TESTING ROOM AND WINDOW DESIGN PARAMETERS FOR DAYLIGHT PERFORMANCE ACCORDING TO BREEAM ASSESSMENT CRITERIA: CASES OF LONDON AND İZMİR

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
İrem SÖNMEZ

June 2019

İZMİR

We approve the thesis of **İrem SÖNMEZ**

Examining Committee Members:

Prof. Dr. Zehra Tuğçe KAZANASMAZ
Department of Architecture, İzmir Institute of Technology

Assoc. Prof. Dr. Mustafa Emre İLAL
Department of Architecture, İzmir Institute of Technology

Assoc. Prof. Dr. Başak KUNDAKÇI KOYUNBABA
Department of Architecture, Yaşar University

14 June 2019

Prof. Dr. Zehra Tuğçe KAZANASMAZ
Supervisor, Department of Architecture, İzmir Institute of Technology

Prof. Dr. Koray KORKMAZ
Head of the Department of Architecture

Prof. Dr. Aysun SOFUOĞLU
Dean of the Graduate School of
Engineering and Sciences

ACKNOWLEDGEMENT

I would like to begin with a major thank to my dear supervisor Prof. Dr. Zehra Tuğçe KAZANASMAZ for giving her support and expert guidance that made this research more meaningful for me. Thank you for your patience, kindness, and encouragement. Thank also to Instructor Dr. Can GÜNDÜZ for inspiring me to choose this research field.

My deepest gratitude goes to my parents Yaşar SÖNMEZ and Günnur SÖNMEZ and my brother İlter SÖNMEZ for their support, understanding, patience, and faith that they offered throughout my education life.

ABSTRACT

TESTING ROOM AND WINDOW DESIGN PARAMETERS FOR DAYLIGHT PERFORMANCE ACCORDING TO BREEAM ASSESSMENT CRITERIA: CASES OF LONDON AND İZMİR

Daylight affects occupants' visual performance in the indoor environment. The amount of daylight determines the quality of the interior. If daylighting is controlled properly, it provides comfortable and healthy spaces for the occupants. It is the primary light source of interior and it saves energy decreasing the use of artificial lighting in the interior. Because of these reasons, daylight performance has a significant role in environmental assessment tools. As BREEAM is the first environmental assessment tool in the world which is published in the UK, it has been the subject matter in this thesis.

BREEAM has 'Daylight' section in 'Health and Wellbeing' category. The illuminance value determines whether to get the credits or not in this category. It has been known that there are architectural parameters such as window size and surface reflectance that affect the illuminance value of the interiors. Each color combination of floor, wall, and ceiling results in a significant average reflectance value. Thus, the purpose of this thesis is to test the whole impact of these room and window design parameters on daylight performance according to BREEAM(universities, colleges, and higher education-occupied spaces) criteria with the cases of London and İzmir. The daylight performance simulation models of the reference rooms generated with four material alternatives were built in RELUX, under clear and overcast sky conditions. Simulations run for London and İzmir covering solstice and equinox days. Findings were discussed in the view of daylighting criteria of BREEAM. In general, daylight criteria of BREEAM which is based on conditions of London (UK) were found to be suitable and applicable for cases in İzmir.

ÖZET

ODA VE PENCERE TASARIM PARAMETRELERİNİN BREEAM DEĞERLENDİRME KRİTERLERİNE GÖRE DOĞAL AYDINLATMA PERFORMANSI İÇİN TEST EDİLMESİ: LONDRA VE İZMİR ÖRNEKLERİ

Doğal aydınlatma, kullanıcıların iç mekandaki görsel performansını etkiler. Doğal aydınlatma miktarı iç mekanın kalitesini belirler. Eğer doğal aydınlatma uygun şekillerde kontrol altında tutulursa kullanıcılar için konforlu ve sağlıklı mekanlar sağlar. Doğal aydınlatma iç mekanın birincil ışık kaynağıdır ve iç mekanlarda yapay aydınlatma kullanımını azaltarak enerji tasarrufu sağlar. Bu nedenlerden dolayı, doğal aydınlatma performansının çevresel değerlendirme araçlarında önemli bir rolü vardır. BREEAM dünyada yayınlanan ilk çevresel değerlendirme aracıdır ve İngiltere'de yayınlanmıştır, bu sebeple bu tezin konusu olmuştur.

BREEAM'in 'Sağlık ve Refah' kategorisinde 'Doğal Aydınlatma' bölümü bulunmaktadır. Aydınlık değeri bu kategoriden kredi alınıp alınamayacağını belirler. İç mekanın aydınlık değerini etkileyen pencere boyutu ve yüzey yansıması gibi mimari parametreler olduğu bilinmektedir. Zemin, duvar ve tavanın her renk kombinasyonu önemli bir ortalama yansıtma değeri oluşturur. Bu nedenle, bu tezin amacı, oda ve pencere tasarım parametrelerinin BREEAM (üniversiteler, kolejler ve yüksek öğretimde kullanılan alanlar) kriterlerine göre Londra ve İzmir örneklerinde doğal aydınlatma performansı üzerindeki etkisini test etmektir. Dört malzeme alternatifi ile oluşturulan referans odaların günışığı performansı simülasyon modelleri RELUX programında açık ve bulutlu gökyüzü koşullarında üretildi. Simülasyonlar gündönümü ve ekinoks günlerini kapsayan şekilde Londra ve İzmir için yapıldı. Elde edilen sonuçlar BREEAM'in doğal aydınlatma kriterleri doğrultusunda tartışıldı. Genel olarak, Londra'daki (İngiltere) koşullara dayanan BREEAM'in doğal aydınlatma kriterlerinin İzmir'deki durumlar için uygun ve uygulanabilir olduğu tespit edildi.

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

Figure **Page**

Figure **Page**

LIST OF TABLES

Table **Page**

Table **Page**

CHAPTER 1

INTRODUCTION

1.1. Problem Definition

Daylight is an important issue for an indoor environment that affects the user's visual performance and comfort. Daylight is the best light source for interior spaces. It creates comfortable, healthy and workable interiors (Galatioto and Beccali 2016). It saves energy decreasing the use of artificial light. These two concerns make daylighting significant in 'green building rating schemes'(C. Reinhart and Selkowitz 2006).

Environmental performance assessment tools and methods serve as green building rating schemes. They score and rate building according to criteria of several sections, such as energy, health, comfort. Some of these, at the same time, are related to daylighting performance and factors of indoor spaces (Giarma, Tsikaloudaki, and Aravantinos 2017). BREEAM, for example, is well-known and has a wider application in practice and research. It pays attention especially to daylighting due to several criteria (health and comfort). To test BREEAM assessment tool's daylighting criteria which are based on daylight factor and illuminance, room and window design parameters are needed to be analyzed using a lighting simulation program.

