THE USE OF ORIGAMI-BASED KINETIC FACADE COMPONENT TO IMPROVE DAYLIGHT PERFORMANCE IN TERMS OF LEED CRITERIA: A CASE OF IZTECH INNOVATION CENTER

A Thesis Submitted to
the Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Architecture

by
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July 2020

İZMİR

ACKNOWLEDGEMENTS

I would like to begin with a major thank to my dear supervisor Prof. Dr. Z. Tuğçe KAZANASMAZ who gave me the chance to work on this study. Thank you for your all supports, kindness and sensibility in the whole thesis process

I also thank to Prof. Dr. Koray KORKMAZ who made major contributions with his consultancy in all parts in the thesis.

I would like to thank to Assist.Prof. Dr.. A. Erdem ÇETİN and Assoc.Prof. Yenal AKGÜN for giving me courage and belief.

My longlasting friend Kaan Tatar who always supports me, thank you for every favour you made even you are far away.

At last but not least my special thanks goes to my parents Lale YASİNCİ and Ali YASİNCİ and Remzi YASİNCİ for their understanding, patience and supports in my education life.

ABSTRACT

THE USE OF ORIGAMI-BASED KINETIC FACADE COMPONENT TO IMPROVE DAYLIGHT PERFORMANCE IN TERMS OF LEED CRITERIA: A CASE OF IZTECH INNOVATION CENTER

Novel solutions in sustainable design due to advancing technology are increased besides bringing new problems. One major problem is originated with the usage of fully-glazed surfaces on the building facade without any justification. Fully-glazed facades may lead to higher energy consumption and visual discomfort. In such office buildings where most of the working time is in the daytime, this situation causes a decreasing in employees' performance and high energy usage.

Kinetic facades have emerged as a design solution to control daylight efficiency. Such adaptive elements with varying geometry and material can be applied to the facade according to the form, orientation, location of the building and the climate of the region. Therefore, the number of such studies must be increased. In this study, a determined part of the origami pattern (chicken wire) that consists of seven joints and six panels with a single degree of freedom as a spherical mechanism for the kinetic facade component was used. The aim is to increase daylight efficiency with three-dimensional shape changes in this kinetic facade in terms of LEED daylight criteria. IZTECH Innovation Center is modelled in Revit apply scenarios including variations of timeline, kinetic facade component's opening angles and material type. The performance of the kinetic facade is evaluated according to illuminance and sDA values calculated. As a result, a direct correlation between the customization of facade elements according to sunlight and daylight usage was observed. Findings provided us a guidance on how to apply the kinetic facade elements according to daylight.

ÖZET

DOĞAL AYDINLATMA PERFORMANSININ LEED ÖLÇÜTLERİNE GÖRE GELİŞTİRİLMESİ İÇİN ORİGAMİ TABANLI HAREKETLİ CEPHE BİLEŞENİNİN KULLANILMASI: İYTE İNOVASYON MERKEZİ ÖRNEĞİ

Gelişen teknolojiye bağlı olarak sürdürülebilir tasarımda yeni çözümlerle birlikle yeni sorunlar artırılmaktadır. Bina cephesinde tamamen camlı yüzeylerin herhangi bir gerekçe olmadan kullanılmasıyla önemli bir sorun ortaya çıkar. Tamamen camlı cepheler daha yüksek enerji tüketimine ve görsel rahatsızlığa neden olabilir. Çalışma süresinin çoğunun gündüz olduğu ofis binalarında, bu durum çalışanların performansında düşüşe ve yüksek enerji kullanımında neden olur.

Kinetik cepheler, gün ışığı verimliliğini kontrol etmek için bir tasarım çözümü olarak ortaya çıkmıştır. Değişen geometri ve malzemeye sahip bu tür uyarlanabilir elemanlar cepheye biçim, yön, binanın yeri ve bölgenin iklimine göre uygulanabilir. Bu nedenle, bu tür çalışmaların sayısı arttırılmalıdır. Bu çalışmada, kinetik cephe bileşeni için küresel bir mekanizma olarak tek bir serbestlik derecesine sahip yedi eklem ve altı panelden oluşan origami deseninin (tavuk teli) belirli bir kısmı kullanılmıştır. Amaç, bu kinetik cephede üç boyutlu şekil değişiklikleri ile LEED gün ışığı kriterleri açısından gün ışığının verimliliğini artırmaktır. İYTE İnovasyon Merkezi Revit'de, zaman çizelgesi, kinetik cephe bileşeninin açılma açıları ve malzeme tipi çeşitlerini içeren uygulama senaryolarında modellenmiştir. Kinetik cephenin performansı, hesaplanan aydınlık ve sDA değerlerine göre değerlendirilir. Sonuç olarak, cephe elemanlarının güneş ışığına göre özelleştirilmesi ile gün ışığı kullanımı arasında doğrudan bir korelasyon gözlenmiştir. Bulgular bize kinetik cephe elemanlarının gün ışığına göre nasıl uygulanacağı konusunda rehberlik sağlamıştır.

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

Figure **Page**

Figure **Page**

LIST OF TABLES

Tables **Page**

Tables **Page**

CHAPTER 1

INTRODUCTION

1.1. Theoretical Background

The excessive depletion of natural resources has been a source of global warming and global pollution. This circumstance led to emerging the term, denominated ‘’Sustainability’’. This term is turned to be as sustainable architecture which finds a way to solve global environmental problems with sustainable remedies in the discipline of architecture. The use of natural light in buildings is one of the major concepts in such a remedy (Komiyama, Hiroshi, and Takeuchi 2013, Inan, Tugba, and Başaran 2017).

Sustainable solutions increase owing to technological developments. Besides the technological development, it brings different environmental problems together. This situation influences architecture as it does in every field. The study focuses on the solution of the problem occurred in terms of technology and aesthetics. The main problem in the research is defects of superabundant dimension glazed surfaces usage in facades without any justification, just applied to give a modern and aesthetic view. This situation causes fully-glazed buildings which receive an extreme amount of daylight. The over-lit fully- glazed building can get more disadvantage than any benefit. Such disadvantages are increasing heating and cooling loads, operating costs, and leading problems in visual comfort conditions. Despite these problems, the number of fully-glazed façades in buildings increase day by day due to this reason such as Visual discomfort, heat loss (Winter condition) , heat load (Summer condition) , fully glazed buildings facades must be designed according to sustainable architecture criteria (Mahmoud, Ahmed, and Elghazi 2016).

There are several certification systems recognized. For instance, LEED, BREAM, and Greenstar are the most known certification systems. These certification systems analyze buildings sustainability rating. The purpose of these certificates is to evaluate the building sustainability. Human health, comfort and energy efficiency are evaluation parameters for these certifications. Lighting is an important topic in these certification systems. LEED daylighting criteria present three options. These options with points are simulation: option1 spatial daylight autonomy and annual sunlight exposure (2–3 points, 1-2 points healthcare) , option2 simulation: illuminance calculations (1–2 points) , option3 measurement (2-3 points, 1-2 points healthcare). Option1; with annual computer simulations that spatial daylight autonomy 300/50% (sDA300/50%) of at least 55%, 75%, or 90% is achieved in regularly occupied floor area. Option2; Illuminance levels are between 300 lux and 3,000 lux for 9 a.m and 3 p.m both on a clear-sky day at the equinox is demonstrated with computer modelling. Rating is made with accomplished by gradually with the percentage of the occupied area provided. Option3; according to illuminance levels between 300 lux and 3,000 lux for the floor area, floor area are measured with 4-month intervals. Rating system is identical with option2 (LEEDV4). Minimum area to comply, Average daylight illuminance (averaged over entire space) , Minimum daylight illuminance at the worst lit point are evaluated in BREAAM. Lux values vary according to the type of building. (BREEAM Hea 01 Visual comfort). Greenstar daylighting criteria is based on ISO 15469:2004 (E) / CIE S 011/E: 2003 Spatial distribution of daylight.

1.2. Problem Statement

Despite maximizing daylight usage is one of the significant topics to design sustainable buildings, it does not mean that using daylight as much as possible with an uncontrollable way is appropriate to achieve sustainability rules in building design. Especially fully-glazed facades in buildings can cause visually uncomfortable interior spaces because of glare in addition to high amounts of cooling loads during summer seasons or even in winter seasons (Altan, Ward, Mohelníková, Vajkay 2008, Yücel, Arıcı Karabay 2011). Nowadays, people spend considerable parts of their lives in office fully glazed facade buildings or fully glazed multi-storey buildings. Although most of the working time is in the daytime one-third of the energy consumption of the offices is spent on lighting requirements (Linhart, Wittkopf and Scartezzini 2010).

In various weathering and lighting conditions, daylight usage can be maximized without any light pollution through the self-adapting facade elements. The facade system must adjust itself according to changing sunlight angle and intensity. It should prevent sunlight or receive sunlight to the interior space, according to lighting criteria. This function makes it the main focus of the dynamic approach and adaptive systems that reconfigure themselves to meet comfort metrics and users' needs in conceiving of an envelope that is multifunctional, responsive and active (Loonen, Trčka, Cóstola and Hensen 2013, Favoino et al,: 2016).

1.3. Purpose of the Study

The main purpose of the study is to test an innovative design approach in a fully-glazed facade building to improve daylight efficiency. Iztech is designated as a case study for this research. The simulation method is implemented in the building according to several variations as a timeline, kinetic facade component's bending angles, material type and orientation. The facade proposal's layouts were determined according to these variations. In addition to the facade layouts performance is calculated according to sDA and illuminance level. The results are evaluated according to LEED lighting criteria.

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1.4. Structure of the Study

The definition of the problem and the solutions that are mplemented against it are mentioned briefly. The first chapter of the thesis consists of introduction which gives brief information about fully glazed facades, problem statement which includes the effect of the fully glazed facades and purpose of the study that explains the importance of the study.

Firstly, the development of the fully glazed facade is mentioned, then the effect of the fully glazed facades is explained with details in chapter two. It is explained how daylight usage should be according to sustainable certificate systems. Then mechanisms are described. It is explained how mechanisms are applied to the kinetic facade with case studies.

Chapter 3 includes the construction phase of the kinetic module, the features of the current building and the problem of sun exposure. Modelling phase in Revit is explained in detail.

Chapter 4 consists of 4 phases of anlyszes to achieve optimum daylight performance according to LEED criteria. Effects of opening angle and material used in the component are analyzed. It is aimed that achieve 2 points with the optimum pattern shaped according to analyzes.

The last chapter gives brief information about whole thesis. Results in chapter 4 are evaluated. According to the evaluation, the conclusion is drawn about which topics should be studied for the development of the thesis.

CHAPTER 2

ADAPTIVE FACADE DESIGN

Increasing transparency trend in architecture has caused problems, especially in the facade. This situation led to higher energy consumption, visual and thermal comfort challenges. Meeting these challenges became a starting point of adaptive facades (Bedon et al.: 2019). The “adaptive” meaning in this term is the capability to interact with the environment. Adaptive facades adjusted mechanically or chemically supply energy saving and thermal, visual comfort (Attia 2017).

2.1 Development Fully Glazed Facades in Buildings

The facade is a complicated envelope between the inside of buildings and the environment. The main function of the facade is proving quality interior conditions against several climates variations and external effects (Herzog, Krippner, Lang 2004). Fully glazed facade design beginning is considered with Chrystal Palace in 19 centuries. The use of glass on high building facades provides reducing the load on the carrier system and the building cost. For this reason, glass usage on facade played an essential role in high rise buildings (Bal 2003). Today, glazed facade as a dominant architecture trend aims more aesthetic construction and to bring more daylighting, though these openings or transparent areas of the construction receive a superabundant amount of daylight. This condition may cause heating and lighting discomfort (Altan, Ward, Mohelníková, Vajkay 2008).

2.2. The Usage and Defects of Fully Glazed Facade

Nowadays, people suppose that glass facades that have become an architectural trend provide high interior quality. (Touma, Ouahrani 2017) Fully glazed facade enhances the aesthetic of the structure. Large glazing areas in the facade is suitable for receiving more daylight, although this situation leads to increased energy requirements for providing thermal comfort (Touma, Ghali, Ghaddar, Ismail 2016). Fully glazed facades allow as much daylight indoors as possible. Although fully glazed facades are convenient to use daylight, this situation may cause visual discomfort.

2.2.1. Glare and Unexpected Reflections

In a fully glazed facades window to wall ratio is maximized as much as possible. Though maximizing window-to-wall ratio with fully glazed facades provides positive effects of daylight, this subject may lead to problems that distort visual comfort, such as glare caused fatigue for people. Glare reduces vision and causes eye symptoms (Glimne and Österman 2019).

According to Society of North America (IESNA, 2000) , glare caused visual discomfort and low visibility, is defined as high shining higher than from the adaptation of the eye within the visual field leads. Glare divided into two types as discomfort glare and disability glare. Disability glare that reduces eye contrast sensitivity with extensive light above the adaptation level of eye is the effect of stray light. When disability glare occurred, visual awareness of occupants reduction is observed. Occupants may react like trying to shade interior for that reason (Osterhaus 2005). Discomfort glare effects visual performance that defined as speed and accuracy of visual task. In an environment where discomfort glare is high, the blink rate reduction (one of the characteristics of fatigue) is was observed (Hamedani et al.: 2020). Discomfort glare is one of the key points to be considered for the performance of occupants focused on high visual demand tasks. Daylighting usage provides increment cognitive performance and eyestrain reduction while the wrong usage of daylight causes eyestrain and discomfort from glare. (Jamrozik et al.: 2019).

2.2.2. Heat Abduction and Transmission

The facade that serves as separators between the interior and exterior of the building plays a crucial role in thermal comfort. The rise in the use of fully glazed facades without considering environmental conditions increases the energy consumption for heating or cooling. Fully glazed facades are insufficient to supply thermal comfort against changing climatic conditions. (Altan, Ward, Mohelníková, Vajkay 2008).

Glazed surface increases the energy consumption for thermal comfort because of its thermophysical properties are not convenient to provide thermal comfort (Touma, Ouahrani 2017). Increasing glazing surfaces on facade causes additional heat load in winter and cooling load in summer (Yücel, Arıcı Karabay 2011). The space load occurred by glazed surface divide into groups as radiation and solar absorption. The radiation is transmitted by the glazed surface through to the interior space. It causes to increase in the cooling load. Besides this, absorbed solar radiation increases the temperature on a window or glass surface. This way, a situation that threatens the thermal comfort occurs (Touma, Ghali, Ghaddar and Ismail 2016). Disadvantages caused by all thermophysical properties of glass, besides there is also the problem of heat leakage from the joints. Air leaky joints on the window cause heat abduction.

2.2. Daylighting Criteria in Existing Sustainable Certificate Systems

Due to the development of industrialization and the increase in population, natural resources have been polluted and decreased. Since the continuity of this situation is not possible for humanity, the concept of sustainability was born. The emergence of timber scarcity as an effect of the rapid depletion of natural resources in the industrial revolution enabled the concept of sustainability to be addressed for the first time. Sustainability called the ability to be permanent was emerged by World Commission on Environment and Development (WCED) with Brundtland Report titled “Our Common Future” in 1987. The emergence of timber scarcity as an effect of the rapid depletion of natural resources in the industrial revolution enabled the concept of sustainability to be addressed for the first time. This Uncontrolled and unlimited usage of natural resources has led to the destruction or reduction of natural resources. This issue caused global warming, climate change, and pollution of air-soil resources (Şen, Kaya, Alpaslan, 2018 and Bozlağan 2015).

The construction sector has a great impact on the environment as well as the economic impact, thus buildings directly affect the environment and global warming. For a sustainable future, the aim should be to reduce or eliminate the negative impact of buildings on the environment. Besides, the economic and social aspects of buildings should be taken into consideration. Social, environmental and economic in the construction industry should not be ignored (Asman, Kissi, Agyekum, Baiden, Badu

2019). Within this scope, green buildings term has emerged. Green building design provides sustainable solutions without harm to nature as energy efficiency, water conservation and healthy space experience (Erlalelitepe, Gökçen, Kazanasmaz 2011).

With starting the development of green buildings process, assessment tools and grading system for green buildings has occurred, thus many green rating tools around the world came into operation. The first of these green rating tools is Building Research Establishment Environmental Assessment Method (BREEAM) in 1990 England. The second of green rating tools was published Leadership in Environmental and Energy Design (LEED) US Green Building Council (USGBC). After these two green rating tools, many green building assessment tools like CASBEE (Japan, since 2001) , Green Star (Australia, since 2003) , Green Mark Scheme (Singapore, since 2005) , ASGB (China, since 2006) are used widely as a green building rating system (Illankoon, Tam, Le, Shen 2017 and He, Kvan, Liu, Li 2018). Although all green rating tools aim the same fundamental to reach a sustainable future, there are varieties in credit precedence and scores according to the social, economic and environmental conditions of the regions where the green rating tools are located (Varma, Palaniappan 2019).

2.2.1. The Usage of Daylighting

Daylighting is one of the potential passive strategies to improve energy performance and users visual comfort in existing offices without expensive installation (Lim, Kandar, Ahmad, Ossen, Abdullah 2012) and also, daylight provides a better perception of objects and better colour rendering. Beside of these daylighting provides circadian rhythms that reinforce psychological benefits and usage of daylighting improve work efficiency for personnel (Boubekri 2008). For employees who spend most of their time in the office, daylighting performance is an important topic.

As mentioned in the book written by Boubekri in 2008, after the energy crisis of 1973, the principles of passive solar design, which use less energy for lighting and use it as an alternative source in daylight, were emerged. Light affects the retina of our eyes and in this way, our visual system affects our metabolism and endocrine systems. This situation gives people psychological resistance to anxiety and depression. In addition to this, daylighting improves working and learning efficiency. In addition to its psychological effects, daylight is indirectly a solution against heart and bone diseases.

Today, glass surfaces are an important element in building design, even fully glazed facades, which consist entirely of glass surfaces, are frequently encountered (Touma and Ouahrani 2017). These large glazing facades allow natural lighting and improve a building in the aesthetical aspect (Touma, Ghaddar, Ghali and İsmail 2016). This situation provides a hundred percentage or close to a hundred percentage window-wall ratio. Fully glazed facades allow as much daylight indoors as possible. Though maximizing window-to-wall ratio provides positive effects of daylight, this subject may lead to problems that distort visual comfort, such as glare caused fatigue for people. Glare reduces vision and causes eye symptoms (Glimne and Österman 2019). High-rise fully glazed towers, becoming the dominant architectural typology for new buildings in the Middle East countries, building raises major visual and thermal disturbance problems caused by solar radiation (Giovannini, Verso, Karamata, Andersen 2015).

2.2.2. LEED Criteria

LEED the most globally accepted (Leadership in Energy and Environmental Design) standards are the most widely used green building rating system in the world. The aim of this green rating system is to constituting healthier and sustainable buildings without harm to people and nature. LEED provides a work pattern for building owners, operators and design team to guide with a scheme based on implementing practical and measurable green building design, construction, operation (Majumda 2019, Kriss 2014) (http://leed.usgbc.org/leed.html). In LEED V4 credits are evaluated eight categories as (i) Location and Transportation, (ii) Sustainable Sites, (iii) Water Efficiency, (iv) Energy and Atmosphere, (v) Materials and Resources, (vi) Indoor Environmental Quality,(vii) Innovation and (viii) Regional Priority. In total it contains 110 points that can potentially be received with all these categories. The daylighting criteria of the LEED are located in the Indoor Environmental Quality section (https://www.usgbc.org/resources/leed-v4-building-design-and-construction-current-version).

The daylighting criteria of the LEED are located in the Indoor Environmental Quality section. Providing sufficient daylighting brings lots of benefits such as a reduction in electric consumption, enhancing productivity, reducing lethargy and depression. The daylighting criteria intend to reduce electrical lighting, provide positive effects of daylighting and make a connection between the interior and outdoor. The daylighting quality has standards in LEED criteria. This credit based on simulation usage for daylight analysis and measurement for estimating daylight quality.LEED tenders 3 options as (i) Simulation Spatial Daylight Autonomy and Annual Sunlight, (ii) Simulation Illumance Calculations, (iii) Measurements to evaluate the daylighting quality (LEED BD+C V4 Reference Guide).

Option1 (Simulation Spatial Daylight Autonomy and Annual Sunlight) demonstrates the percentage of Spatial Daylight Autonomy (sDA 300/50%) with computer simulation in the regularly used floor areas. Spatial daylight autonomy (sDA) is defined as a percentage of analyzed area procured minimum daylight illuminance level in specified part annual working time (Reinhart and Walkenhorst, 2001). Annual sunlight exposure (ASE) is a percentage of analysis that described as the analyzed area receives direct sunlight more than accepted hours per year (Illuminating Engineering Society). The sDA and ASE calculation grids should be no more than 2 feet (600 millimeters) square and work plane height is 30 inches (76 millimeters) above the floor. According to the percentage of sDA credit points are given as 2 points for 55 % and 3 points for 75% in new construction, core and shell, schools, retail, data centers, warehouses and distribution centers, hospitality. In Healthcare %75 is 1 point, %90 is 2 points. The distribution of points is demonstrated in Table 2.1.

Option 2 (Simulation Illuminance Calculations) demonstrates illuminance levels between 300 lux and 3,000 lux levels at 9 a.m. and 3 p.m at the equinox on a clear sky. Option 2 uses meteorological year data for the nearest result. Percentage of regularly occupied floor area is a parameter for categories as new construction, core and shell, schools, retail, data centers, warehouses and distribution centers, hospitality. In healthcare, the percentage of the perimeter floor area is a parameter for evaluating points in LEED criteria. The distribution of points for option 2 is demonstrated in Table 2.2.

Option3(measurement) : In determined two months that displayed in Table 2.3, illuminance levels between 300 lux and 3,000 lux are measured for the working area. 10 foot (3 meters) square grid is used for working spaces larger than 150 square feet (14 square meters). Maximum 10 foot (900 millimeters) square grid is used for 150 square feet (14 square meters) or less working spaces. The distribution of points is demonstrated in the table3 for option3 (LEED BD+C V4 Reference Guide). The distribution of points for option 3 is demonstrated in Table 2.4.

Table 2.1. The distribution of points in option 1.

New Construction, Core and Shell, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality		Healthcare	
Percentage of regularly occupied floor area	Points	Percentage of regularly occupied floor area	Points
55%	2	75%	1
75%	3	90%	2

Table 2.2. The distribution of points in option 2.

New Construction, Core and Shell, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality		Healthcare	
Percentage of regularly occupied floor area	Points	Percentage of regularly occupied floor area	Points
75%	1	75%	1
90%	2	90%	2

Table 2.3. Timing of measurements for illuminance.

If first measurement is taken in …	take second measurement in …
January	May-September
February	June-October
March	June-July, November-December
April	August-December
May	September-January
June	October-February
July	November-March
August	December-April
September	December-January, May-June
October	February-June
November	March-July
December	April-August

Table 2.4. The distribution of points in option 3.

New Construction, Core and Shell, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality		Healthcare	
Percentage of regularly occupied floor area	Points	Percentage of regularly occupied floor area	Points
75%	2	75%	1
90%	3	90%	2

2.2.3. BREEAM Criteria

BREEAM (Building Research Establishment Environmental Assessment Method) published in 1990 is the first environmental certification system in the world. Breeam aims to promote high-performance projects and support for inspiring work for the future with rewarding the sustainability of the project. It consists of 10 categories: Management, Health and Wellbeing, Energy, Transport, Water, Materials, Waste, Land Use and Ecology, Pollution and innovation (BREEAM UK New Construction 2018).

The daylighting criteria are located in Hea 01 Visual comfort, the first section of Health and Wellbeing. The visual comfort criteria aim to enhance the positive effects of sunlight and reduce artificial light usage. Hea 01 Visual comfort criteria are divided into four parts as (i) Control of glare from sunlight, (ii) Daylighting, (iii) Viewout, (iv) Internal and external lighting levels, zoning and control. There are three options for evaluating daylight criteria. The first one uses the daylight factor for evaluating daylight criteria. According to the first option, %2 daylight factor must be met for education buildings, healthcare buildings, multi-residential buildings, office buildings, crèche buildings, courts, industrial and other building types. These requirements vary in prison buildings and sales areas. The minimum areas percentage that provides %2 daylight factor is %80. This condition changes in sales areas to %35. Credits vary according to building types and usage. In the second option, the illuminance level is used in for the working area. The average illuminance and minimum percentage area to comply is represented in the table4. The third option is only used as an alternative way in health facilities. Conditions as %80 minimum complied area, %2 median daylight factors and %0,6 minimum daylight factors should be met for 1 credit. To get 2 points, the median daylight factor should be increased from %2 to %3 and the minimum daylight factor from %0,6 to 0,9 in public areas and consulting rooms (BREEAM UK New Construction 2018).

Table 2.5. Requirements and credits of BREEAM daylighting creteria in option2.

Area Type	Credits	Minimum area to comply	Average daylight illuminance	Minimum daylight illuminance at worst lit point
Education buildings				
Preschools, schools, further education-occupied spaces	2	80%	At least 300 for 2000 hours per year or more	At least 90 lux for 2000 hours per year or more
Higher edcuation-occupied spaces	1	60%	At least 300 for 2000 hours per year or more	At least 90 lux for 2000 hours per year or more
OR Higher education-occupied spaces	2	80%	At least 300 for 2000 hours per year or more	At least 90 lux for 2000 hours per year or more
Healthcare buildings				
Staff and public areas	1	80%	At least 300 for 2000 hours per year or more	At least 90 lux for 2000 hours per year or more
Occupied patiens areas and consulting rooms	1	80%	At least 300 for 2000 hours per year or more	At least 90 lux for 2000 hours per year or more
Staff and public areas	2	80%	At least 300 for 2650 hours per year or more	At least 90 lux for 2650 hours per year or more
Occupied patiens areas and consulting rooms	2	80%	At least 300 for 2650 hours per year or more	At least 90 lux for 2650 hours per year or more
Multi residential buildings				
Kitchen	2	100%	At least 100 for 3450 hours per year or more	At least 30 lux for 3450 hours per year or more
Living rooms, dining rooms, studies	2	80%	At least 100 for 3450 hours per year or more	At least 30 lux for 3450 hours per year or more
Non-residential or comunal occupied spaces	2	80%	At least 200 for 2650 hours per year or more	At least 60 lux for 2650 hours per year or more
Retail buildings				
Sales areas	1	35%	At least 200 lux point daylight illuminances for 2650 hours per year or more	
Other occupied areas	1	80%	At least 200 lux for 2650 hours per year or more	At least 60 lux for 2650 hours per year or more
Prison buildings				
Cells and custody cells	2	80%	At least 100 lux for 3150 hours per year or more	N/A
Internal association or atrium	2	80%	At least 300 lux for 2650 hours per year or more	At least 210 lux for 2650 hours per year or more
Patient care spaces	2	80%	At least 300 lux for 2650 hours per year or more	At least 210 lux for 2650 hours per year or more
Teaching, lecture and seminar spaces	2	80%	At least 300 lux for 2000 hours per year or more	At least 90 lux for 2650 hours per year or more
Office Buildings				
All occuppied spaces, unless indicated in Daylighting - relevant building areas	2	80%	At least 300 lux for 2000 hours per year or more	At least 90 lux for 2000 hours per year or more
Creche buildings				
All occuppied spaces, unless indicated in Daylighting - relevant building areas	2	80%	At least 300 lux for 2000 hours per year or more	At least 90 lux for 2000 hours per year or more
Courts, Industrial and All other building types				
All occuppied spaces, unless indicated in Daylighting - relevant building areas	1	80%	At least 300 lux for 2000 hours per year or more	At least 90 lux for 2000 hours per year or more

2.2.4. Green Star Criteria

Green Star lunched by Green Building Council of Australia GBCA evaluates the environmental contribution of the design. Green star has 100 points that distributed between eight categories. The project in Green Star is evaluated from one to six stars. One to six stars illustrate respectively, minimum practice, average practice, good practice, best practice, Australian excellence and world leadership (Mattoni et al .: 2018).

Daylighting criteria in visual comfort part of the Green Star aims to at least %50 accessing daylight. There are three options to evaluate daylighting. The first option includes manual calculations to estimate daylight utilization. In this calculation, glazed area overshadowing is negligible and calculations should be made for each space. The second option is based on the daylight factor. In 50% of the occupied area, the daylight factor must be at least 2,0%. Daylight autonomy is used in the third option with using a simulation model. At least 160 lux is met in the occupied area for 80% of the standard usage time. All of these options provide 1 point. Enhancing points is achievable with an increasing percentage of the occupied area. %60 of the occupied area and %90 of the occupied area provides respectively 2 points and 3 points (Green Star IEQ Visual Comfort Draft V0.0 2014, Hraška 2011).

2.2.5 CASBEE Criteria

CASBEE published in japan is an assessment tool for rating environmental performance of the building. Assessment in CASBEE is divided into one to five levels. Minimum requirements achieving is demonstrated with the one-level assessment. As requirements are met in CASBEE, the level increases. Buildings are evaluated as excellent. (S) , very good (A) , good (B*) , fairly poor (B-) and poor (C) according to their grade (CASBEE for Cities 2012 edition).

The daylighting criteria of CASBEE are evaluated in the third section (lighting and illumination) of Environmental quality of building. The daylighting evaluation is based on daylight factor measurements, opening orientation and daylighting devices. The daylight factor requirements for each level and building types is demonstrated in table5. The opening orientation credits follows as level 1 no south faced opening, level

2 no corresponding level, level 3 south faced opening, level 4 no corresponding level, level 5 east and south faced opening. A daylighting device is a tool that enhances productivity such as light shelves, light duct or the optical fibre. The evaluation of daylighting devices is illustrated in table6 (CASBEE for Building 2014 edition).

Table 2.6. The daylight factor requirements and levels of CASBEE daylighting creteria.

Entire Building and Common Properties			
	Offices, School, Factories, Hospitals, Hotels, Apartments		
Building Type	Daylight Factor (DF)		
Level 1	DF<1.0%		
Level 2	1,0%≤DF<1,5%		
Level 3	1,5%≤DF<2,0%		
Level 4	2,0%≤DF<2,5%		
Level 5	2,5%≤DF		
Residential and Accommodation Sections			
	Hospitals, Hotels		Apartments
Building Type	Dayligh Factor (DF)		Dayligh Factor (DF)
Level 1	DF<0,5%		DF<0,5%
Level 2	0,5%≤DF<0,75%		0,5%≤DF<0,75%
Level 3	0,75%≤DF<1,0%		0,5%≤DF<0,75%
Level 4	1,0%≤DF<1,25%		0,5%≤DF<0,75%
Level 5	1,25%≤DF		2,0%≤DF

Table 2.7. Assessment criteria of daylighting devices.

Entire Building and Common Properties			
Building Type	Offices, School Factories		Retailers, Restaurants, Hotels, Hospitals, Apartments
Level 1	(No corresponding level)		(No corresponding level)
Level 2	(No corresponding level)		(No corresponding level)
Level 3	There are no daylight devices.		There are no daylight devices.
Level 4	There is one type of daylight device.		(No corresponding level)
Level 5	There are two or more types of daylight devices or they have advance function.		There are some daylight devices.
Residential and Accommodation Section			
Building Type	Hospitals, Hotels, Apartments		
Level 1	(No corresponding level)		
Level 2	(No corresponding level)		
Level 3	There are no daylight devices.		
Level 4	(No corresponding level)		
Level 5	There are some daylight devices.		

2.3. Definition of Kinetic Facade Mechanics and Mechanisms

Facade elements such as window sashes and doors are the earliest moving elements that have been applied and shaped the shell in the past (Ramzy and Hayed 2011). Nowadays, the kinetic facade is called a building envelope that interacts physically and visually with the environment made of moving surfaces (Moloney 2011). The role of the facade has developed the role as a more compatible from environmental effect with kinetic facades. This way kinetic facades provide energy usage reduction and higher interior quality (Alotaibi 2015). Five design strategies (1.design generation, 2.mechanism, 3.rationalization, 4.materialization and 5.management) are available for kinetic facades for increasing efficiency as much as possible. In the first one, morphological aspects and intended architecture requirement are investigated. The second strategy is based on the investigation of mechanisms on how the requirements supported. The third strategy is a process that includes the requirement of the kinetic facade are met or not. The fourth strategy includes decisions in the implementation process. The fifth strategy works about providing safety and sustainability all along kinetic facade usage time (Megahed 2016). Kinetic facades include mechanisms. The mechanism is called as composition from gears cams and linkages, besides it generally includes other parts as brakes, springs, and clutches (McCarthy and Gim Song 2011). Mechanisms that ensure mobility of the kinetic facade can be divided into three groups as planar, spherical and spatial according to their character of motion (Tsai 2001).

2.3.1. Planar Mechanism

Planar mechanisms can be generated two types of motion in 2-dimension. Bar, cam or gear links can be part of this mechanism. A planar mechanism that provided planar motion is a mechanism which all the moving links move in one plane as indicated in Figure 2.1. Planar mechanisms that operate just lower pair joints are named as planar linkages (Tsai 2001). Planar linkages have the feature that all parts in this linkage have motion in parallels planes. Joints compatible with this motion are prismatic joints that move in parallel lines, revolute joints that have axes perpendicular to the plane, and lines of actions parallel to the plane of gears and cams (McCarthy and Gim Song 2011).

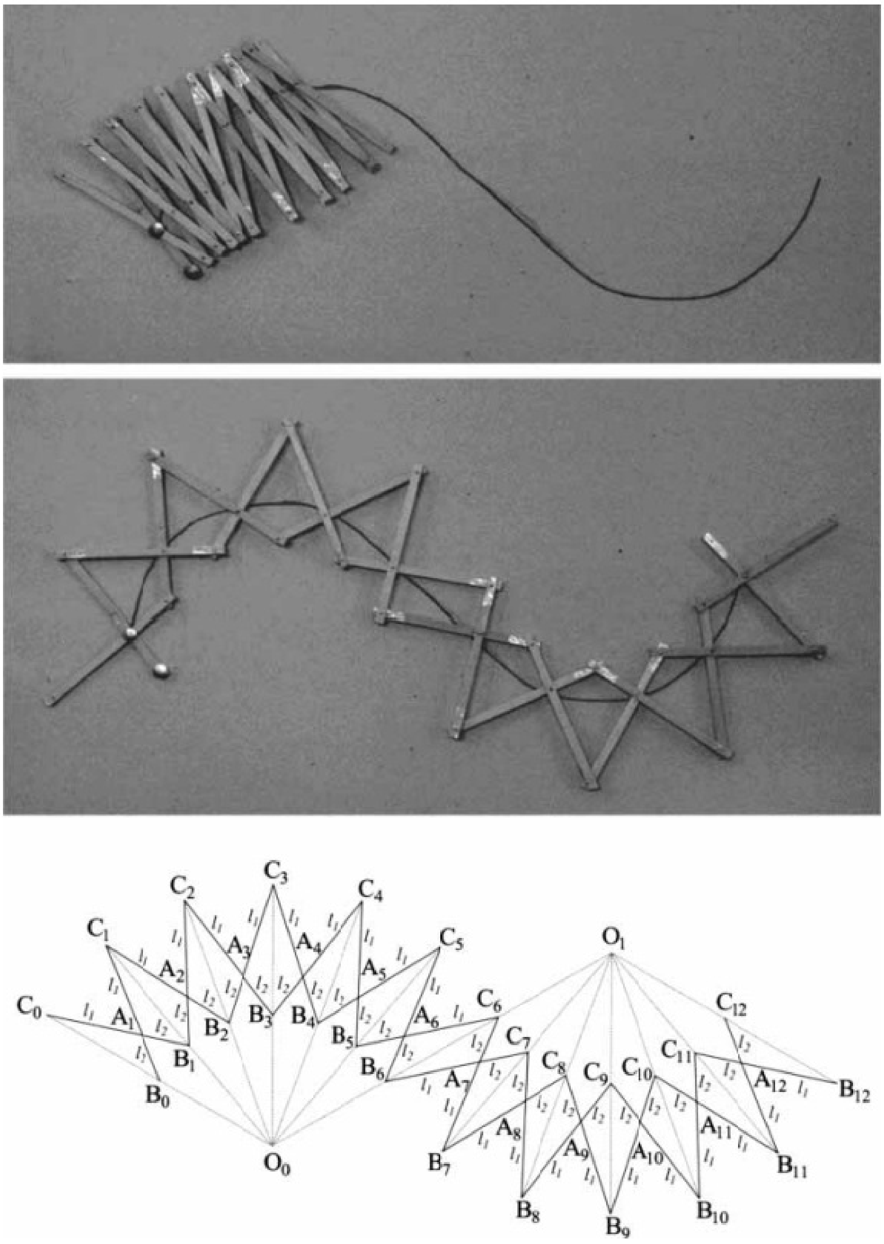


Figure 2.1.Planar mechanism.
(Source: Maden, Korkmaz and Akgün 2011)

2.3.2. Spherical Mechanism

The spherical mechanism that presents 3 types of motion as rotations in 3 direction is a mechanism which all the moving links perform in the centric spherical center (Tsai 2001). Spherical mechanisms operate with spherical linkages. In spherical linkages, all links are delimited to rotate about the same fixed point. Location points of each link lean on this orbit centred spherical center (McCarthy and Gim Song 2011).

