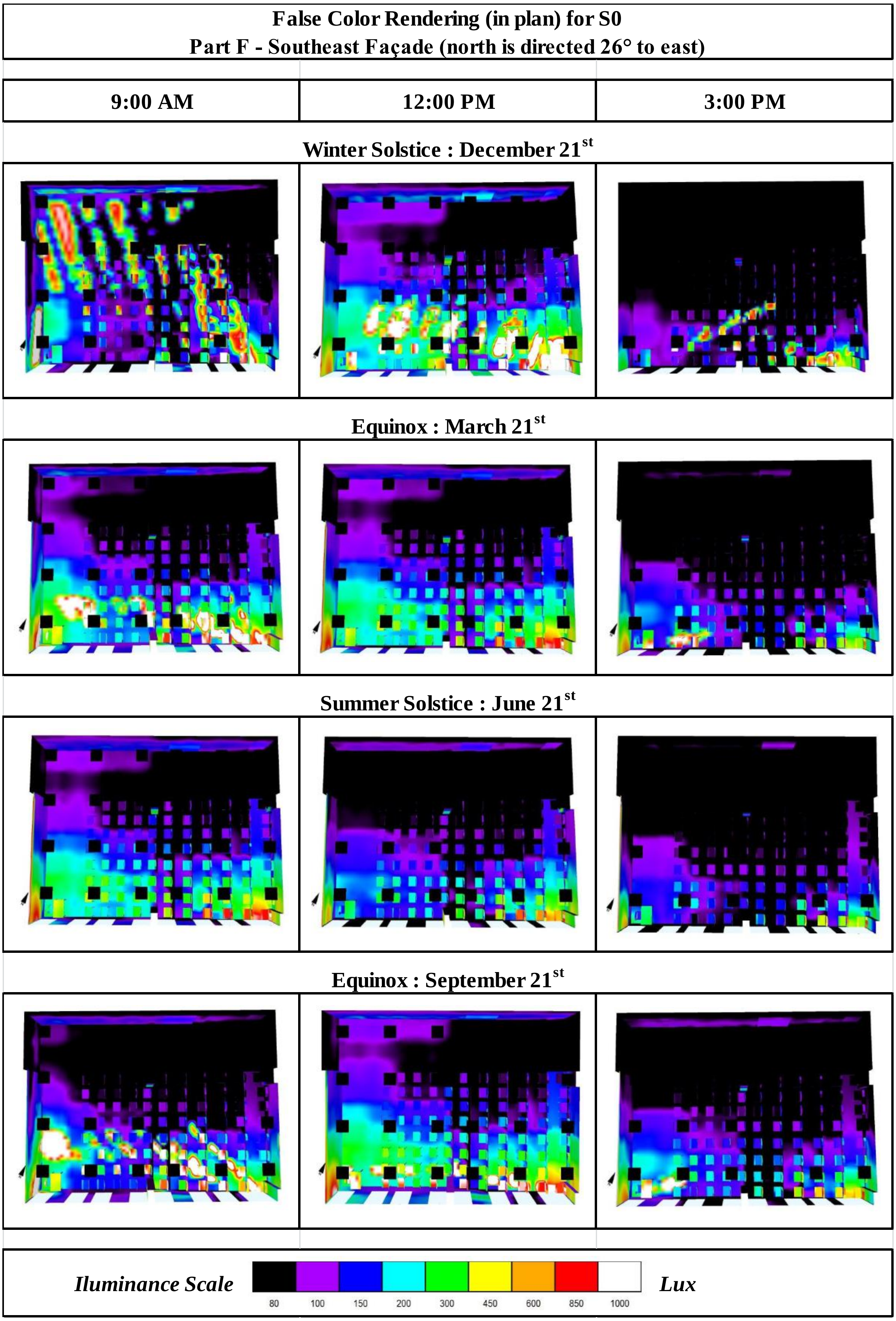


Figure F.3 Part F-False color rendering (in plan) for S0

Table F.2 Part F-Retrofit scenarios (S1-S7)

Retrofit Scenarios (Results taken from DIALux for December 21st)												
Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m²)												
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row** (on) **LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode**												
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux) E_{avg}**	**E_{min}**	**E_{max}**	**UNIFORMITY U_1 E_{min}/E_{avg}**	**U_2 E_{min}/E_{max}**
S1	FT_1 90%	Yes	No	No		FL	**9 AM**	2015	487	4017	0.24	0.12
						FL	**12 PM**	3840	752	17242	0.20	0.04
						FL	**3 PM**	1200	279	6424	0.23	0.04
	FT_2 70%	Yes	No	No		FL	**9 AM**	1567	382	3122	0.24	0.12
						FL	**12 PM**	2968	584	13380	0.20	0.04
						FL	**3 PM**	934	217	4990	0.23	0.04
	FT_3 50%	Yes	No	No		FL	**9 AM**	1120	275	2226	0.25	0.12
						FL	**12 PM**	2138	426	9535	0.20	0.04
						FL	**3 PM**	810	284	3565	0.35	0.08
SD u=3 l=3 distance 30 cm **S2** **Light Shelf** location 220 cm width 290 cm length 100 cm	FT_1 90%	Yes	SD_2 h			FL	**9 AM**	468	256	768	0.55	0.33
						FL	**12 PM**	527	258	1481	0.49	0.17
						FL	**3 PM**	808	254	4777	0.31	0.05
	FT_2 70%	Yes	SD_2 h			FL	**9 AM**	507	277	793	0.55	0.35
						FL	**12 PM**	556	339	1169	0.61	0.29
						FL	**3 PM**	837	347	3758	0.42	0.09
	FT_3 50%	Yes	SD_2 h			FL	**9 AM**	445	242	732	0.54	0.33
						FL	**12 PM**	446	268	847	0.60	0.32
						FL	**3 PM**	697	299	2713	0.43	0.11

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Table F.2 (cont.)

Retrofit Scenarios (Results taken from DIALux for December 21st)												
Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)												
FT: Fenestration Transmittance FC: Fenestration Color = 90% SC: Surface Color = 80% SD: Shading Device (length=25cm); Type h: horizontal v: vertical Angle u: upper l: lower LL: Lighting Fixture Layout; n: Number of Lighting Row (on) LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode												
Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
SD u=3 l=4 distance 30 cm S3	FT_1 90%	No	SD_3 h			FL	9 AM					
						FL	12 PM					
						FL	3 PM					
	FT_2 70%	No	SD_3 h			FL	9 AM					
						FL	12 PM					
						FL	3 PM					
	FT_3 50%	No	SD_3 h			FL	9 AM	456	244	731	0.53	0.33
						FL	12 PM	451	269	880	0.60	0.31
						FL	3 PM	711	314	2754	0.44	0.11
SD u=6 l=6 distance 20 cm S4	FT_1 90%	No	SD_4 h			FL	9 AM	497	281	793	0.57	0.35
						FL	12 PM	508	245	840	0.48	0.29
						FL	3 PM	443	270	746	0.61	0.36
	FT_2 70%	No	SD_4 h			FL	9 AM	455	253	739	0.56	0.34
						FL	12 PM	489	295	813	0.60	0.36
						FL	3 PM	430	260	669	0.61	0.39
	FT_3 50%	No	SD_4 h			FL	9 AM	491	281	753	0.57	0.37
						FL	12 PM	442	260	679	0.59	0.38
						FL	3 PM	498	291	831	0.59	0.35

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Table F.2 (cont.)