BREEAM (Building Research Establishment Environmental Assessment Methodology) (1990), the first environmental assessment tool, is published in the United Kingdom. In BREEAM there are several criteria topics which is related to the building's environmental consideration. These are 'Management', 'Health and Wellbeing', 'Energy', 'Transport', 'Water', 'Materials', 'Pollution', 'Waste', 'Land Use and Ecology' and additional section 'Innovation' (Giarma, Tsikaloudaki, and Aravantinos 2017). The building gets credits according to these topics. It gets the total score collecting points from every category at the end. In BREEAM, there are parameters which are related to daylighting. They are situated under the 'Health and Wellbeing' section as a 'Visual Comfort' section. These parameters are 'Glare Control', 'Daylighting', 'View Out', and 'Internal and External Lighting Levels, Zoning and Control' (Giarma, Tsikaloudaki, and Aravantinos 2017).

The 'Daylighting' parameter of BREEAM considers the daylighting performance of the interior. There are two main alternatives for measuring the sufficiency of it. The first alternative is daylighting factor and the second one is illuminance levels of indoor area (Giarma, Tsikaloudaki, and Aravantinos 2017). Daylight performance of the interior is studied by researchers over the years, daylighting factor and illuminance values are the key points of it. In view of this knowledge, this study examines the room and window design parameters by the view of daylighting criteria of BREEAM.

Daylight factor is the most common and easiest measuring element for quantifying daylight which is in the indoor environment that going into through the window (Acosta et al. 2015). The ratio of the inside horizontal illuminance to the outside horizontal illuminance is calculated as the daylight factor. It is observed under the lowest exterior daylight in the sky which is the overcast sky condition (Acosta, Campano, and Molina 2016).

The daylight comes directly from the sky. However, according to Li et al. (2006), the daylight is going into indoor by the effect of internal and external factors. The width, length, height, and location of the indoor environment and size of the window and also, the material of the floor, ceiling, and walls have an impact on the performance of the daylight as internal factors. In addition, the light which is reflected from outside from the ground and other buildings or blocked by other elements from outside can be classified as external factors that affect the performance of daylight (Li et al. 2006). There are different parameters which can change the illuminance value of the indoor environment. Especially, interior design parameters as the choice of materials and colors are the most important elements that affect daylighting performance. Also, the combination of materials determine the average reflectance value of the room and it affects the illuminance value of the interior.

Several case studies have tested daylight performance with the view of different criteria. For example, Li et al. (2006) analyzed daylighting performance and energy use using computer simulation techniques for the typical domestic unit in Hong Kong. He cared about building area and orientation, glass type, window type, shading, and external obstruction as building parameters that affect indoor daylight illuminance. Width, depth, and height of the room, glass area, window sill height, the transmittance of the window, average reflectance of the interior surface, and reflectance for ground and external obstructions were used for calculation of daylighting as parameters (Li et al. 2006). In another example, Acosta et al. (2015) studied windows under overcast sky circumstances which affect daylight factor and energy saving. The dimension, location, and form of the window and room reflectance were changeable. A total of 28 different simulation models were prepared in lighting simulation program Daylight Visualizer 2.6 integrating these geometrical parameters (Acosta et al. 2015). Konis (2013) studied daylighting performance with daily and seasonal sun and sky parameters for an open-plan office building in San Francisco, California (Konis 2013). Ochoa et al. (2012) examined low energy consumption and high visual comfort by the parameter of changing the window size and analyzed by using computer simulation programs (Ochoa et al. 2012). In addition, Giarma, Tsikaloudaki, and Aravantinos (2017) made a critical review of environmental performance assessment tools from the viewpoint of daylighting and visual comfort criteria. BREEAM, LEED, SBToll and CASBEE assessment tools have been dealing with to understand their potentials in satisfying general considerations of visual comfort (Giarma, Tsikaloudaki, and Aravantinos 2017). In view of all these recent researches in daylight performance, there was a need to test the impact of room and window design parameters on daylight performance in a reference room. To achieve this, BREEAM assessment criteria become to key concern whether it is applicable in such a room located both in İzmir and London (two significant locations corresponding to different seasonal sky conditions). No specific study directly showing this comparison was found.

1.2. Objective of the Study

The purpose of this study is to test room and window design parameters for daylight performance according to BREEAM assessment criteria with cases of London and İzmir. There are two reference rooms which are located in London and İzmir. The reference room for London has two alternative window size and four different interior material combination which has different indoor illuminance value. Also, the same alternatives are applying to the other reference room which is located in İzmir. Finally, a total of 128 simulations are provided by lighting simulation program which is RELUX. Geographical location differences of the rooms will show how much convenient daylighting criteria of BREEAM for İzmir location because BREEAM is developed in the United Kingdom.

1.3. General Method and Outline

This section gives information about the whole of outline and method of the thesis. This thesis consists of five chapters. The first chapter is 'Introduction'. The importance of visual comfort and daylighting in the indoor environment and the relationship between the environmental assessment tool which is BREEAM is explained. The necessity of testing room and window design parameters for daylighting performance is mentioned and how they are evaluated with BREEAM assessment criteria.

In the second chapter, related literature about the general design criteria and measurements standards of daylighting performance for educational buildings are investigated. The daylighting and visual comfort criteria of BREEAM assessment tool are clarified. Then, the impact of room materials, colors, and window size are explained from the point of daylighting performance of interior. Also, the other researches about daylighting issues of BREEAM are selected and explained with their similar and different aspects.

In the third chapter, firstly, the geometry of the reference room is introduced with the reference researches. Then, the location and climate data about London and İzmir are clarified with detailed information. After that, the daylighting performance simulation models of reference rooms in RELUX are explained with specifications of daylighting criteria of BREEAM, material alternatives of reference rooms, and how they are simulated in RELUX.

In chapter four, the simulations are activated for the reference room A and B by using four different material combinations. Every reference room and material combination are activated for four different dates in a year. According to the simulation results, the room and window design parameters differences and their illuminance values are compared and evaluated with daylighting criteria of BREEAM.

In the last chapter, the conclusion and discussion are derived from the analysis results, and the thesis sums up briefly.

CHAPTER 2

REVIEW OF THE RELATED LITERATURE

In this chapter, firstly, daylighting performance is explained shortly and design criteria of daylighting performance and measurements standards of daylighting are explained. The following section gives information about environmental assessment tools. It focuses on BREEAM as an environmental assessment tool and its visual comfort criteria related to daylighting. This section also includes room and window design parameters based on room materials, colors and window size. The last section focuses on selected research about daylighting issues of BREEAM.