The distance between all location points of each link and center point is equal. Spherical mechanisms provide occasions for kinetic structure design, in addition, spherical mechanisms are convenient for kinetic structure inspired by origami. In this study, a component consisting of two co-acting spherical mechanisms was selected. Three positions of a four-bar spherical mechanism model are indicated in Figure 2.2. As demonstrated in Figure 2.2, the axis of all revolute joints concur at a mutual point. The usage of the spherical mechanism in architecture is indicated in Figure 2.3 as kinetic sun shading component of Al-Bahr Tower.

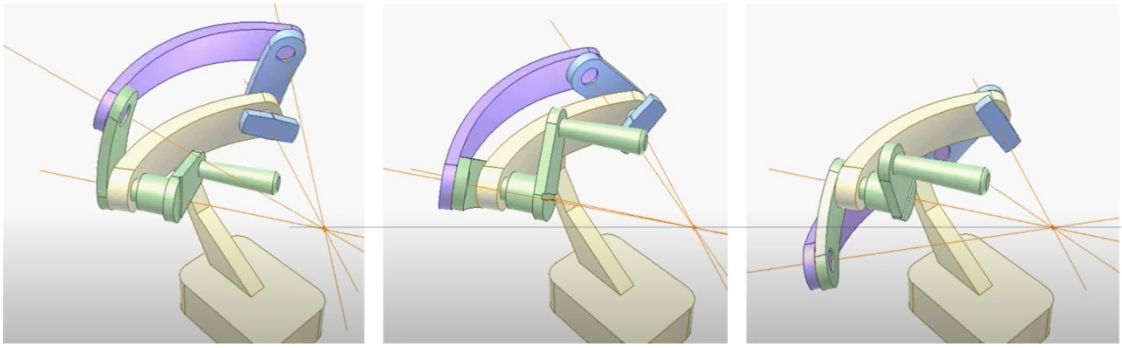


Figure 2.2.Three positions of four-bar spherical mechanism model.
(Source: Url1)

Figure 2.3.Spherical mechanism usage as sun shading component.
(Source: Url2)

2.3.3. Spatial Mechanism

The spatial mechanism is a mechanism that moves spatially. If the motion of the mechanism is not spherical or planar it is named as spatial motion, thus he spatial motion can not be classified as spherical or planer. Although spatial mechanism differs from the spherical or planar mechanism, the spatial mechanism may have links that work as a planar motion in a non-parallel plane to another link that works as a planar motion.

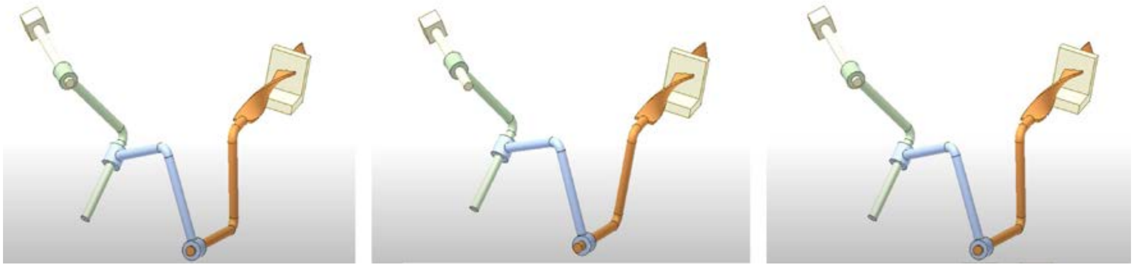


Figure 2.4.Three positions of four-bar spatial mechanism model.
(Source: Url3)

2.4. Definition of Adaptive Facade

The adaptation can be defined as a variance process to ensure better conditions in its life cycle. With the development of technology, the adaptation term reflected in the architecture. This situation became a starting point of the adaptive facade. The adaptive facades work as a moderator like how human skin reacts from exterior conditions. Adaptive facades can provide control of daylighting, ventilation, noise, thermal mass and humidity. This way, kinetic facades ensure higher interior comfort and reduction on energy consumption. The solar radiation that affects directly the visual quality and indoor temperature is a primary issue to take into consideration for adaptive facade design (Romano, Aelenel, Aelenei, Mazzucchelli 2018, Loonen, Martinez, Facoino, Brzezicki, Ménézo, La Ferla, Aelenei 2015 and Aelenei, Aelenei, Vieira 2016).

2.5. Implementing Mechanisms for Adaptive Facade Modules

Kinetic facades consist of mechanisms that provide motion in the facade. Motions as folding, scaling, sliding, rotating in the facade, is achievable with these mechanisms. These mechanisms have capabilities to adjust dynamic daylighting in real-time changing shapes. Parametric design is an available design tool for detecting optimal form or variation in the design process of kinetic facades (Hosseini et al.: 2019, Hosseini, Mohammadi, Santin, 2019). The parametric design formulates the geometric relation between design elements with parameters. Changing or reformulating parameters occur in new geometry (Eltaweel, SU 2017).

For instance, Al Bahr tower one of the most iconic facades for kinetic architecture is covered by triangular solar screens. These facade elements optimize solar exposure with folding motion like origami umbrellas. When direct sunlight access, the kinetic facade component inspired by the traditional Islamic object the “Mashrabiya”, turns into its unfolded form. This way, the building is protected from direct sunlight effects with control software. The kinetic facade module consists of 14 components (Figure 2.5). The kinetic facade module works as a linkage mechanism by power comes from the actuator according to data come from software (Attia 2017, Karanouh, Kerber 2015).

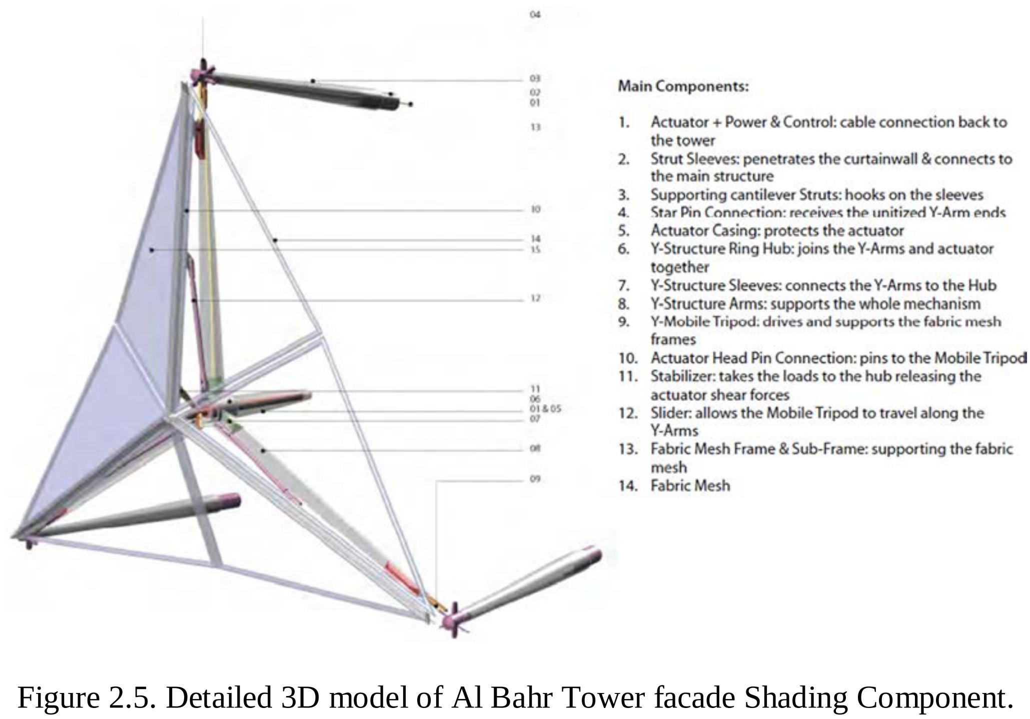


Figure 2.5. Detailed 3D model of Al Bahr Tower facade Shading Component.
(Source: Shahin 2018)

Research written by Nagy, Svetozarevic, Jayathissa, Begle, Hofer, Lydon, Willmann and Schlueter in 2016 is about the performance of the adaptive solar facade. In this research, adaptive solar facade provides %25 energy efficiency. Adaptive solar facade component consists of four parts as the shading panel, photovoltaic module, the soft-pneumatic actuator, the cantilever, and the supporting frame and cable net (Figure 2.6). The soft-pneumatic actuator includes three inflatable chambers. This way, the soft-pneumatic actuator made of elastic materials provides orienting with compressed air (Figure 2.7). Cantilever ensures rotation. Frame and cable carry the mechanism. Cantilever and the soft-pneumatic actuator are supervised with the control system.

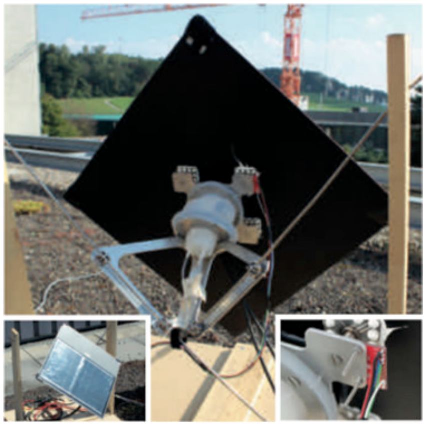


Figure 2.6. Adaptive solar facade component.
(Source: Nagy et al 2016)

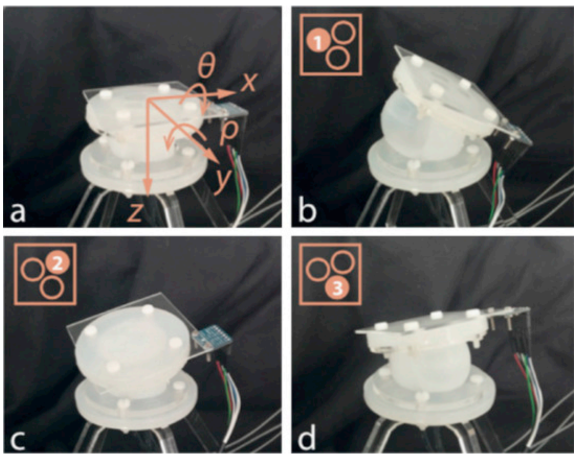


Figure 2.7. The Soft-pneumatic Actuator.
(Source: Nagy et al 2016)

2.6. Selected Studies about Daylight Performance of Adaptive Facade

This section consists of the selected researches about the effect of kinetic facades on daylighting usage. The integration of kinetic facades for better daylighting performance is explained, besides, the effects of integrated facades are analyzed.

The study written by Mahmoud and Elghazi (2016) is about improving kinetic facade design with various software and evaluating the performance of different motions in kinetic facade components. Firstly, the authors explain kinetic facade, kinetic facade parameters and simulation tools. The research consists of two phases. In the first phase, the daylighting performance of case study set to 20% the Window–Wall-Ration in Egypt, is evaluated as a base case. In the second phase, the authors investigate the daylighting performance of facade consisted of kinetic hexagonal components demostrated in figure 2.6 two motions as rotation and translation. The authors use Rhino/Grasshopper for the parametric design process and DIVA-for-Rhino for daylighting evaluation in this study. Authors use LEED V4 daylighting requirements as a criterion. According to results, both kinetic facade designs ensure daylighting requirements better than the base case. Rotational motion provides better daylighting condition than translation motion (Mahmoud, Elghazi 2016).

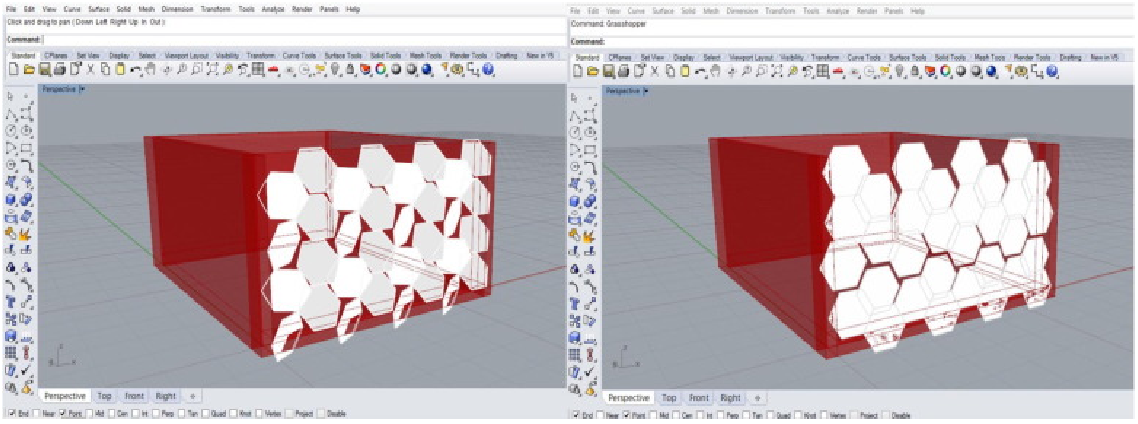


Figure 2.8. Kinetic hexagonal components.
(Source: Mahmoud, Elghazi 2016)

Pesenti, Masera, and Fiorito (2015) wrote a paper about the optimisation of a shading system to ensure daylighting quality and reduce energy consumption. Origami pattern (Figure 2.4) is selected as a shading element because of its motion types as overlapping, expanding and bending for this paper. The authors use Grasshopper to EnergyPlus for thermal analyses and Radiance and Daysim for daylight analyses. The case study of this paper is office room south facing in Milano. The authors compare the daylighting performance of two different facade materials. The first one is a metal opaque surface with 68% reflectance, 1% specularity and 1% roughness. The second one semi-transparent plastic surface with 5% reflectance, 1% specularity and 1% roughness. The main objective of this analysis is determining the optimum percentage of displacement and materials for shading system performance. According to results, the authors detect the most efficient pattern configuration and materials, thus configurations ensure a better adaptation of the shading system (Pesenti, Masera and Fiorito 2015).

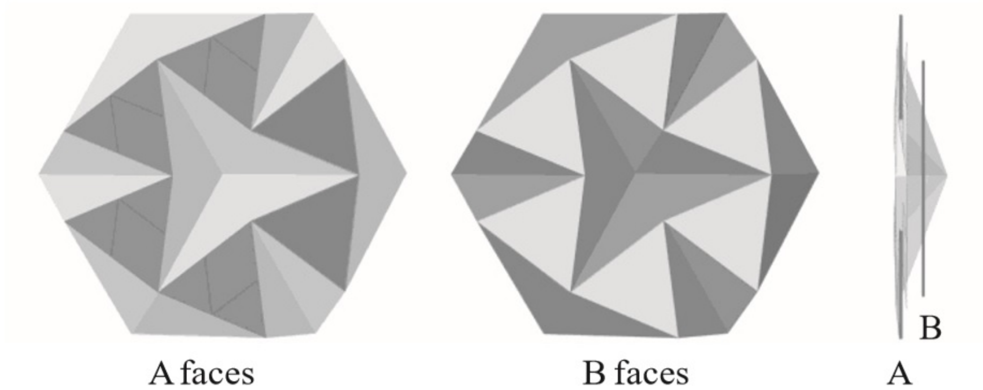


Figure 2.9. Simplification of the origami pattern's geometry.
(Source: Pesenti, Masera, and Fiorito 2015)

The article written by Elghazi, Wagdy and Abdalwaha (2015) is about the daylighting performance of origami-based facade design. Firstly, the authors explain the kinetic architecture and its benefits. Following this, the authors give information about the origami concept. Then, they define of kaleidocycle module (Figure 2.10) used in the facade for this study. The authors explain daylighting simulation tools and the importance of the parametric design. The Authors use Rhinoceros, Grasshopper, Daysim and Radiance as simulation tools. Author determine twenty square meters office located in Aswan, Egypt as a case study. The case study has an only south facade. The authors compare the daylighting performance of the static kaleidocycle facade (optimized according to daylighting comfort) as a base case and kinetically actuated kaleidocycle facade optimized for daylighting comfort under the same conditions. According to results, the performance of kinetically actuated kaleidocycle facade provides better daylighting performance than the base case (Elghazi, Wagdy and Abdalwaha 2015).

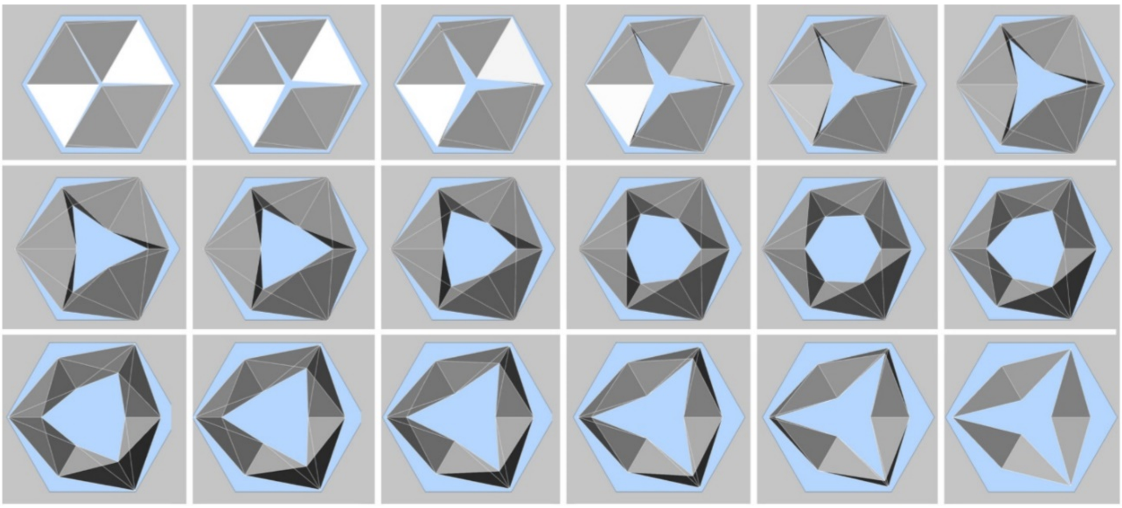


Figure 2.10. Kaleidocycle form variations according to kaleidocycle rotation Angles. (Source: Elghazi, Wagdy and Abdalwaha 2015)

Tabadkani, Banihashemi and Hosseini (2018) wrote an article about developing a shading system with parametric analysis for daylighting performance. The author gives information about the usage and benefits of daylighting. Following this, visual comfort indices and parametric design are explained. The authors use Rhino/Grasshopper and DIVA-for-Grasshopper for this research. The kinetic facade component inspired by Islamic Star Pattern named Rossette is identified (Figure 2.11). South-facing office (WWR 89.5%) located in Tehran with is selected as a case study. The authors define the distance between Rosette protection, rotation angle for motion and facade, materials according to optimum values for daylighting criteria. The authors compare Rosette protection, unprotected skin and only louvre protected facade performance. According to results, only Rosette protection meets LEED V4 daylighting criteria (Tabadkani, Banihashemi and Hosseini 2018).

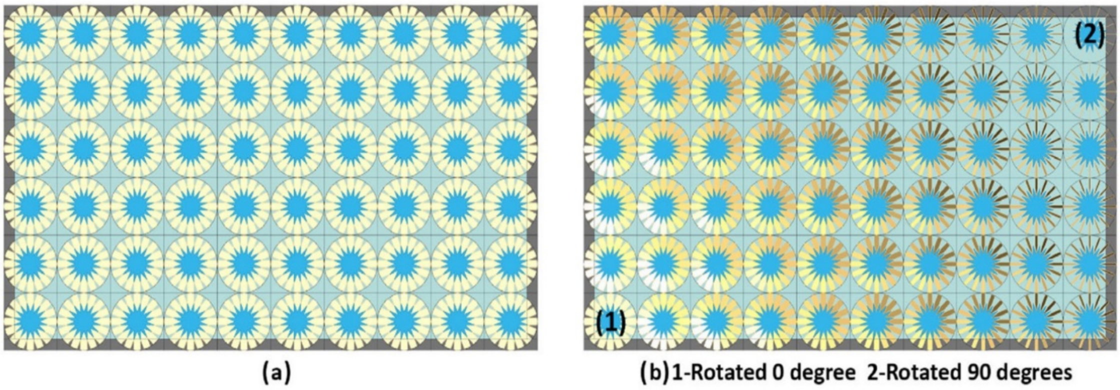


Figure 2.11.Rosette form variations according to rotation Angles.
(Source: Tabadkani, Banihashemi and Hosseini 2018)

Figure 2.12. Test room model for three cases as a plain window, two-dimensional and three-dimensional shape changes. (Source: Hosseini, Mohammadi and Santin 2019).

The article written by Hosseini, Mohammadi and Santin is about the performance of kinetic facade components shape variations. The authors compare the three-dimensional shape changes and two-dimensional shape changes according to the visual comfort value. Firstly, the authors mention the benefits and utilization of daylight. The authors give brief information about facade components into two groups as static and dynamic. The authors determine office building in Yazd Iran as a case study. Windows only located in south facade with 85 percentage window to wall ratio.

The authors determine cases as a plain window (static) , two-dimensional shape changes in the facade (kinetic) and three-dimensional shape changes in the facade (kinetic). The authors Rhinoceros, Grasshopper, and Diva. In plain window case, visual discomfort is observed with simulation results. Both kinetic facades provide more visual quality than the plain window. According to results, three-dimensional shape changes facade provides more visual quality than two-dimensional shape changes facade (Hosseini, Mohammadi and Santin 2019).

CHAPTER 3

CASE STUDY of IZTECH INNOVATION CENTER

3.1. Description of Physical Facility

IZTECH Innovation Building is located at 38 ° 31'N Latitude 26 ° 63'L Longitude within the campus of İzmir Institute of Technology. IZTECH Innovation Center location is denoted with red colour in Figure 3.1. The building has 7510 square meters of indoor space. The building consists of 4 floors as basement, ground, the first and the second floor. Commercial areas, workshops, promotion office, event hall, information, car park, security and management rooms are on 3132 square meters as the basement floor. Cafeteria and offices are on 1515 square meters as the ground floor. On the first floor (1252 square meters) , there are offices and four guest rooms. The second floor (1611 square meters) consists of warehouses, the area called incubation center and offices. The building contains offices, meeting halls, technical training rooms, guest rooms, cafeteria and technical workshop. The facade of the building is completely covered with glass. Additively, there are aluminum shading elements on the north, east and south side of the building envelope (Figure 3.2.).

3.2. Daylight Assessment Criteria in LEED

IZTECH Innovation Building modelled with Revit for daylight assessment of the building (Figure 3.3) is evaluated according to LEED Daylighting Criteria. LEED Daylighting Criteria Option 2 is selected for Daylighting evaluating. According to Option 2, the occupied areas illuminance must be between 300 lux and 3,000 lux levels at 9 a.m. and 3 p.m at the equinox on a clear sky. Besides this, it is scored according to the percentage of surface area supplying this requirement. According to the percentage of the regularly occupied area 75% brings 1 point, 90% brings 2 points (Table 2.2).

The area called Incubation Center, parking garage and warehouse areas are excluded from the evaluation. According to daylighting values at various times, the movement of the adaptive facade differs from another timeline. This situation brings

Figure 3.1.IZTECH Innovation Center location.

Figure 3.2.IZTECH Innovation Center.

different adaptive facade variations. Because of these reasons, different facade variations of the adaptive facade are evaluated for the different timeline to get maximum indoor daylighting quality. According to LEED Daylighting Criteria Option 2, It is aimed to get 2 points with new adaptive facade design.

Figure 3.3. IZTECH Innovation Center model in Revit.

3.3. Adaptive Facade Design with a Kinetic Component

Adaptive facades are the building elements that provides indoor environmental quality against outdoor conditions (Romano, Aelenel, Aelenei, Mazzucchelli 2018, Loonen et al.: 2015, Aelenei, Aelenei, Vieira 2016). Providing indoor environmental conditions may happen in different ways. In this study, adaptive facade applied for IZTECH Innovation Building contains kinetic shading components.

The first phase of the kinetic component is the design stage. Kinetic facade component was inspired by the origami figure named chicken wire indicated in Figure 3.4. Origami is an ancient art of paper folding technique. When chicken wire tessellation folds, concave and convex 3D shapes occur. There are two main fold that are mountain and valley folds. In Origami, the crease of the convex is called a mountain fold. The valley fold is the crease of the concave (Dureisseix, 2012). The kinetic facade component has three types of elements as frame, skeleton and coating. The kinetic facade component consists of one moveable part of the chicken wire pattern. It is an one degree of freedom mechanism that can be actuated with one motor. The facade component is designed to cover the surface area of the window that has a width of one meter. The full glazed facade is covered with kinetic origami unit used in the study. It is intended to provide daylight comfort in this way. The part of the Chicken wire pattern that determined for kinetic facade component with its valley and mountain folds indicated in Figure 3.5.

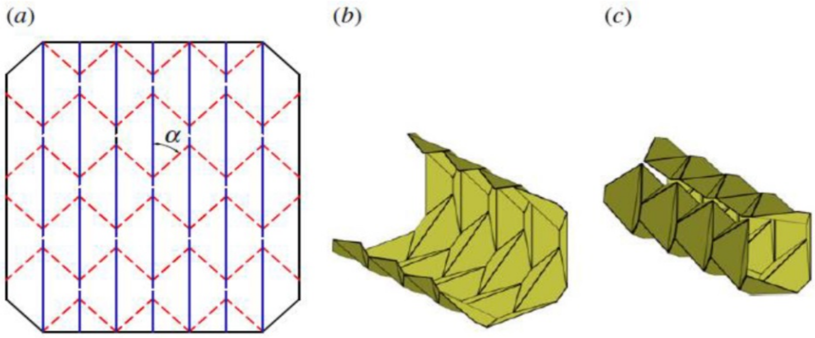


Figure 3.4. (a) The chicken wire tessellation (b) partially folded position (c) pre interface position.

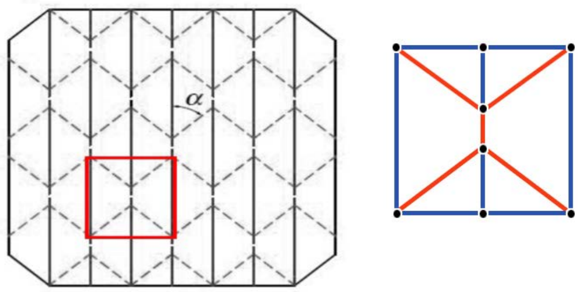


Figure 3.5. Chicken wire pattern and determined part of the pattern for kinetic component with its mountain folds that are indicated red colour and valley folds that are indicated blue colour.

The second stage is the determination of module geometry and formulas. In Figure 3.6 demonstrates point names. The distance between point g and point h is 120 cm as the base in the x-plane. The distance between point g and point g 'determines the length of the kinetic element in the y plane. Point b shows the height of the module in the z plane. Point e shows the projection of Point b. Point j is the projection of Point c on [e,f] line (Figure 3.12.). Point f is in the middle of point g and h. Point g, point f, point h and point e are fixed points. Point a, point b and point c are moving points. Point a can move horizontally between point g and point f. Point b can move vertically. The point c is on a 60-centimeter circle with a central point b (Figure 3.7). The location of the point c is the intersection point of the b-centered circle and the a-center 60-centimeter diameter sphere. Point c is always in the lower position of the distance between point g and h (Figure 3.8, Figure 3.9). Basic formulas used in this component demonstrated in Figure 3.10.

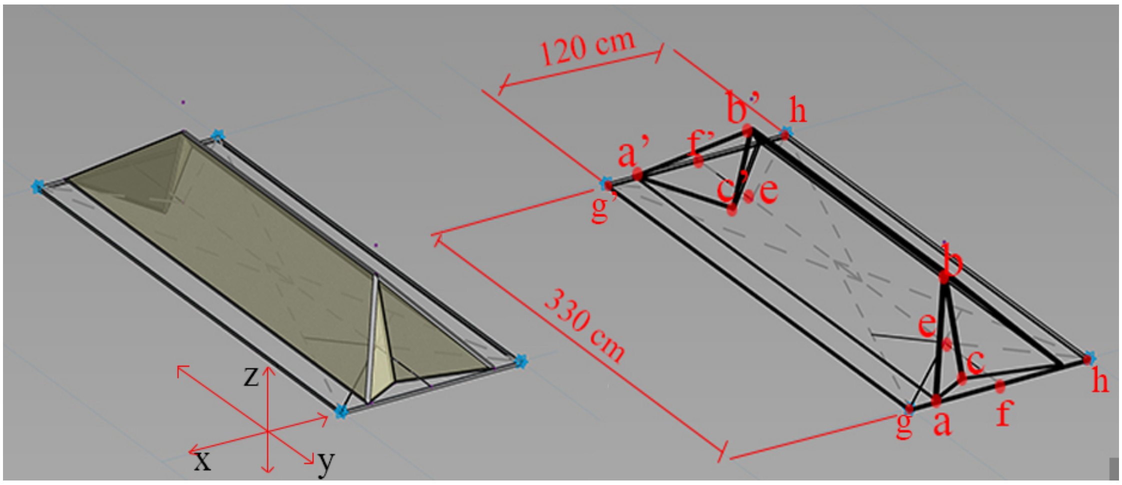


Figure 3.6. Kinetic component points.

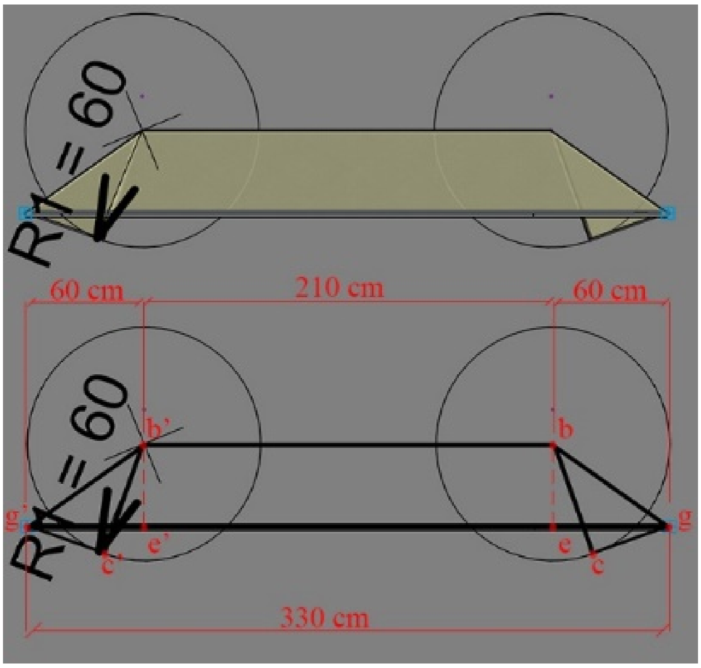


Figure 3.7. Kinetic component b centered circle; Point c location.

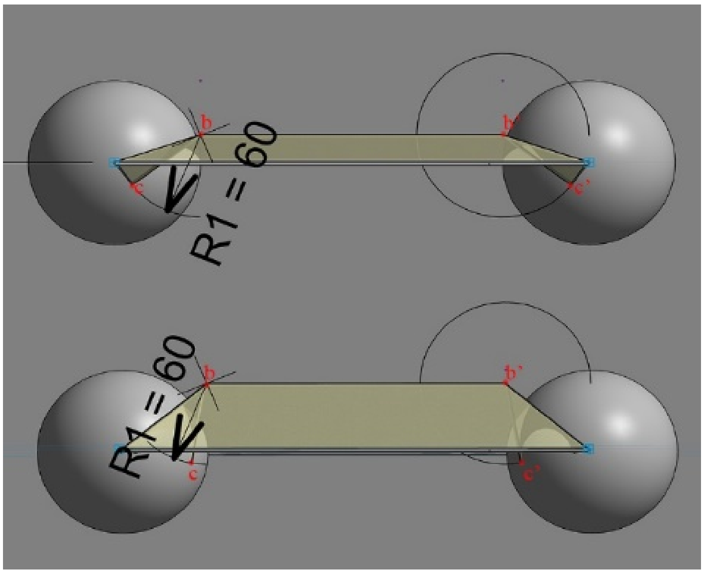


Figure 3.8.Location changes in point c with different shape changes.

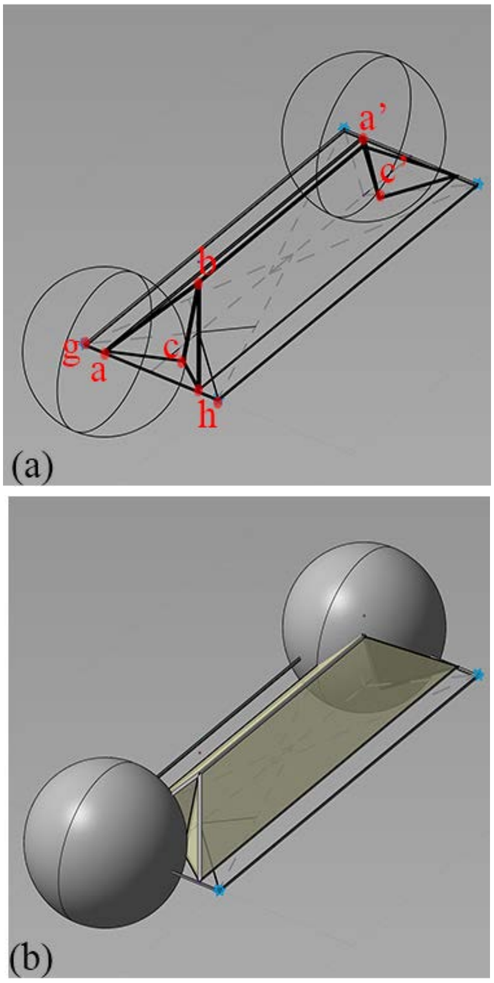


Figure 3.9.Point c location.

Parameter	Value	Formula	Lock
Construction			
Construction Type		=	
Materials and Finishes			
Finish		=	
Dimensions			
L1 (default)	84.85	= sqrt(R1 ^ 2 + R1 ^ 2)	☐
Lenght g-h (base) (report)	120.00	=	
Openning Angle (default)	60.00°	= ([Distance a-f] / [Distance e-b])	
Distance e-b (default)	30.00	=	☐
e-b Max (default)	60.00	= [Lenght g-h (base)] / 2	☐
R1 (default)	60.00	= [Lenght g-h (base)] / 2	☐
Distance a-f (default)	51.96	= sqrt(L1 ^ 2 - [Distance e-b] ^ 2 - R1 ^ 2)	☐
Distance a-b (default)	84.85	= sqrt(([Lenght g-h (base)] / 2) ^ 2 + ([Lenght g-h (bas	☐
pMax (default)	103.92	= sqrt([Lenght g-h (base)] ^ 2 - ([Lenght g-h (base)] /	☐
Analytical Properties			
Identity Data			

Figure 3.10.Point c location with formulas.