Part F - Southeast Façade (north is directed 26° to east)
(Room Z06 : h=3.40 m, Area= 128.19 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
SD u=2-3 l=2-3 distance 40 cm **S5** **Light Shelf** location 220 cm width 290 cm length 100 cm	FT_1 90%	Yes	SD_5 v			FL	**9 AM**	906	231	3084	0.26	0.07
						FL	**12 PM**	1303	346	14380	0.27	0.02
						FL	**3 PM**	582	357	886	0.61	0.4
	FT_2 70%	Yes	SD_5 v			FL	**9 AM**	705	181	2399	0.26	0.08
						FL	**12 PM**	1014	275	11158	0.27	0.02
						FL	**3 PM**	524	312	854	0.60	0.37
	FT_3 50%	Yes	SD_5 v			FL	**9 AM**	505	132	1702	0.26	0.08
						FL	**12 PM**	871	343	7985	0.39	0.04
						FL	**3 PM**	467	265	822	0.57	0.32
SD u=2-3 l=2-3 distance 40 cm **S6**	FT_1 90%	No	SD_6 v			FL	**9 AM**					
						FL	**12 PM**					
						FL	**3 PM**					
	FT_2 70%	No	SD_6 v			FL	**9 AM**					
						FL	**12 PM**					
						FL	**3 PM**					
	FT_3 50%	No	SD_6 v			FL	**9 AM**	517	129	1754	0.25	0.07
						FL	**12 PM**	892	337	7993	0.38	0.04
						FL	**3 PM**	463	256	815	0.55	0.31

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Table F.2 (cont.)

Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)													
FT: Fenestration Transmittance **FC: Fenestration Color = 90%** **SC: Surface Color = 80%** **SD: Shading Device** (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower** **LL: Lighting Fixture Layout; n: Number of Lighting Row** (on) **LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode**													
Scenario	**FT**	**Light Shelf**	**SD Type**	**SD Angle**	**LL n**	**LT**	**Hour**	**ILLUMINANCE (Lux)**			**UNIFORMITY**	
								E_{avg}	**E_{min}**	**E_{max}**	**U_1 E_{min}/E_{avg}**	**U_2 E_{min}/E_{max}**
SD u=4-6 l=4-6 distance 23 cm **S7**	FT_1 90%	No	SD_7 v			FL	**9 AM**	508	252	880	0.50	0.29
						FL	**12 PM**	517	266	928	0.51	0.29
						FL	**3 PM**	505	282	837	0.56	0.34
	FT_2 70%	No	SD_7 v			FL	**9 AM**	464	225	834	0.48	0.27
						FL	**12 PM**	533	278	963	0.52	0.29
						FL	**3 PM**	496	277	835	0.56	0.33
	FT_3 50%	No	SD_7 v			FL	**9 AM**	451	222	811	0.49	0.27
						FL	**12 PM**	469	236	876	0.50	0.27
						FL	**3 PM**	468	238	802	0.51	0.3

Table F.3 Part F-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of illuminance & uniformity

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Illuminance & Uniformity (Results taken from DIALux for December 21st)

Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)

FT: Fenestration Transmittance
FC: Fenestration Color = 90%
SC: Surface Color = 80%
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical Angle u: upper l: lower**
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type; FL: Fluorescent LED: Light Emitting Diode

Scenario	FT	Light Shelf	SD Type	SD Angle	LL n	LT	Hour	ILLUMINANCE (Lux) E_{avg}	E_{min}	E_{max}	UNIFORMITY U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
S4	FT_2 70%	No	SD_4 h	u=0° l=30°	1	FL	**9 AM**	455	253	739	0.56	0.34
				u=0° l=75°	1	FL	**12 PM**	489	295	813	0.60	0.36
				u=0° l=0°	1	FL	**3 PM**	430	260	669	0.61	0.39
S8	FT_2 70%	No	SD_4 h	u=0° l=30°	1	LED	**9 AM**	436	263	657	0.60	0.40
				u=0° l=75°	1	LED	**12 PM**	471	304	823	0.64	0.37
				u=0° l=0°	1	LED	**3 PM**	411	276	670	0.67	0.41
S7	FT_3 50%	No	SD_7 v	u=30° l=45°	2	FL	**9 AM**	451	222	811	0.49	0.27
				u=60° l=75°	2	FL	**12 PM**	469	236	876	0.50	0.27
				u=0° l=0°	2	FL	**3 PM**	468	238	802	0.51	0.30
S9	FT_3 50%	No	SD_7 v	u=30° l=45°	2	LED	**9 AM**	409	224	687	0.55	0.33
				u=60° l=75°	2	LED	**12 PM**	428	274	746	0.64	0.37
				u=0° l=0°	2	LED	**3 PM**	427	262	675	0.61	0.39

Table F.4 Part F-Comparison of selected optimum retrofit scenarios for horizontal and vertical shading devices in terms of energy consumption

Comparison of Selected Optimum Retrofit Scenarios for Horizontal and Vertical Shading Devices in terms of Energy Consumption (Results taken from DIALux for December 21st)

Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)

FT: Fenestration Transmittance
SD: Shading Device (length=25cm); **Type h: horizontal v: vertical** **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
LT: Lighting Fixture Type;
FL : Fluorescent **Luminous Flux: 3834 lm; Power=70 W**
LED : Light Emitting Diode **Luminous Flux: 3400 lm; Power=41 W**
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2)

Scenario	FT	SD Type	SD Angle	LL n	LT	Hour	ENERGY CONSUMPTION Time h	Floor Area %	Energy Wh	kWh/a a:300 d	LENI
S4	FT_3 50%	SD_4 h	u=0° l=30°	1	FL	9 AM	3	25	1260	1134.0	8.8
			u=0° l=75°	1	FL	12 PM	3	25	1260		
			u=0° l=0°	1	FL	3 PM	3	25	1260		
S8	FT_3 50%	SD_4 h	u=0° l=30°	1	LED	9 AM	3	25	738	664.2	5.2
			u=0° l=75°	1	LED	12 PM	3	25	738		
			u=0° l=0°	1	LED	3 PM	3	25	738		
S7	FT_3 50%	SD_7 v	u=30° l=45°	2	FL	9 AM	3	50	2520	2268.0	17.7
			u=60° l=75°	2	FL	12 PM	3	50	2520		
			u=0° l=0°	2	FL	3 PM	3	50	2520		
S9	FT_3 50%	SD_7 v	u=30° l=45°	2	LED	9 AM	3	50	1476	1328.4	10.4
			u=60° l=75°	2	LED	12 PM	3	50	1476		
			u=0° l=0°	2	LED	3 PM	3	50	1476		

Table F.5 Part F-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the horizontal shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Horizontal Shading Devices (S4-FT2) (Results taken from DIALux)

Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=30°	1	455	253	739	0.56	0.34
	March 21st			605	316	987	0.52	0.32
	June 21st			495	260	771	0.53	0.34
	September 21st			507	263	735	0.52	0.36
12 PM	December 21st	u=0° l=75°	1	489	295	813	0.60	0.36
	March 21st			486	280	813	0.58	0.34
	June 21st			405	221	648	0.55	0.34
	September 21st			483	277	802	0.57	0.35
3 PM	December 21st	u=0° l=0°	1	430	260	669	0.61	0.39
	March 21st			504	298	745	0.59	0.40
	June 21st			445	262	630	0.59	0.42
	September 21st			654	378	1067	0.58	0.35

Table F.6 Part F-Retrofitting the results for the horizontal shading devices by using the fixed panels at W/S S&E

Retrofitting the Results for the Horizontal Shading Devices at W/S S&E (S4-FT2) (Results taken from DIALux)

Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m²)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=0° l=0°	1	455	253	739	0.56	0.34
	March 21st	u=30° l=60°	2	568	318	866	0.56	0.37
	June 21st	u=0° l=0°	1	495	260	771	0.53	0.34
	September 21st			507	263	735	0.52	0.36
12 PM	December 21st	u=0° l=75°	1	489	295	813	0.60	0.36
	March 21st			486	280	813	0.58	0.34
	June 21st	u=45° l=75°	2	471	240	812	0.51	0.30
	September 21st	u=0° l=75°	1	483	277	802	0.57	0.35
3 PM	December 21st	u=0° l=0°	1	430	260	669	0.61	0.39
	March 21st			504	298	745	0.59	0.40
	June 21st			445	262	630	0.59	0.42
	September 21st	u=0° l=45°		469	267	737	0.57	0.36

Outdoor & indoor perspective views for S8 in *Winter Solstice : December 21 st*
Part F - Southeast Façade (north is directed 26° to east)