2.1. Daylighting Performance of Educational Buildings

In educational buildings, daylight is an important factor that affects students' learning capacity, performance, and health (Winterbottom and Wilkins 2009; Wu and Ng 2003). A sufficient amount of light in the interior makes the classroom charming to students. It provides the sense of being in a wider space and has a favorable effect for learning motivation and also it increases the quality of teaching (Yener, Güvenkaya, and Sener 2009; Al-Khatatbeh and Ma'bdeh 2017).

2.1.1.Design Criteria of Daylighting Performance

The daylight is the primary light source for the buildings. However, the important point is not the amount of daylight that coming into the interior. The important point is the quality of daylight that coming into the indoor environment and how it creates comfortable places for the users (Tsikra and Andreou 2017). Daylighting performance of the interior space has a direct impact on the building occupants performance. If the daylighting is used correctly in the interior, it provides comfortable, healthy, and remarkable spaces for the users. However, if it is not used completely right, it creates an uncomfortable and inadequate visual performance for the occupants of the building (Leslie 2003).

Educational buildings are mostly using in the day time. The daylighting performance is an important factor for the indoor environment of educational buildings and its occupants (Heschong, Wright, and Okura 2002). Educational buildings are using for teaching and working activity by the teachers and also, studying and learning activity by the students. In addition, reading and writing are the primary activity that students do in the classroom and they need proper visual comfort in order to read and write easily (Yener, Güvenkaya, and Sener 2009). In the classroom, the student reads what teacher write to the board and then writes to his or her notebook. When the student is doing this activity, she or he has to look long and close distance one after the other. Because of this, daylighting has an important role for concentration and visual comfort of the student (Yener, Güvenkaya, and Sener 2009).

The analysis of daylighting performance in the educational building shows that students' concentration and exam results increase and they spend their time in a better and comfortable physical condition (Plympton et al. 2000; Erlalelitepe, Aral, and Kazanasmaz 2011). Students performance and learning capacity are increasing with daylight. It is approximately changing 7% to 37%. If an average student changes her or his standard classroom to the classroom that is used effective daylight performance, the performance and learning capacity of an average student is supposed to increase approximately 11% (Heschong, Elzeyadi, and Knecht 2002). All these positive effects of daylight create better and effective educational indoor environments for its occupants.

There is a critical point about the daylight which is the intensity of daylight. There is no rule like more daylight is creating better indoor environments. The proper daylight performance should provide adequate lighting in the interior in order to not disturb any occupant (Leslie 2003; Erlalelitepe, Aral, and Kazanasmaz 2011). In the indoor environment, if there is a zone in the screen or surface which is brighter than the total brightness of the surface, this position creates glare in the interior. The glare divide into two which is disability glare and discomfort glare. Disability glare affects the visual performance of occupant and visibility of the environment. In addition, discomfort glare creates headache and the eyes getting tired (Winterbottom and Wilkins 2009). As a result of this, the visual performance and comfort of the user are getting worse and difficult (Osterhaus 2005; Winterbottom and Wilkins 2009). The aim of the designing daylighting performance is providing better, comfortable and healthier interiors for the occupants. All the educational building types, primary schools to university buildings, have the same importance about daylighting.

2.1.2.Measurement Standards of Daylighting

The educational buildings are important because of their function. The daylighting measurements have specific regulations and standards for the educational buildings. The aim of this is controlling and providing the occupants' needs. However, specifications about daylighting are not yet improved properly because of the variable form of the daylight and differentiation of every interior spaces (Erlalelitepe, Aral, and Kazanasmaz 2011). The classrooms should have enough value of illuminance in order to write and read in between the vertical board and horizontal desk surface (Yener 2002). There are parameters for measuring daylight such as; daylight factor, illuminance, daylight and window size, and glare.

The daylight factor is one of the parameters that evaluate the daylight in the indoor environment. The explanation of daylight factor is the ratio of internal horizontal illuminance at a random point in the interior without shadow to outer horizontal illuminance under a CIE overcast sky (C. F. Reinhart, Mardaljevic, and Rogers 2006; Mardaljevic and Christoffersen 2017). French daylight regulations suggest 1.5% daylight factor in an overcast sky condition for classrooms. However, British regulations suggest 2% daylight factor for classrooms (Erlalelitepe, Aral, and Kazanasmaz 2011).

The illuminance is the other parameter for measuring daylight. The unit of illuminance is lux. The International Commission on Illumination (CIE) is published the illuminance standard of classrooms as 300 lux. When the illuminance is measured, the reference planes are considered. There are two kinds of reference planes which are the horizontal reference plane that is above the desks and the vertical reference planes that are parallel to each wall. CIBSE (2004) recommends a range of illuminance which is in between 300 to 500 lux according to the types of classrooms (Winterbottom and Wilkins 2009). In general, 300 lux for the horizontal plane which is above the desks and 500 lux for the vertical plane which is on the board (Yener 2002; Erlalelitepe, Aral, and Kazanasmaz 2011; Al-Khatatbeh and Ma'bdeh 2017). The minimum value of the reference plane, which is on the board, is 300 lux. Because, it should not under the horizontal reference plane value in order to focus the students to the board (Yener, Güvenkaya, and Sener 2009).

The building envelope has openings and windows and the daylight is coming from these apertures. The size of the apertures affects the calculation of the daylight factor and the illuminance (Erlalelitepe, Aral, and Kazanasmaz 2011). Because it directly affects the amount of daylight that comes to the indoor environment. According to the British regulations, if the room depth is under 8 meter, the area of the window is 20% of the wall area which has the window on it. If the room depth above 14 meters, the area of the window is 35% of the wall area which has the window on it (Erlalelitepe, Aral, and Kazanasmaz 2011).

The glare has to be under controlled in order to not affect negatively the visual comfort of occupants. If the sunlight enters directly from the window, it reflects from other surfaces and disturbs the occupant's eyes (Osterhaus 2005). The main aim is to avoid glare in the indoor environment in order to increase daylight quality of the interior.

There some other parameters that affect the measurement of daylighting such as; illumination level of the exterior, location of the room, the dimension of the room, the dimension of the window, type of window glazing, and reflectance of interior surfaces (Yener 2002).

2.2. Environmental Performance Assessment Tools

The construction industry has a significant mission for the countries. It has to correspond to the requirement of community and increase the standard of living. It helps to build up the economy of a country. However, the construction industry is a kind of a consumption industry for a country. Natural resources and energy are the main elements that firstly are affected negatively by the construction industry. For example, fresh water sources, green fields, forest lands, and raw materials are damaged and consumed directly or indirectly for the construction industry. Also, the production process of construction materials consumes global energy. As a result of these negative sides of the construction industry, there are global effects which are increasing carbon emission, global warming and environmental breakdown (Doan et al. 2017).