The third phase is modelling the kinetic component in Solidworks 2018 (Figure 3.11.). This way the components mechanism was determined. The component was prepared as horizontal. The horizontal component can also work as a vertical static shading element. The vertical component can also work as a horizontal shading element indicated in figure 3.12. The components degree of freedom is calculated with Grubler Kutzbach formula is given below (Phillips, 2006).

$$M = \lambda(n-1) - \sum_{i=1}^{5}(\lambda - i)j \tag{3.1}$$

In this formula, the DoF of space in mechanism operates is called as λ. The number of panels is named with n and number of joints in mechanism is named with j_1. All joints in chicken wire pattern are revolute joints that have one degree of freedom. The number of higher pairs is demonstrated with j_2. There are no higher pairs in this mechanism, so j_2 is reduced from eq (3.2). λ is equal 3 for spherical mechanisms. For spherical mechanisms Grubler Kutzbach formula is demostrated as follows,

$$M = 3(n-1) - 2j_1 - j_2 \tag{3.2}$$

The selected part of the chicken wire pattern consists of 7 revolute joints and 6 panels (Figure 3.13). The selected part of the chicken wire pattern mobility can be calculated as follows,

$$M = 3(n-1) - 2j_1$$
$$M = 3(6-1) - 7 \times 4 = 1 \tag{3.3}$$

This result demonstrates that the mechanism has one degree of freedom with the Grubler Kutzbach formula. The one degree of freedom mechanism means mechanism can move with one engine or force. Besides, a draft that runs two-component with a single-engine was made (Figure 3.14). With the method made in the draft, it was observed that more than two-component can be moved with a single-engine.

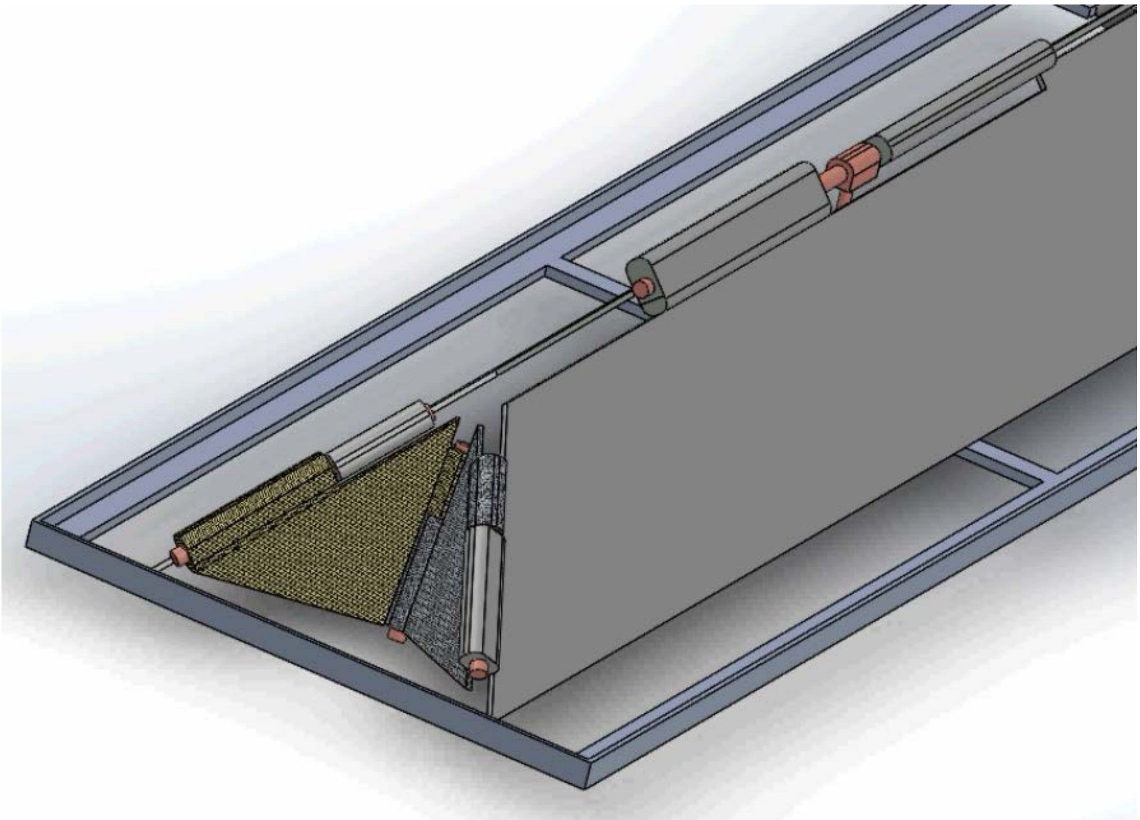


Figure 3.11.Component model in Solidworks 2018.

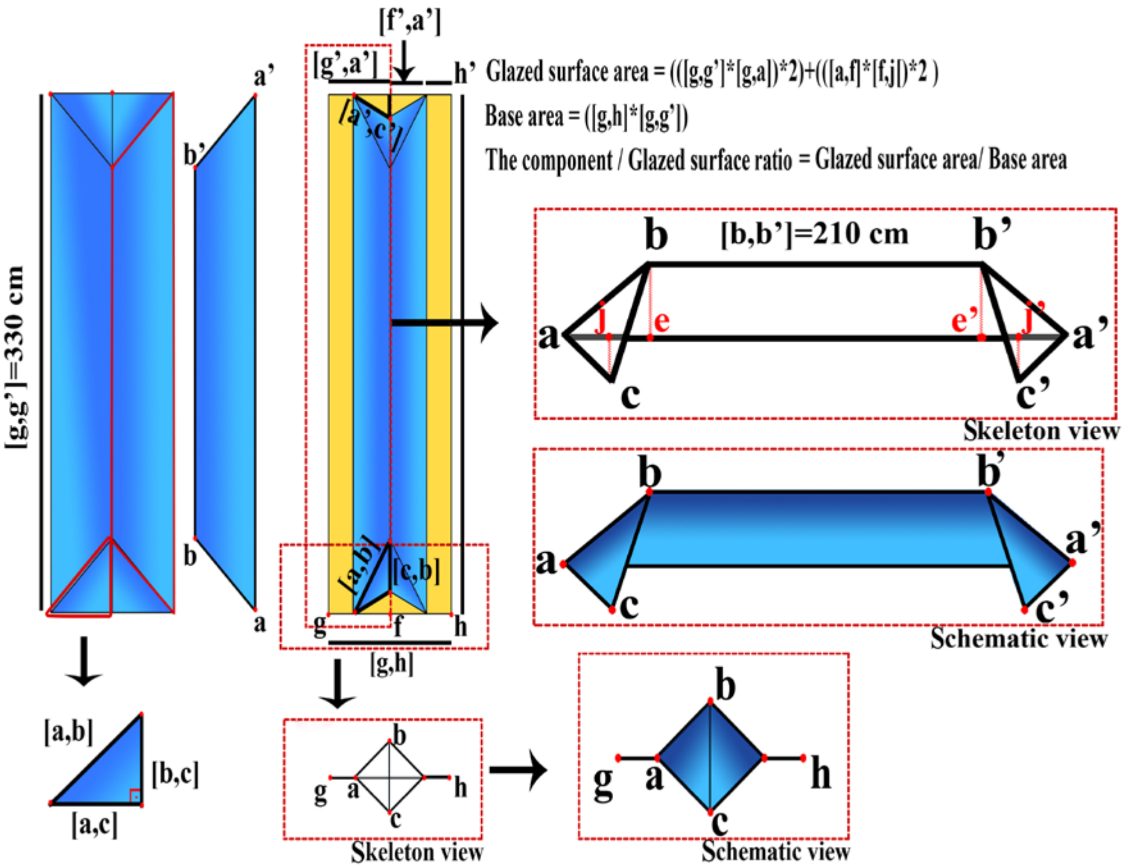


Figure 3.12. Calculation of the vertical component and its schema.

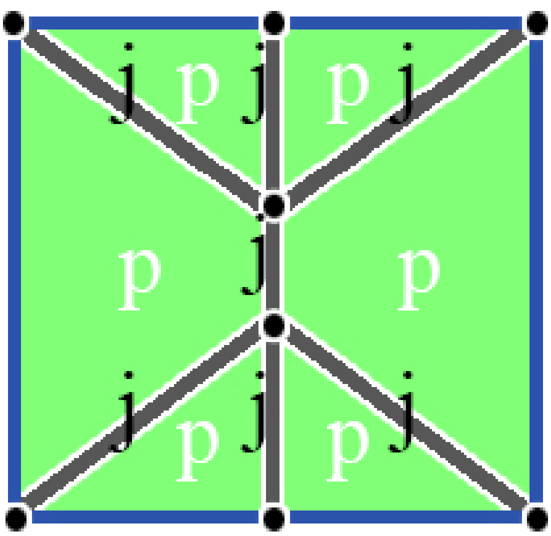


Figure 3.13. Joints are demonstrated with grey colour and panels are demonstrated with green colour in the selected part of the chicken wire pattern.

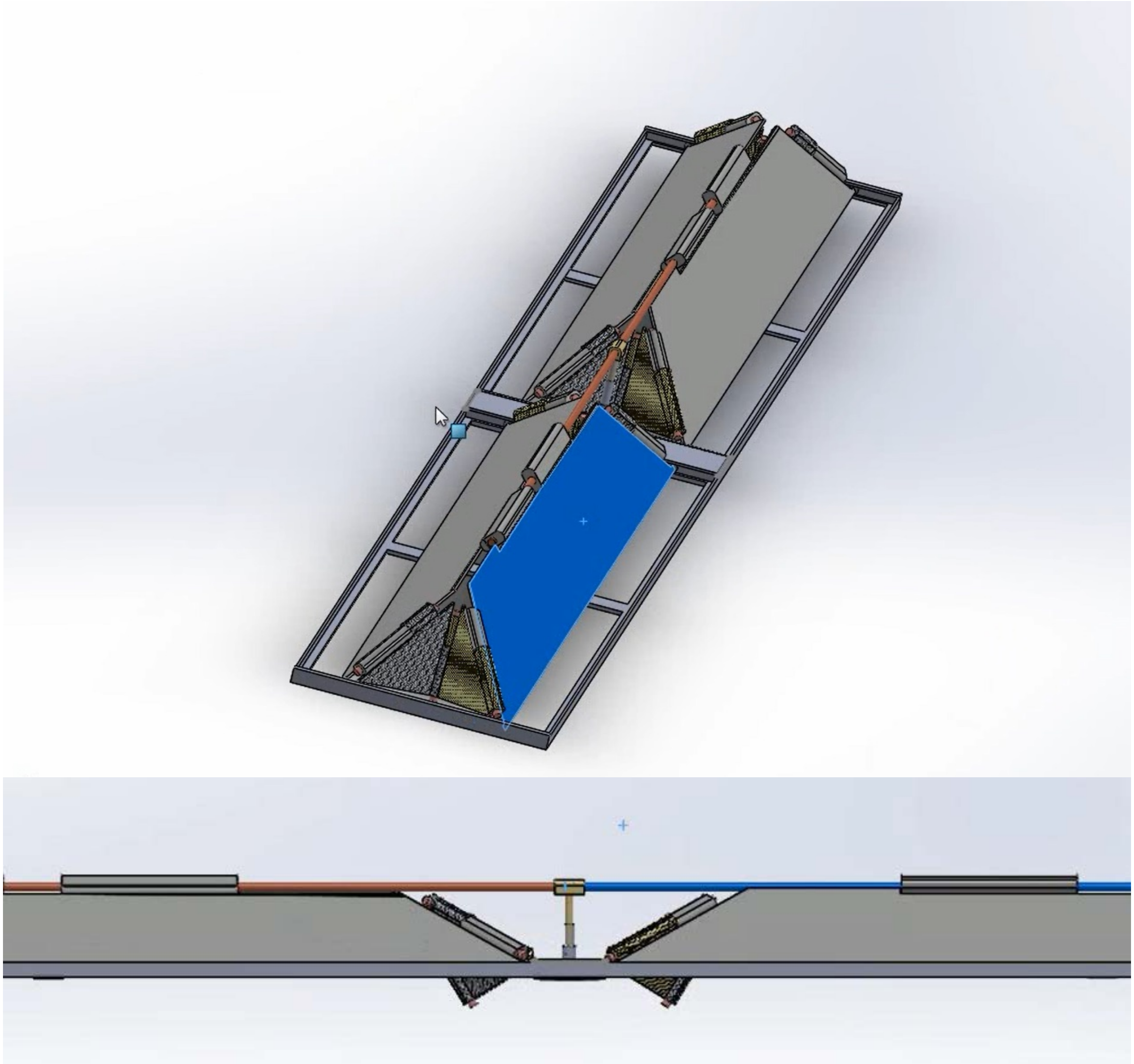


Figure 3.14.Two-component with a single-engine.

3.3.1 Opening Angle

Opening angle indicated in Figure 3.15 is an angle between [a,b] and [b,c]. The opening angle is found in the project by the ratio of length [a,f] to length [e,b] (Figure 3.10). The opening angle defines a glazed area on the surface. As shown in figure 3.12, if the alpha angle increases, the distance between Point f and Point j ([f, j]) and the distance between Point a and Point f ([a,f]) decreases. Thus, the amount of direct sunlight penetrated the interior from the glazed surface on the component is reduced. There is an inverse proportion between the opening angle and the glazed surface. If the opening angle increase, the transparent surface area decreases proportionally. This way, the opening angle determines how much sunlight will penetrate to indoor.

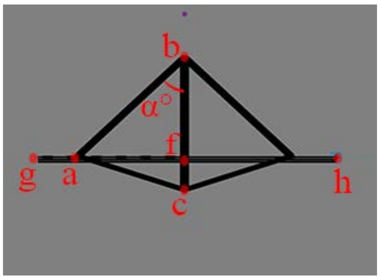


Figure 3.15.Opening angle demostrated as alpha angle (α °).

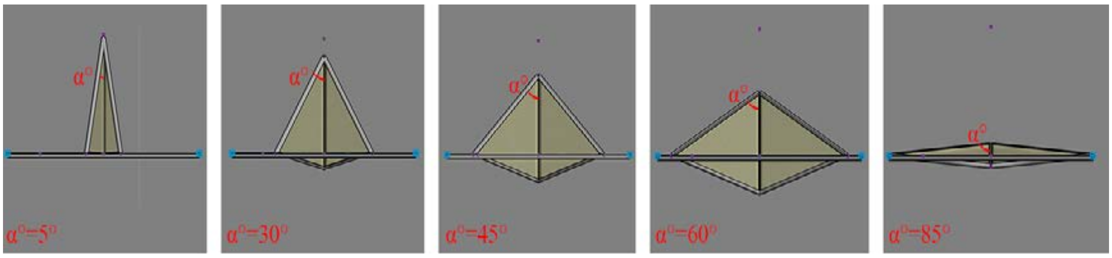


Figure 3.16.Shape variations with opening angle.

3.3.2 Material Type (Transmittance)

The optical properties of the material used in the fenestration and in the shading device on the façade elements determine the amount of daylight penetrated to the indoor environment. Sunlight which has directional character may be blocked while daylight which has diffuse character may be taken in. Here, the frame of the kinetic facade component is made of stainless steel (its material group is defined as “metal” in Revit Material Library and its RGB is as 80 80 80 and reflectance is 31%) because it has a bearing task. Stainless steel is used as the material to provide a stable movement for the skeleton. The coating material plays a key role in determining diffused daylighting because it is the element with the highest surface area in the component (Figure 3.17). The selected material has no critical effect on the movement of the facade. It is suitable to test different materials and transmittance properties in this way. However, the permeability of the coating materials inside the frame; that is the transmittance, can vary and that can be tested in coating inside the frame to provide better daylight quality. Revit material library presents a variety of used for material properties. The coating material is selected as the fabric mesh (RGB is as 255 255 255, reflectance is 100%) whose transmittance can be modified in the library (Figure 3.17). It has a quality of being a sun shading material itself and it does not have any specular reflection.

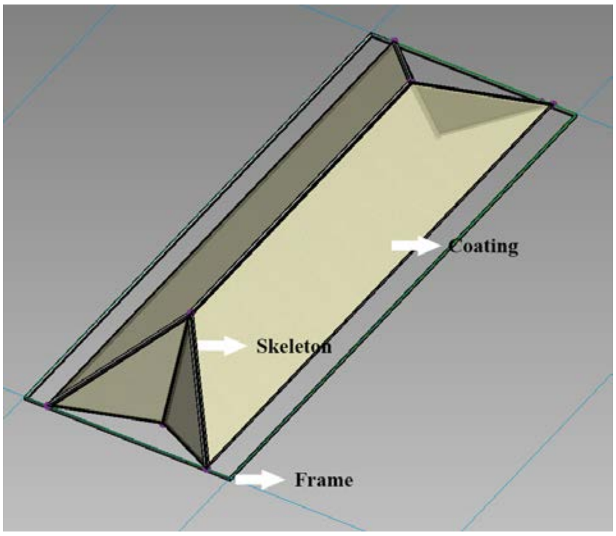


Figure 3.17.Elements of kinetic component.

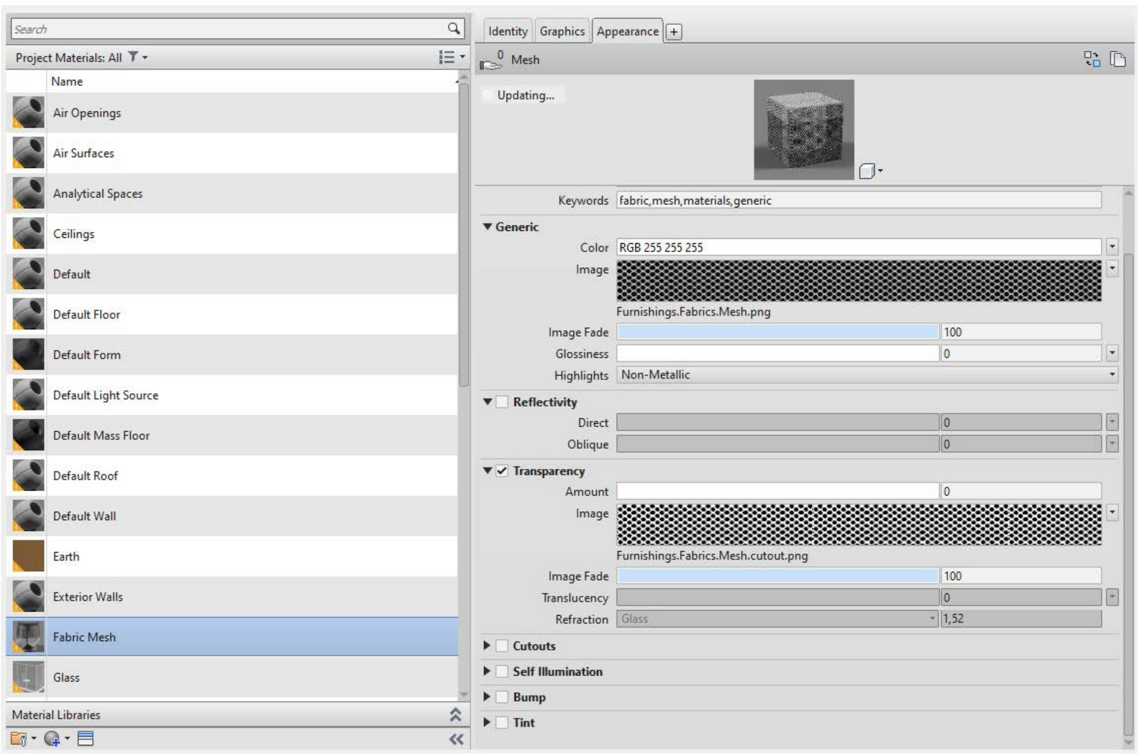


Figure 3.18.Coating material used on the component in Revit material library.

3.4 . Modelling with Revit

IZTECH Innovation Building and kinetic components are modelled with Revit. Revit plug-in Insight 360 is used for daylight analysis. Revit plug-in Insight 360 lighting analysis gives six outputs as Daylight autonomy, Daylight factor, illuminance, LEED IEQc8 option 1, LEED v4 EQc7 option 2 and Solar access. The location of the project is defined in Revit. In the timeline between January 1 to December 31, sDA calculation is made in 60.96 cm grided occupied area. The threshold percentage levels are editable; however, two options of 55% and 75% of room area must exceed sDA (300/50) lx are conventional settings. Almost 20% of room area must be below ASE (1000/250). Daylight factor analysis works on the user-defined the percentage of the threshold value; the default value begin from 2 % DF to 20% DF and analysis plane grided 30.48cm or 182.88cm height is 81,28 cm above the floor. Illuminance analysis works user-defined threshold lux value defined as 300 lux and 3000lux and analysis plane grided 30.48cm or 182.88cm height is 81.28cm above the floor.

Revit can run analysis to check the performance of the building according to LEED criteria as well. It has two options. First, the threshold level is defined as between 10 footcandle to 500 footcandle (107.63lux to 5381.95lux). Weather data is defined as clear sky day within 15 days near September 21st, at 9 am and 3 pm in LEED IEQc8 option 1 analysis. The user selects occupied areas grid lengths as 30.48cm or 182.88cm. Second option includes dates of two equinoxes and takes the averages of their results, so “Equinox averages 9 am and 3 pm” defined as a timeline on LEED v4 EQc7 option 2. The threshold levels are between 300 to 3000 lux in a clear sky. Occupied area grid size as 30.48cm or 182.88cm is defined from the user. Revit analyzes daylight conditions in rooms, takes the averages of results on floors and the average results of the whole project. In Solar access analysis, location, time range, threshold values and analysis plane height are editable from the user. In this study, LEED option 2 is determined as the analysis type since it covers all equinoxes and provides information about whether the building passes the LEED threshold values or not.

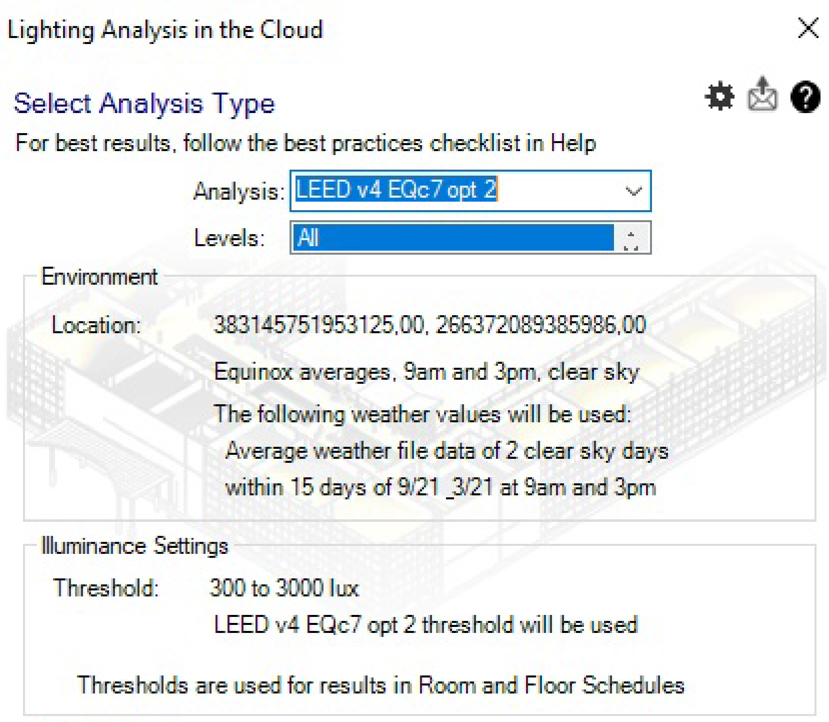


Figure 3.19. LEED IEQc7 option 2 Analysis in Revit.

Firstly, the existing building is modelled in terms of its geometric information and physical properties (Figure 3.20 and Figure 3.21). The floor height is 3.26m in the basement, the ground and the first floor. The highest distance from the floor level to the ceiling is 4.10 the second floor. Walls are covered with the material of white paint (RGB 208 209 207, reflectance is 63%). Ceilings are made of concrete (RGB 115 116 108, reflectance is 18%) and floors are covered with vinyl composition tile (RGB 104 103 102, reflectance is 15%) according to Revit library properties. Secondly, daylight analysis of the modelled building is executed to understand its daylight behaviour in the actual conditions according to LEED IEQc7 option 2 Analysis. Then non-sunshade elements version of the existing building is analyzed to evaluate the daylight performance, so the maximum sunlight entering the building is measured (Figure 3.22). Regarding the findings at 9 am, almost half of the rooms and areas are under the excessive direct daylight which is above 6000 lx. Sun patches are dominating the inside of the building. Although sunpatched decreased in the analysis at 3 pm, the majority of the rooms and areas have got illuminance values above 2000 lx. So, which surfaces must be covered by the adaptive facade is determined considering these high values of illuminance in this way (Figure 3.22 and Figure 3.23).

Figure 3.20. South and east facades of the non-sunshade elements version of the IZTECH Innovation Center Modelled by Revit.

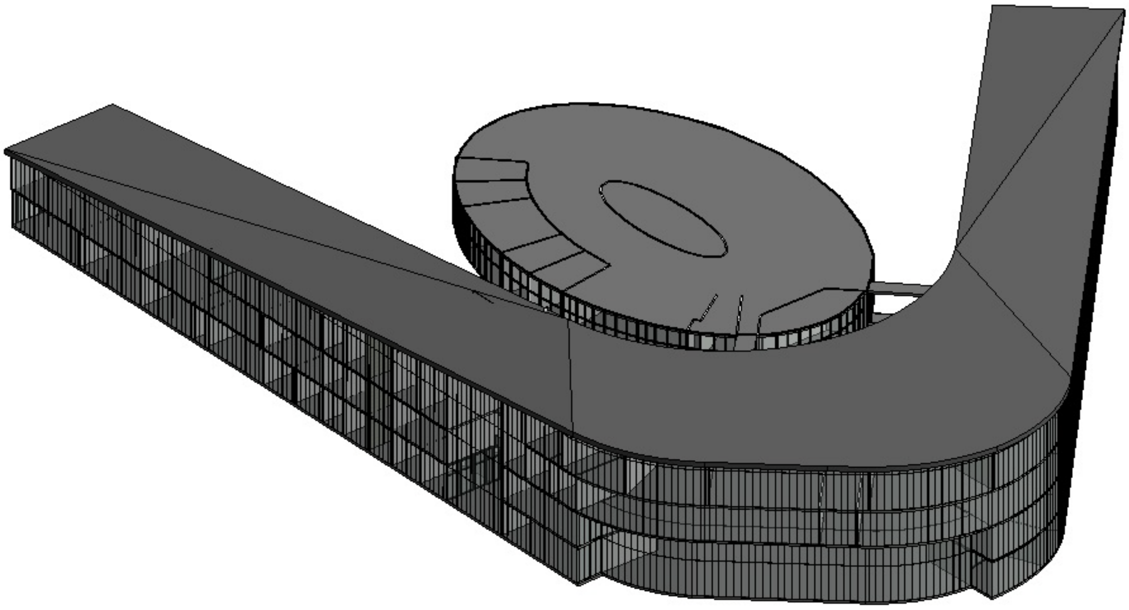


Figure 3.21. Non-sunshade elements version of the IZTECH Innovation Center modelled by Revit with areal view.

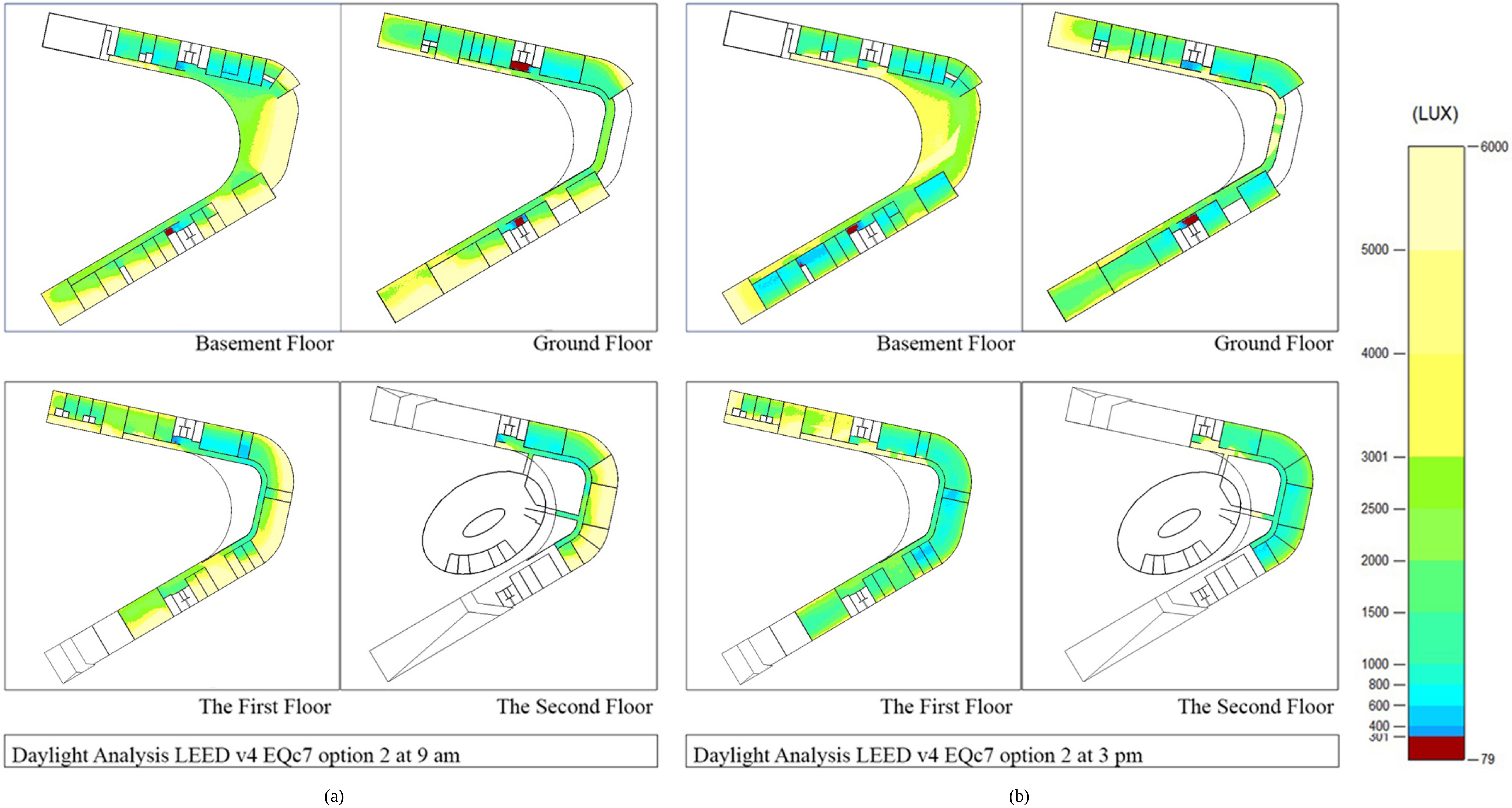


Figure 3.22.Non-sunshade elements version of the IZTECH Innovation Building Daylight Analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

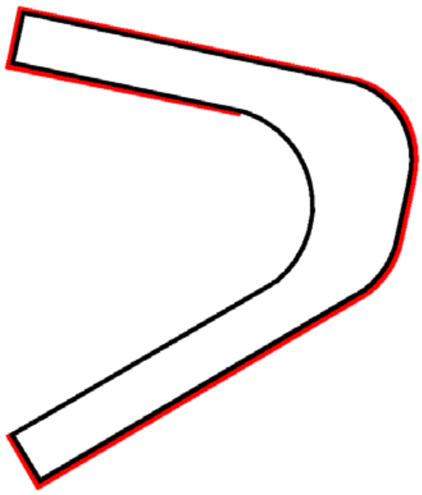


Figure 3.23. Covered surfaces by adaptive the facade of IZTECH Innovation Building are demostrated with red lines.

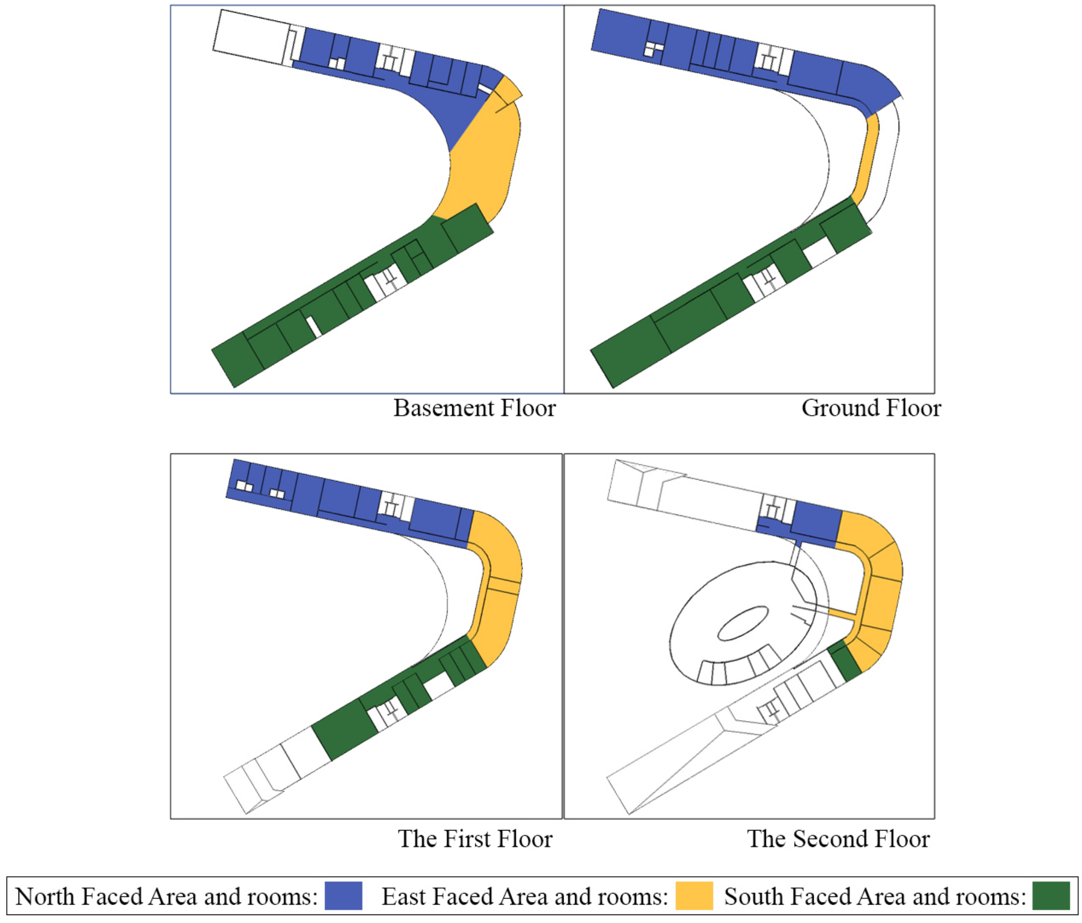


Figure 3.24. Rooms and areas classified according to direction.

Finally, the daylight performance of the building is tested when the proposed adaptive facade is applied according to its opening angles and materials used in the kinetic component. The maximum amount of sunlight entering the spaces in the non-sunshade elements version of the existing building varies regarding the facade orientation. Rooms and areas in the building modelled with Revit are classified according to the directions as demonstrated in Figure 2.24.The kinetic component variations consist of twenty versions according to the material permeability which corresponds to the transmittance values and the opening angle of the kinetic component.