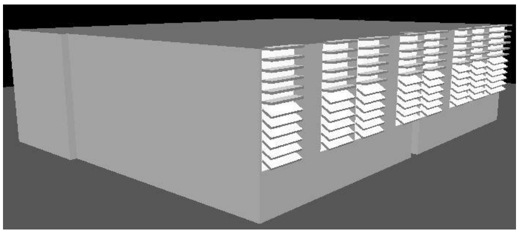
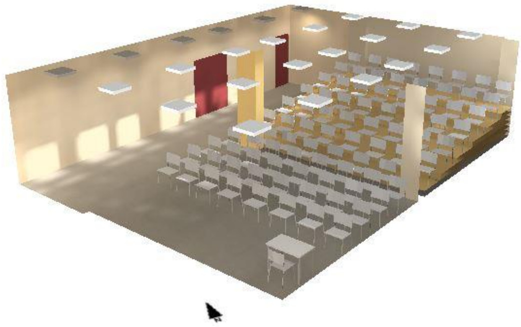
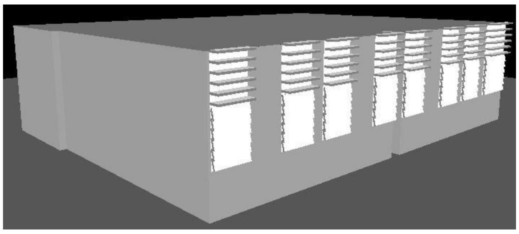
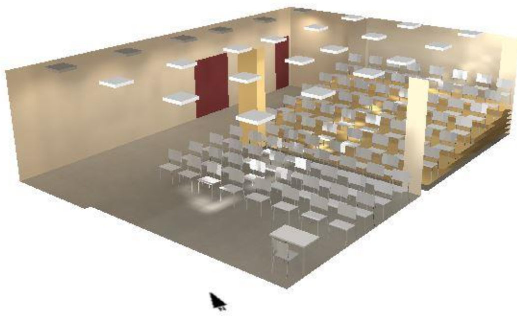
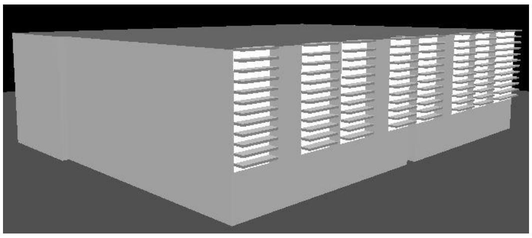
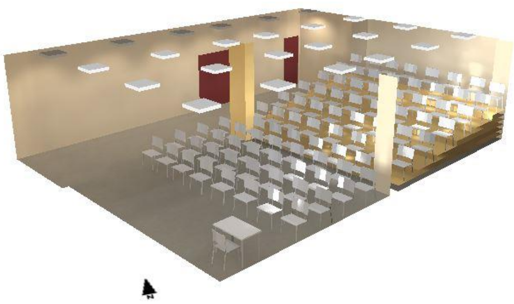
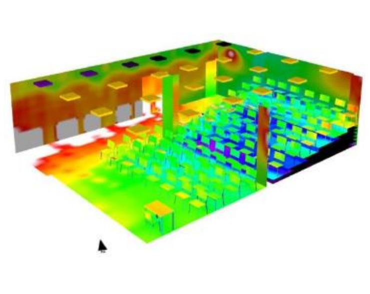
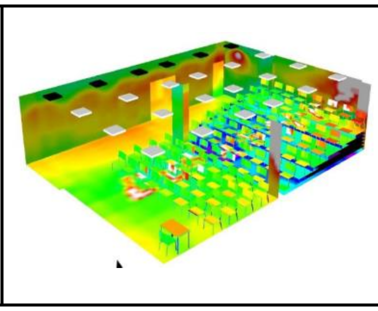
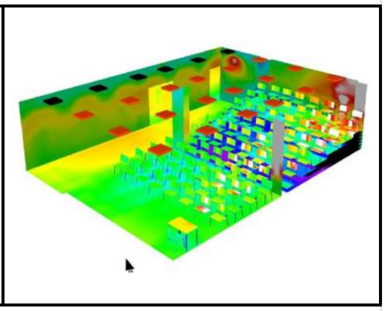
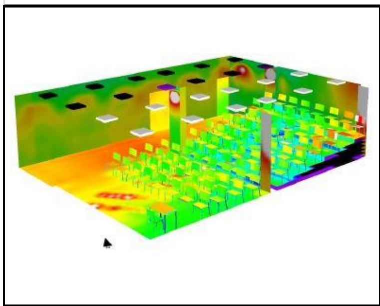
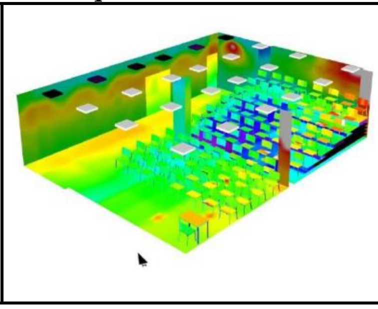
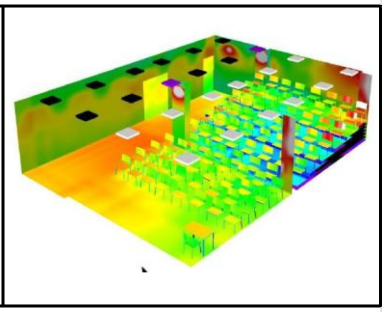
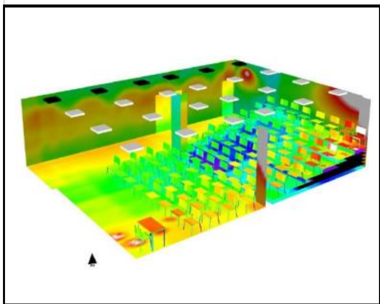
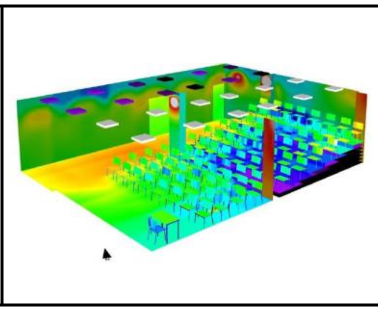
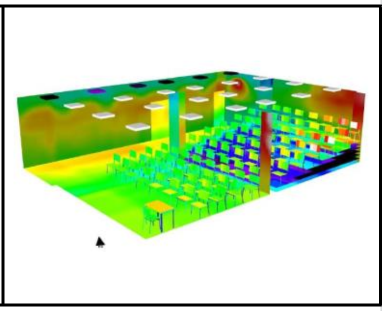
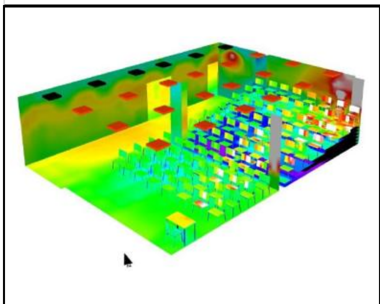
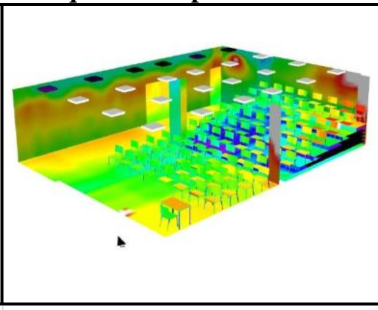
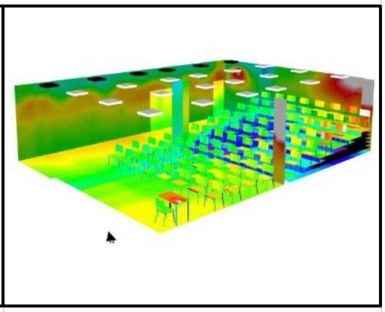
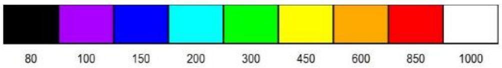
Outdoor Perspective	Indoor Perspective
9:00 AM	
	