The idea of sustainable design and high-performance buildings began to appear in the 1990s. They try to reduce the negative effects of the construction industry. On the other hand, the buildings' quality has an impact on the users. They directly affect the quality of life, performance of the work, motivation of employee and health of the user with air and daylight standard. These concepts come to the forefront in the building design stage because of the environmental and user-oriented concerns. Moreover, the awareness of sustainability and the environmental impact bring the new systems to the building marketplace. The environmental assessment tools come to exist as a result of the idea of sustainability. These tools creating a common language that using by architects, builders, interior architects, landscape architects, construction managers, and building owners (Todd et al. 2001; Lachman et al. 2013; Doan et al. 2017).

These environmental assessment tools evaluating the sustainability of the buildings however, there is no necessity to use these tools. If the building evaluated by one of the environmental assessment tools and receive a certificate, this brings prestige to the building. Also, it encourages the other buildings to apply to the environmental assessment tools (Uyan 2010).

The environmental assessment tools are rating systems for sustainable buildings to control environmental pollution, provide energy efficiency, improve user's health conditions, and minimize consumption of natural resources.(Doan et al. 2017; Suzer 2019) There is more or less 600 green rating system in the world (Doan et al. 2017). These green rating systems are prepared according to the needs of each country by the professionals in different disciplines and scientific organizations of them. There are also countries that do not have their own green rating system. In this situation, they have to use other countries green rating systems which are widely used across the globe (Uyan 2010). There is no international environmental assessment tool which is answering all the requirements of Turkey (Said and CANKAYA UNIVERSITY 2019). The concerns about sustainability and green building started in the begging of 2000s with the effects of the World Green Building Council and Kyoto Protocol. After that awareness of green building's importance, the Turkish Green Building Association was established in 2009. It is called ÇEDBİK (Çevre Dostu Yeşil Binalar Derneği). However, ÇEDBİK does not give certification to all types of buildings, it gives certification only the new housing buildings. In order to answer all types of buildings, ÇEDBİK suggests applying BREEAM and LEED as environmental assessment tools. Because there is no specific environmental assessment tool in Turkey (Chergia 2012; Said and CANKAYA UNIVERSITY 2019).

The first environmental assessment tool is BREEAM (Building Research Establishment Environmental Assessment Method) which is published in 1990 and developed by Building Research Establishment in the UK (Nguyen and Altan 2011). The second tool is LEED (Leadership in Energy and Environmental Design) which is developed by the US Green Building Council (USGBC) in 1998 (Awadh 2017). In 2009, the Gulf Organization of Research and Development (GORD) published GSAS (Global Sustainability Assessment System) in Qatar. In 2010, Abu Dhabi Urban Planning Council (UPC) published Estidama Pearl Building Rating System (PBRS) as a green rating system (Awadh 2017). There are some other green rating tools that are using by other countries. For instance, CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) in Japan, GREEN GLOBES in Canada, BEAM (Building Environmental Assessment Method) in Hong Kong, DGNB (Deutsche Gesellschaft für Nachhaltiges Bauene. V.) in Germany, BCA (Building and Construction Authority) in Singapore, and Green Star in Australia are using for rating sustainability of building performances (Doan et al. 2017; Awadh 2017). All of these green rating systems are leading and guiding the building design stages into the framework of sustainability (Awadh 2017).

2.2.1. What is BREEAM?

BREEAM (Building Research Establishment Environmental Assessment Method) is the first environmental assessment tool in the world published in 1990. It was launched by the Building Research Establishment in the UK (Doan et al. 2017). BREEAM evaluates environmental impacts and minimizes the negative environmental effects of the building throughout its life. Because of this, it encourages to design and builds sustainable and green-friendly buildings (Diş and Canbaz 2015). The new building, renewed building, additional building, whole building or part of a building can be evaluated by BREEAM. Moreover, the categories and criteria of BREEAM are updated according to the new improvements in technology (Uyan 2010; Iyer-Raniga and Wasiluk 2007).

In 1993, the first revision of BREEAM was published and it contained offices. The second was version developed in 1998 and it involved education building, office building, industrial building, and retail building types. After that, BREEAM New Construction 2011 and 2014 was launched. BREEAM International for New Construction was prepared in 2016 and it is the latest version of it that is used in worldwide (Sinou and Kyvelou 2006; Lee 2013; Awadh 2017).

BREEAM International New Construction 2016 has nine different environmental categories and the tenth one has a different character. According to these categories, the building takes credits from each other (BINC16 2017a). The first category is Management (21 credits) that contains project brief, design, life cycle cost and service life planning, construction, commissioning, handover, and aftercare of the building. The second category is Health and Wellbeing (25 credits) which supports the enhance visual and thermal comfort, indoor air quality, health and safety of users, acoustic performance, water quality and accessibility (BINC16 2017b). The third category is Energy (37 credits), it encourages the energy efficient building design and reducing the use of energy and carbon emission. Also, it is important to use sustainable and energy efficiency solutions for the life cycle of the building (BINC16 2017c).The next category is Transport (13 credits), it is promoting sustainable transportation solutions and focusing easy access to public transportations (BINC16 2017d). The fifth category is Water (10 credits), it is encouraging the sustainable use of water with controlled water consumption (BINC16 2017e). The sixth category is Materials (12 credits), it focuses on decreasing the effect of the material through producing, manufacturing and recycling process of it (BINC16 2017f). The seventh category is Waste (10 credits), the aim is reducing the waste of building in the construction process and operational process (BINC16 2017g). The eight categories are Land Use and Ecology (10 credits), it encourages ecological protection of the land use (BINC16 2017h). The ninth category is Pollution (13 credits), it controls the night time light, air, noise, water, and land pollution in the life cycle of building (BINC16 2017i). And the additional category is Innovation. In consequence of this scoring system, the building takes credits from each category and has a total score. As a result of evaluation, the building takes a certified according to its percentage of total score which can be unclassified (<30%), pass (≥30%), good (≥45%), very good (≥55%), excellent (≥70%), outstanding (≥85%) (BINC16 2017a; Lee 2013; Awadh 2017).

2.2.2. Visual Comfort Criteria for BREEAM

BREEAM has nine environmental categories. Health and wellbeing category is the second category with the most point weight (25 credits). In general, this category gives weight to indoor environmental quality with considering comfort, health, and safety of building users (BINC16 2017b; Awadh 2017).

Visual comfort is the first section of health and wellbeing category. The aim is providing the best visual performance, perception, control, and comfort for building occupants in an indoor environment. The daylighting, artificial lighting and user control are important for the design process. In the visual comfort section, the credit that building gets can be changed according to building type or area type. Education buildings (preschools, schools, universities, colleges, and higher education buildings), residential institutions (kitchen, living rooms, dining rooms, studies, non-residential or communal occupied spaces), residential dwellings (kitchen, living rooms, dining rooms, and studies), retail buildings (sales area and other occupied areas), industrial, office, and all other building types (internal association or atrium area, teaching, lecture and seminar spaces) are the building types that are evaluating and getting different credits from visual comfort section in BREEAM (Uyan 2010; BINC16 2017b).