Utilizing combinations of the kinetic component variations, a total of 20 adaptive façade is generated 0%, 20%, 30%, and 40%, while transmittance opening angles became 4 °, 30 °, 45 °, 60 °, and 85 °. For understanding the effect of variation of the facade element used on the adaptive facade for each room and facade, the facade of the building is completely covered with the same variation of the kinetic component and analyzed. In this way, we can observe every variation affects for each room at 9 am and 3 pm. Depending on which variations give the optimal result for each room, the facade of the rooms is covered with the variation that gives the most optimal result. Since the adaptive facade has different forms at different times, different adaptive facade variations have been tested in the same time interval. The effect of the adaptive facade on daylight usage was tested. The aim is to find the pattern variation that gives the best daylighting lighting performance.

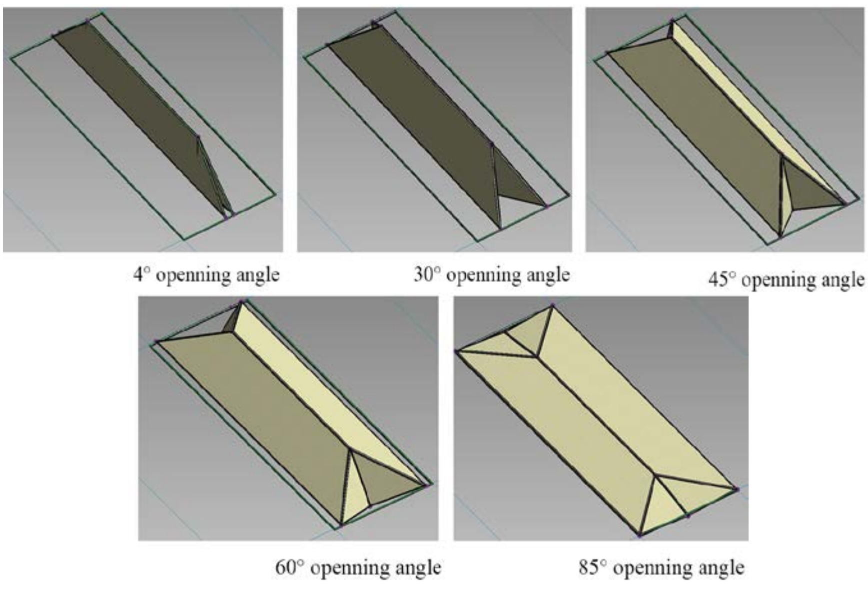


Figure 3.25. Form effects on variation accoding to openning Angle.

CHAPTER 4

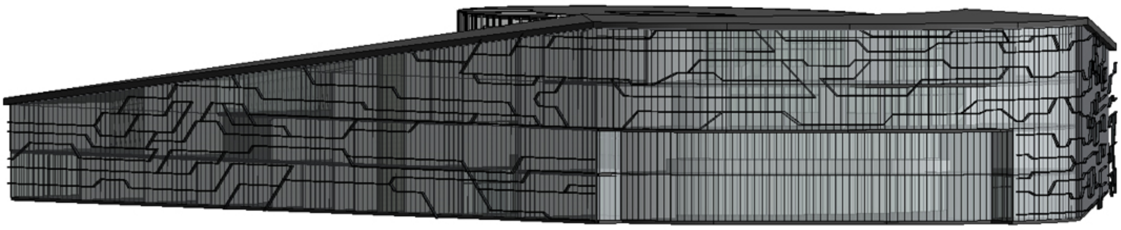
RESULTS

The objective of this chapter is figure out how the adaptive façade variations resulted in daylight performance according to LEED criteria. This chapter involves four main sections; the daylight performance of the Existing Condition of IZTECH Innovation Center, daylight performance regarding opening angles of the kinetic facade component, daylight performance with regarding transmittance value of the kinetic facade component material and optimum solution for daylight with kinetic component variations. The first section demonstrates the daylight performance of the existing building. The second and third sections demonstrate the potential of the kinetic facade on daylight performance. Results of the second and the third section are compared for optimal daylight performance. In this way, the optimal variation for each room is aimed. The fourth section aims optimal daylight performance of the building with an adaptive facade.

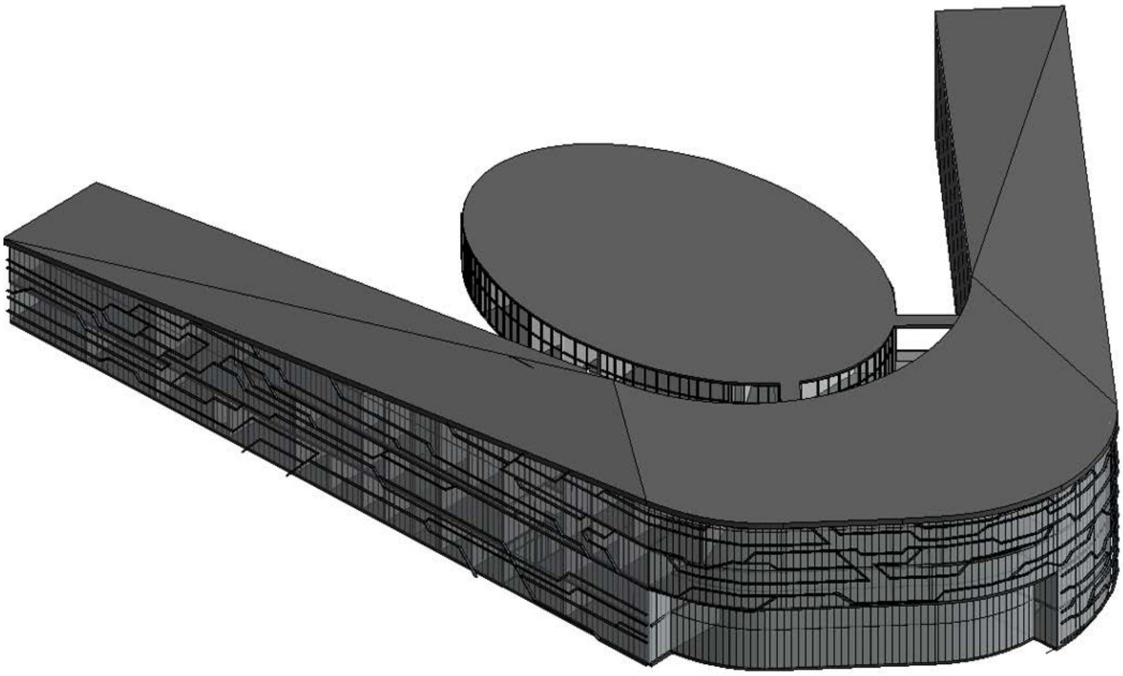
4.1. Existing Condition of IZTECH Innovation Center

As a pre-study, the existing version of IZTECH Innovation Center was generated in Revit with the existing horizontal façade elements in the same location (Figure 4.1). The location data was input in Revit together with the information about weather and site settings. Offices in IZTECH Innovation Center have various depths and widths. The width of the rooms is between 2.00 cm and 2.80 m. Rooms which are in 3.00 cm and 5.00 cm width are indicated in Figure 4.2. The depth of some other rooms varies from 8.30 cm to 10.60 cm. Rooms with depth more than 8.50 m are indicated in Figure 4.3. Only two rooms located in the basement floor have a lower depth size than the other rooms. These rooms are indicated in Figure 4.4. The height of the basement, ground and the first floor is 3.26 m. The highest point on the second floor is 4.10 m. Walls of the model is covered with white colour with a reflectance value of 63%. Floors of the model were covered by vinyl composition tile with 15% reflectance . Ceilings of the model were made of lightweight concrete with a reflectance value of

18%. The facade consists of horizontal aluminum joineries and glazed surfaces. All materials used in the model were selected in Revit material library.



(a)



(b)

Figure 4.1. Existing version of IZTECH Inovation Center modelled with Revit; (a) south and east facades, (b) aerial view.

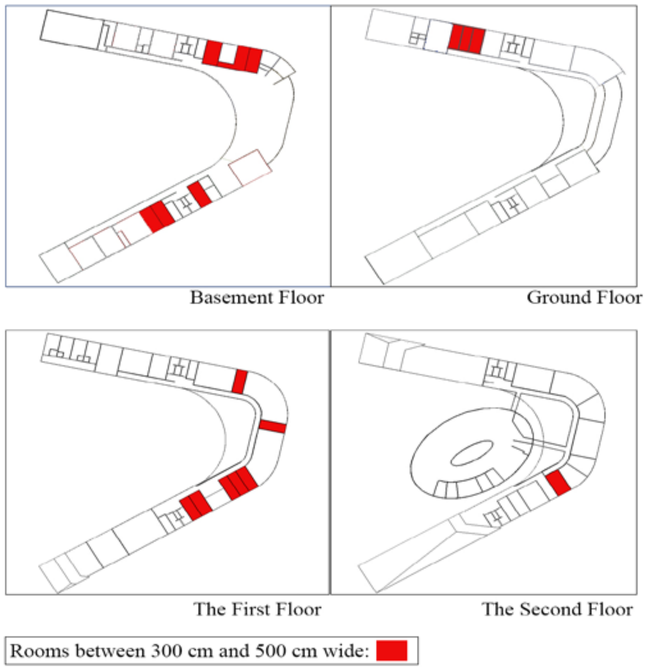


Figure 4.2. Rooms with a range of widths from 3.00 m to 5.00 m indicated with red colour.

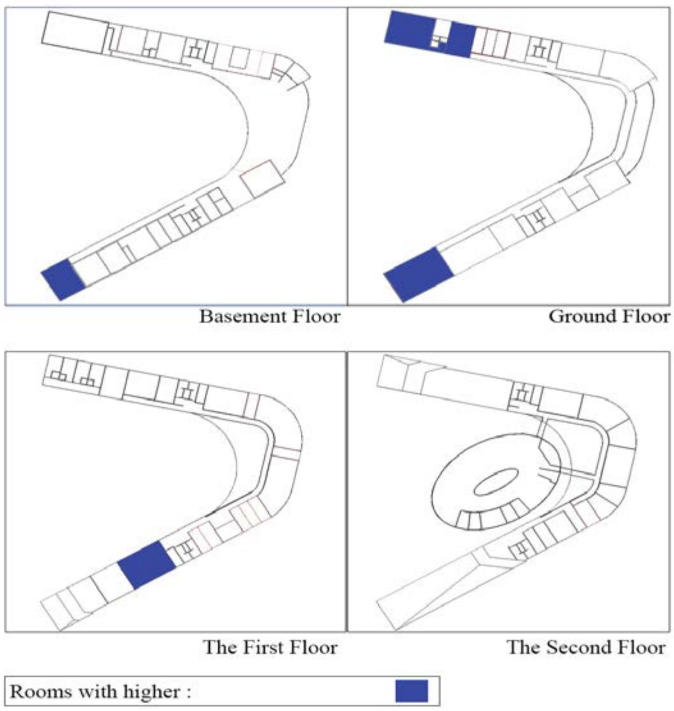


Figure 4.3. Rooms with depth more than 8.50 m indicated with blue colour.

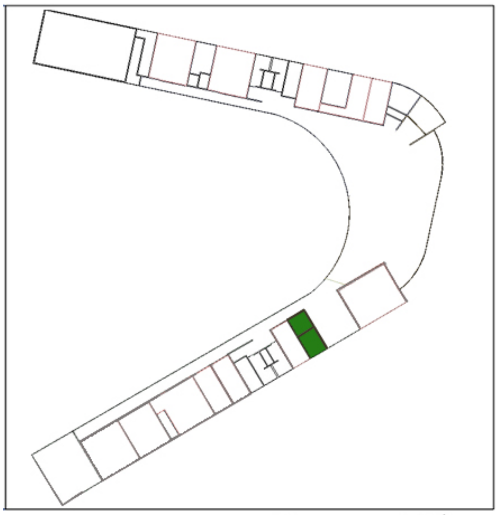


Figure 4.4. Rooms with depth lower than 8 m indicated with green colour.

After the modelling process, LEED IEQc7 option 2 Analysis was made. LEED IEQc7 option 2 Analysis gives two results for 9 am and 3 pm. The aim of this section is to understand how existing facade effects daylight performance of the existing version of IZTECH Innovation Center. It is observed that how much daylight is penetrated in which zone of the rooms or areas with this analysis. In this way, the analysis is indicated whether it meets the LEED Daylighting criteria or not for each room and area. Table 4.1 summarizes that the threshold value is exceeded on every floor except for the second floor at 3 pm. As seen in Table 4.1, the illuminance value is higher than the threshold and it demonstrates a lot of direct daylight penetrates to the interior at 9 am. Almost 40 % of each floor area receives illuminance values higher than 3000 lux which is very excessive, while the rest of the area satisfies the threshold values of daylight on every floor. Especially, 5000 and more illuminance occurs in the south, east-facing rooms and south side of north-facing rooms. This value is too high for the threshold value between 300 lx and 3000 lx (Figure 4.5). This high illuminance value is observed to be the same value from the front side of the room to the inside. Except for the technical corridor in front of the toilets, there is no area or room which is below the threshold value. Rooms exceeding the threshold value at according to the results at 3 pm are less than the ones result at 9 am (Table 4.1). Almost 30 % of the basement floor, 20 % of the ground and first floor and only 8 % of the second floor get the excessive daylight and sunlight. The rest of the area satisfies the daylight availability successfully. The number of rooms facing directly west is less than the number of rooms directly facing east. In the most of west-facing areas and rooms, the threshold value is exceeded at 3 pm. Values above the threshold value are observed near the facades of the rooms facing south at 3 pm (Figure 4.6). Although illuminance value is suitable at 3 pm for rooms with a range of widths from 3.00 m to 5.00 m, illuminance value is very highly above the threshold at 9 am. Rooms receive sunlight directly in the morning. It is observed that illumination with daylight e levels above the threshold for rooms with depth more than 8.50 m at both timelines. The existing façade elements cannot avoid direct sunlight satisfactorily.

Table 4.1. The Percentage of the Floor Area that Provides LEED Daylight Criteria / floor area.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 75% within & 3pm: 83% & both: 61% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	60	950	40	641	0	5	69	1100	31	488	0	7	41	657
The Ground	1402	65	910	34	472	1	20	76	1100	20	286	1	16	52	726
The First	1371	62	830	38	511	0	3	83	1051	22	294	0	0	50	667
The Second	643	59	378	41	264	0	0	92	590	8	52	0	0	53	340

The analysis demonstrates that rooms do not have the problem as not getting enough sunlight and even the main problem is observed to get too much direct sunlight. For this reason, visual discomfort as glare may be occurred, because of getting too much direct sunlight. The suggested adaptive facade must transform direct daylight penetrated into diffuse daylighting for east and south-facing rooms to indoor at 9 am. Besides this, direct daylight penetrated to indoor must be balanced for south zones in north-facing rooms and areas at 3 pm. The whole building fails to get any credit of LEED with only 48 % of all the areas are within the threshold values.

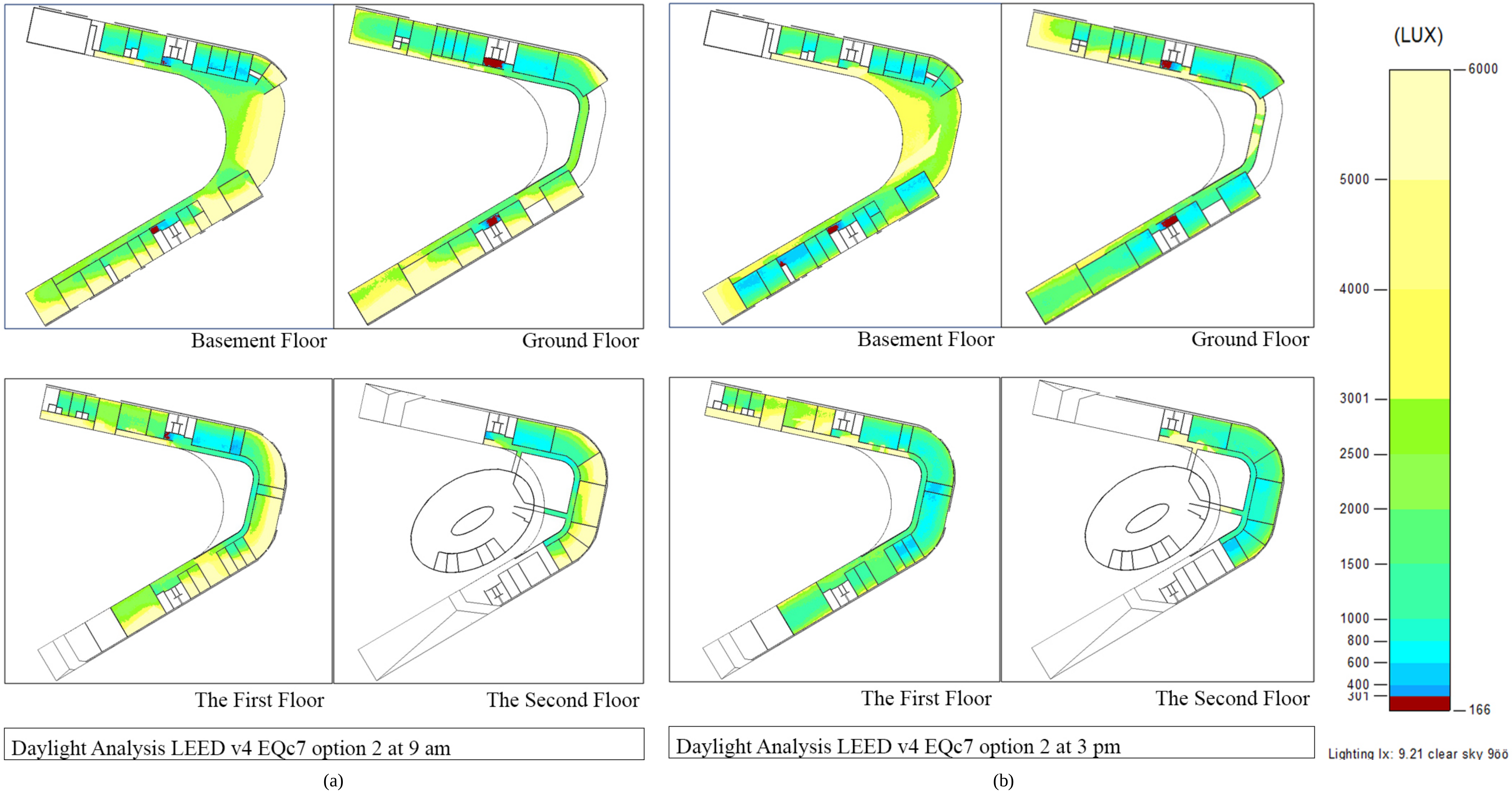


Figure 4.5.Existing version of the IZTECH Innovation Building Daylight Analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

4.2. Adaptive Facade Versions According to Opening Angle

In this phase of the study, the effect of the kinetic component on the daylight performance is analyzed according to its opening angle. For this reason, all kinetic components adjust in adaptive the facade with the same opening angle. This phase consists of four steps. The adaptive facade components are adjusted at a 4-degree angle as the opening angle in the first step (Figure 4.6). The opaque (0% transmittance) fabric mesh is selected for this phase to understand the effect of the opening angle clearly.

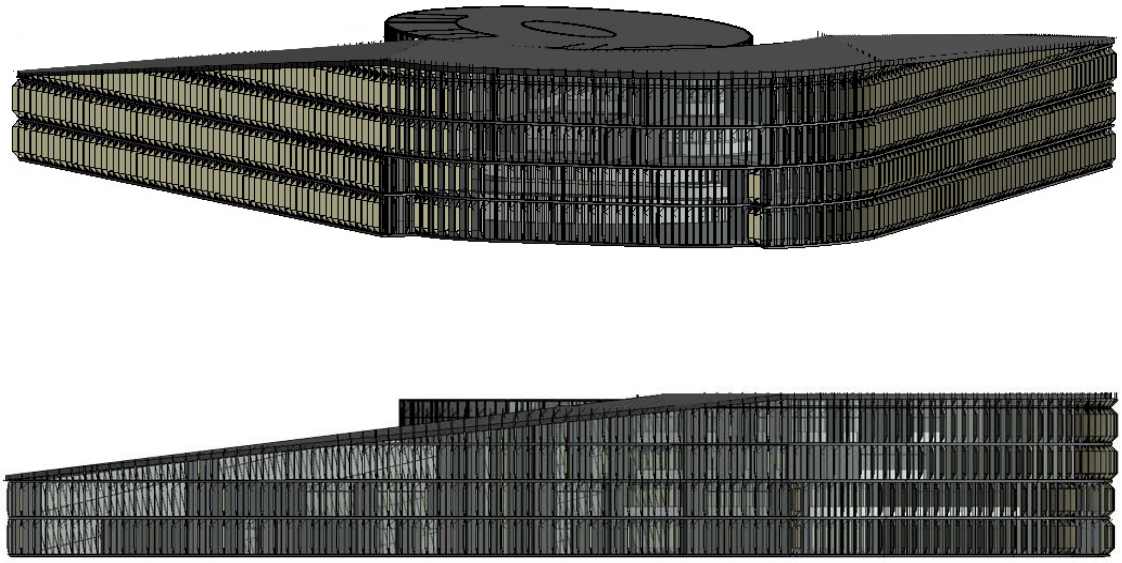


Figure 4.6. IZTECH Innovation Center with adaptive facade model according to all components with 4-degree opening angle.

A certain amount of improvement on Daylight performance is observed at both timelines as 9 am and 3 pm as summarized in Table 4.2. Almost 20 % of each floor have exceeded the 3000 lux of illuminance. That is almost half of the exceeding areas in the existing version of the building. However, now around 3% of the floor area is below the threshold value (300 lux). Regarding the findings, almost 75 % of the whole floor area receives the daylight within the threshold range (300-3000 lux) at 9 am but this rate is higher at 3 pm with a value of 83 %. The daylight availability is improved with around 10 % when we compared this 4-degree-angle-façade with the existing façade. The whole building satisfies the LEED criteria with 61 % rate.

The direct sunlight penetrated to the interior occurs at the south and east-facing rooms and areas. This causes a higher illuminance level above the threshold level for LEED IEQc7 option 2. For the south and east-facing rooms illuminance is above the threshold (3000lux) in the morning. Rooms that could not get enough light were identified on the north-facing rooms with a range of widths from 3.00 m to 5.00 m at 9 am. This is the main reason for the increase in the area below the threshold at 9 am. Higher illuminance level above the threshold level is observed at the south side of the north-facing rooms and areas at 3 pm. Areas which cannot satisfy the daylight availability are observed on most of the south-facing rooms and the room with a range of widths from 3.00 m to 5.00 m on the first floor at 3 pm (Figure 4.7).

Applying this 4-degree-angle façade, the building still fails to get any credit with a rate of 61% of floor area within the thresholds. So, the angle is set to be 30 degrees for the second step as explained below.

Table 4.2.The percentage of the floor area that provides LEED Daylight Criteria / floor area for 4-degree opening angle components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00																
9am: 75% within & 3pm: 83% & both: 61% within thresholds																
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	71	1127	27	425	3	41	79	1258	14	229	7	106	53	847
The Ground	1402	78	1100	18	254	3	48	83	1171	13	189	3	43	66	926
The First	1371	78	1066	20	275	2	30	83	1140	14	191	3	40	65	892
The Second	643	71	458	28	179	1	6	91	582	7	42	3	18	63	406

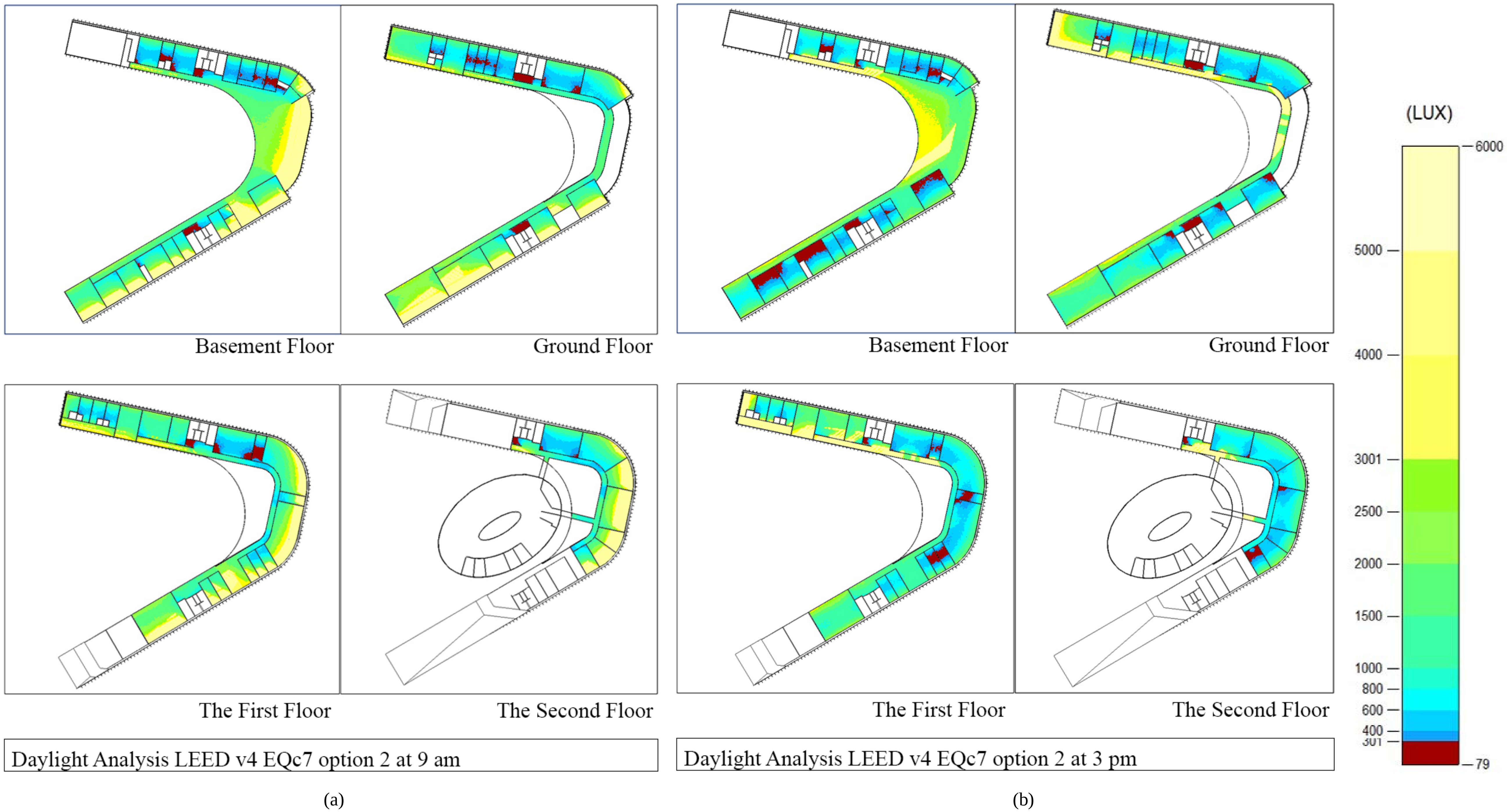


Figure 4.7. 4-Degree opening angle components version of the IZTECH Innovation Building Daylight Analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

In the second phase, the building consists of the adaptive facade with 30-degree opening angle kinetic components version (Figure 4.8). A slightly better convalesce on daylight performance at 30-degree opening angle version (Table 4.3) is observed when we compare the findings of the previous version as in Table 4.2 and the 30-degree-angle version as in Table 4.3. It demonstrates that the direct daylight penetrated to the interior has become a little transforms a bit diffused. Although an improvement convalesce is observed, illuminance is still excessive above the threshold especially at 9 am. Almost 77% of all floor area falls in the threshold range at 9 am while 1-6% of floor area remains below 300 lux at 9 am and 3 pm. Low illuminance values are observed in the south and east-facing rooms and areas in the morning. Areas which do not receive adequate daylight occur in the north-facing rooms at 9 am.

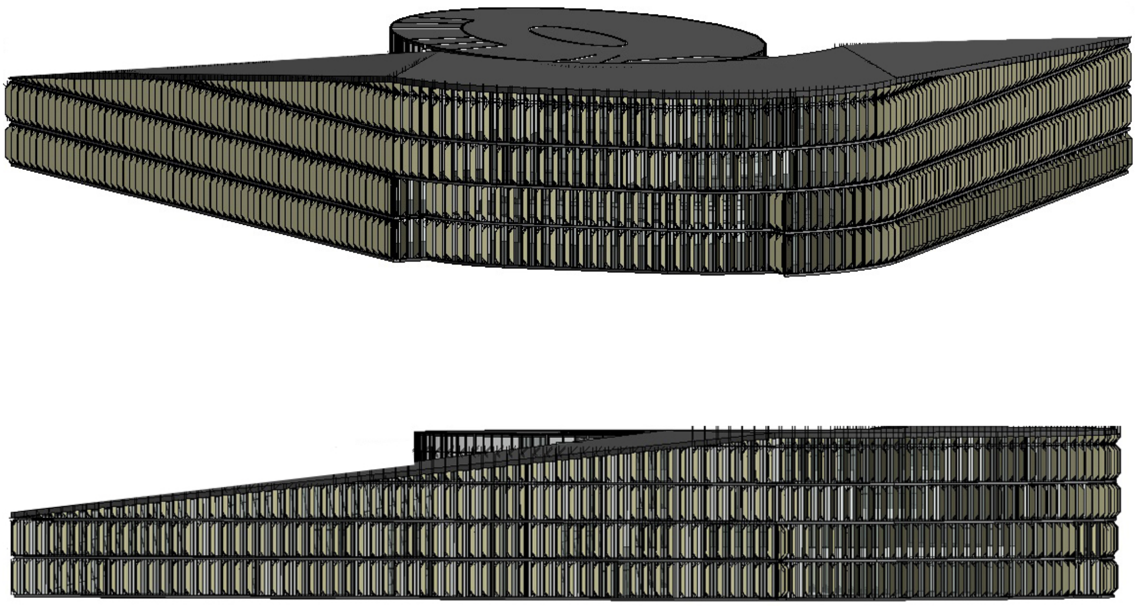


Figure 4.8. IZTECH Innovation Center with adaptive facade model according to all components with 30-degree opening angle.

There are still some areas which are almost 13 % of each floor area on the ground and first floor and pass the threshold value (3000lux). Around 20-24% of floor areas of the basement and second floor which correspond to the east-facing common area receives excessive daylight. Regarding the findings, almost 77 % of the whole floor area receives the daylight within the threshold range (300-3000 lux) at 9 am but this rate is higher at 3 pm with a value of 83 %. The daylight availability is improved with around 1-3 % when we compared this 30-degree-angle-façade with 4-degree-angle-façade. The whole building satisfies the LEED criteria with 62 % rate. But still, the uilding cannot get the desired LEED credits.

In detail, although the east-facing rooms on the second floor are suitable for daylight performance in the afternoon, there are some rooms which lack adequate daylight penetration in the east on the first floor and south-facing rooms in all floors at 3 pm. Illuminance is above the threshold at the south side of the north-facing rooms at 3 pm (Figure 4.9). At both timelines, areas above the threshold are reduced and regions below the threshold are increased.

Applying this 30-degree-angle façade, the building still fails to get any credit from LEED, so, the angle is set to be 45 degrees for the third step as explained below. Secondary aims are now to reduce the illuminance values on south and east-facing rooms at 9 am and the illuminance values at the south side of the north-facing rooms and areas.

Table 4.3. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 30-degree opening angle components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00																
9am: 77% within & 3pm: 83% & both: 62% within thresholds																
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	73	1168	20	326	6	100	79	1257	10	157	11	179	55	884
The Ground	1402	78	1093	13	183	9	126	82	1156	10	139	8	108	65	907
The First	1371	82	1121	13	185	5	65	84	1149	11	156	5	66	67	917
The Second	643	73	470	24	155	3	18	91	582	6	37	4	24	64	411

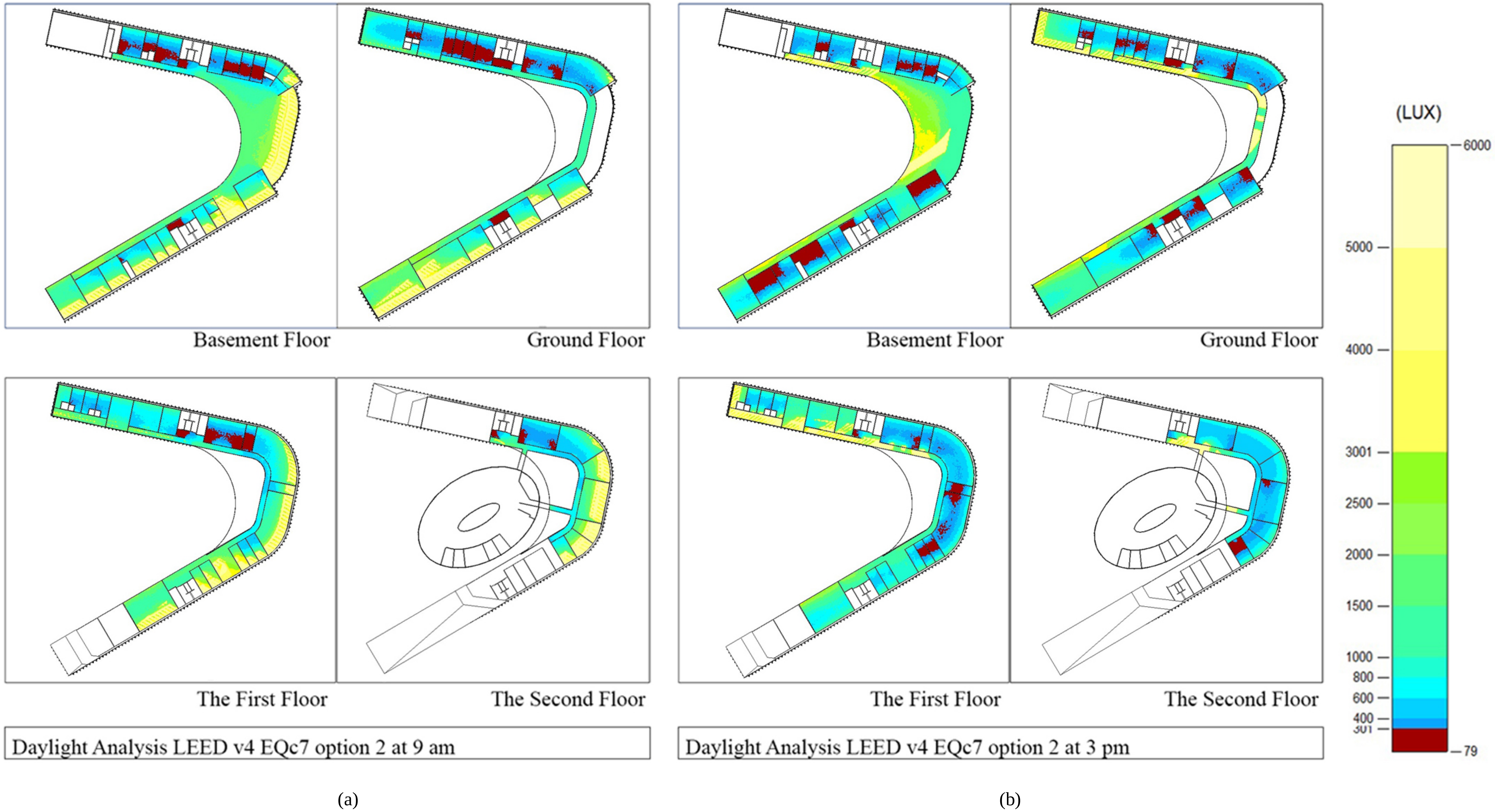


Figure 4.9.30-degree opening angle components version of the IZTECH Innovation Building Daylight Analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

The third phase consists of the analysis of the adaptive facade with 45-degree-opening angle kinetic components (Figure 4.10). In this version, the daylight performance of the adaptive façade is improved with 45-degree opening angle components at 9 am, however, the daylight performance at 3 pm is reduced (Table 4.4).