12:00 PM	
	
3:00 PM	
	

Figure F.4 Part F-Outdoor & indoor perspective views for retrofitted S8

False Color Rendering (in perspective) for S8
Part F - Southeast Façade (north is directed 26° to east)

9:00 AM	12:00 PM	3:00 PM
Winter Solstice : December 21st		
		
Equinox : March 21st		
		
Summer Solstice : June 21st		
		
Equinox : September 21st		
		

Iluminance Scale 

Lux

Figure F.5 Part F-False color rendering (in perspective) for retrofitted S8

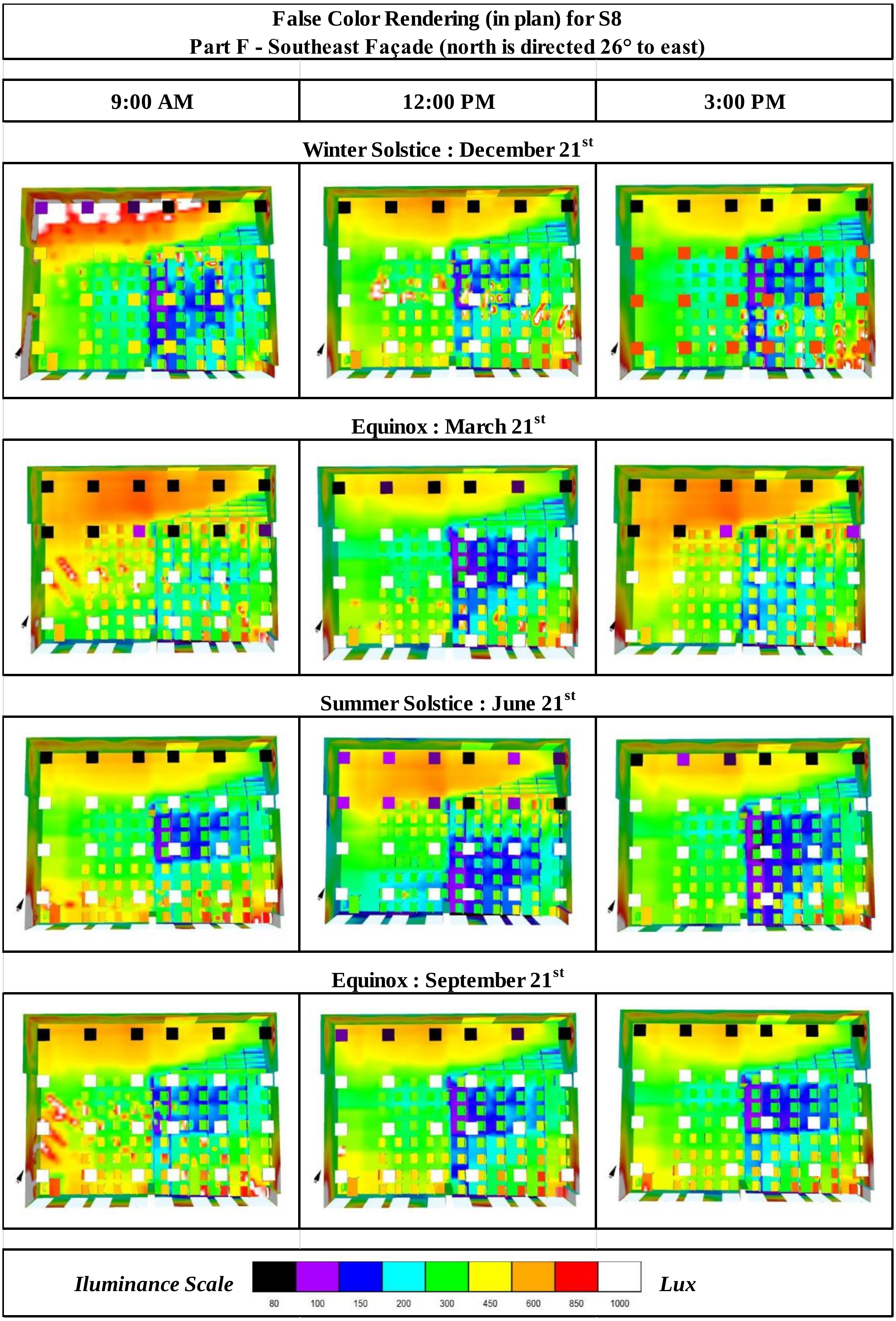


Figure F.6 Part F-False color rendering (in plan) for retrofitted S8

Table F.7 Part F-Simulation for W/S S&E with the same parameters selected as an optimum scenario of December 21st for the vertical shading devices

Simulation for W/S S&E with the Same Parameters Selected as an Optimum Scenario of December 21st for the Vertical Shading Devices (S7-FT3) (Results taken from DIALux)

Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row** (on)

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	December 21st	u=30° l=45°	2	451	222	811	0.49	0.27
	March 21st			492	284	829	0.58	0.34
	June 21st			436	233	803	0.53	0.29
	September 21st			442	231	801	0.52	0.29
12 PM	December 21st	u=60° l=75°	2	469	236	876	0.50	0.27
	March 21st			471	223	853	0.47	0.26
	June 21st			417	198	787	0.47	0.25
	September 21st			2469	226	16504	0.09	0.01
3 PM	December 21st	u=0° l=0°	2	468	238	802	0.51	0.30
	March 21st			524	283	824	0.54	0.34
	June 21st			541	316	836	0.58	0.38
	September 21st			597	344	853	0.58	0.40

Table F.8 Part F-Retrofitting the results for the vertical shading devices by using the fixed panels at W/S S&E

Retrofitting the Results for the Vertical Shading Devices at W/S S&E (S7-FT3) (Results taken from DIALux)

Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)

SD: Shading Device (length=25cm); **Angle u: upper l: lower**
LL: Lighting Fixture Layout; **n: Number of Lighting Row (on)**
Panel length: 25 cm
Vertical; height: window height, location: head of each side of window
Horizontal; width: window width, location: top of window

Hour	W/S Solstices & Equinoxes	SD Angle	LL n	ILLUMINANCE (Lux)			UNIFORMITY	
				E_{avg}	E_{min}	E_{max}	U_1 E_{min}/E_{avg}	U_2 E_{min}/E_{max}
9 AM	21st December	u=30° l=45°	2	451	222	811	0.49	0.27
	21st March			492	284	829	0.58	0.34
	21st June			436	233	803	0.53	0.29
	21st September			442	231	801	0.52	0.29
12 PM	21st December	u=60° l=75°	2	469	236	876	0.50	0.27
	21st March			471	223	853	0.47	0.26
	21st June	u=30° l=75°		487	236	882	0.49	0.27
	21st September	u=90° l=90°	3	1749	342	16347	0.18	0.02
3 PM	21st December	u=0° l=0°	2	468	238	802	0.51	0.30
	21st March			524	283	824	0.54	0.34
	21st June			541	316	836	0.58	0.38
	21st September			597	344	853	0.58	0.40