The assessment criteria of visual comfort are separated into five-part. These are prerequisite, glare control (1 credit), daylighting (up to 4 credits - depending on building type), view out (1 credit), internal and external lighting (1 credit). The first criteria of visual comfort are prerequisite and there is no credit for this section. The fluorescent lamps of the building have to arrange and fit as high-frequency ballast. The buildings have to take 'criterion 1 only (high-frequency ballast)' to have minimum standards of BREEAM rating level (BINC16 2017c). The second criteria is glare control. The aim of glare control is preventing energy consumption for lightings. To use maximum daylight in the workspaces and other critical spaces, the glare control systems are designed properly. The important point about the glare control system is not to block entering daylight into the indoor environment, in the cloudy weather conditions. The position of shading elements are compatible with lighting systems to control glare (BINC16 2017b). The third criterion of visual comfort is daylighting. In order to get credit, average daylight factor, uniformity, illuminance, and space type are determinative factors (Giarma, Tsikaloudaki, and Aravantinos 2017; BINC16 2017b). The fourth criterion is the view out. In this section, the aim is providing an adequate view out for building occupants. Area of the window opening and room depth are the measurement of criteria. If the distance from the window to the workspace is 7 meter or less, the window opening size has to be 20% of the surrounding wall. If the distance from the window to the workspace is 8 meter -11 meters, the window opening size has to be 25% of the surrounding wall area. If the distance from the window to the workspace is 11 meter - 14 meter or less, window opening size has to be 30% of the surrounding wall area. If the distance from the window to the workspace is 14 meter or more, window opening size has to be 35% of the surrounding wall area. For the residential buildings and institutions, the distance from the window to the relevant area is 5 meter and window opening size has to be ≥20% of the surrounding wall area (Uyan 2010; Giarma, Tsikaloudaki, and Aravantinos 2017; BINC16 2017b). The fifth criteria of visual comfort is internal and external lighting levels, zoning and control. Interior lighting is designed according to appropriate illuminance (lux) levels of each area in order to provide convenient concentration and comfort level of building occupant. In the areas that computer screens are used, there are special provisions for lighting design in order to control glare in the indoor area and avoid screen reflections. All of the external lightings of the construction site are organized according to proper illuminance levels. There are specifications about external lighting such as EN 13201 Road Lighting and EN 12464-2:2014 Lighting of workplaces (Uyan 2010; BINC16 2017b). Internal lighting is divided into the zones and is controlled by the building occupants. In the office spaces, the zones can include a maximum of four workplaces and are controlled independently. Also, window neighbor workplaces and other workplaces are zoned and controlled separately. For the seminar rooms, speaker and audience areas are zoned and controlled separately. Moreover, in the educational buildings, the teachers can access and manually control the lightings easily in the classrooms (Uyan 2010; BINC16 2017b).

2.2.2.1.Daylighting

The third criteria of visual comfort section in BREEAM is daylighting. There are two alternatives for evaluation of daylighting. The first evaluation procedure is looking for average daylight factor and daylighting uniformity. And the second evaluation procedure is looking for space types and their illuminance requirements (BINC16 2017b).

For the daylight factor of the first alternative procedure; the average daylight factor required by latitude (degrees) can change according to building type. Also, the minimum area to comply with daylight factor affects the number of credits that can take from this section. In order to have adequate daylight in the building, minimum 80% of the floor area needs 2%an average daylight factor. The average daylight factor changes according to building types, these are education buildings, residential institutions, residential dwellings, retail buildings, and industrial, office, and all other building types (Giarma, Tsikaloudaki, and Aravantinos 2017; BINC16 2017b).

The education buildings are split into two categories which are preschools, schools and universities, colleges, and higher education buildings. If preschools and schools have an average daylight factor in 80% of the floor area, they take 2 credit. Universities, colleges, and higher education buildings have an average daylight factor in 60% of the floor area, they gain 1 credit or 80% of the floor area they gain 2 credits. The other building type is residential institutions, which contains a kitchen, living rooms, dining rooms, study areas, and non-residential or communal occupied spaces. They receive 1 credit if all of them have an average daylight factor in the 80% of the floor area. Residential dwellings are the other building type that contains a kitchen, living rooms, dining rooms, and study areas. If they have an average daylight factor in the 80% of the floor area, they take 2 credits for kitchen and 2 credits for other spaces. The retail buildings divide as sales areas and other occupied areas. If sales areas have an average daylight factor in the 35% of the floor area, they receive 1 credit. And also, other occupied areas receive 1 credit, if they have an average daylight factor in the 80% of the floor area. The last building type contains industrial, office and all other building types. They include internal association or atrium area, teaching, lecture and seminar spaces, and all occupied spaces. If they have an average daylight factor in the 80% of the floor area, they take 1 credit (BINC16 2017b).

The first alternative procedure has a second part which is about the daylighting uniformity criteria. There is a ratio between the minimum and average weight of daylight factor, this is the daylighting uniformity ratio (Giarma, Tsikaloudaki, and Aravantinos 2017). The value of a uniformity ratio is at least 0.3. If space has a glazed roof like an atrium, the value of a uniformity ratio minimum of 0.7. Moreover, Minimum 80% of the area has a view from a tabletop height which is 0.85 meter for residential buildings and residential institutions and 0.7 meters for other types of buildings. Also, the room depth criterion is satisfied with: $d/w + d/HW < 2/(1-RB)$. According to the formula; d is the room depth, w is the room width, HW is the window head height from floor level, and RB is the average reflectance of surfaces in the rear half of the room (Giarma, Tsikaloudaki, and Aravantinos 2017; BINC16 2017b).

The illuminance level of the indoor area type is using as the second evaluation procedure of daylighting in visual comfort section. The space type, minimum area to comply, average daylight illuminance (averaged over entire space), and minimum daylight illuminance at the worst lit point are the evaluation criteria for the daylight illuminance criteria. The amount of light, which is falling on a surface per unit area, is the illuminance and it is measured with lux (BINC16 2017b).