8% of ground and first floor and 12- 16 % of basement and second floor have exceeded the 3000 lux of illuminance. However, around 18 % of the ground floor area and 5-13 % of the others are below the threshold value (300 lux) at 9 am. These rates have increased when we compare them to the previous versions. Regarding the findings, almost 77 % of the whole floor area receives the daylight within the threshold range (300-3000 lux) at 9 am but this rate is more at 3 pm with a value of 83 %. The daylight availability gets lower with around 5-11 % when we compared this 45-degree-angle facade with 30-degree-angle facade. The whole building satisfies the LEED criteria with 60 % rate which is exactly the similar in the 4-degree-angle facade, but fails to get any credit.

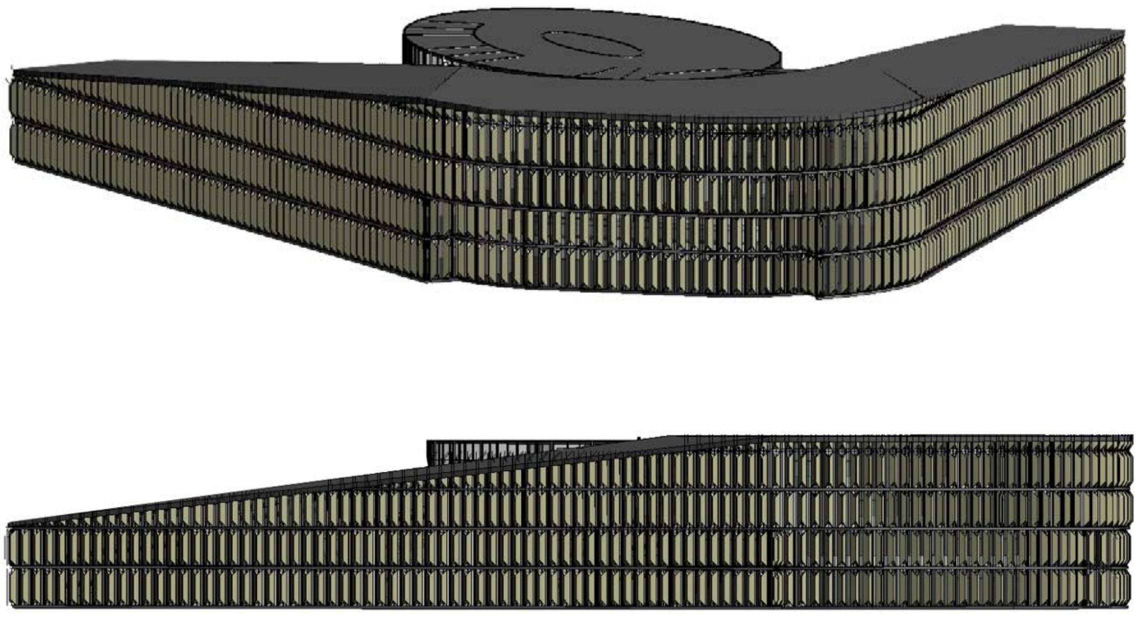


Figure 4.10. IZTECH Innovation Center with adaptive facade model according to all components with 45-degree opening angle.

Illuminance is reduced on the east and south-facing rooms at 9 am. Areas which do not receive enough daylight has increased with 45-degree opening angle version on the north-facing rooms in the morning. Those rooms have been affected with a higher rate than other rooms. Areas not receiving suitable amount of daylight has also increased on the south and east-facing rooms and areas on basement, ground and the first floor at 3 pm. Additionally, illuminance values of the north-facing area and rooms are reduced in the afternoon. However, daylight performance of the north and east-facing area and rooms on the second floor is increased, in this way at 3 pm.

Despite the increase in daylight performance at 9 am, the increase of the areas receiving enough daylight prevents getting enough daylighting performance. This demonstrates that the opening angle of components on the north-facing rooms and areas north side must be reduced in the morning. Besides, the bending angle of the components on the south side of the north-facing rooms and area must be increased at 9 am for 0% transmittance coating material (Figure 4.11). Concluding with these proposals, the next phase involves the application of 60-degree-opening angle kinetic components. The aim is to check the change in these performance rates.

Table 4.4. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 45-degree opening angle components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 79% within & 3pm: 78% & both: 61% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	77	1224	12	194	11	175	69	1107	13	204	18	282	54	863
The Ground	1402	76	1069	8	111	16	222	77	1083	9	124	14	195	62	874
The First	1371	83	1139	8	105	9	127	81	1109	9	127	10	134	66	910
The Second	643	74	477	16	102	10	64	80	513	5	34	15	96	57	366

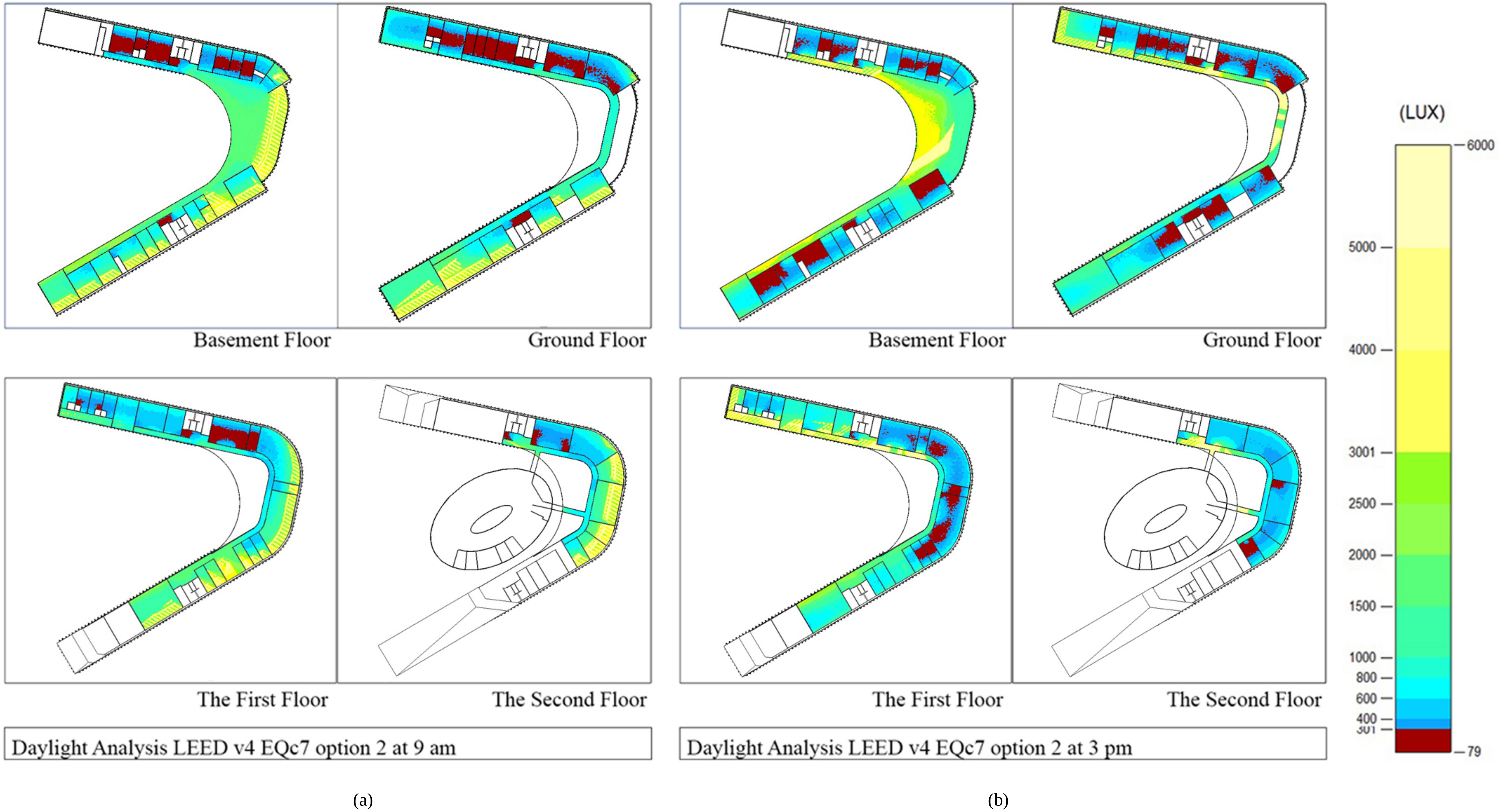


Figure 4.11. 45-degree opening angle components version of the IZTECH Innovation Building Daylight Analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

The fourth phase consists of the adaptive facade with 60-degree opening angle kinetic components (Figure 4.12). Areas which do not receive suitable amount of daylight has increased on the north-facing rooms on all floors at both timelines. These areas cause the main decrease in daylight performance according to LEED criteria. The whole building failed to get any credit with only 41 % of areas satisfying the threshold range. This facade version has become unsuccessful one.

Only 5-12 % of each floor have exceeded the 3000 lux of illuminance in the morning and in the afternoon. The whole building becomes darker. Regarding the findings, almost 61 % of the whole floor area receives the daylight within the threshold range (300-3000 lux) at 9 am but this rate is lower at 3 pm with a value of 49 %. The daylight availability is sharply declined with around 14-29 % when we compared this 60-degree-angle-facade with the previous facade.

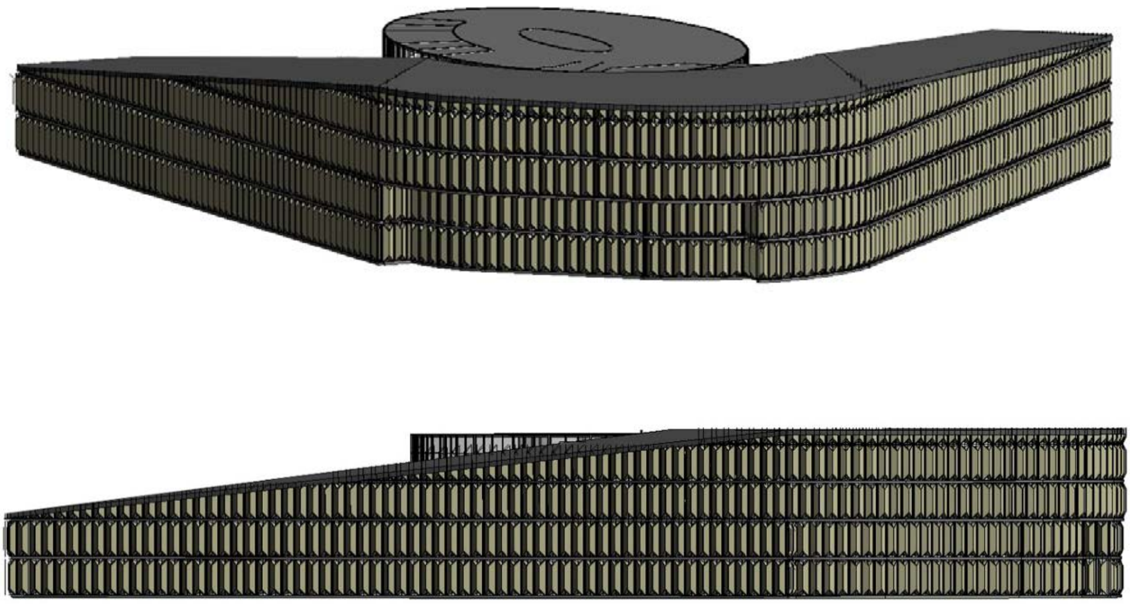


Figure 4.12. IZTECH Innovation Center with adaptive facade model according to all components with 60-degree opening angle.

In detail, although daylight performance increases on the south and east-facing rooms, areas which cannot receive adequate daylight penetration increases in these rooms at 9 am. The rise of poorly lighted areas is more effective than the rise of daylighting performance on this south-facing rooms. This case negatively affects overall daylighting performance at both timelines as 9 am and 3 pm (Table 4.4). Daylight performance of all north-facing rooms is reduced critically. Poorly lighted areas are increased in all east-facing rooms on the first and second floor. The south-facing rooms on the basement floor have poor daylight performance (Figure 13). It is observed that

Table 4.5. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 60-degree opening angle components version.

<table>
<tr><td colspan="16">LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00</td></tr>
<tr><td colspan="16">9am: 61% within & 3pm: 49% & both: 39% within thresholds</td></tr>
<tr><td colspan="2"></td><td colspan="6">9 am threshold results</td><td colspan="6">3 pm threshold results</td><td colspan="2">Both time</td></tr>
<tr><td>Floor Name</td><td>Total floor area</td><td colspan="2">Within threshold</td><td colspan="2">Above threshold</td><td colspan="2">Below threshold</td><td colspan="2">Within threshold</td><td colspan="2">Above threshold</td><td colspan="2">Below threshold</td><td colspan="2">within threshold</td></tr>
<tr><td></td><td>m²</td><td>%</td><td>Area m²</td><td>%</td><td>Area m²</td><td>%</td><td>Area m²</td><td>%</td><td>Area m²</td><td>%</td><td>Area m²</td><td>%</td><td>Area m²</td><td>%</td><td>Area m²</td></tr>
<tr><td colspan="16"></td></tr>
<tr><td>The Basement</td><td>1594</td><td>69</td><td>1094</td><td>6</td><td>103</td><td>25</td><td>396</td><td>52</td><td>823</td><td>12</td><td>183</td><td>37</td><td>587</td><td>45</td><td>709</td></tr>
<tr><td>The Ground</td><td>1402</td><td>54</td><td>757</td><td>5</td><td>65</td><td>41</td><td>581</td><td>52</td><td>724</td><td>7</td><td>97</td><td>41</td><td>581</td><td>39</td><td>554</td></tr>
<tr><td>The First</td><td>1371</td><td>59</td><td>812</td><td>4</td><td>57</td><td>37</td><td>502</td><td>55</td><td>750</td><td>6</td><td>81</td><td>39</td><td>540</td><td>39</td><td>536</td></tr>
<tr><td>The Second</td><td>643</td><td>62</td><td>396</td><td>9</td><td>61</td><td>29</td><td>186</td><td>28</td><td>181</td><td>5</td><td>31</td><td>67</td><td>430</td><td>21</td><td>132</td></tr>
</table>

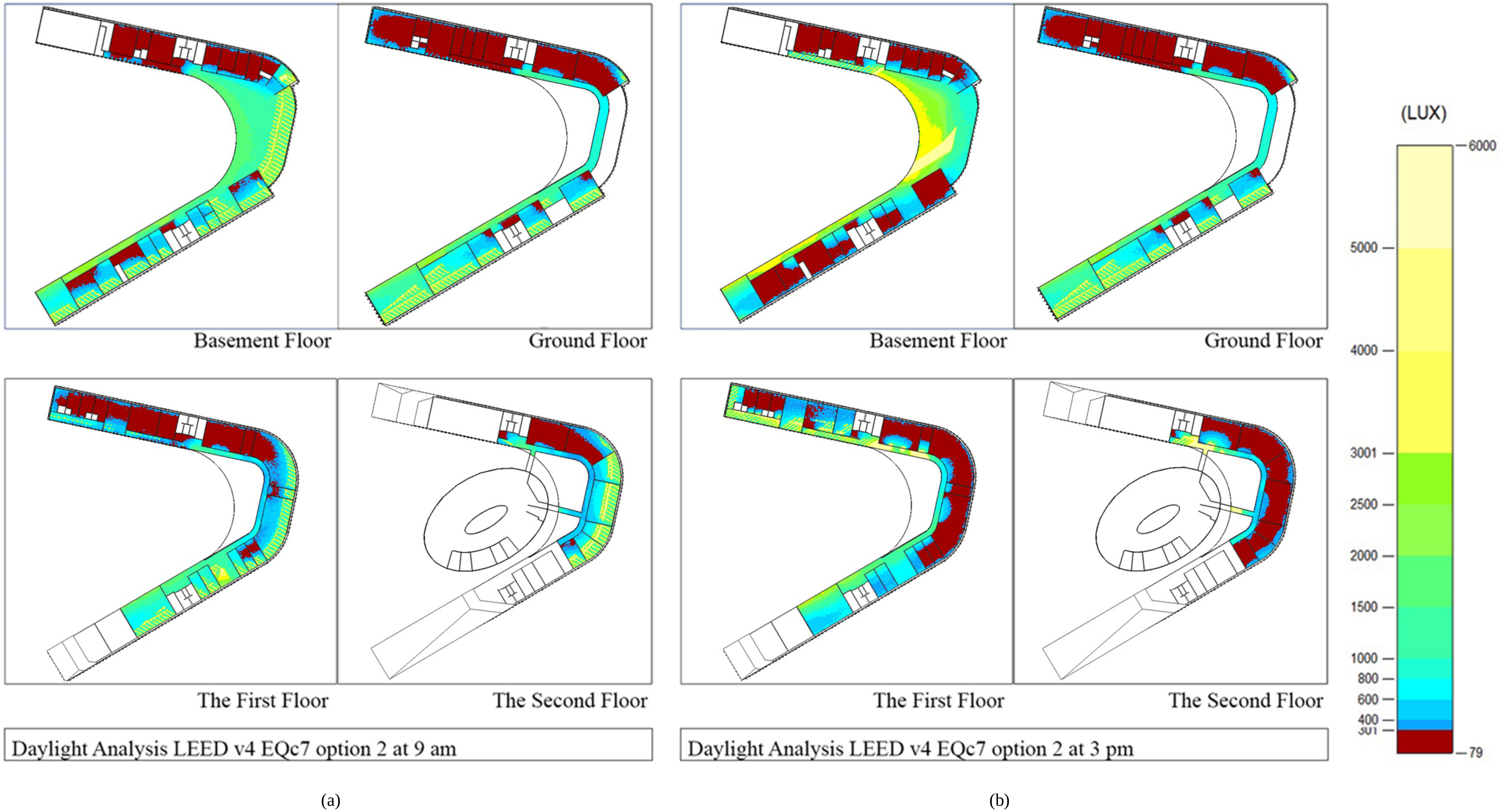


Figure 4.13. 60-degree opening angle components version of the IZTECH Innovation Building Daylight Analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

The fifth phase consists of the adaptive facade with 85-degree opening angle kinetic components (Figure 4.14). It is observed that areas below the threshold rises at both 9 am and 3 pm. Most of the daylight that penetrates into the interior blocked by this version of the kinetic component. For this reason, the excessive area which receives not enough daylight is more than the previous version.

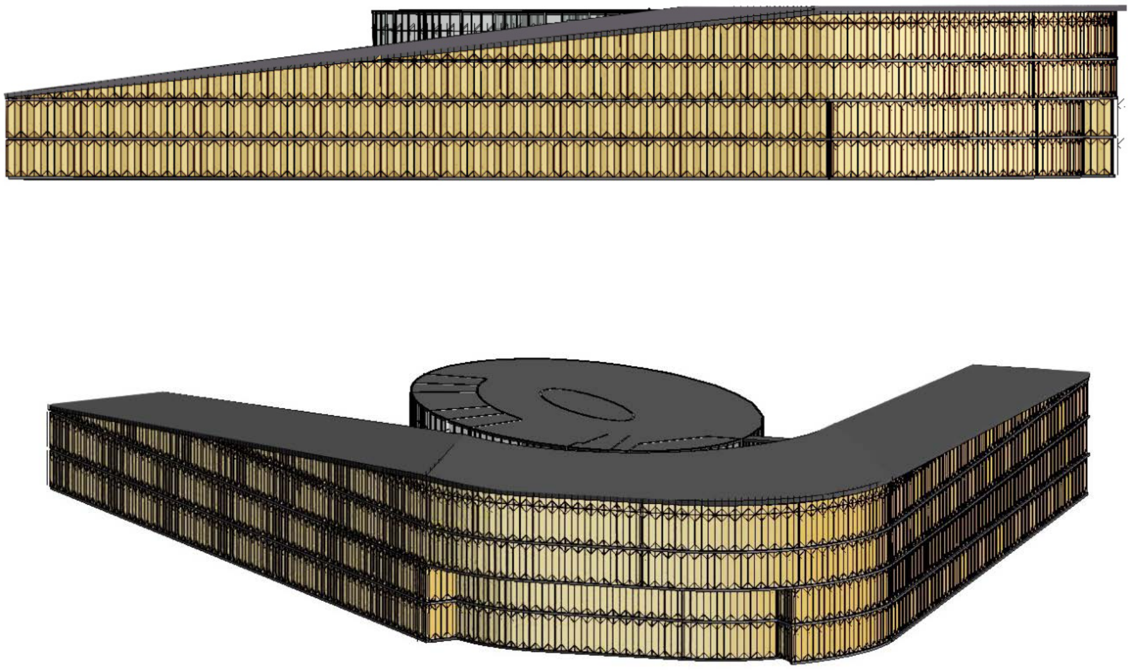


Figure 4.14. IZTECH Innovation Center with adaptive facade model according to all components with 85-degree opening angle.

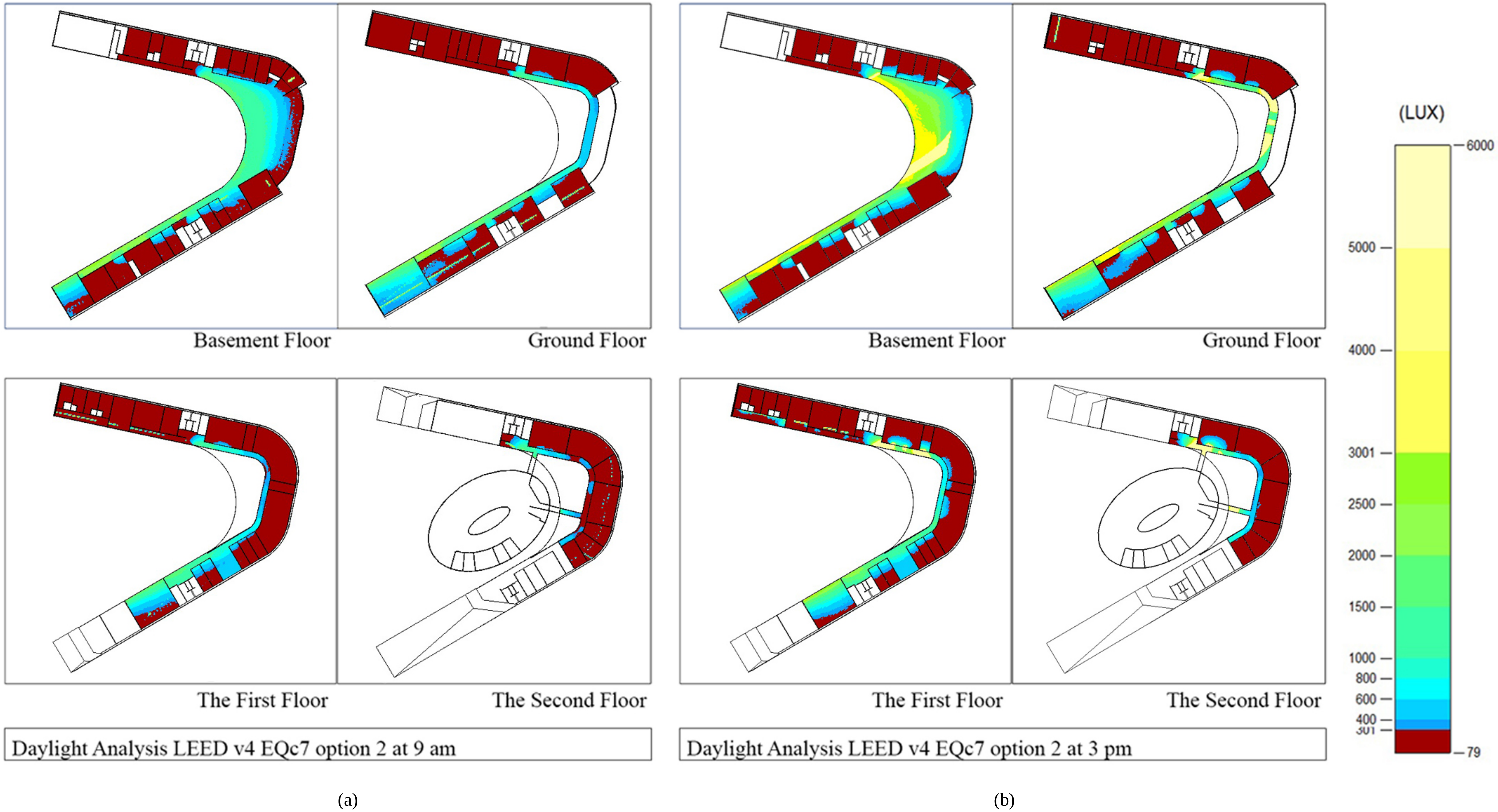
It is observed that areas below the threshold rises at both 9 am and 3 pm. Most of the daylight that penetrates into the interior blocked by this version of the kinetic component. For this reason, the excessive area which receives not enough daylight is more than the previous version.

Around 0-1% of the area is above the threshold at 9 am while 3-11% of the area is above the threshold at 3 pm (Table 4.6). In almost all rooms, there are areas that cannot get enough daylight (Figure 4.15). The area below the threshold increases critical. The version does not receive enough daylight. Because of this, this facade version has become the most unsuccessful one for daylighting performance.

Table 4.6. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 85-degree opening angle components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00																	
9am: 33% within & 3pm: 35% & both: 26% within thresholds																	
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	44	699	0	2	56	893	43	678	11	179	46	736	32	517
The Ground	1402	35	484	1	8	65	911	35	486	5	71	60	846	29	404
The First	1371	27	369	0	2	73	999	33	457	3	34	64	879	24	334
The Second	643	14	91	0	1	86	551	20	131	4	25	76	487	9	60

All analyses evaluated in this section demonstrates that coating material with 0 % transmittance is suitable for shading. Although this coating material is suitable for shading, it doesn't provide adequate daylight performance to illuminate the interior according to LEED criteria. Additionally, Table 4.1 demonstrates that even when the building gets a high amount of daylight very satisfactorily, the facade could not provide sufficient daylight on the north-facing rooms in the morning and in the south-facing rooms in the afternoon (Figure 4.7). For this reason, various transmittance values are analysed in the next section with each opening angle analysed in this section.



(a) (b)

Figure 4.15. 85-degree opening angle components version of the IZTECH Innovation Building Daylight Analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

4.3. Adaptive Facade Versions According to Material (Transmittance)

In this section of the study which consisted of six phases, the effect of transmittance value is analysed on the kinetic component. In addition to the previous section, the coating material was analysed with various transmittance value. The first phase is related to the performance of the kinetic component which has 4-degree opening angle with various transmittance (20%, 30% and 40%) of the coating material. The second phase consists of the performance of the kinetic component which has a 30-degree opening angle with various transmittance (20%, 30% and 40%) of the coating material. The effect of various transmittance (20%, 30% and 40%) of the coating material in the kinetic component which has a 45-degree opening angle was analysed in the third phase. Results of the component which has a 60-degree opening angle with various transmittance were determined in the fourth phase. The fifth phase consists of the performance of the kinetic component which has a 85-degree opening angle with various transmittance (20%, 30% and 40%) of the coating material. Effect of the various transmittance values (20%, 30% and 40%) used on daylight performance was compared in the sixth phase.

In the first phase, building facade consists of components that have a 4-degree opening angle with the various transmittance coating material. The highest amount of daylight penetrates into the interior when the facade consists of 4-degree opening angle components. The maximum area above the threshold and the minimum area below the threshold are observed in this way. Daylight performance of the 4-degree opening angle component with the component is summarized for 20% transmittance coating material in Table 4.7. The table indicates that there are some rooms which have less adequate daylight penetration in the north on the basement and second floor at 3 pm. There is a room that does not get enough daylight in the north on the first floor at 9 am. All floors exceed from the threshold with a minimum 19%. The threshold value has been exceeded at least % 19 on all floors at 9 am. The threshold value has been exceeded at least 14% on all floors without the second floor at 9 am. Incubation Centre prevents daylight into the second floor at 3 pm. This is the reason why the change on the 2nd floor is not like the other floors at 9 am and 3 pm.

Table 4.7. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 4-degree opening angle with 20% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 75% within & 3pm: 86% & both: 63% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	70	1120	29	464	1	10	84	1331	15	244	1	18	56	892
The Ground	1402	79	1113	19	266	2	24	84	1183	14	199	2	21	66	925
The First	1371	79	1082	21	281	1	8	86	1176	14	195	0	0	66	910
The Second	643	70	448	30	191	1	4	93	599	6	42	0	2	63	408

There is no critical alteration about the area above the threshold In the 4-degree opening angle component between 20% transmittance and 30% transmittance. When the transmittance increases the area above the threshold increases. Although the area above the threshold in the basement floor increased at 9 am and 3 pm, lack adequate daylight penetration area increased by 1 m² in 30% transmittance performance analysis when the daylight performance between 20% transmittance and 30% transmittance is compared (Table 4.7 and Table 4.8). The only significant variance is the reduction on lack of daylight penetration area (Figure 4.17).

In the 40% transmittance version of the 4-degree angle component, the area above the threshold increase in all floors both at 9 am and 3 pm (Table 4.7). The increment on the area above the threshold between 40% transmittance version and 30% transmittance version is higher than the increment on the area above the threshold between 30% transmittance version and 20% all floors both at 9 am and 3 pm without the second floor at 3 pm. The increase in the 2nd floor at 3 pm is not subject to this diagnosis. All lack of daylight penetration area reduced on 40% transmittance version (Figure 4.17). (Table 4.8 and Table 4.9). The only significant variance is the reduction on lack of daylight penetration area (Figure 4.18).

Table 4.8. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 4-degree opening angle with 30% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 75% within & 3pm: 86% & both: 62% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	70	1118	29	466	1	9	84	1331	15	247	1	16	56	889
The Ground	1402	79	1111	19	268	2	24	84	1182	14	199	2	21	66	923
The First	1371	79	1081	20	281	1	9	86	1176	14	195	0	0	66	910
The Second	643	70	447	30	191	1	4	93	599	6	42	0	2	63	407

Table 4.9. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 4-degree opening angle with 40% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 73% within & 3pm: 84% & both: 59% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	69	1096	31	490	0	7	79	1262	20	323	1	9	51	806
The Ground	1402	78	1096	20	287	1	20	83	1165	16	219	1	19	64	893
The First	1371	76	1043	24	323	0	5	85	1167	15	204	0	0	63	868
The Second	643	68	437	31	202	0	3	93	599	7	43	0	0	62	398

The reason for the slight alteration in the analysis is that all elements of the kinetic component are very close together. Very close elements in the kinetic component work like one part vertical shading element that has less transmittance from the coating material.