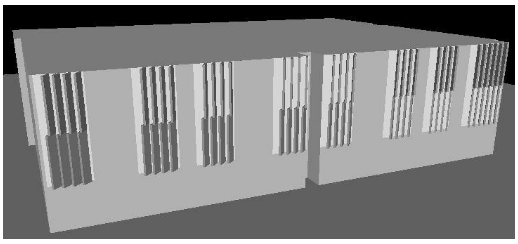
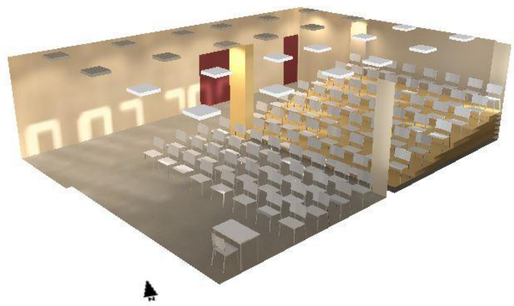
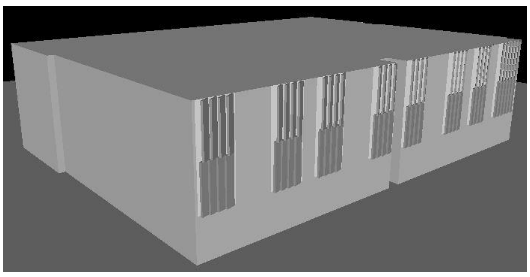
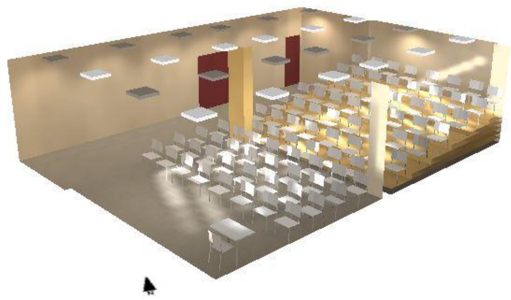
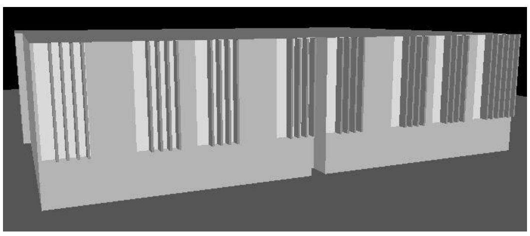
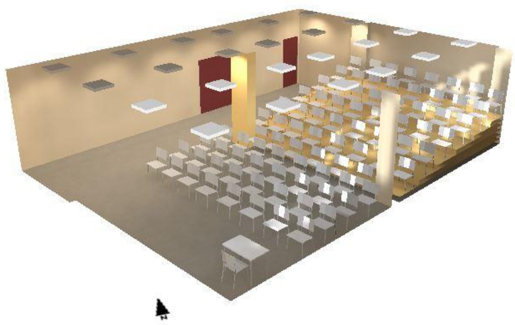
Outdoor & indoor perspective views for S9 in *Winter Solstice : December 21 st* Part F - Southeast Façade (north is directed 26° to east)	
Outdoor Perspective	**Indoor Perspective**
9:00 AM	
	