The education buildings can take up to 2 credits available. Preschools and schools have to have minimum 80% area to comply in order to take 2 credits and university, colleges, and higher education building types have to have minimum 60% area to comply in order to take 1 credit. In detail, they need to have the average daylight illuminance can be at least 300 lux for 2000 hours per year or more and the minimum daylight illuminance at the worst lit point can be at least 90 lux for more than 2000 hours per year. In the residential institutions, if kitchens have 100% area to comply, they receive 1 credit. Also, they need to have the average daylight illuminance can be at least 100 lux for 3450 hours per year or more and the minimum daylight illuminance at the worst lit point can be at least 30 lux for more than 3450 hours per year. If non-residential or communal spaces have 80% area to comply, they receive 1 credit. They need to have the average daylight illuminance can be at least 200 lux for 2650 hours per year or more and the minimum daylight illuminance at the worst lit point can be at least 60 lux for more than 2650 hours per year. In residential dwellings, kitchens have 100% area to comply, they receive 2 credit. Also, they need to have the average daylight illuminance can be at least 100 lux for 3450 hours per year or more and the minimum daylight illuminance at the worst lit point can be at least 30 lux for more than 3450 hours per year. Living rooms, dining rooms, and study areas have 100% area to comply, they receive 1 credit. Also, they need to have the average daylight illuminance can be at least 100 lux for 3450 hours per year or more and the minimum daylight illuminance at the worst lit point can be at least 30 lux for more than 3450 hours per year. In retail buildings, sales areas have 35% area to comply, they receive 1 credit. They need to have at least 200 lux point daylight illuminance for 2650 hours per year or more. Other occupied areas that in the retail buildings have 80% area to comply, they receive 1 credit. In addition, they need to have the average daylight illuminance can be at least 200 lux for 2650 hours per year or more and the minimum daylight illuminance at the worst lit point can be at least 60 lux for more than 2650 hours per year. Industrial, office, and all the other building types are the last building section. Internal association or atrium area of them have 80% area to comply, they receive 1 credit. They need to have the average daylight illuminance can be at least 300 lux for 2650 hours per year or more and the minimum daylight illuminance at the worst lit point can be at least 210 lux for more than 2650 hours per year. Moreover, teaching, lecture, seminar spaces and all occupied spaces need to have the average daylight illuminance can be at least 300 lux for 2000 hours per year or more and the minimum daylight illuminance at the worst lit point can be at least 90 lux for more than 2000 hours per year.

2.2.3.Room and Window Design Parameters

The amount of daylight affects the occupants' comfort and visual performance (Galatioto and Beccali 2016). Room and window design parameters are the factors that affect daylight in the first degree. The reflection of light is changing the value of daylight in the indoor environment. The room surfaces which are floor, walls, and ceiling can be made of different material which has different color, texture, matte or shiny finishing. And also, the size of the window directly affects the quantity of daylight that reaches the interior.

2.2.3.1.Room Materials and Colors

The daylight is not only coming from the sky as one direction to the indoor environment. The amount of daylight is increasing with the surfaces that reflect the daylight. In that position, the materials, textures, and the surface color of the indoor environment has an important role for daylighting (Acosta et al. 2015; Schmid and Uehara 2017).

Every material surface has a different reflectance value. The reflectance of the surface has the ability to distribute and reflect daylight. As general information, light colors for interior elements provide to create brighter indoor environments and white is the most emitting color that spread daylight (Schmid and Uehara 2017; Jafarian et al. 2018).As a result of this, the quality and amount of daylight can change the visual perception of the interior spaces. The walls, floor, ceiling, and furnishings are the surfaces of the indoor environment which have reflectance value. The materials, textures, and colors of interior surfaces are chosen according to the needs of function and its users of the interior space (Oral, Yener, and Bayazit 2004). According to the combination of interior surface materials, they can provide an appropriate indoor environment for occupants. At the same time, they can create an interior space that has the glare of daylight which gives a feeling of discomfort and inefficient visual perception with the different reflectance value of material surfaces.

The daylight comes from outside to the inside as a form of the ray with a stable form and angle. The amount of reflectance is calculated with the light that reflected the contrary angle. Moreover, the reflectance value of the surface is changing with its color and material. The value is changing in between 0% and 100%. The color and brightness level of the surface directly affects the amount of reflectance. For instance, white matte paint wall has 80% value in reflectance. However, if the same color white has a shiny finishing, it has 90% value in reflectance. Also, the black matte painting wall has 5% value in reflectance (Jafarian et al. 2018). The brightness level of the surface effects the reflectance value of the material. Moreover, the daylight, window, and surfaces of an interior connected to each other with the light. In order to not create a sharp contrast between the surfaces and daylight, the lighter colors are chosen for the surfaces (Leslie 2003). In this way, the occupants have better visual comfort in the interior.

2.2.3.2.Window Size

Windows are one of the most important elements of the building envelope. The windows are designed in the early building design stage with building enclosure and plan organization. They are directly affecting the daylighting, cooling, heating, and acoustic performance of the building (Hiyama and Wen 2015). Also, they separate the outside environment from the indoor environment. Moreover, they physically separate the outside and inside of the building from heat, light, wind, and noise. However, they visually connect the outside and inside of the building with view out (Oral, Yener, and Bayazit 2004).

Usually, the occupants want bright and spacious indoor environments in order to feel healthy and wellbeing (CIBSE, n.d.). The windows have an important role in order to provide these specifications. The geometry of the window affects the indoor environment quality in the first stage. The windows need some necessities in order to create proper interior space, such as; the dimension and the position (Fontenelle and Bastos 2014). The proper size and location of the windows allow the daylight to the interior space. According to the amount of daylight, it has positive and negative effects on building occupants. As positive effects, it increases motivation, learning level, productivity, concentration, and health. However, as negative effects, it creates glare and uncomfortable visual environment (Kazanasmaz et al. 2016; Osterhaus 2005).

The windows are used technically as a daylight source. However, it can create a glare if, direct sunlight reflects from neighbor building facades or enters the indoor environment. As a result of this, the daylight is shining into the eyes of building users and creates visual discomfort in the interior space. For example, if there is an indoor area that is used computers, the glare has to prevent. Because there is no visual comfort between the eyes of the occupant and the computer screen (Osterhaus 2005).

In the design stage of the window, the dimension of it is important. Because the proper window dimension increases the positive effects and decreases the negative effects of daylight. The glazing and the opaque area have a balance between them in order to use efficient daylight availability in the indoor environment. The window-to-wall ratio (WWR) determine the transparency of the building envelop. Because of this, WWR is planned at the beginning of the design (Kazanasmaz et al. 2016; Goia 2016).

2.3. Selected Research About Daylighting Issues of BREEAM

This section focuses on the selected researches about daylighting issues of BREEAM. It explains how researches looking at daylighting issues from different sides. Also, it tries to show the importance of daylighting criteria rather than other criteria of BREEAM.