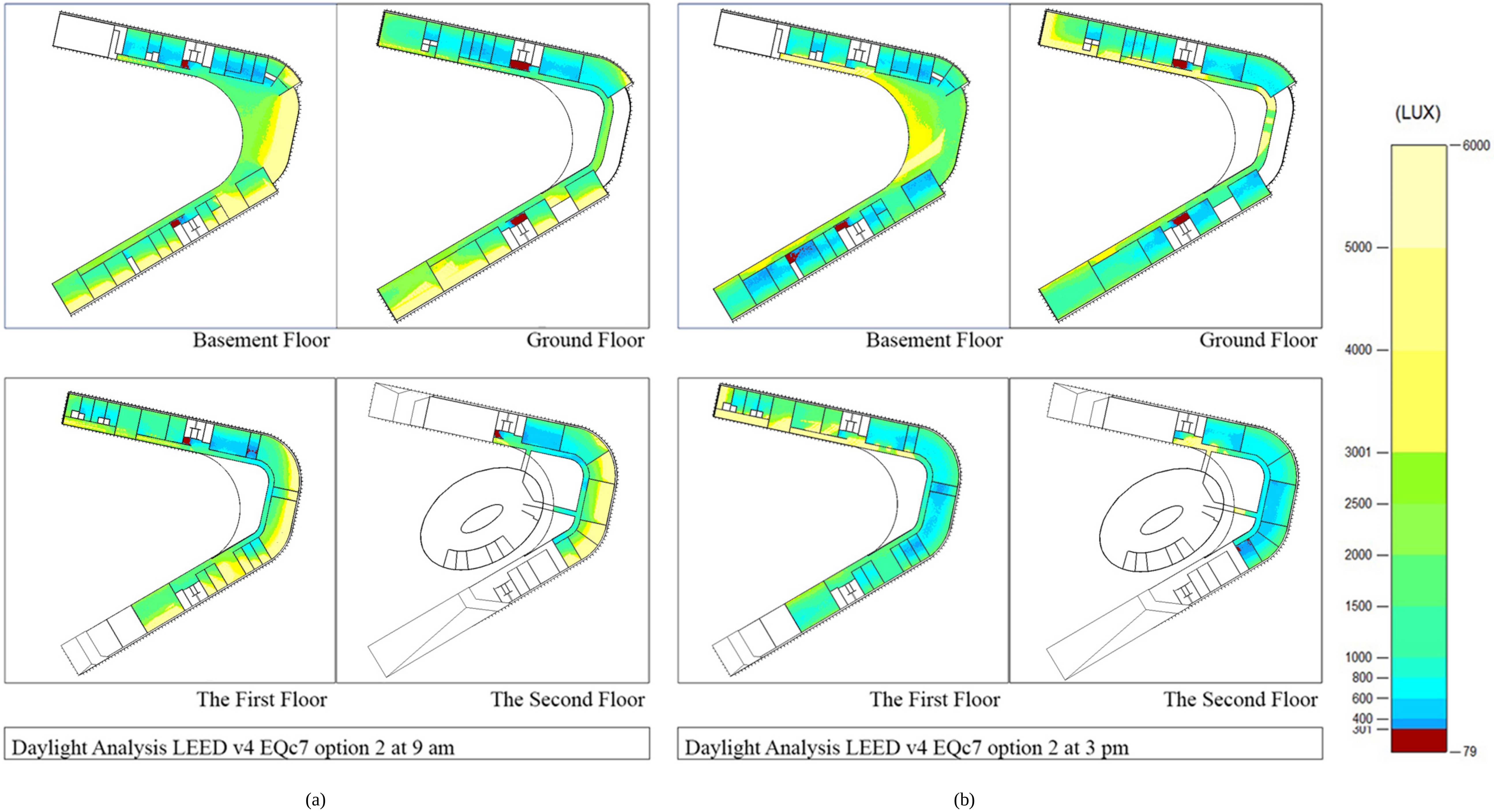
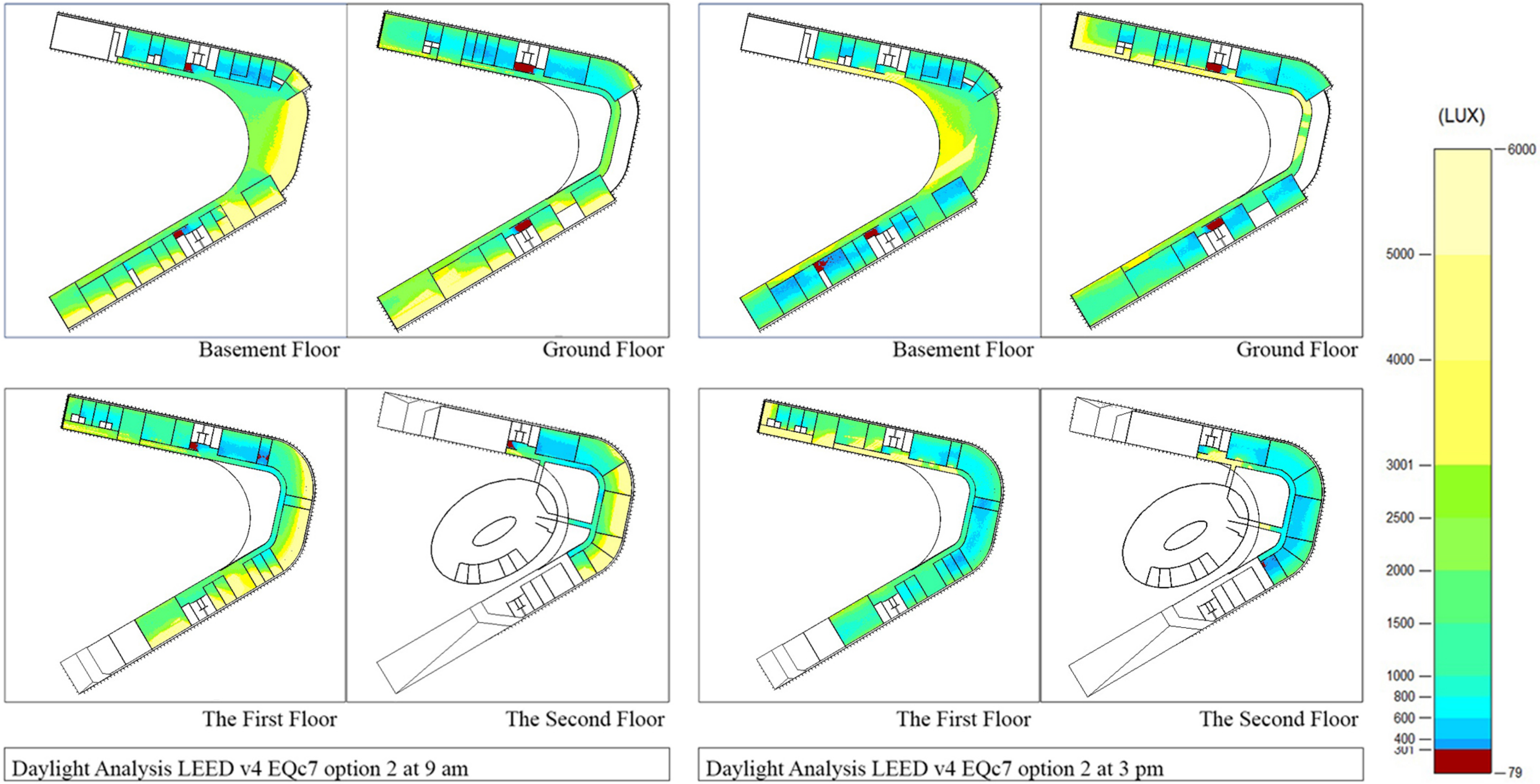


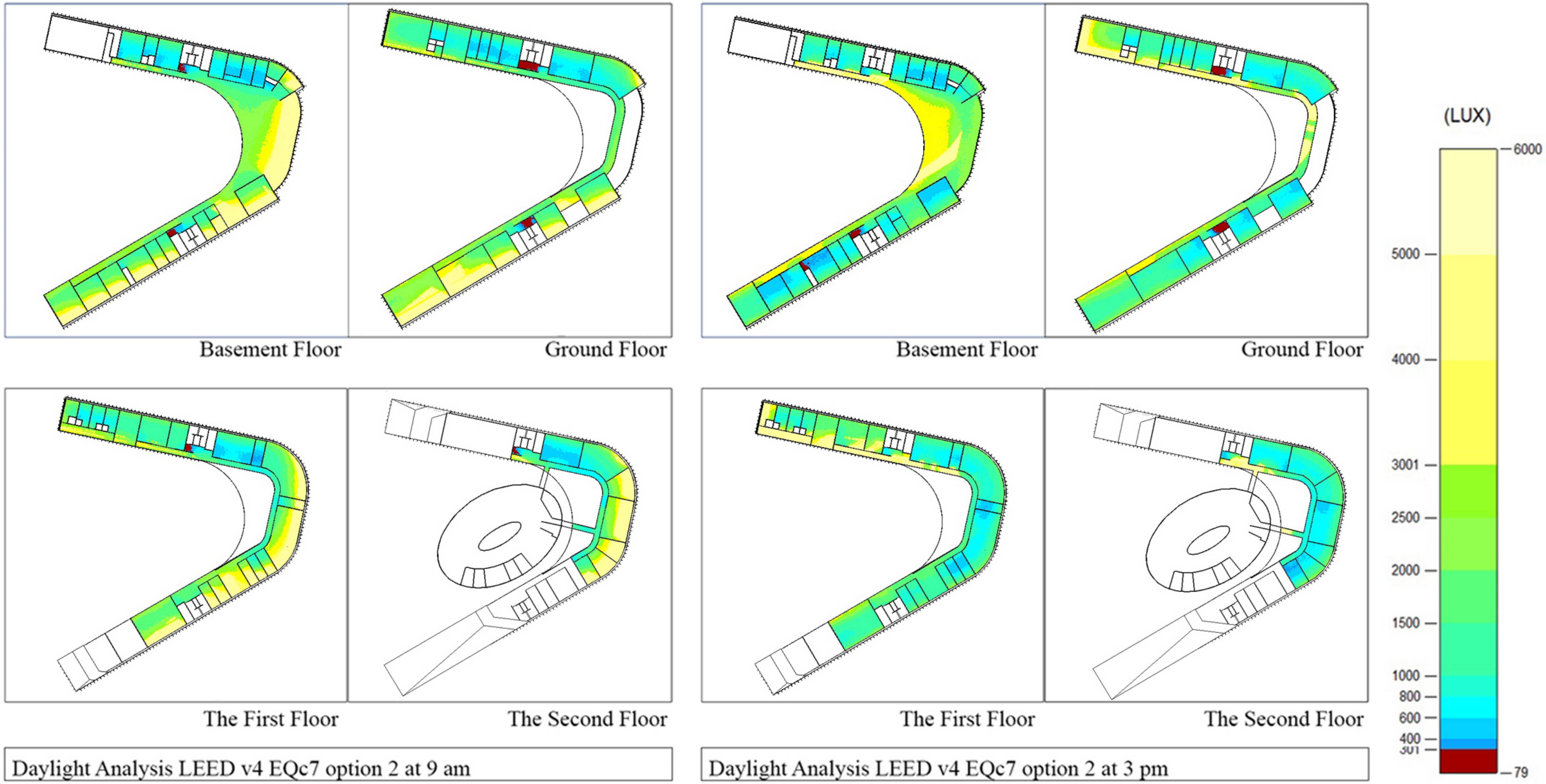
Figure 4.16. 4-degree opening angle components with 20% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.



(a)

(b)

Figure 4.17. 4-degree opening angle components with 30% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.



(a) (b)

Figure 4.18. 4-degree opening angle components with 40% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

In the second phase, the adaptive facade consists of 30-degree opening angle kinetic components with various transmittance. The effect of transmittance on daylight performance on the component is observed more clearly than the first phase. While the angle remains constant as 30-degree, the coating material with various transmittance used is changed. When we compare the findings of the previous phase, the area above the threshold decrease in all versions of the 30-degree angle for the at 9 am. In the second phase that consists of 3 parts as 20%, 30% and 40% transmittance phase, the 30-degree kinetic component is analysed.

In the first part, daylight performance of the 30-degree angle kinetic component with 20% transmittance is demonstrated in Table 4.10. It indicates that the direct daylight penetrated to the interior is reduced. Although the reduction of the direct daylight, there is still superabundant daylight penetrated to the interior in the basement and the second floor at 9 am according to LEED criteria (Table 4.10). This version of the kinetic component can bring 1 point at both 9 am and 3 pm. Unfortunately, the same situation is not valid to get 1 point, considering that both within thresholds. Because components are perceived as static shading elements in Revit. This demonstrates that the kinetic component with 20% transmittance coating material can achieve 1 point.

Table 4.10. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 30-degree opening angle with 20% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 78% within & 3pm: 84% & both: 64% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	74	1184	22	356	3	54	79	1252	14	220	8	122	55	871
The Ground	1402	81	1136	14	194	5	72	86	1208	11	155	3	40	69	970
The First	1371	83	1140	15	197	3	34	87	1186	12	163	2	21	70	962
The Second	643	73	470	24	156	3	17	90	580	6	37	3	25	64	410

The areas receiving enough daylight increases at both 9 pm and 3 am when we compare the 4-degree angle kinetic component with 20% transmittance version of the kinetic component. The significant part of areas receiving enough daylight is on rooms in the north at 9 am and rooms in the south at 3 pm (Figure 4.19).

14-24 % of each floor has exceeded the 3000 lux of illuminance at 9 am (Table 4.10). Most of this area in the south and east side of the building. This demonstrates that 30-degree angle versions of the components (20% transmittance and more transmittance versions) can not provide enough shading. According to Figure 4.18, a similar result is valid at 3 pm except on the second floor. Most of the areas exceeded the 3000 lux of illuminance at 3 pm is on the south side of the north-facing rooms. Areas below the threshold at 3 pm at east is on the first and second floor. There are areas that not enough daylight penetrated at the south-facing rooms for all floors at 3 pm. Rooms in the north side have areas below the threshold in the basement, ground and first floor.

The second part consists of a 30-degree angle kinetic component with 30% transmittance. It is observed clearly that when the transmittance percentage increase, areas that not enough daylight penetrated into the interior decrease. Table 4.11 demonstrates that using %30 transmittance on the kinetic component can bring 1 point at both 9 am and 3 pm according to LEED criteria.

Table 4.11. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 30-degree opening angle with 30% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 78% within & 3pm: 84% & both: 63% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	75	1191	23	361	3	41	78	1248	15	233	7	112	55	871
The Ground	1402	81	1130	15	205	5	67	85	1187	13	178	3	37	67	943
The First	1371	83	1136	15	209	2	26	86	1174	13	180	1	17	67	947
The Second	643	73	471	25	159	2	12	90	581	6	40	3	21	64	412

Daylight penetration into interior increased on all floor at both 9 am and 3 pm, except the second floor at 3 pm. Percentage above the threshold increases from 22% to %23 for basement floor at 9 am and 24% to 25% for the second floor at 9 am. Percentage above the threshold of the ground and first-floor increase from 14% to 15% at 9 am. The rise in the percentage above the threshold is observed at 3 pm when we compare Table 4.10 and Table 4.11. Although there is no increase in percentage on the second floor at 3 pm, the area above the threshold has increased in square meters. The effect of the 30% transmittance on the component is demonstrated clearly in Figure 4.18. The rise in transmittance provides satisfying daylight areas instead of areas below the threshold

The rise of poorly lighted areas is effective to reduce areas above the threshold. Areas below the threshold reduced at the north-facing rooms on the basement, first and second floor at 9 am (Figure 4.20). The reduction in the areas below the threshold reduced at the north-facing rooms on the ground floor at 9 am is more than other floors. Areas above the threshold slightly increased on rooms at the south and east at 3 pm. All areas that get not enough daylighting performance reduced at 3 pm. It is observed that the effect of the direct sunlight that comes from the east on the basement and ground floor is similar.

In the last part of the second phase, the facade is covered by a 30-degree component with 40% transmittance coating material. 30-degree component with 40% transmittance allows more daylight into the interior. This situation provides a reduction in the area that receive not enough sunlight when we compare the first, second and third part of this phase. Reduction in the area below the threshold conjunction with the rise in the area above the threshold is observed. Reduction in the area below the threshold conjunction with the rise in the area above the threshold is observed. According to LEED criteria, this version can bring 1 point at 9 am and 3 pm in spite of though the rise above the threshold (Table 4.12).

The alteration in areas which lack adequate enough daylight penetration between 30% and 40% transmittance is more than alteration between 20% and 30% transmittance. It indicates that 40% material provides daylight came from outside is more directly comes into the interior against 30% and 20% transmittance. This 10% change may lead to more critical outcomes from the change between 20% and 30% transmittance in terms of the area above the threshold. The area below the threshold reduce on all floors at 9 am and 3 pm. Particularly, diminishment on the basement floor at 9 am is the highest diminishment when the %10 transmittance differing values are compared with 66 m². In addition this, the difference in the area above the threshold between 30% and 40% transmittance on the first floor at 3 pm is the highest difference with 72 m².

Table 4.12. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 30-degree opening angle with 40% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 80% within & 3pm: 84% & both: 65% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	76	1214	23	368	1	12	78	1242	19	305	3	46	55	877
The Ground	1402	83	1164	15	211	2	28	85	1189	14	191	2	22	70	975
The First	1371	83	1141	16	214	1	15	86	1182	14	186	0	2	70	961
The Second	643	74	478	25	160	1	4	92	590	6	42	2	11	67	428

The decrease in the area below the threshold is observed in all room in the north (Figure 4.21). Although the reduction in the area below the threshold in rooms in the north is observed, there is too much area above threshold in the south-facing rooms at 9 am and south side of the area in the north at 3 pm. There is no area below the threshold in east-facing rooms on the second floor.

In detail, 74-76 % of the basement and second floor and 83 % of the ground and first floor meet LEED daylight criteria (300-3000 lux) at 9 am. 85-92 % of the ground, first and second floor is within the threshold. 1-2 % area at 9 am and 3-0% area at 3 pm receives less than 300 lux.

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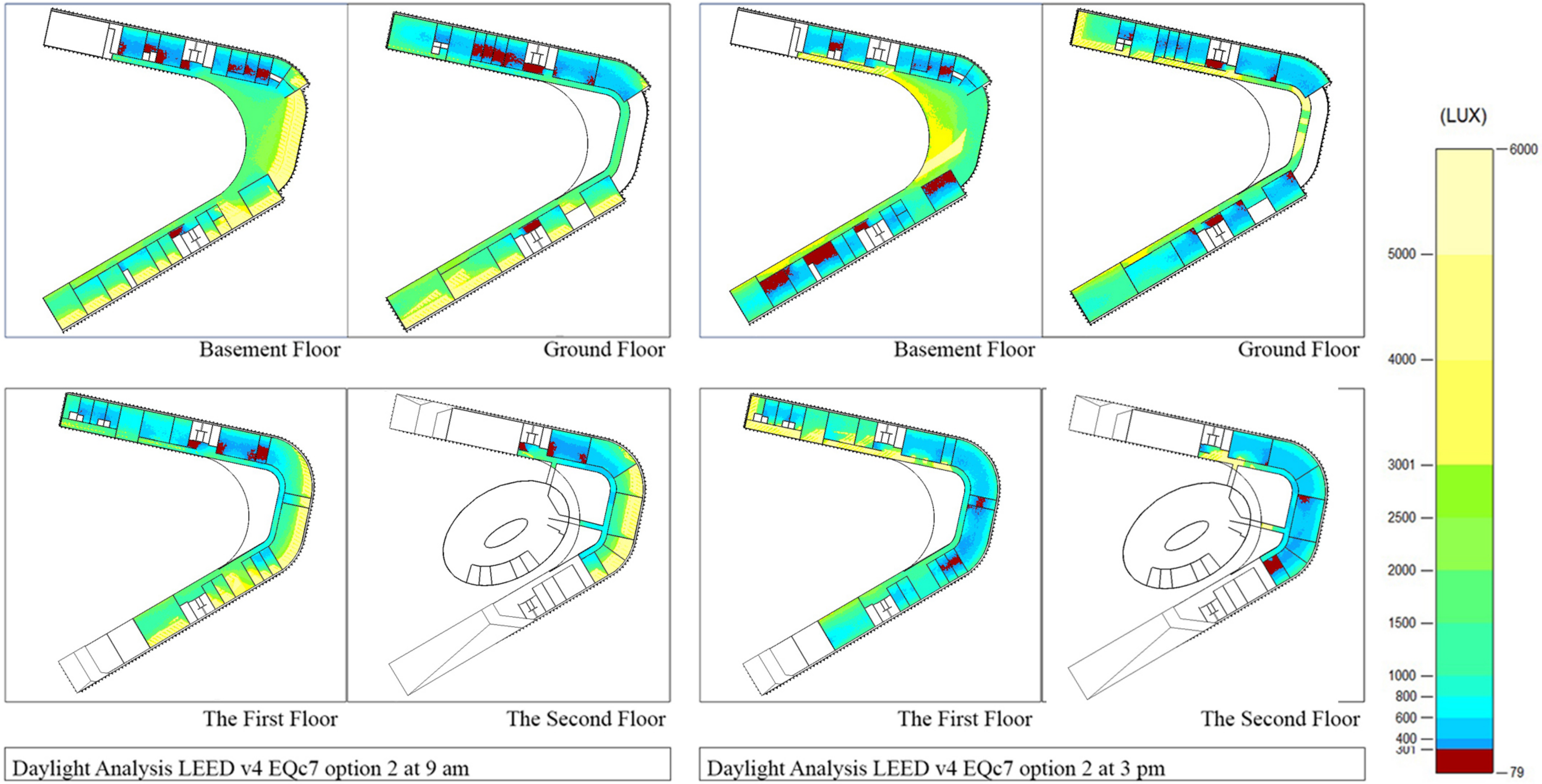
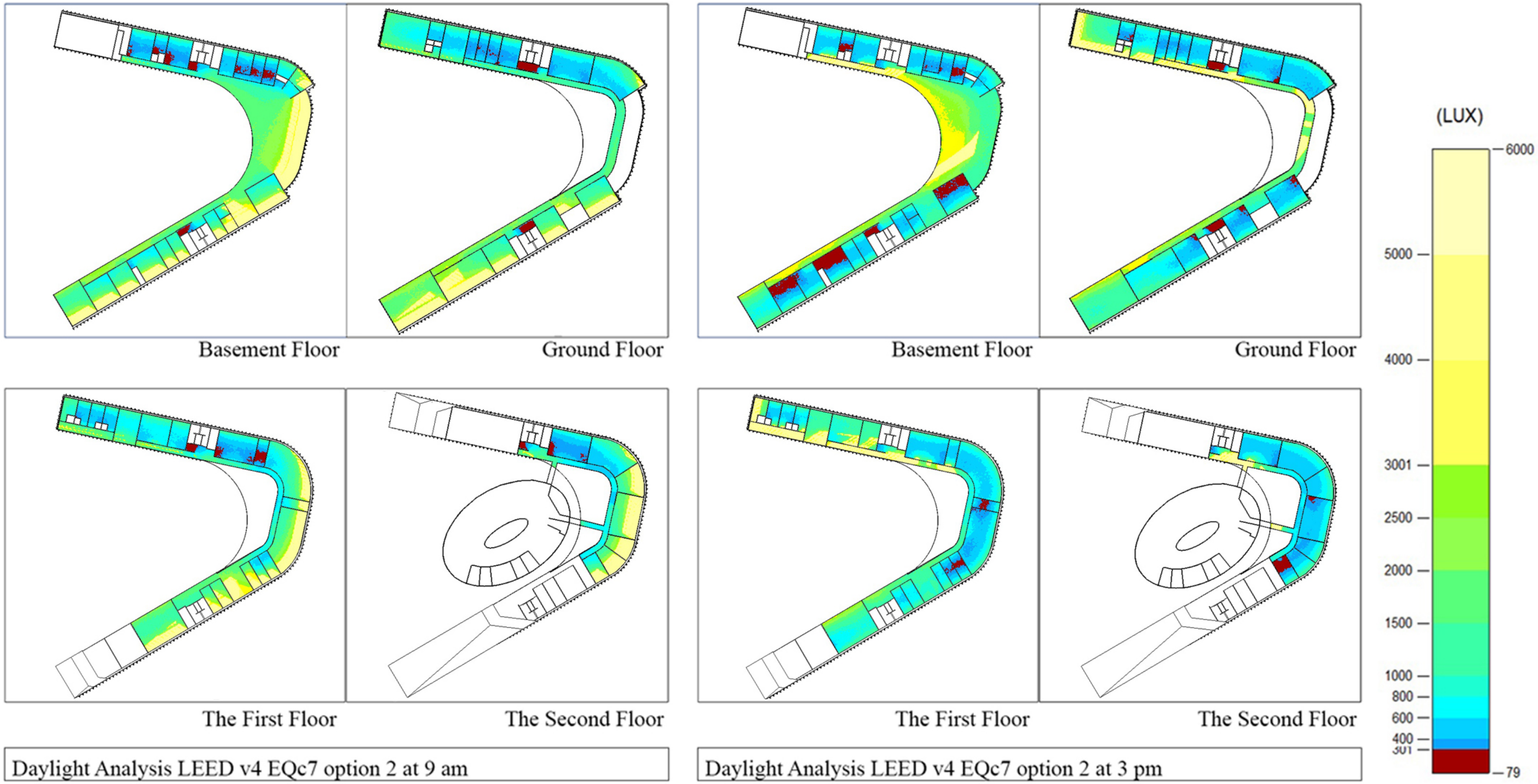


(a) (b)

Figure 4.19. 30-degree opening angle components with 20% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.



(a) (b)

Figure 4.20. 30-degree opening angle components with 30% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

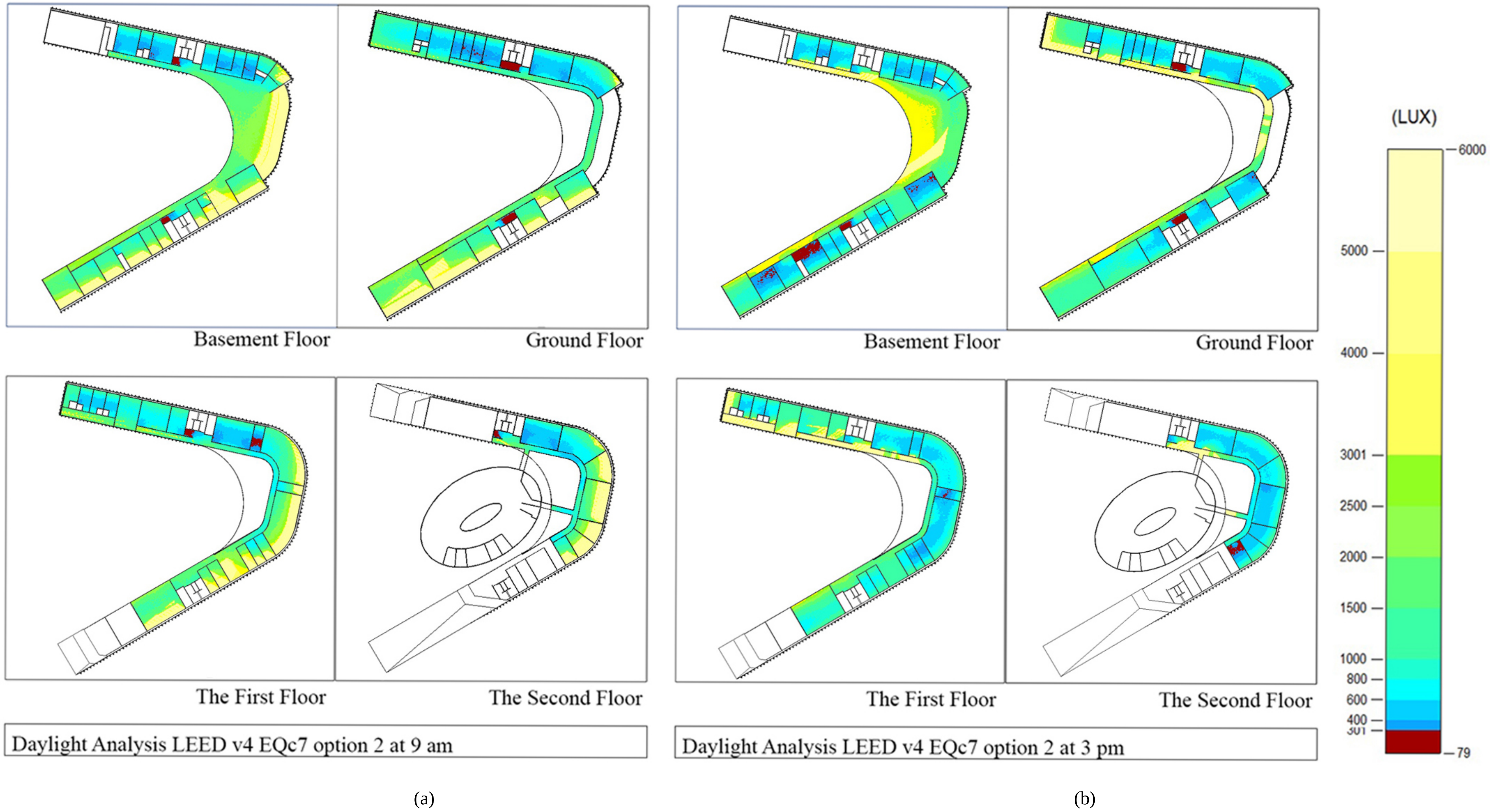


Figure 4.21. 30-degree opening angle components with 40% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

The third phase consists of the analysis of the adaptive facade covered by 45-degree-opening angle kinetic components with the various coating materials (20%,30% and 40% transmittance). The coating material with the same transmittance (which transmittance used in the analysis) is analysed on the facade covered by 45-degree-opening angle kinetic components. The third phase consists of three parts as 20%,30% and 40% transmittance analysis. When we compare the findings on the 30-degree component versions between 45-degree component versions with the same transmittance, it is observed that the rise in the area below the threshold and the reduction in area above the threshold on the 45-degree component versions.

The first part of the third phase, the daylight performance of the 45-degree angle kinetic component with 20% transmittance is demonstrated in Table 4.13. 8-17 % of all floors have exceeded the area above the threshold at 9 am. Analysis at 3 pm indicates that 5-13 % of all area receives more than 3000 lux of illuminance at 3 pm. This version has the lowest area above the threshold in this phase. Whole floor area receives the daylight within the threshold. According to Table 4.13, almost 77 % of the total floor area meets LEED criteria (300-3000 lux) at 9 am. This rate is slightly lower at 3 pm as 76%.

Table 4.13. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 45-degree opening angle with 20% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 77% within & 3pm: 76% & both: 60% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	76	1210	13	214	11	170	70	1121	13	200	17	272	54	854
The Ground	1402	76	1064	8	116	16	222	77	1086	9	125	14	192	62	872
The First	1371	82	1129	8	114	9	126	81	1111	10	133	9	127	66	899
The Second	643	73	467	17	111	10	64	80	514	5	35	15	94	56	359

The daylight penetrated into the interior reduce on the east and south-facing rooms in the whole building at 9 am as indicated in Figure 4.22 when we compare the 30-degree opening angle kinetic component with 20% transmittance (Figure 4.19). Although the reduction in the daylight that penetrates into the interior, there is still area above the threshold at the east and south side of the building at 9 am. Besides, the area below the threshold increase room in the north on all floors at 9 am. More area below the threshold in east and north-facing rooms than the facade that consists 30-degree opening angle kinetic component with %20 transmittance is observed.

In the second part, the daylight performance of the 45-degree angle kinetic component with 30% transmittance is demonstrated in Table 4.14. It is observed that the regions that do not get enough daylight decrease with the increase of transmittance used in the component. The area above the threshold enhances when we compare 20% transmittance version. It is observed that areas that have lack adequate daylight penetration in, reduce. While the area within the threshold (300-3000 lux) decrease in 74% from 77% from 9 am, the area that meets LEED daylight criteria increases in 78% from 76% at 3 pm.

Table 4.14. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 45-degree opening angle with 30% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 74% within & 3pm: 78% & both: 56% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	70	1123	21	332	9	138	73	1160	14	224	13	209	48	766
The Ground	1402	74	1037	14	193	12	172	78	1101	12	172	9	130	58	820
The First	1371	80	1096	14	186	6	89	82	1119	13	176	6	76	63	857
The Second	643	68	436	24	155	8	52	85	547	6	40	9	56	55	351

Almost 21-24 % of the basement and second floor and 14-15 % of the ground and first floor have exceeded the 3000 lux of illuminance at 9 am. In addition to this, around 12% of the ground floor area and 6-9 % of the others are below the threshold value (300 lux). According to analysis at 3 pm, around 12-14% of the basement, ground and first floor area of the total area on these floors receives much daylight that exceeds the threshold. The rise is observed in the area above the threshold on the second floor at 3 pm when we %20 transmittance version and 30% transmittance version are compared. The area below the threshold is 13% on the basement floor. Almost 9-10% area that receives not enough daylight is on the ground and second floor. The first floor includes a 6% area below the threshold at 3 pm. The area above and below the threshold is indicated in Figure 4.23. There is a minor reduction in the area below the threshold on the north side of all floors at 9 am. The areas that receive excessive daylight rises in the south on all floors at 9 am. According to analysis indicated Figure 4.20 at 3 pm, the area below the threshold decreases in all floors. There are no critical changes observed in the area below the threshold on the north side of the building.

Finally, the building consists of the adaptive facade with 45-degree opening angle kinetic components that have 40% transmittance version. A slightly changes on overall daylight performance at 40% transmittance version is observed when we compare the analysis in the previous part. When analyses (30% and 40% transmittance versions of the 45-degree opening angle component) are compared, there is no critical change observed in the area above the threshold at 9 am (Table 4.14 and Table 4.15). Although the area above the threshold at 9 am is identical, the area below the threshold reduces in the %40 transmittance version.

There is slight variance about the area above the threshold is observed in the ground, first and second floor at 3 pm between 30% and 40% transmittance versions. The only variance about the area above the threshold in the area above the threshold is on the basement floor. 5% more area that exceeds 3000 lux than the 30% transmittance version of 45-degree opening angle is observed between two analyses on the basement floor at 3 pm. The highest areas that receive not enough daylight areas are on the ground floor with 9% at 9 am and on the basement floor with 9% at 3 pm. Around the 2-5% the area below the threshold is in the first, ground and second floor at 9 am and 3 pm. The area below the threshold on the second floor is 3% at 9 am and 5% at 3 pm. The slight reduction in the area below the threshold is observed on the basement floor at 9 am (Figure 4.24). The area that receives less 300 lux of illuminance reduces on the ground floor at 9 am. There is no critical changes on the first and second floor at 9 am in Figure 4.24. A reduction is observed on the basement and first floor at 3 pm. The most reduction in the area below the threshold at 3 pm is observed. The reduction in the area above the threshold on the ground floor in the north is observed at 3 pm.

Table 4.15. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 45-degree opening angle with 40% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 77% within & 3pm: 81% & both: 59% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	73	1165	21	335	6	93	72	1154	19	299	9	141	48	758
The Ground	1402	78	1087	14	195	9	120	82	1152	13	187	5	64	63	886
The First	1371	82	1123	14	192	4	56	84	1157	13	181	2	32	67	913
The Second	643	73	467	24	156	3	20	89	571	6	42	5	30	62	398

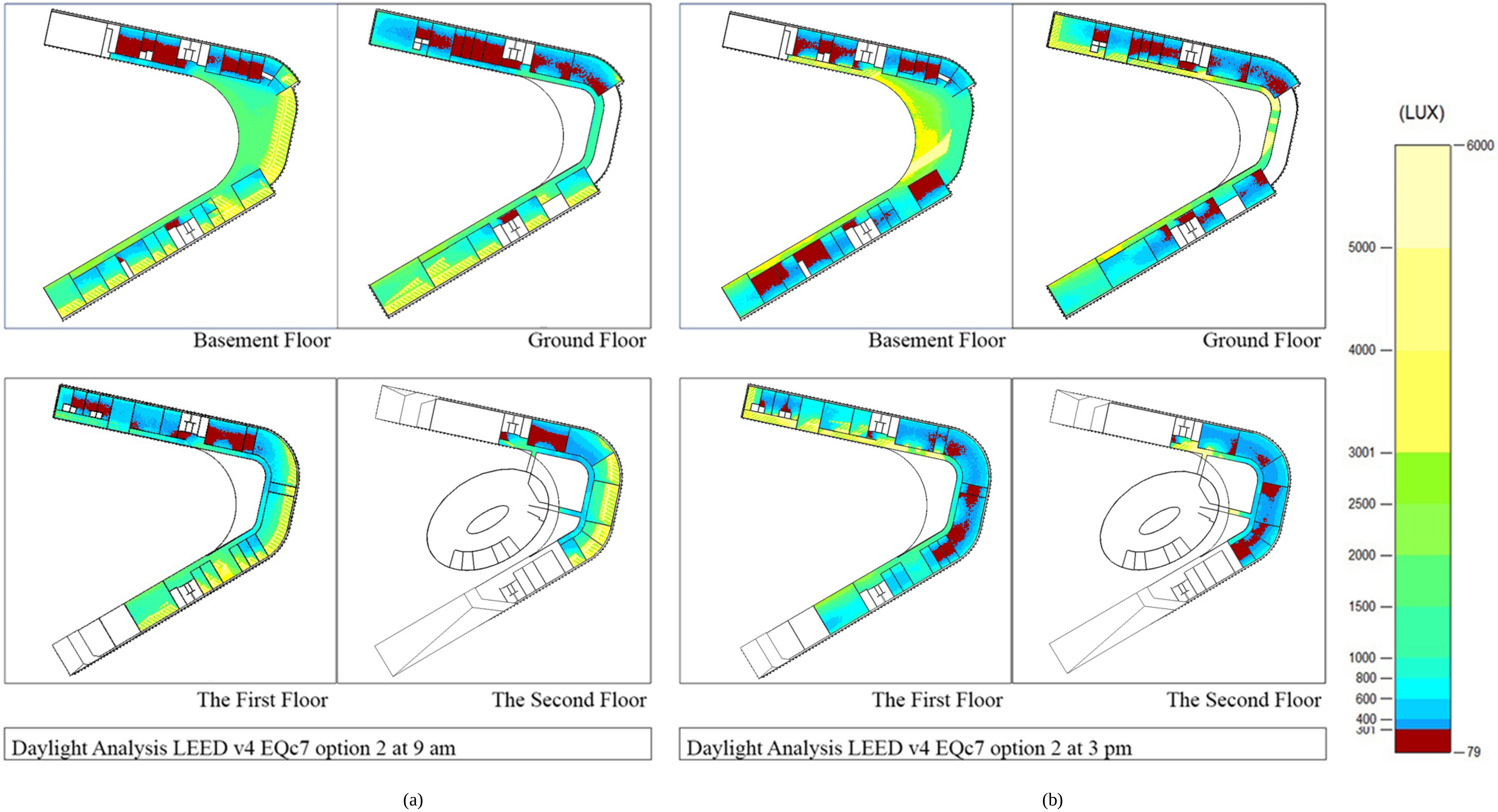


Figure 4.22. 45-degree opening angle components with 20% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

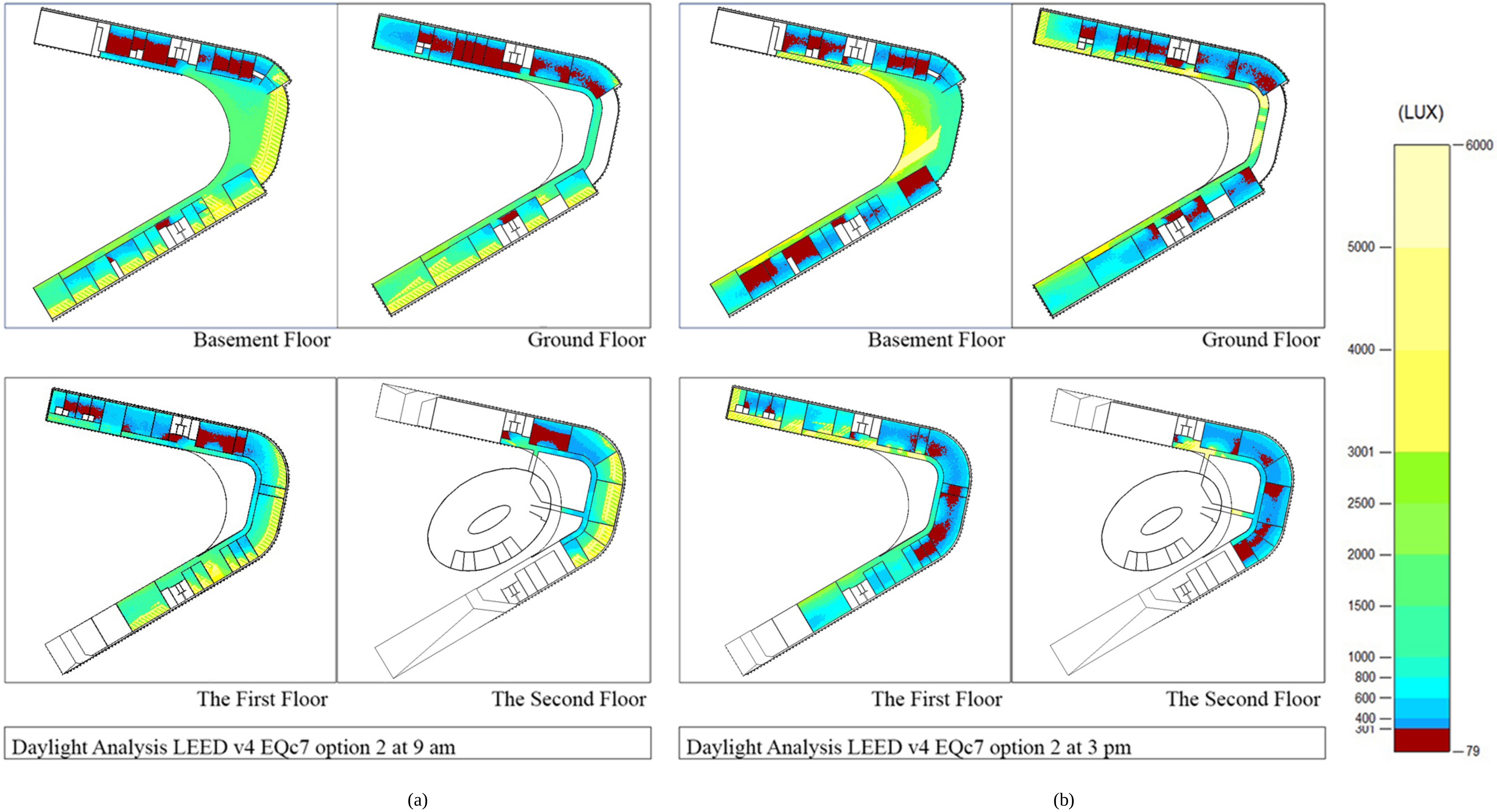


Figure 4.23. 45-degree opening angle components with 30% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

(a) (b)

Figure 4.24. 45-degree opening angle components with 40% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

The fourth phase consists of the analysis that include daylight performance of the kinetic components got 60-degree opening angle with various transmittance (20%, 30% and 40%) of the coating material. In general, the area above the threshold reduces and the area below the threshold increase when we compared the 45-degree opening angle with the same transmittance versions. According to transmittance used in the kinetic component, this part demonstrates the potential of the component that turns direct daylight into diffuse lighting in low glazed surface area. The fourth phase consists of three parts as respectively, of 20%, 30% and 40 of the coating material analysis.