12:00 PM	
	
3:00 PM	
	

Figure F.7 Part F-Outdoor & indoor perspective views for retrofitted S9

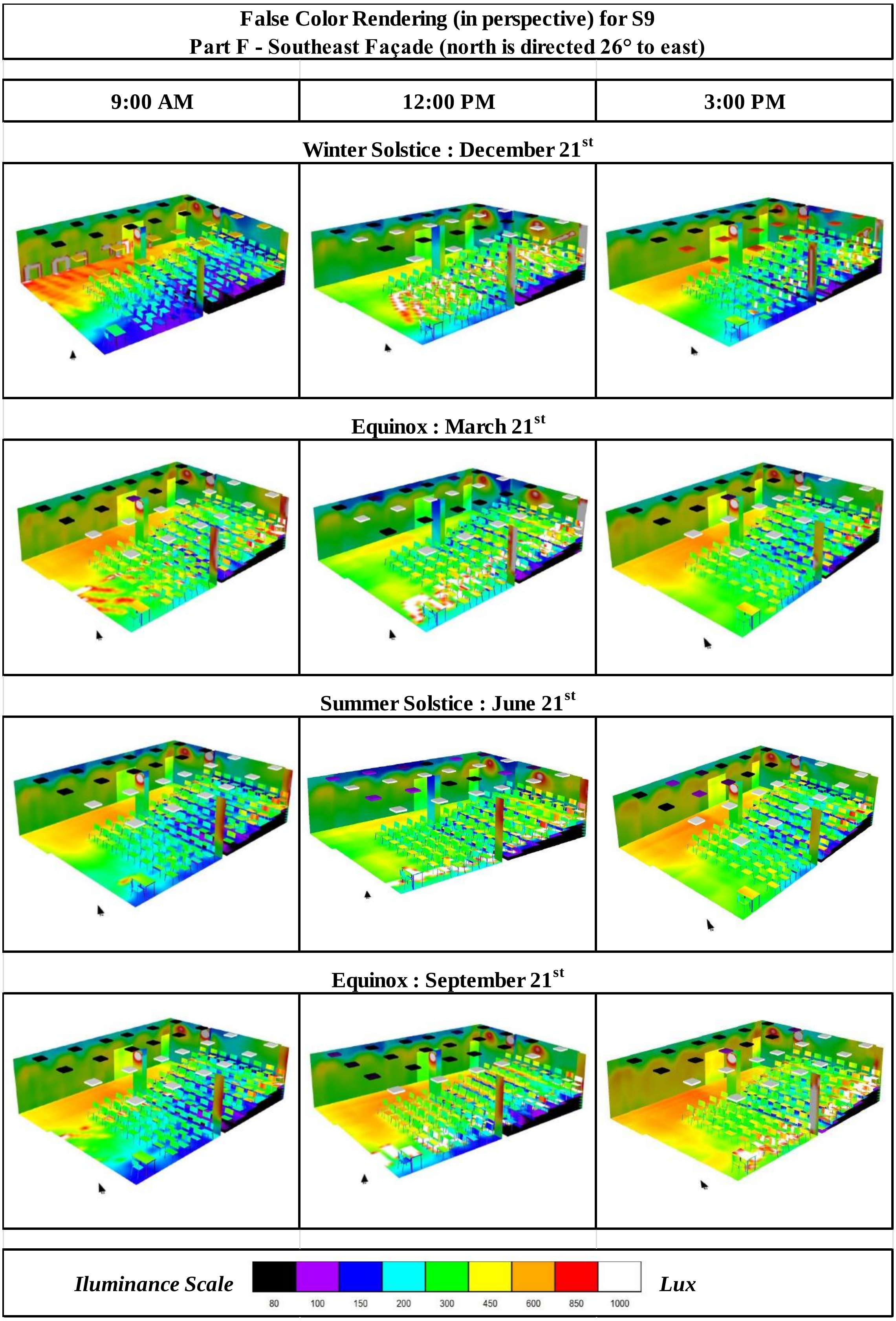


Figure F.8 Part F-False color rendering (in perspective) for retrofitted S9

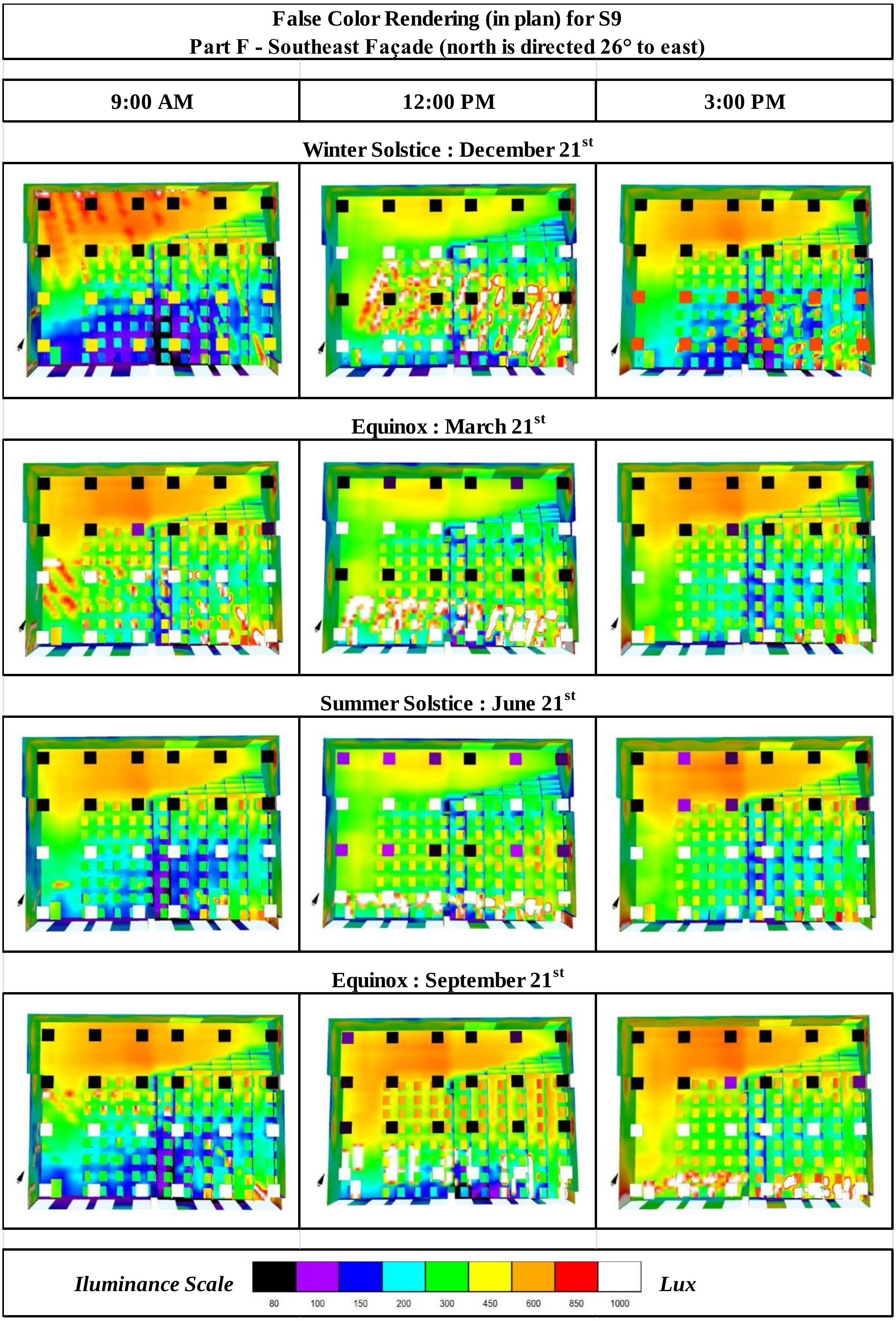


Figure F.9 Part F-False color rendering (in plan) for retrofitted S9

Table F.9 Part F-Comparison of lighting fixture type energy consumption for optimum results of the horizontal shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Horizontal Shading Devices

Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)

SD: Shading Device; Type : horizontal; upper: 6 lower: 6
LL: Lighting Fixture Layout; n: Number of Lighting Row (on)
LT: Lighting Fixture Type;
FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W
LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W
LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day

W/S Solstices & Equinoxes	Hour	ENERGY CONSUMPTION								
		LL	Time h	Floor Area %	S4-FT2 with FL			S8 with LED		
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI
December 21st	9 AM	1	3	25	1260	283.5	2.2	738	166.1	1.3
	12 PM	1	3	25	1260			738		
	3 PM	1	3	25	1260			738		
March 21st	9 AM	2	3	50	2520	378.0	2.9	1476	221.4	1.7
	12 PM	1	3	25	1260			738		
	3 PM	1	3	25	1260			738		
June 21st	9 AM	1	3	25	1260	378.0	2.9	738	221.4	1.7
	12 PM	2	3	50	2520			1476		
	3 PM	1	3	25	1260			738		
September 21st	9 AM	1	3	25	1260	283.5	2.2	738	166.1	1.3
	12 PM	1	3	25	1260			738		
	3 PM	1	3	25	1260			738		
Annual Energy Consumption					**FL**	**1323.0**	**10.3**	**LED**	**774.9**	**6.0**

Table F.10 Part F-Comparison of lighting fixture type energy consumption for optimum results of the vertical shading devices

Comparison of Lighting Fixture Type Energy Consumption for Optimum Results of the Vertical Shading Devices											
Part F - Southeast Façade (north is directed 26° to east) (Room Z06 : h=3.40 m, Area= 128.19 m^2)											
SD: Shading Device; Type : vertical; upper: 4-6 lower: 4-6 LL: Lighting Fixture Layout; n: Number of Lighting Row (on) LT: Lighting Fixture Type; FL : Fluorescent; Luminous Flux: 3834 lm; Power=70 W LED: Light Emitting Diode; Luminous Flux: 3400 lm; Power=41 W LENI: Lighting Energy Numeric Indicator; kWh/(a.m^2) a: annual; p: period; d: day											
W/S Solstices & Equinoxes	Hour	ENERGY CONSUMPTION									
		LL	Time h	Floor Area %	S7-FT3 with FL			S9 with LED			
					Energy Wh	kWh/a p: 75 d a: 300 d	LENI	Energy Wh	kWh/a p: 75 d a: 300 d	LENI	
December 21st	9 AM	2	3	50	2520	567.0	4.4	1476	332.1	2.6	
	12 PM	2	3	50	2520			1476			
	3 PM	2	3	50	2520			1476			
March 21st	9 AM	2	3	50	2520	567.0	4.4	1476	332.1	2.6	
	12 PM	2	3	50	2520			1476			
	3 PM	2	3	50	2520			1476			
June 21st	9 AM	2	3	50	2520	567.0	4.4	1476	332.1	2.6	
	12 PM	2	3	50	2520			1476			
	3 PM	2	3	50	2520			1476			
September 21st	9 AM	2	3	50	2520	661.5	5.2	1476	387.5	3.0	
	12 PM	3	3	75	3780			2214			
	3 PM	2	3	50	2520			1476			
Annual Energy Consumption					FL	2362.5	18.4	LED	1383.8	10.8	

APPENDIX G. ANNEX F. BENCHMARK VALUES AND LIGHTING DESIGN CRITERIA

Table G.1 Annex F. Benchmark values and lighting design criteria (EN15193, 2007)

Annex F
(informative)
Benchmark values and lighting design criteria
Table F.1 — Bench mark default value

	Qual. class	Parasitic Emergency kWh/(m²/year)	Parasitic Control kWh/(m²/year)	PN W/m²	t_D h	t_N h	F_C no cte illiminance	F_C cte illiminance	F_O Manu	F_O Auto	F_D Manu	F_D Auto	no cte LENI Limiting value Manu kWh/(m²/year)	no cte LENI Limiting value Auto kWh/(m²/year)	cte illiminance LENI Limiting value Manu kWh/(m²/year)	cte illiminance LENI Limiting value Auto kWh/(m²/year)
Office	*	1	5	15	2250	250	1	0.9	1	0.9	1	0.9	42.1	35.3	38.3	32.2
	**	1	5	20	2250	250	1	0.9	1	0.9	1	0.9	54.6	45.5	49.6	41.4
	***	1	5	25	2250	250	1	0.9	1	0.9	1	0.9	67.1	55.8	60.8	50.6
Education	*	1	5	15	1800	200	1	0.9	1	0.9	1	0.8	34.9	27.0	31.9	24.8
	**	1	5	20	1800	200	1	0.9	1	0.9	1	0.8	44.9	34.4	40.9	31.4
	***	1	5	25	1800	200	1	0.9	1	0.9	1	0.8	54.9	41.8	49.9	38.1
Hospital	*	1	5	15	3000	2000	1	0.9	0.9	0.8	1	0.8	70.6	55.9	63.9	50.7
	**	1	5	25	3000	2000	1	0.9	0.9	0.8	1	0.8	115.6	91.1	104.4	82.3
	***	1	5	35	3000	2000	1	0.9	0.9	0.8	1	0.8	160.6	126.3	144.9	114.0
Hotel	*	1	5	10	3000	2000	1	0.9	0.7	0.7	1	1	38.1	38.1	34.6	34.6
	**		5	20	3000	2000	1	0.9	0.7	0.7	1	1	72.1	72.1	65.1	65.1
	***	1	5	30	3000	2000	1	0.9	0.7	0.7	1	1	108.1	108.1	97.6	97.6
Restaurant	*	1	5	10	1250	1250	1	0.9	1	1	1	-	29.6	-	27.1	-
	**	1	5	25	1250	1250		0.9	1	1	1	-	67.1	-	60.8	-
	***	1	5	35	1250	1250	1	0.9	1	1	1	-	92.1	-	83.3	-
Sport places	*	1	5	10	2000	2000	1	0.9	1	1	1	0.9	43.7	41.7	39.7	37.9
	**	1	5	20	2000	2000	1	0.9	1	1	1	0.9	83.7	79.7	75.7	72.1
	***	1	5	30	2000	2000	1	0.9	1	1	1	0.9	123.7	117.7	111.7	106.3
Retail	*	1	5	15	3000	2000	1	0.9	1	1	1	-	78.1	-	70.6	-
	**	1	5	25	3000	2000	1	0.9	1	1	1	-	128.1	-	115.6	-
	***	1	5	35	3000	2000	1	0.9	1	1	1	-	178.1	-	160.6	-
Manufacture	*	1	5	10	2500	1500	1	0.9	1	1	1	0.9	43.7	41.2	39.7	37.5
	**	1	5	20	2500	1500	1	0.9	1	1	1	0.9	83.7	78.7	75.7	71.2
	***	1	5	30	2500	1500	1	0.9	1	1	1	0.9	123.7	116.2	111.7	1.5.0