Uyan (2010) wrote a thesis about sustainability assessment principles of lighting systems in the buildings. Before focuses on lighting systems, the author explains, in general, starting from the concept of sustainability and architecture, the history and today's meaning of sustainability. After that, he continues the idea of sustainable lighting systems and their effects. Then, the author explains the character of LEED, BREEAM, CASBEE, and GreenStar and their lighting criteria in detail. In the chapter of BREEAM and lighting, he gives general scoring information about BREEAM and the possible credits that can get from visual comfort section which contains daylighting and lighting criteria. Also, the assessment criteria of visual comfort are clarified. The measurement specifications and the credits of them are explained. However, there are some other lighting specifications which are related to general building condition. They are not directly about lighting. As a conclusion, the author gives the regulations and standards of lighting in Turkey and in the world (Uyan 2010).

Giarma, Tsikaloudaki, and Aravantinos (2017) wrote an article about daylighting and visual comfort in buildings' environmental performance assessment tools and its critical review. The starting point of the article is environmental performance assessment tools and their importance. BREEAM, LEED, CASBEE, and SBTool are the tools that are examined. Firstly, the authors explain each assessment tool with their history, valid building types, versions of them for different regions, assessment categories, the classification system of tools and general considerations. After that general information, the authors focus on daylighting and visual comfort parameters of each tool in detail. They give an explanation about measurement standards, evaluation criteria, and available credits for BREEAM and other assessment tools (Giarma, Tsikaloudaki, and Aravantinos 2017).

Altomonte et al. (2017) wrote an article about occupant satisfaction with indoor environmental quality with a comparison of BREEAM and non-BREEAM certified office building. Firstly, the authors explain the importance of indoor environmental quality and its relation to environmental assessment tools. Then, they give information about BREEAM's categories and rating system. After that, four buildings are selected for comparison of health and wellbeing category in order to analyze indoor environmental quality. Glare control, internal and external lighting levels are the items of health and wellbeing category that is related to daylight. Information about the category is collected by using questionnaires and surveys. The results of them show the satisfaction of occupants. Amount of light and visual comfort are the categories that are about daylight (Altomonte et al. 2017).

Piasecki et al. (2018), wrote an article about the approach of including TVOCs (total volatile organic compounds) concentration in the indoor environmental quality model with the case studies of BREEAM certified office buildings. Indoor environmental quality is important for office buildings because the officers should use their working hours effectively. Air quality, visual, acoustic, and thermal comfort are the categories that affect indoor environmental quality. And also, they affect the rating of BREEAM certification. Satisfaction with the quality of lighting is one of the subjects of the internal environment quality. In order to evaluate the visual comfort category of BREEAM, the daylight illuminance level is determinant for evaluation of the amount of daylight. After that, four buildings are selected for the case study and they are compared and contrasted by emissions, environmental performance, and indoor air quality tests. And they analyzed according to the BREEAM requirements (Piasecki et al. 2018).

CHAPTER 3

THE PROCEDURE

This chapter involves three subsections which are reference room, locations, and simulation models. Firstly, the dimensions of the reference rooms and general material selection are explained. Then, detailed climate and sun path information about London and İzmir location are given. The last section includes BREEAM criteria of analysis, material alternatives of reference rooms, and the steps of the modeling phase in RELUX.

3.1.The Geometry of Reference Rooms

The reference room is using as a default model for the simulation of building performance tools in order to compare and contrast the parameters of simulations. The definition of the reference room is taken from a study of C. Reinhart, Jakubiec, and Ibarra (2013) and visual comfort criteria of BREEAM (BINC16 2017b). According to C. Reinhart, Jakubiec, and Ibarra (2013), the sizes of the reference room should be 3 to 5 meter width, 5 to 8 meter depth, and 3 to 4 meter height. However, visual comfort category of BREEAM gives maximum room dimensions for reflectance values. If the room is 3 meter width and 5.4 meter depth, the window head height has to be 2.5 meters. According to these dimensions, the value of reflectance of the room is 0.5 (BINC16 2017b). The reference room dimensions of this study is a combination of this information.

The reference room has two variations according to its window size. The reference room A is a rectangular box whose dimensions are 3 meter width and 5.4 meter depth (Table 3.1). Its height is 2.7 meters and 2.5 meter window head height with a 0.8 m-canopy on the south elevation(Figure 3.1). The window is in a south facing one which is 3meter in width, 1.5 meters in height; while the reference room B is 1.5 meter in width and 1.5 meters in height (Figure 3.2).

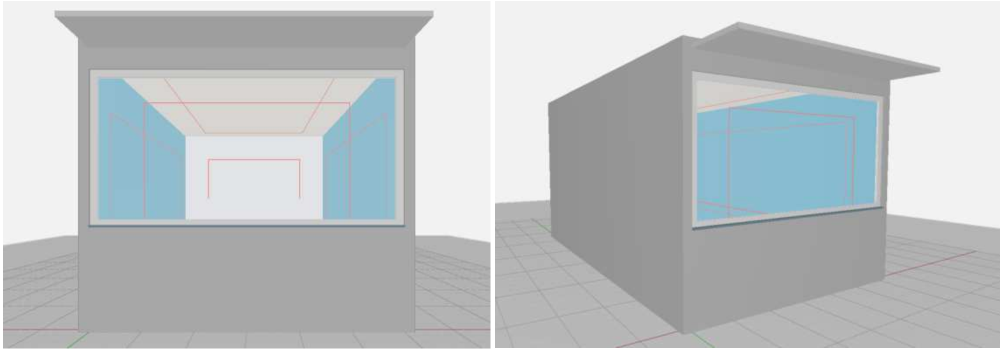


Figure 3.1. Front and perspective view of the reference room A which has a 3 meter width window.

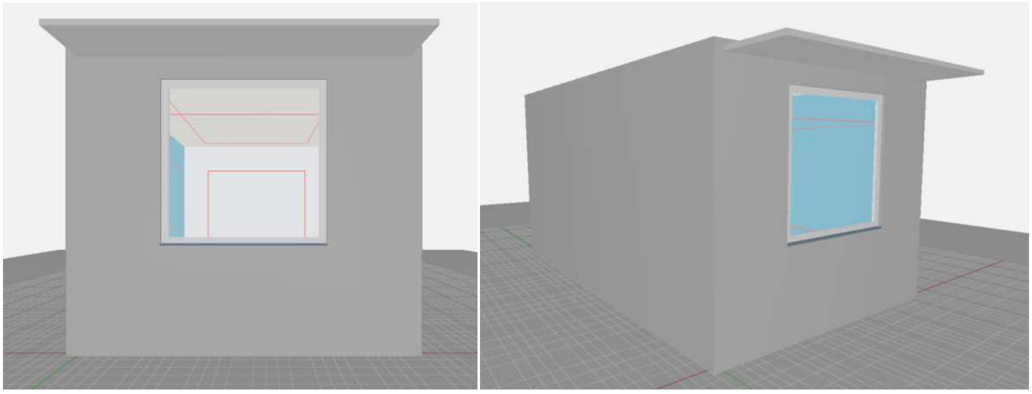


Figure 3.2. Front and perspective view of the reference room B which has a 1.5 meter width window.