. The first part of the fourth phase includes the daylight performance analysis of the kinetic component got 60-degree opening angle with 20% transmittance of the coating material. All area below the threshold increases in kinetic component 60-degree opening angle with 20% transmittance version when we compared 60-degree opening angle with 20% transmittance version and all versions of the 45-degree opening angle.

Table 4.16. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 60-degree opening angle with 20% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 63% within & 3pm: 52% & both: 40% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	69	1105	7	106	24	382	54	858	11	174	35	561	46	736
The Ground	1402	56	783	5	67	39	553	53	750	7	97	40	556	41	576
The First Floor	1371	59	847	4	59	34	465	58	794	6	88	36	489	41	563
The Second	643	63	343	10	62	28	177	30	190	5	32	65	421	22	140

Around 4-10% of the area above the threshold on all floors at 9 am. 24% of the total area of the basement floor is below the threshold. 40% of the total area on the ground floor receives not enough daylight at 9 am and 3 pm. The total area includes of 28% area below the threshold on the second floor at 9 am and %65 area below the threshold at 3 pm. Around 35-36% of the area below the threshold on the basement and first floor at 3 pm. In Fıgure 4.25 demonstrated that all north-facing rooms are below the threshold at both 9 am and 3 pm. The area that receives deficiently daylight occurs on south-facing rooms at 9 am. The excessive area below the threshold is observed on the first and second floor at 3 pm (Table 4.16).

In the second part, building facade consists of components that have a 60-degree opening angle with the 30% transmittance coating material. It is observed that all area below the threshold reduces and all area above the threshold increases when the transmittance rises 20% to 30% for the kinetic component with 60-degree opening angle (Table 4.16 and Table 4.17).

Table 4.17. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 60-degree opening angle with 30% transmittance components version.

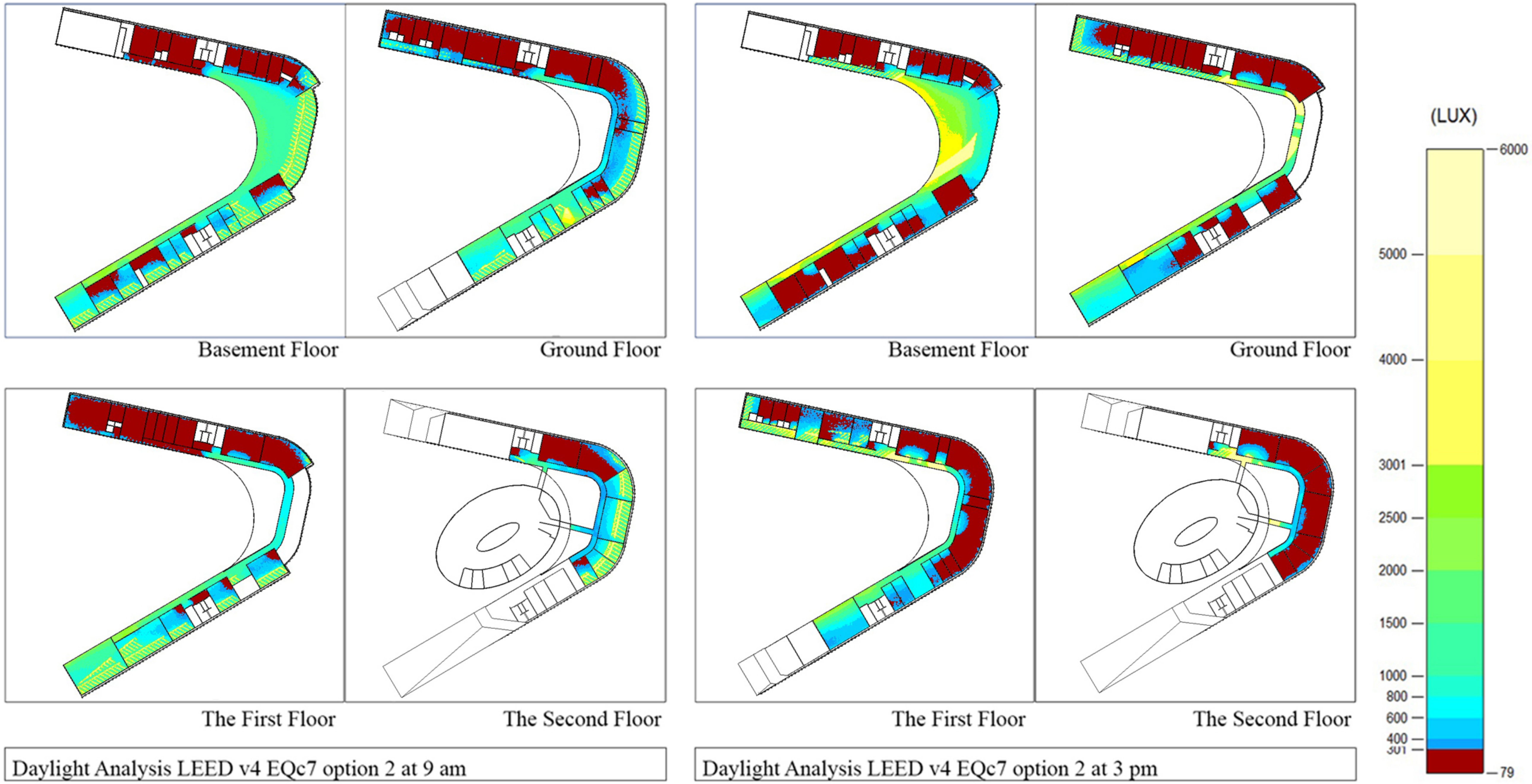
LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 63% within & 3pm: 59% & both: 40% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	64	1021	18	282	18	290	59	944	12	194	29	456	41	648
The Ground	1402	59	824	11	160	30	419	59	830	10	142	31	430	41	575
The First	1371	67	920	11	145	22	306	64	879	12	159	24	332	44	602
The Second	643	57	367	22	139	21	136	49	313	6	39	45	290	27	175

According to Table 4.17, 18-22% of the total area on the basement and second floor receives more than 3000 lux of illuminance at 9 am. The area below the threshold on the ground floor and the first floor at 9 am is 11%. Around the 18-22% of the basement, ground and the second floor is the area below the threshold at 9 am. The first floor consists of %18 area below the threshold. Between 10-12 % area above the threshold.in on the ground and the first floor at 3 pm. The reduction of all area below the threshold is observed in Figure 4.22. The area below the threshold reduces all floor at both 9 am and 3 pm.

Table 4.18. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 60-degree opening angle with 40% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 67% within & 3pm: 65% & both: 44% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m^2	%	Area m^2	%	Area m^2	%	Area m^2	%	Area m^2	%	Area m^2	%	Area m^2	%	Area m^2
The Basement	1594	68	1091	18	285	14	217	60	948	17	278	23	367	40	644
The Ground	1402	63	882	12	165	25	356	66	930	11	155	23	317	47	653
The First	1371	71	969	11	149	18	253	70	961	12	163	18	247	49	675
The Second	643	62	399	22	139	16	105	68	438	6	41	25	164	40	255

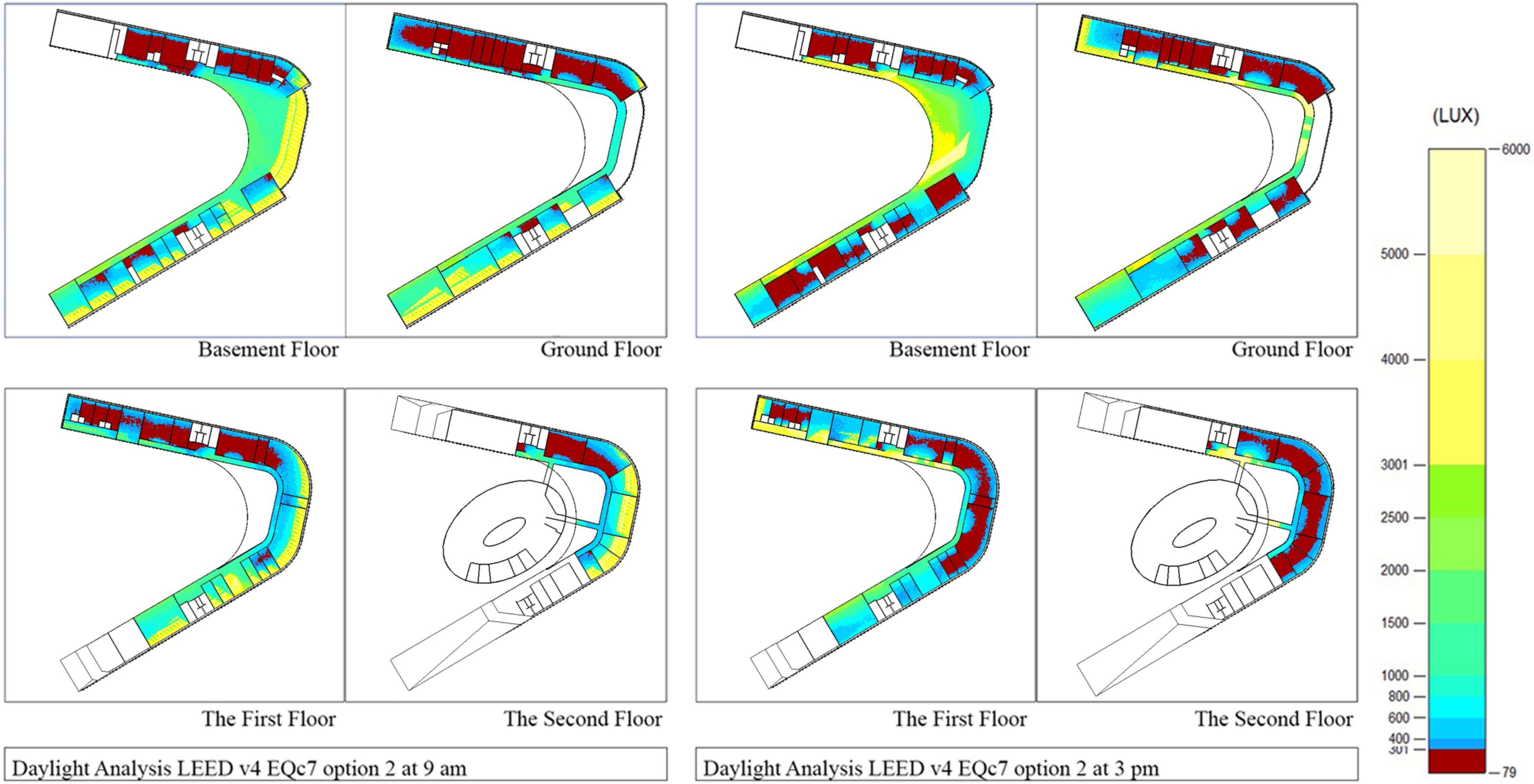
Daylight performance of the kinetic component that has a 60-degree opening angle with 40% transmittance is analysed in the last part of the fourth phase. It is observed that the area that does not receive daylight reduces in the 40% transmittance version (Table 4.18) when the 40% transmittance version and 30% transmittance version (Table 4.17) are compared. There is no critical variance observed in the area above the threshold at 9 am between 40% transmittance version and %30 transmittance version. Although the percentage of the area above the threshold is almost identical, the high reduction in the area below the threshold is observed. Around the 14-18 of the area is below the threshold on the basement, first and second floor at 9 am. 25% of the total area of the ground floor is below the threshold at 9 am while 30% total area is below the threshold in the 30% transmittance version on the ground floor at 9 am. Around 11-18 % of the area above the threshold on the basement, ground and the first floor. The percentage of the area above the threshold on the ground floor at 3 pm is similar with %30 transmittance version on the same floor and time. In Figure 4.27, it is observed clearly the area below the threshold reduces in the north on all floors at both 9 am, 3 pm and east-facing rooms on the first and second floor at 3 am in the 40% transmittance version when %30 transmittance and 40% transmittance are compared.



(a)

(b)

Figure 4.25. 60-degree opening angle components with 20% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.



(a)

(b)

Figure 4.26. 60-degree opening angle components with 30% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

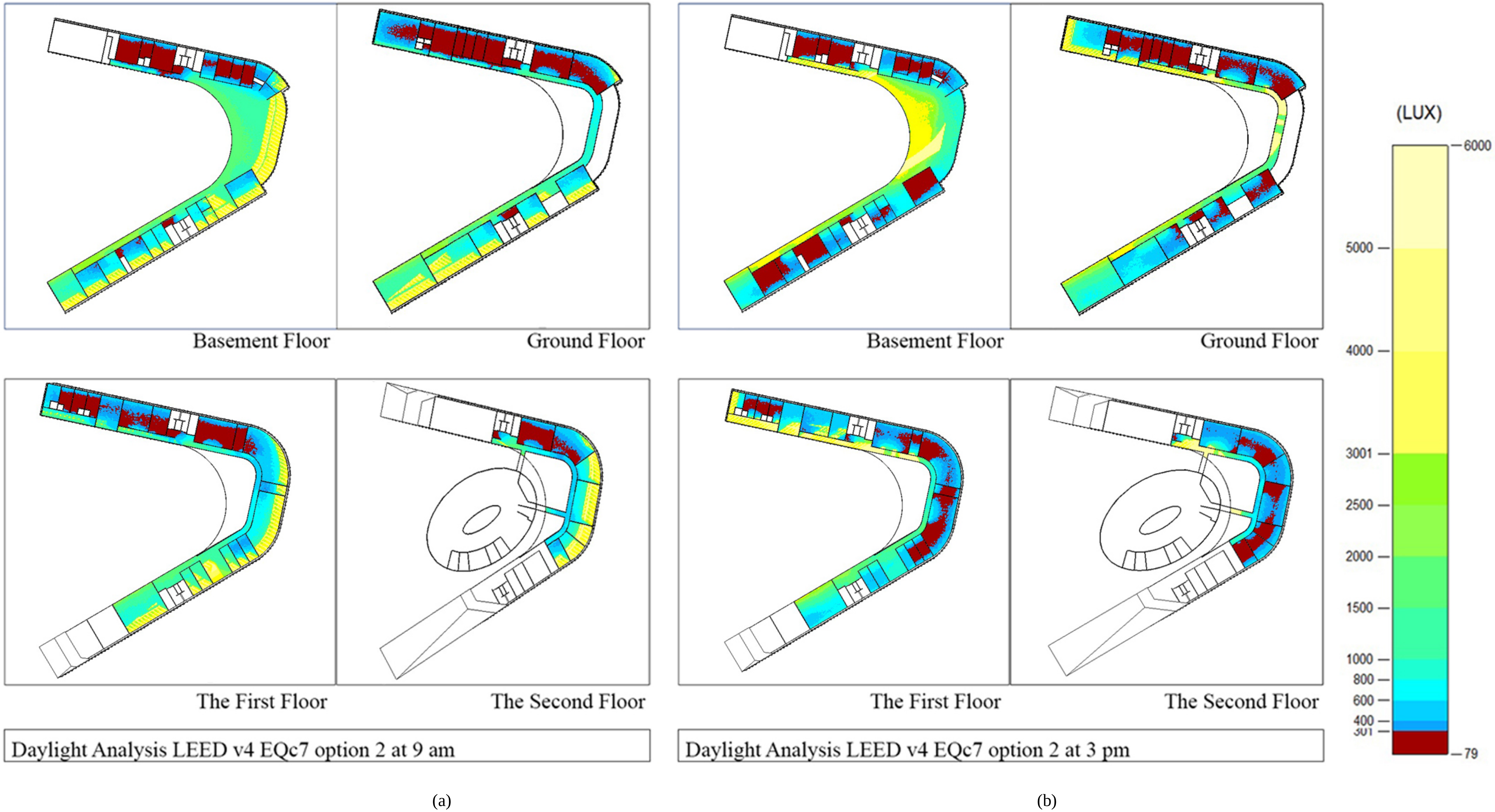


Figure 4.27. 60-degree opening angle components with 40% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

In the fifth phase, the most obstructing form of daylight was examined with various transmittance (20%, 30% and 40%) of the coating material. 85-degree opening angle version of the component has the lowest glazed surface area in the kinetic component. According to various transmittance, the maximum daylight blocking potential is observed, in this way. 85-degree opening angle version of the component provides the minimum area above the threshold. This phase includes 3 parts as 20% transmittance, 30% transmittance and 40% transmittance versions of the kinetic component with 85-degree opening angle. The minimum area above the threshold for each transmittance (20%, 30% and 40%) of the coating material is indicated in the following parts, respectively.

In the first part, the daylight performance of the 85-degree angle kinetic component with 20% transmittance is demonstrated in Table 4.19. It is observed that the area below the threshold increase with the increase of opening angle used in the component. This version has the most area that does not get enough daylight between all versions.

Table 4.19. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 85-degree opening angle with 20% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 34% within & 3pm: 36% & both: 28% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	46	740	0	2	53	852	43	693	10	162	46	738	36	572
The Ground	1402	36	509	1	8	63	885	34	482	5	71	61	850	31	435
The First	1371	28	380	0	3	72	988	35	479	2	34	63	858	25	344
The Second	643	14	91	0	1	86	551	21	132	4	24	76	487	9	61

According to analysis at 9 am, the most area above the threshold among all floors is 8m² on the ground floor. On other floors, it varies between 3 and 1m² at 9 am. The basement floor has 53% area below the threshold. Around 63% of the ground floor area on the ground floor is below the threshold. The percentage of the area below the threshold is 72% on the first floor at 9 am. In the second floor, the area that receives not enough daylight is 86%. The most area above the threshold is 162 m² on the ground floor. Almost 2-5% of the ground , first and second floor have exceeded the threshold at 3 pm. In this part, the lowest percentage of the area that receives not enough daylight is 46% on the basement floor at 3 pm. 61-63 % area of the ground and first floor is below the 300 lux of illuminance. The second floor has 76% of the total floor area is below the threshold (Table 4.19). All north and east-facing rooms on all floors are almost completely area below the threshold at 9 am (Figure 4.28). The area below the threshold on the edge of the basement floor in the east is observed. The slightly rare area above the threshold is on the ground floor at 9 am. Areas above the threshold and within the threshold increased on the north and east at 3 pm unlike the situation at 9 am. Although the overall area that daylight penetrates into interior more than 300 lux increased at 3 pm, there is still the excessive area below the threshold.

The second part of the fifth phase includes the daylight performance of the kinetic component which has a 85-degree opening angle with 30% transmittance. The reduction in the area below the threshold is observed (Table 4.20) when we compared the 20% transmittance version of the same opening angle (Table 4.19).

There is no variance in the area above the threshold at 9 am between 30 transmittance version and 20% transmittance version. 42% of the total area on the basement floor, 57% of the total area on the ground floor and 65% of the total area on the first floor and 74% of the total area on the second floor are below the threshold. According to Table 4.17, the lowest area below the threshold at 3 pm is 44% on the basement floor. The area below the threshold on the ground and the first floor is around 54-57%. The second floor has 76% area below the threshold at 3 pm. Although, according to 30% transmittance of 85-degree opening angle version all area above the threshold increase or equal when we compare the 20% transmittance of the same opening angle, 1m² reduction in the area above the threshold is observed on the ground floor at 3 pm in the 30% transmittance version. According to Figure 4.29, the rise in the daylight that penetrates into the interior is observed on all floors at both 9 am and 3 pm. The reduction in the area below the threshold is observed on all floors the south and east at 9 am. In addition, the area below the threshold reduces on the west and the south side of the north-facing rooms at 3 pm.

Table 4.20. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 85-degree opening angle with 30% transmittance components version.

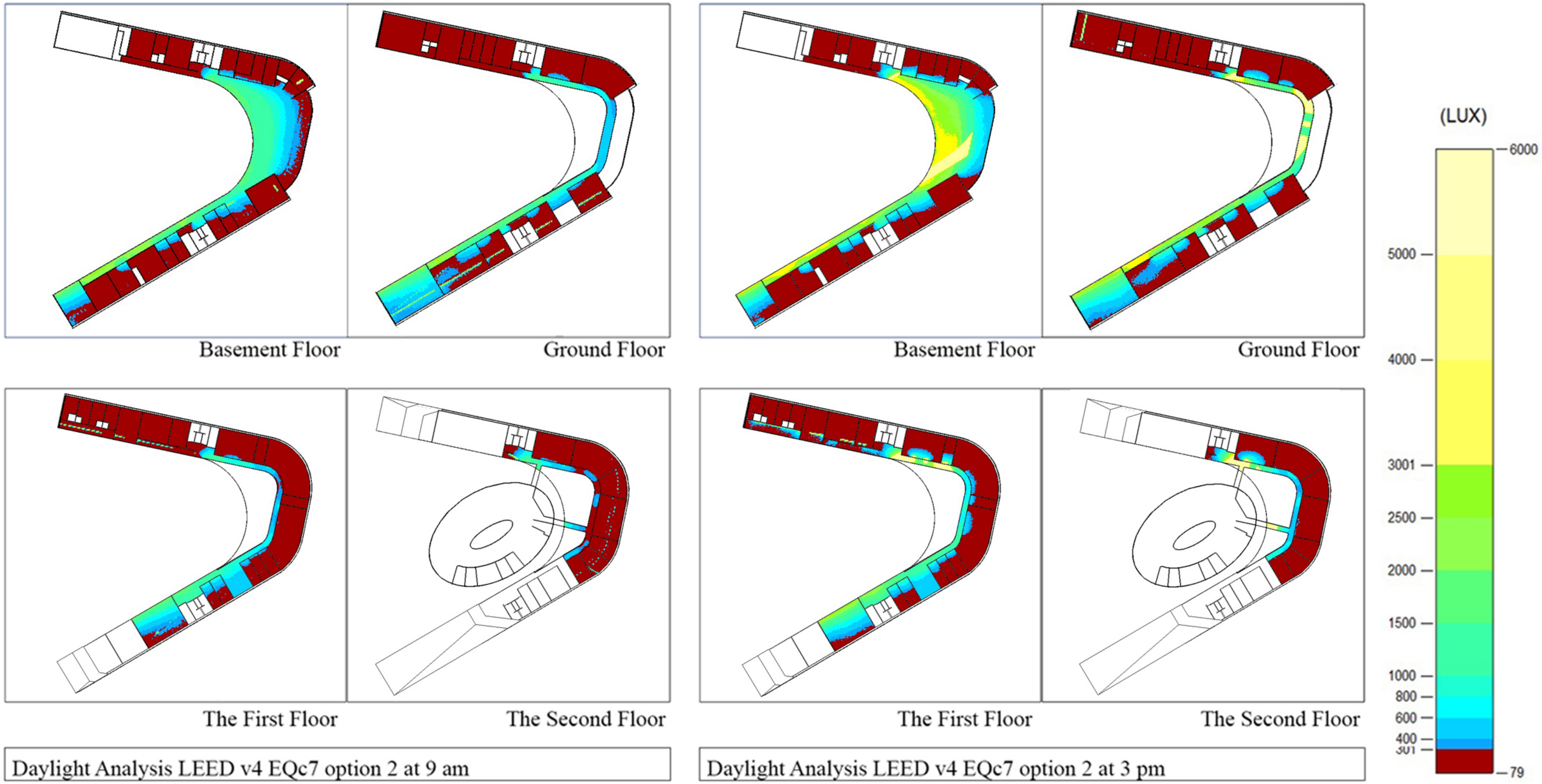
LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00																
9am: 43% within & 3pm: 40% & both: 30% within thresholds																
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	57	916	0	2	42	675	45	720	11	170	44	704	40	637
The Ground	1402	43	602	1	8	57	793	41	569	5	70	54	764	31	435
The First	1371	35	481	0	3	65	888	41	561	2	34	57	775	26	360
The Second	643	26	168	0	1	74	473	20	131	4	25	76	486	9	60

The facade consisted of 85-degree opening angle components with %40 transmittance is analysed in the last part of the fifth phase. It has been observed that the daylight entering increases with the increase of transmittance. In this way, the area below the threshold in 40 % transmittance version reduces as demonstrated in Table 4.21 when we compare the 30% transmittance and 40% transmittance version.

The reduction in the area that receives not enough sunlight in %40 transmittance version at 9 am is more than the reduction in the area that receives not enough sunlight at 3 pm when the 30% transmittance and 40% transmittance version are compared. The area above the threshold is the same with 30% transmittance version at 9 am. The slightly arise is observed in the area above the threshold with 40% transmittance version at 3 pm. The lowest area that receives not enough daylight is 36% on the basement floor at 9 am. Around 52-54% of the area below the threshold is on the ground and the first floor at 9 am. 61% of the total area on the second floor receives not enough daylight at 9 am. A slight reduction in the area below the threshold on all floors is observed from 30% transmittance version. A variance is clearly observed between 40% transmittance version from 30% transmittance version. It is observed that the area that does not receives more than 300 lux of illuminance or near the 300 lux of illuminance turn into the area that receives more daylight (Figure 4.30).

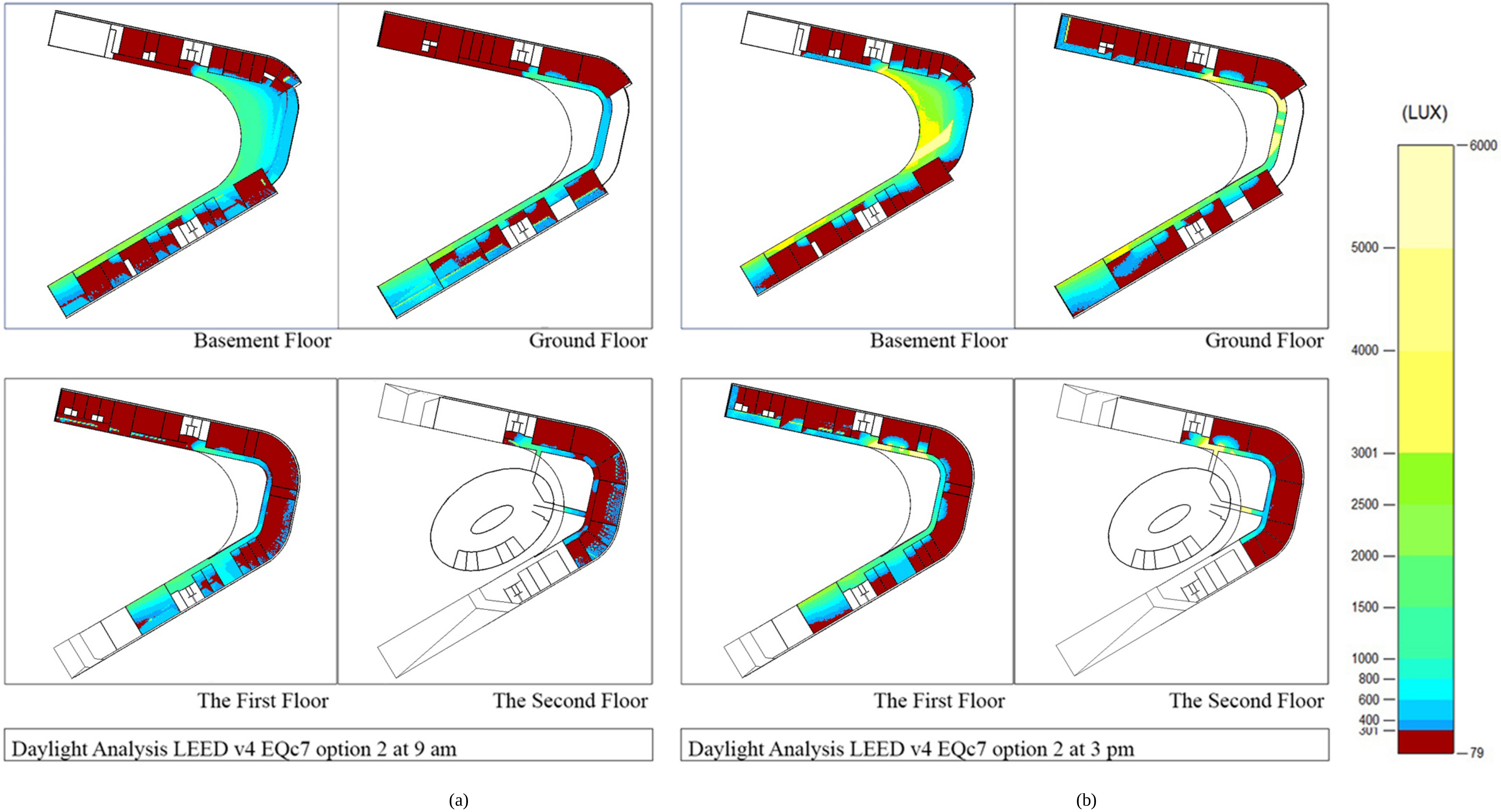
Table 4.21. The percentage of the floor area that provides LEED Daylight Criteria / floor area for 85-degree opening angle with 40% transmittance components version.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 51% within & 3pm: 41% & both: 33% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	64	1018	0	2	36	573	46	739	11	170	43	685	42	668
The Ground	1402	47	664	1	8	52	731	43	597	5	70	52	735	35	488
The First	1371	45	622	0	3	54	745	43	587	3	35	55	749	31	426
The Second	643	38	247	0	1	61	394	20	132	4	26	75	485	10	66



(a) (b)

Figure 4.28. 85-degree opening angle components with 20% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.



(a) (b)

Figure 4.29. 85-degree opening angle components with 30% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

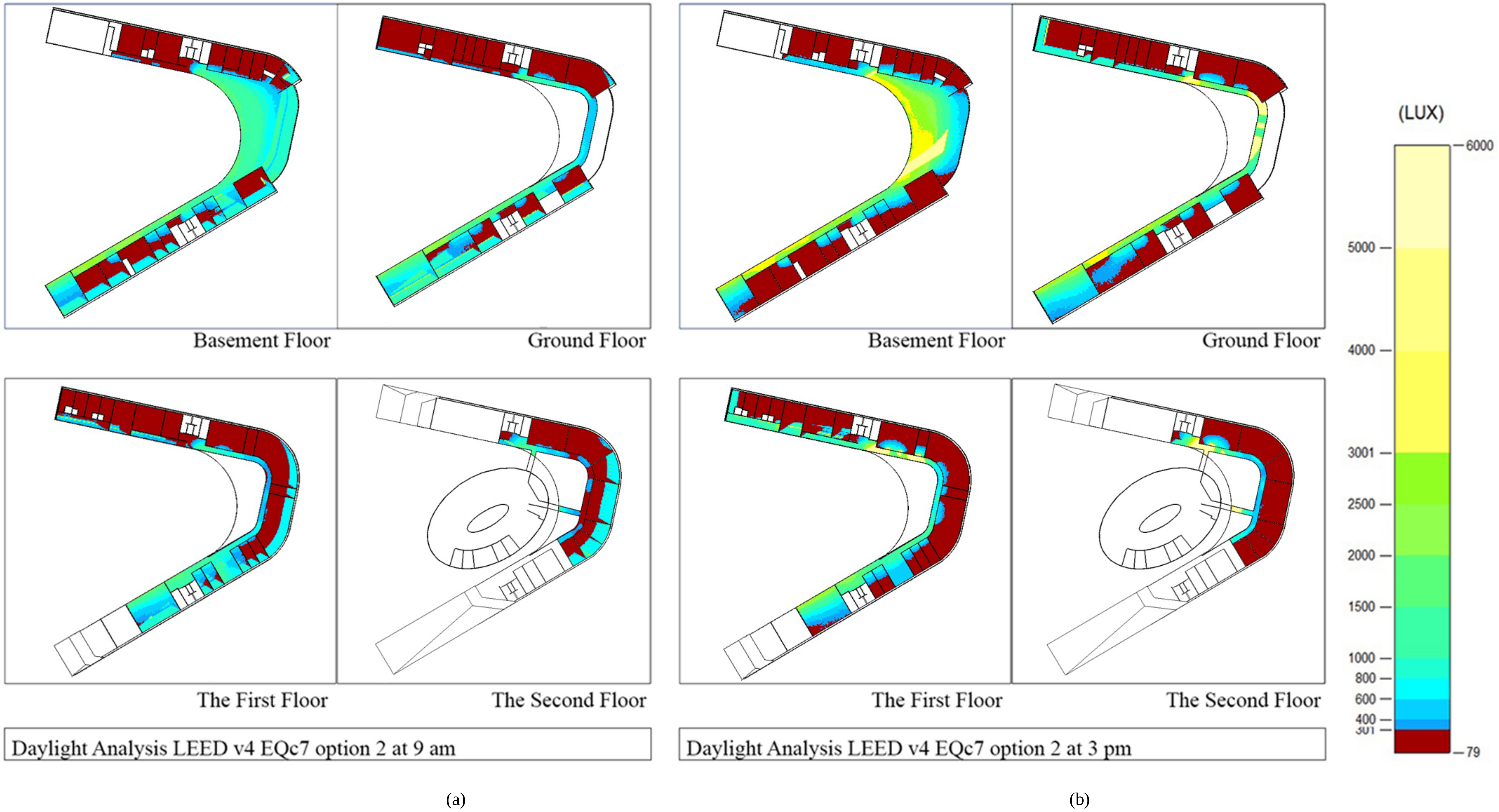


Figure 4.30. 85-degree opening angle components with 40% transmittance version of the IZTECH Innovation Building Daylight analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

According to coating materials (20%, 30% and 40% transmittance) used in the component were analysed with various opening angle (4-degree, 30-degree, 45-degree, 60-degree and 85-degree) in previous phases. The potential of these materials was evaluated in this way. In all three materials with various transmittance, the potential to obtain credits was observed according to the LEED daylighting criteria in 30-degree and 45-degree opening versions.