(cont. on next page)

Where LENI = $\{F_c \times P_N / 1000 \times [(t_D \times F_D \times F_O) + (t_N \times F_O)]\} + 1 + \{5/t_y \times [t_y - (t_D + t_N)]\}$ [kWh/(m^2 x year)] (F1)

PN is the installed lighting power density load in the building in W/m²

cte is constant illuminance control system

Manu is manual control lighting system

Auto is automatic control lighting system

Lighting should be designed and installed by following good lighting practices. The lighting design criteria are given in the EN 12464-1 "Lighting of workplaces – Indoor work places" and EN 12193 Sports Lighting. Each of the criteria has to be considered. The lighting design should fulfil the basic lighting requirements. For an improved lighting design, to achieve better comfort conditions, well-being of and acceptance by the user the following three lighting design classes should be considered:

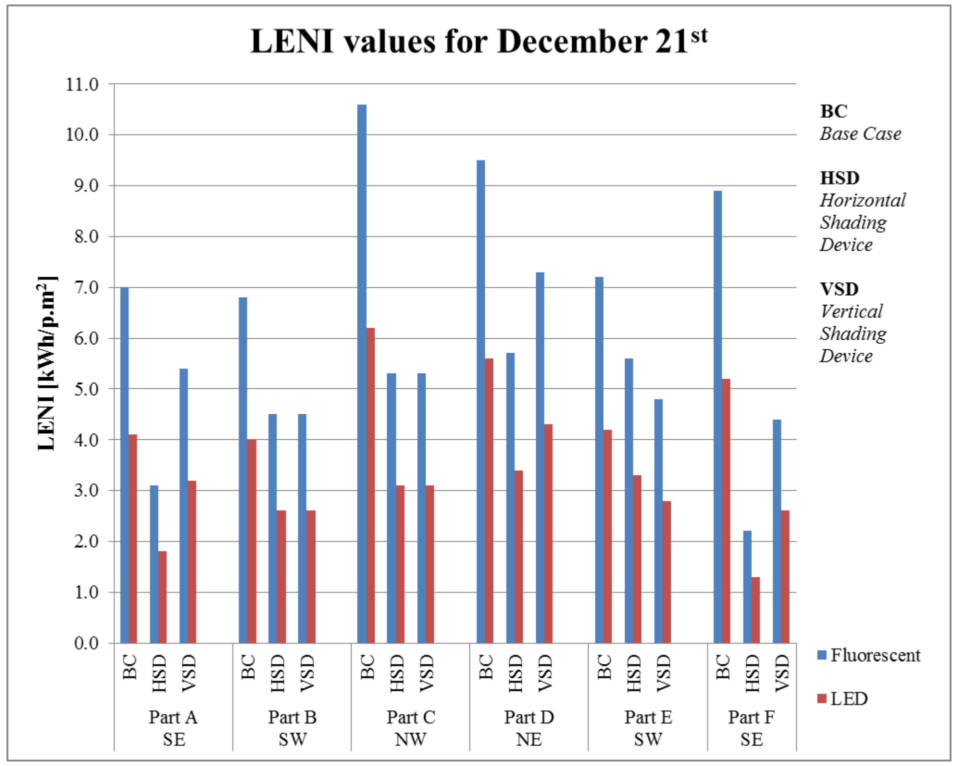
Quality class (Qual. Class)

* basic fulfilment of requirements

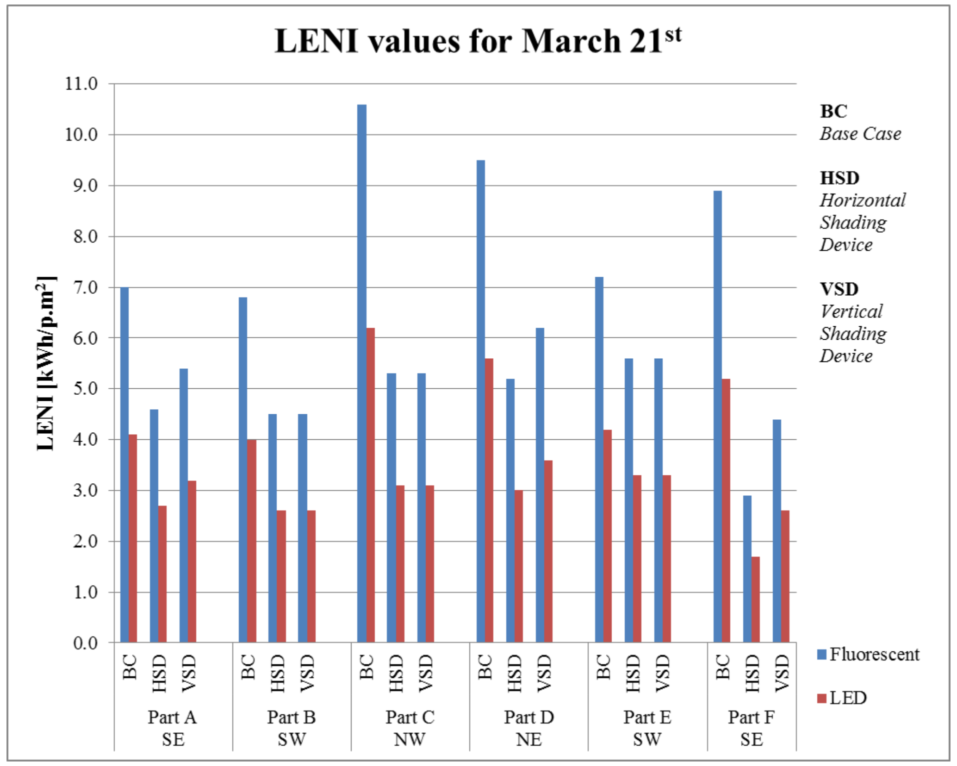
** good fulfilment of requirements

*** comprehensive fulfilment of requirements. The lighting design criteria are listed in Table F2.

APPENDIX H. LENI VALUES FOR ALL PARTS



(a)



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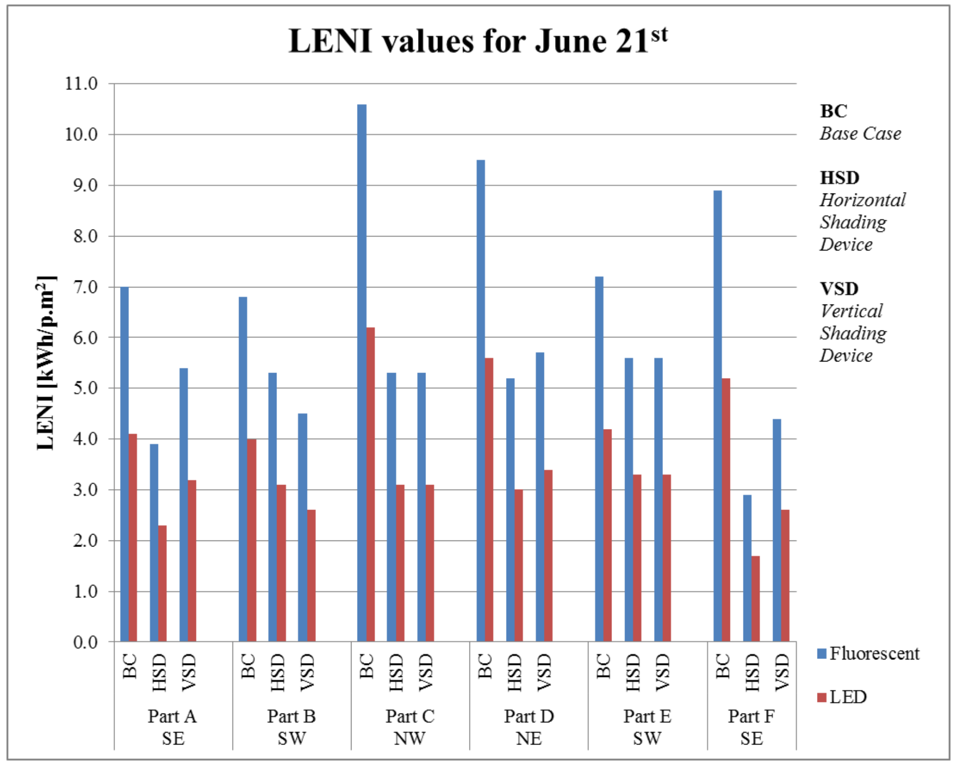

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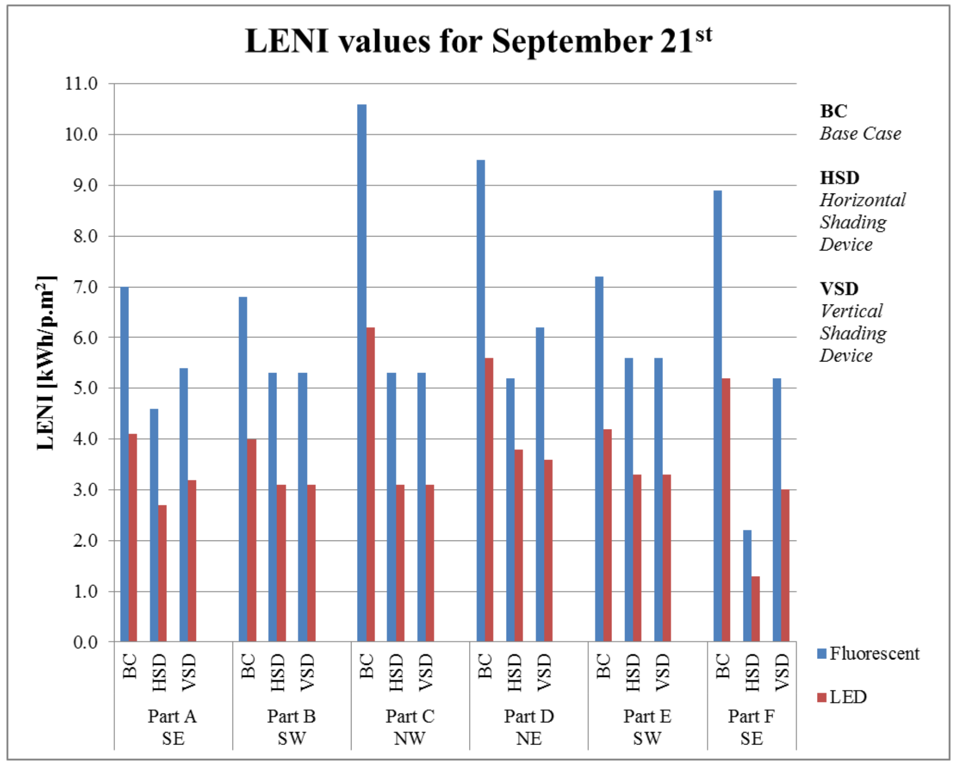

(d)

Figure H.1 LENI Values of all parts for W/S S&E (a-d)

APPENDIX I. ENERGY CONSUMPTION FOR ALL PARTS

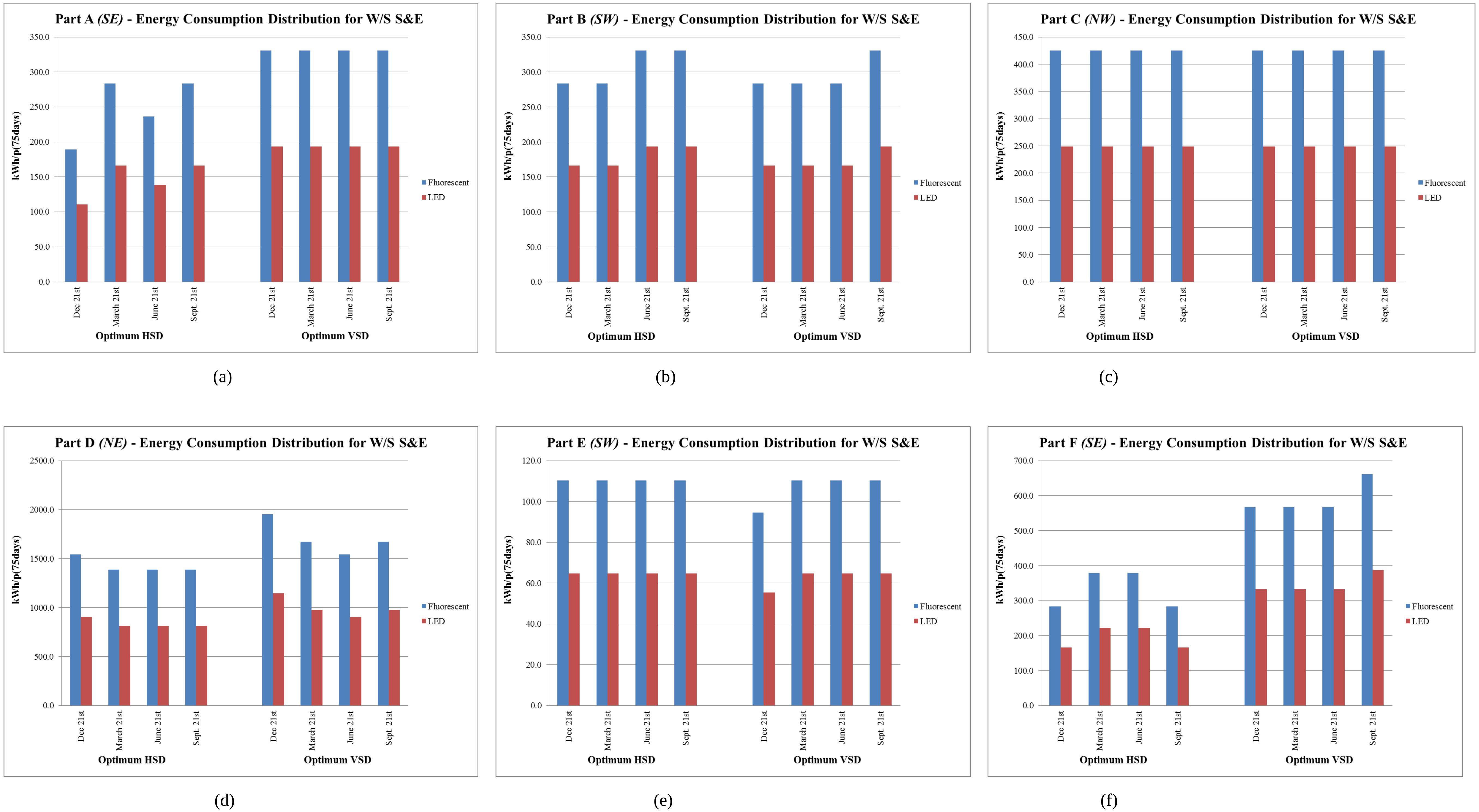

Figure I.1 Energy consumption distribution of W/S S&E for all parts (a-f)

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