According to the feature of converting the direct light into diffuse light, 40% transmittance versions provide the most efficiency while 20% of transmittance versions provide at least performance. Although coating material with 40% transmittance is the best for diffuse lighting, it is the worst for obstruction of daylight among all materials analysed. According to the effect of variances in the opening angle on the area above the threshold, the material which has 20% transmittance affects more than the material which has 30% transmittance. This situation indicates that the material with 20% transmittance obstructs more daylight while material with 30% transmittance converts more direct light into diffuse light.

The material used in the component must obstruct for the area that receives excessively daylight while it turns direct light into diffuse light to provide better daylight performance. Therefore, the material with 30% is selected for the next section.

4.4. The Optimal Pattern of the Adaptive Facade

This phase of the study aims to the best daylighting performance with kinetic components. Kinetic components with various opening angle and the coating material which has 30% transmittance were used for enhancing daylight performance. The previous phase was used as a reference to adjust the opening angle. Trial and error method has been used in this phase. Components various opening angle on the adaptive facade occurs pattern on the facade. Many patterns were applied, the patterns that provide the best daylighting performance were demonstrated in this phase.

According to the alternation of daylight during the day, the pattern which provides the best daylighting performance changes, thus two patterns occurs to enhance daylight performance at 9 am and 3 pm. These two patterns must supply at least 90% of the total area is within the threshold to get 2 points in LEED daylighting criteria according to the time set. The optimal pattern was represented as south-facing rooms as elevation A, east-facing rooms as elevation B, north-facing rooms as elevation C and south side of the north-facing as elevation (Figure 4.31). Elevations vary because of the shape changes in the kinetic components. For this reason, elevations in this section indicated according to 9 am and 3 pm. This phase consists of the 2 parts as the optimal pattern at 9 am and the optimal pattern at 3 pm.

In the first part, the opening angle of the kinetic pattern adjusted for the best daylight quality. Analyzes about the material which has 30% transmittance in the third section at 9 am is used as a guide for optimizing the pattern. The main problem to optimize daylight quality at 9 am is receiving too much daylight from the east and south. The aim in the first part is bringing enough daylight from the east and south-facing rooms and providing daylight quality at the north-facing rooms.

Table 4.22. The percentage of the floor area that provides LEED Daylight Criteria / floor area for optimal pattern at 9 am.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00															
9am: 94% within & 3pm: 73% & both: 69% within thresholds															
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		Both time within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
Basement Floor	1594	94	1491	6	97	0	6	69	1099	19	309	12	185	64	1026
Ground Floor	1402	94	1312	5	70	1	20	82	1143	14	195	5	64	77	1078
The First	1371	95	1296	5	71	0	4	76	1043	14	191	10	137	72	988
The Second	643	91	586	8	53	0	3	56	360	7	43	37	239	54	348

In elevation A (Figure 4.32) , opening angles between 60 and 85-degree were used commonly to block direct daylight came from the south and east. In places not included in the evaluation, the 4-degree opening angle was used. 45-degree or less opening angle was used rarely to receive more daylight. Around the 60 and 85-degree opening angle on all floors was adjusted commonly in the east-facing rooms. Around the 30 and 45-degree opening angle rarely were used in the elevation B (Figure 4.33). To maximize daylight that penetrates into the interior in the north-facing rooms, the 4-

degree opening angle was used in the whole facade at the north (Figure 4.34). Between 30 and 60-degree opening angle were used rarely for blocking the area above the threshold at the south side of the north-facing areas (Figure 4.35).

94% of the total area receives 300-3000 lux of illuminance in the whole building with the optimal pattern at 9 am (Table 4.22). This is enough to get 2 points according to LEED criteria at 9 am. All floors provide at least 91% of the area within the threshold at 9 am. Although the pattern provides high daylight quality at 9 am, analysis a 3 pm indicates that daylight quality is not as effective as in the same pattern. It is observed that in Figure 4.36, the area above the threshold is reduced in the whole building

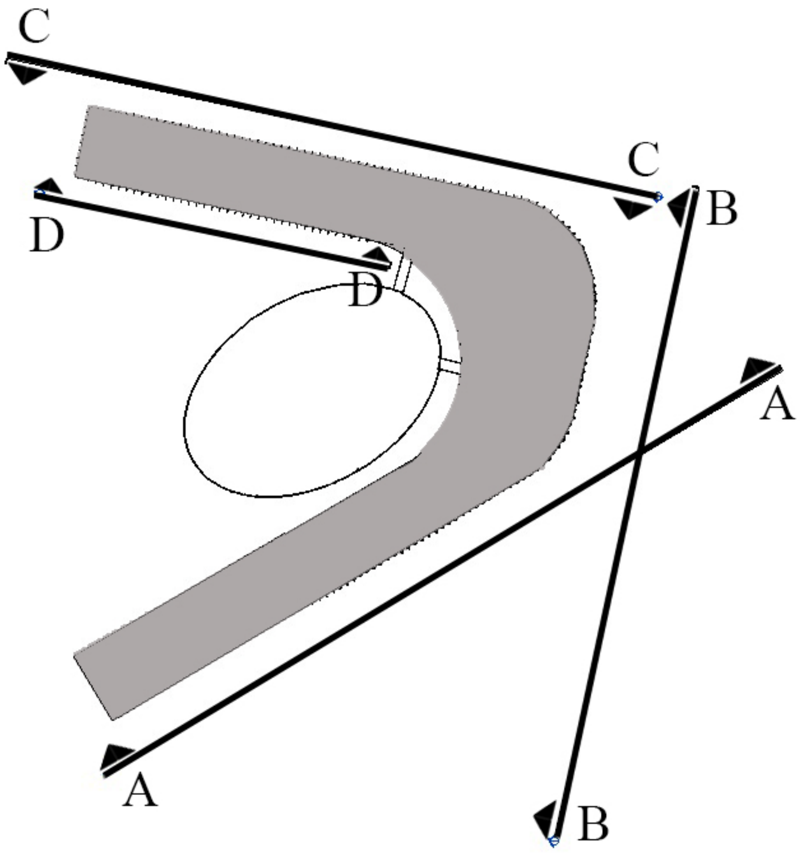


Figure 4.31. Elevations of the IZTECH INOVATION CENTER with their names.

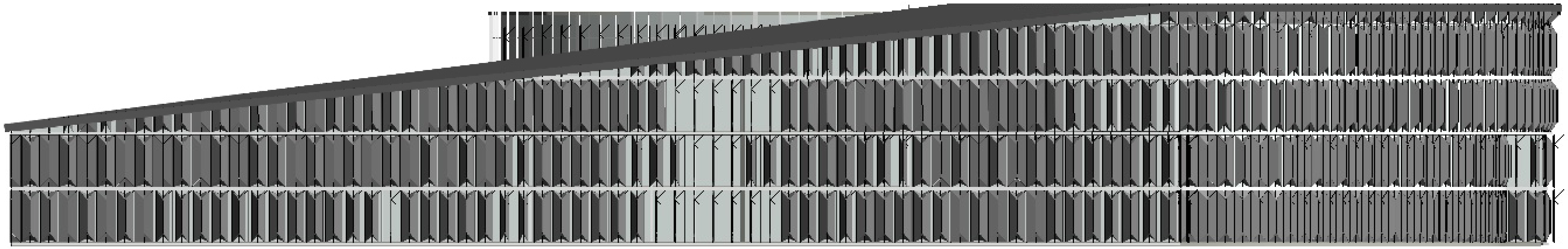


Figure 4.32. Elevation A with optimal kinetic facade pattern at 9 am..

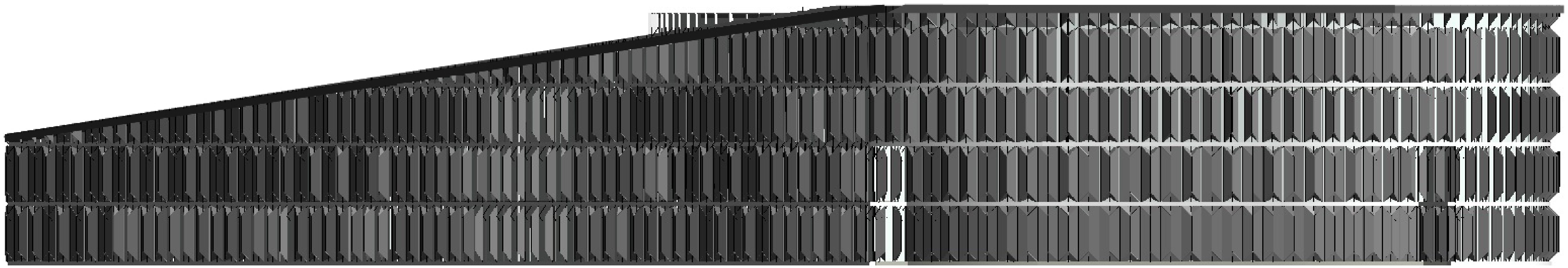


Figure 4.33. Elevation B with optimal kinetic facade pattern at 9 am.

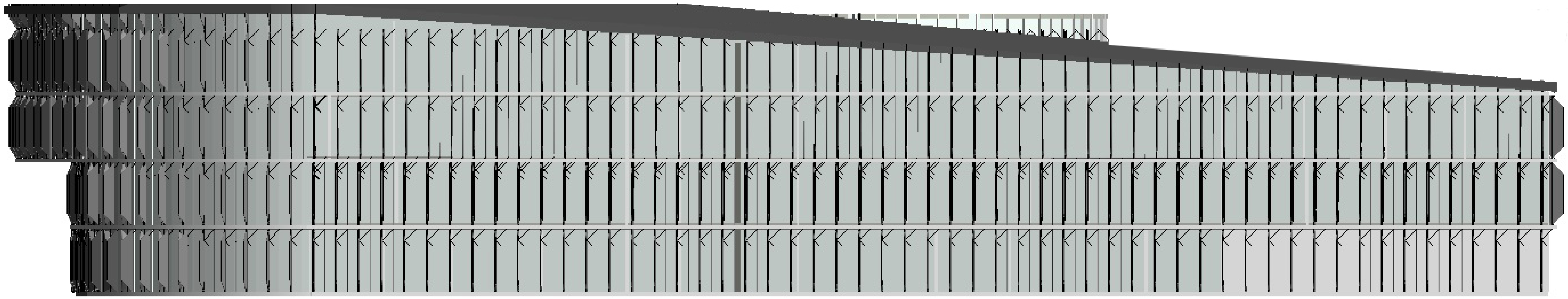


Figure 4.34. Elevation C with optimal kinetic facade pattern at 9 am.

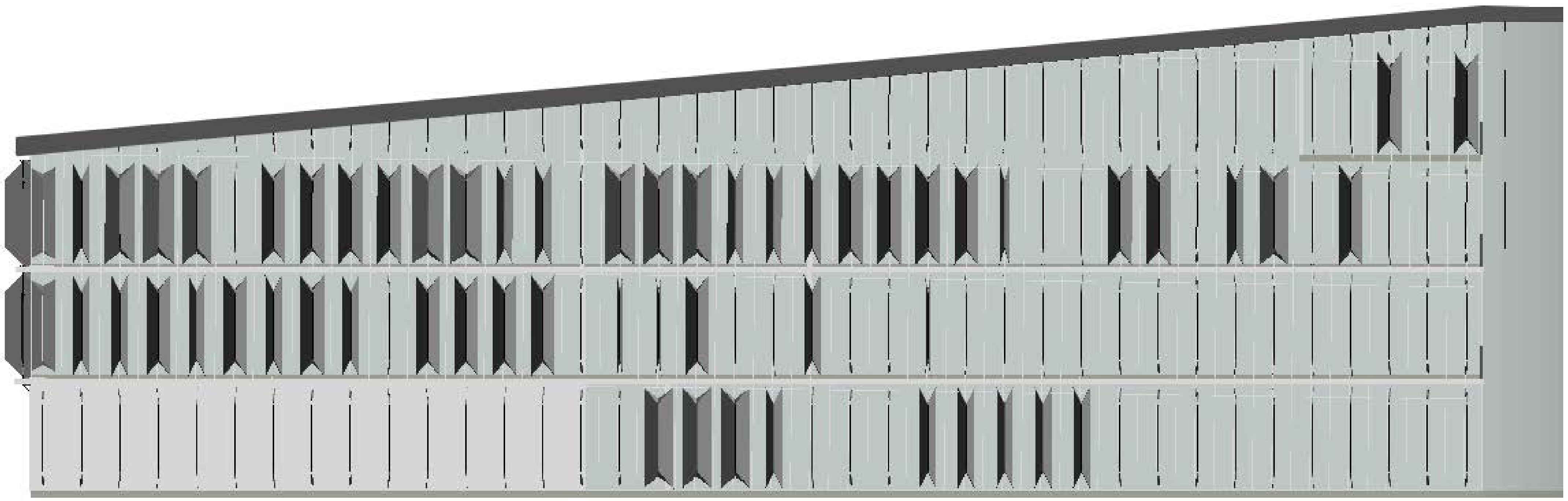
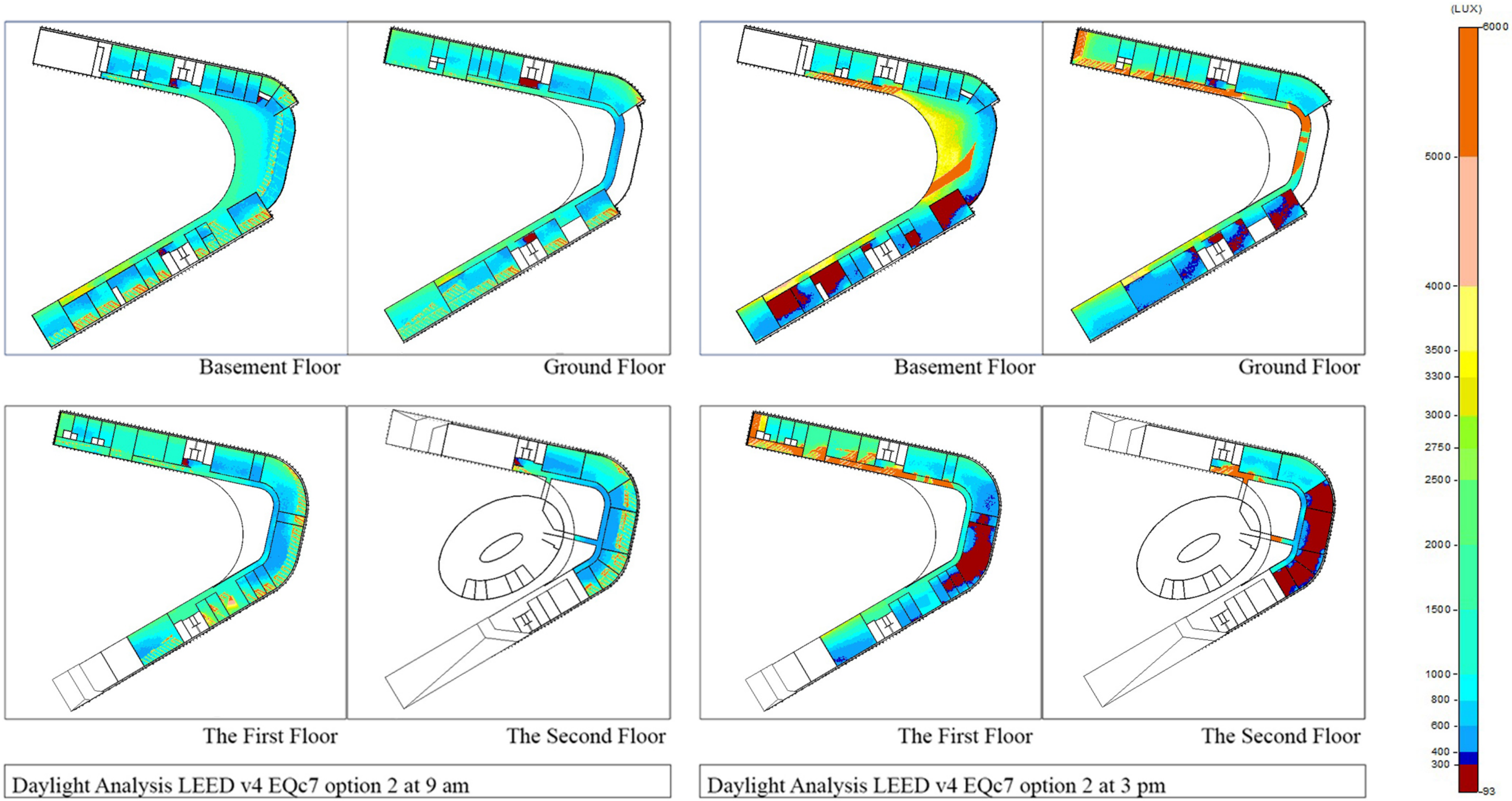


Figure 4.35. Elevation D with optimal kinetic facade pattern at 9 am..



(a) (b)

Figure 4.36. Optimum facade pattern at 9 am of the IZTECH Innovation Building Daylight Analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

In the second part of the phase, the optimal pattern at 3 pm was adjusted. The similar method used in the first part was used for the second part to adjust the optimal pattern at 3 pm. Analyzes about the material which has 30% transmittance in the third section at 3 pm was guidance. The main issue to handle is supplying the balance of daylight penetrated into the interior from the west and south without effectuating area below the threshold.

Table 4.23. The percentage of the floor area that provides LEED Daylight Criteria / floor area for optimal pattern at 3 pm.

LEED v4 EQc7 opt2 Whole Building Results: 383145751953125,00, 266372089385986,00																
9am: 85% within & 3pm: 90% & both: 76% within thresholds																
		9 am threshold results						3 pm threshold results						Both time	
Floor Name	Total floor area	Within threshold		Above threshold		Below threshold		Within threshold		Above threshold		Below threshold		within threshold	
	m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²	%	Area m²
The Basement	1594	85	1360	12	187	3	46	85	1348	15	235	1	10	71	1126
The Ground	1402	89	1246	8	110	3	47	90	1268	8	114	1	20	81	1140
The First	1371	87	1188	12	168	1	15	94	1288	6	82	0	1	81	1108
The Second	643	75	482	24	157	1	4	95	609	5	34	0	0	70	448

Elevation A at 3 pm is demonstrated in Figure 4.37. As indicated in Figure 4.37, between 60 and 85-degree opening angle was commonly used on the west side of all floors. In the middle and east side of all floors, around 4 and 30-degree opening angle was used. The pattern has similarities on the basement and the ground floor in elevation B at 3 pm (Figure 4.38 and Figure 4.33). Less opening angle from the elevation A at 9 am was selected for elevation A at 3 pm. Generally, 45 and 30-degree opening angle were used commonly at the east side of the building (Figure 4.38). Only the 4-degree opening angle was used on the north as in the pattern at 9 am (Figure 4.39). 60-degree and 85-degree opening angle commonly used on the elevation D at 3 pm (Figure 4.40).

According to Table 4.20, 90% of the overall area provides LEED criteria at 3 pm. 85% of the total area is the area on the basement floor that receives enough daylight. Around 90-95% of the area is within the threshold on the ground, first and second floor. The result at 3 pm is enough to get 2 points from LEED daylighting criteria at 3 pm. Also, the pattern used in this part can get 1 point even if all components are static. This area above the threshold in the basement is the most area above the threshold on the overall building (Figure 4.41). There is no critical area below the threshold observed at 3 pm (Table 4.23.)

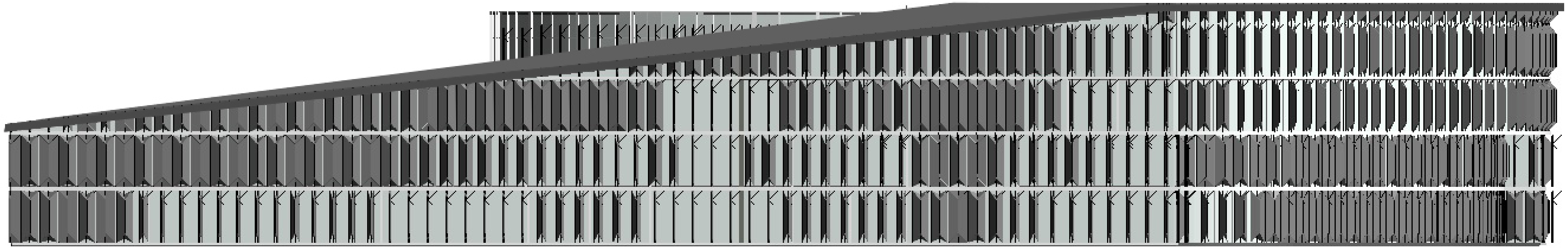


Figure 4.37. Elevation A with optimal kinetic facade pattern at 3 pm.

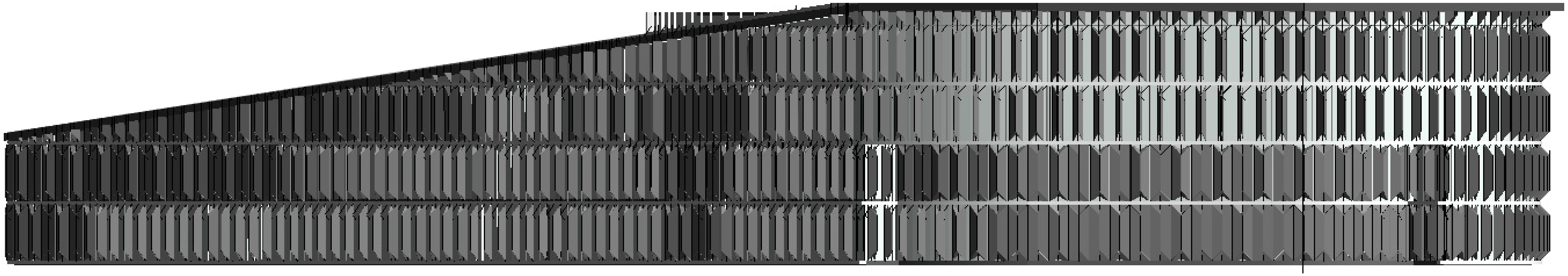


Figure 4.38. Elevation B with optimal kinetic facade pattern at 3 pm.

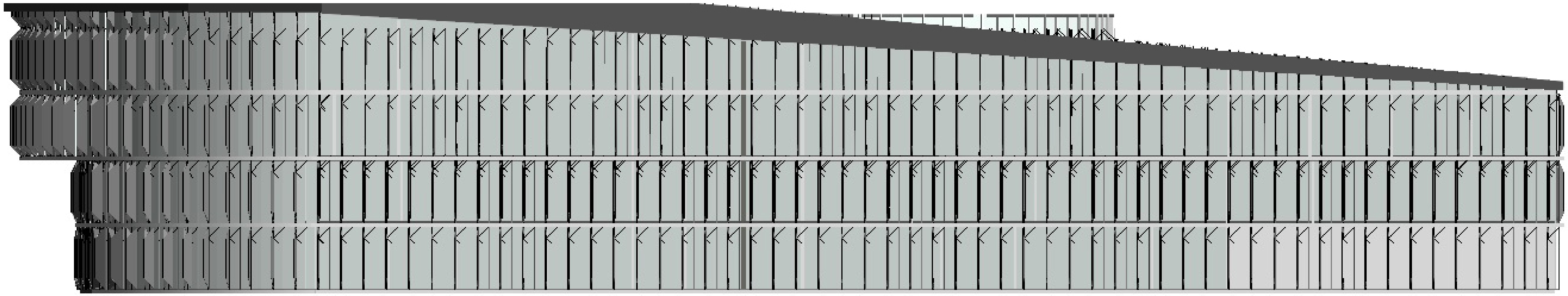


Figure 4.39. Elevation C with optimal kinetic facade pattern at 3 pm.

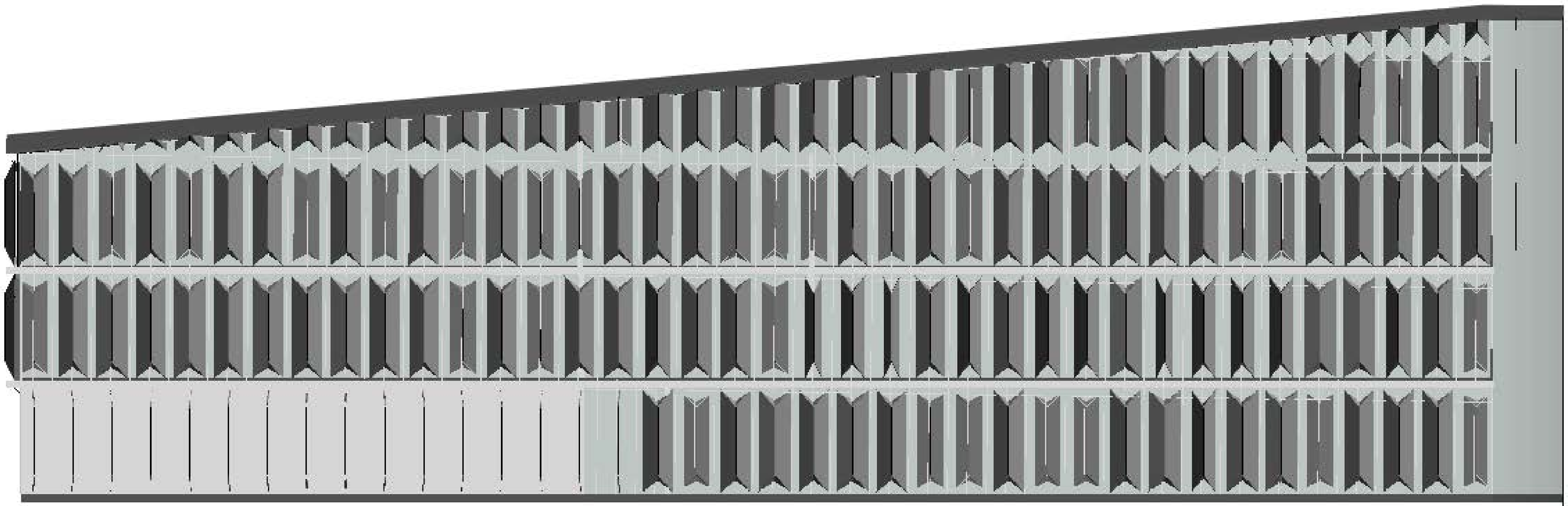
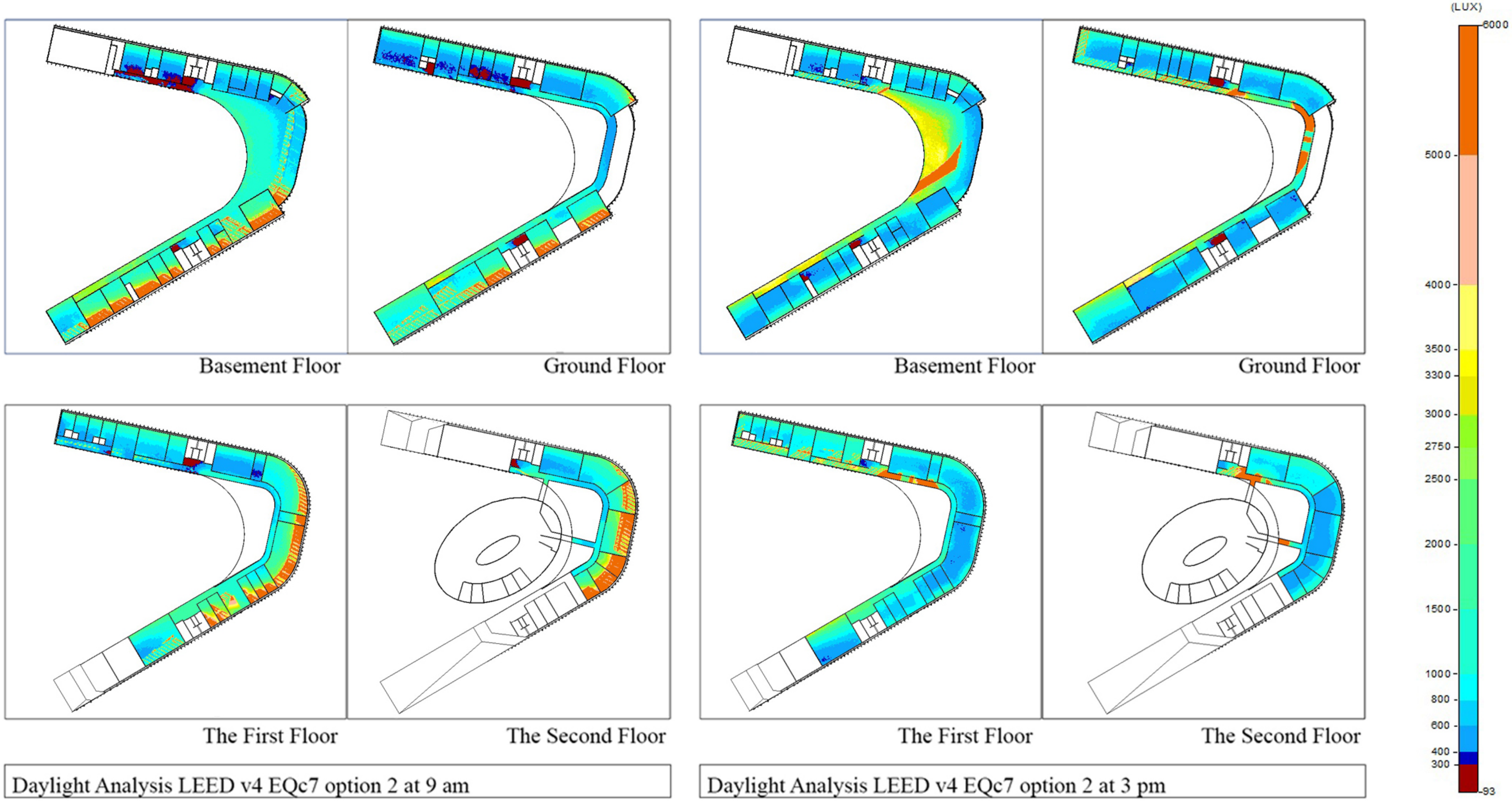


Figure 4.40. Elevation D with optimal kinetic facade pattern at 3 pm.



(a) (b)

Figure 4.41. Optimum facade pattern at 3 pm of the IZTECH Innovation Building Daylight Analysis LEED v4 EQc7 option 2 (a) at 9 am; (b) at 3 pm.

CHAPTER 5

CONCLUSION

The aim of the study is enhancing daylight quality with the adaptive facade covered with kinetic components. This study analyzed how angular variations of shape in the facade component effect daylight performance. Firstly, IZTECH Innovation Center model was prepared in Revit 2020. The kinetic component was modelled in Solid Works 2019 to be designed in terms of its geometry and joints, then kinetic component was modelled in Revit 2020 to be integrated in daylight analysis. Kinetic components were applied to the facade of IZTECH Innovation Center model. Optimum material and shape changes in the adaptive facade were determined with daylight analyzes prepared in Revit plug-in Insight 360. Optimal patterns that consist of variations of form in kinetic components were applied into the adaptive facade. It was indicated that adaptive facade could get 2 points with optimal patterns.

To get optimal daylight performance, optimal material and optimal pattern must be given; so a total of 24 versions of material transmittance and opening angles in the kinetic component was generated and tested in terms of LEED criteria. Results demonstrate that all 3 transmittance materials have the potential to provide better daylight performance when we compared the existing version. According to results, there is no critical alternation observed about daylight performance between 20% and 30% transmittance material with a 4-degree opening angle for kinetic components. In 30-degree opening angle versions, it is observed that 20% transmittance version blocks more daylight without diffuse light, while 30% transmittance version provide more diffuse light (Table 5.1). When we compare components that have 85-degree opening angle with 30% transmittance and 40% transmittance, while 40% transmittance version provides more diffuse light, it receives more daylight into the interior. This situation may cause unexpected reflection or glare in optimal pattern studies. Although for an optimal pattern with 40% transmittance material, the higher opening angles (from the optimal pattern with 30% transmittance) may be selected, 40% transmittance material has more potential for glare(Table 5.2). According to these results, 30% transmittance material is selected as a coating material for the optimal pattern.

Table 5.1. The comparison of kinetic components with 30-degree opening angle for 20% transmittance and 30% transmittance material.

Floor Name	30-degree opening angle components with 20% transmittance version								30-degree opening angle components with 30% transmittance version							
	9 am threshold results				3 pm threshold results				9 am threshold results				3 pm threshold results			
	Above threshold		Below threshold		Above threshold		Below threshold		Above threshold		Below threshold		Above threshold		Below threshold	
	%	m^2	%	m^2	%	m^2	%	m^2	%	m^2	%	m^2	%	m^2	%	m^2
The Basement	22	356	3	54	14	220	8	122	23	361	3	41	15	233	7	112
The Ground	14	194	5	72	11	155	3	40	15	205	5	67	13	178	3	37
The First	15	197	3	34	12	163	2	21	15	209	2	26	13	180	1	17
The Second	24	156	3	17	6	37	3	25	25	159	2	12	6	40	3	21

Table 5.2. The comparison of kinetic components with 85-degree opening angle for 30% transmittance and 40% transmittance material.

Floor Name	60-degree opening angle components with 30% transmittance version								60-degree opening angle components with 40% transmittance version							
	9 am threshold results				3 pm threshold results				9 am threshold results				3 pm threshold results			
	Above threshold		Below threshold		Above threshold		Below threshold		Above threshold		Below threshold		Above threshold		Below threshold	
	%	m^2	%	m^2	%	m^2	%	m^2	%	m^2	%	m^2	%	m^2	%	m^2
The Basement	0	2	42	675	11	170	44	704	0	2	36	573	11	170	43	685
The Ground	1	8	57	793	5	70	54	764	1	8	52	731	5	70	52	735
The First	0	3	65	888	2	34	57	775	0	3	54	745	3	35	55	749
The Second	0	1	74	473	4	25	76	486	0	1	61	394	4	26	75	485

The optimal pattern used in the north at 9 am is same as the optimal pattern used in the north at 3 pm. While between 60 and 85-degree opening was used commonly angle in the south and east at 9 am, between 4 and 45-degree opening was used commonly angle at 3 pm. Although between 30 and 60-degree opening angle was used mostly in the south side of the north-facing area the at 9 am, around 60 and 85-degree opening angle was used in the same side of the facade at 3 pm.

The significance of this study is based on improving the daylight performance of the whole building. The draft of mechanism in the kinetic component was offered. Information was given about how to choose the optimal material. How kinetic components work together were explained for better daylight performance. While examining the effect of the adaptive facade on daylighting performance according to LEED daylight criteria, information collected with an experimental approach about how this was done was given.

Although the optimum pattern at 3 pm could provide daylight quality, there is the area that receives excessive daylight on the basement floor. This problem can be solved by adding kinetic components or shading elements.

In both optimal pattern at 9 am and 3 pm, elevation C has the same pattern. For this reason, the north facade can consist of static shading elements. Thus, it provides cost-efficiency. Some areas on the facade may consist of static shading elements without kinetic components. This way the cost of kinetic facade may decrease. It can be calculated that within what amount of time it will cover its own costs-expenses and surpasses them. Besides, the thermal performance of the kinetic components on the building and which pattern is optimal for thermal performance can be analyzed. In addition, different origami tessellations with different geometry or different variations of chicken wire tessellation as a kinetic facade component can be analyzed for studies in future.

Consequently, the major effect of the adaptive facade was observed on daylighting performance according to LEED criteria. The adaptive facade used in the study was successful to provide better daylight quality. The main aim of the study is to be the guideline for the process of kinetic adaptive facade design with its method. Various mechanisms, materials, methods or kinetic components can be handled as a study to improve the study in future.

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