The materials of the reference room defined for floor, ceiling, and walls. They have different reflectance values. For the reference room, A; the floor has 22%, ceiling 22%, and walls 56% reflectance values of the total room. For reference room B; the floor has 21.5%, ceiling 21.5%, and walls 57% reflectance values of the total room. The reflectance values of interior surfaces directly affect the average reflectance value of the reference room. Four different floor material alternatives are applied for the floor. Two of them are wood parquet and two of them are marble flooring. Different RAL colors are chosen for the ceiling and walls. The material variety creates a difference between the average reflectance values of material combinations.

Table 3.1.Geometrical properties of the reference rooms.

Geometry	**Reference Room A**	Width	3 m
		Depth	5.4 m
		Height	2.7 m
		Window Head Height	2.5 m
		Canopy	0.8 m
		Interior Surface Area	73.26 m^2
		Glazed Area	4.5 m^2
	Reference Room B	Width	3 m
		Depth	5.4 m
		Height	2.7 m
		Window Head Height	2.5 m
		Canopy	0.8 m
		Interior Surface Area	75.51 m^2
		Glazed Area	2.25 m^2

3.2.Location of the Rooms

The first location of the reference room is in London, England, UK (latitude 51° 5' North, longitude -0°1' East). The time zoning of London is UTC+0. The climate type of London is a marine west coast climate. It is explained as mild with no dry season and warm summers. An average temperature of daytime (Table 3.2) in spring 13.3°C, in summer 21°C, in autumn, 14.3°C, and in winter 6.7°C. Moreover, 13.5°C is the average monthly temperature of London (London, England Climate & Temperature n.d.). June, July and August have higher daily average temperatures than other months. The hottest month is July. In addition, December, January, and February have lower daily average temperature than other months. The coldest month is January in London (Average Temperatures in London, England, UK n.d.). The altitude and azimuth angles are determining the position of the sun (Table 3.3). It is changing in every date and hour. In this study, 21st of March, 21st of June, 21st of September, and 21st of December are critical dates for analysis. For these dates, 12:30 pm is specified as a critical hour for activation of the simulation tool. In spring, the sun angles are 38.62^{o} altitude and

187.14^o azimuth in at 12:30 pm on 21stof March. In summer, the sun angles are 61.43^o altitude and 193.36^o azimuth in at 12:30 pm on 21stof June. In autumn, the sun angles are 38.52^o altitude and 191.66^o azimuth at 12:30 pm on 21stof September. In winter, the sun angles are 14.74^o altitude and 187.45^o azimuth at 12:30 pm on 21st of December (Sun Position 2019). London has an average of 1460 hours of sunlight per year that means 3:59 hours sunlight per day in a year (Table 3.4). Moreover, 12:00 hours is the average daylight per day in a year. Also, 33.3% of the daylight hours are sunny and 66.7% of daylight hours are cloudy in London (Sunshine & Daylight Hours in London, England, UK n.d.).

Table 3.2. An average temperature of daytime for London, England, UK.

London, England, UK **Latitude 51° 5' North, Longitude -0°1' East, UTC+0**					
An Average Temperature of Daytime	**Spring**	**Summer**	**Autumn**	**Winter**	**Average Monthly**
	13.3°C	21°C	14.3°C	6.7°C	13.5°C

Table 3.3. Altitude and azimuth values of critical dates and hour for London, England, UK.

London at 12:30 pm	**21st of March**	**21st of June**	**21st of September**	**21st of December**
Altitude	38.62^o	61.43^o	38.52^o	14.74^o
Azimuth	187.14^o	193.36^o	191.66^o	187.45^o

The second location of the reference room is İzmir, Turkey (latitude 38° 4' North, longitude 27°1' East). The time zoning of İzmir is UTC+3. The climate type of İzmir is explained as a hot Mediterranean climate type which is a subtropical climate. It is a mild climate and it has dry and hot summers (Izmir Climate & Temperature n.d.). An average temperature of daytime in spring 21°C, in summer 31.8°C, in autumn at 23.6°C, and in winter is 13°C (Table 3.5). The monthly average temperature of İzmir is

Table 3.4. An average daylight and sunlight information for London and İzmir.

	London Latitude 51° 5' North Longitude -0°1' EastUTC+0	**İzmir Latitude 38° 4' North Longitude 27°1' East UTC+3**
Average sunlight per year	1460 hours	3008 hours
Average sunlight per day	3:59 hours	8:14 hours
Average daylight per year	12:00 hours	12:00 hours
Sunny daylight hours	33.3%	68.6%
Cloudy daylight hours	66.7%	31.4%

18.9°C. June, July, and August are the months that have higher daily average temperatures than the other months. In addition, July is the hottest month in İzmir. December, January, and February are the months that have a lower daily average temperature than others. Also, January is the coldest month (Average Temperatures in İzmir, Turkey n.d.). The sun position of the critical dates and hour of simulation tool are important. In spring, the sun angles are 44.42^{o} altitude and 140.26^{o} azimuth in at 12:30 pm on 21st of March. In summer, the sun angles are 63.42^{o} altitude and 116.8^{o} azimuth in at 12:30 pm on 21st of June. In autumn, the sun angles are 46.45^{o} altitude and 144.4^{o} azimuth at 12:30 pm on 21st of September. In winter, the sun angles are 23.89^{o} altitude and 155.05^{o} azimuth at 12:30 pm on 21st of December (Table 3.6) (Sun Position 2019). İzmir has an average of 3008 hours of sunlight per a year which means an average of 8:14 hours sunlight per a day in a year (Table 3.4). Also, it has an average of 12:00 hours of daylight per day in a year. Moreover, 68.6% of daylight hours are sunny and 31.4% of daylight hours are cloudy (Sunshine & Daylight Hours in İzmir, Turkey n.d.).

Table 3.5. An average temperature of daytime for İzmir, Turkey.

İzmir, Turkey Latitude 38° 4' North, Longitude 27°1' East, UTC+3					
An Average Temperature of Daytime	**Spring**	**Summer**	**Autumn**	**Winter**	**Average Monthly**
	21°C	31.8°C	23.6°C	13°C	18.9°C

Table 3.6. Altitude and azimuth values of critical dates and hour for İzmir, Turkey.

İzmir at 12:30 pm	**21st of March**	**21st of June**	**21st of September**	**21st of December**
Altitude	44.42°	63.42°	46.45°	23.89°
Azimuth	140.26°	116.8°	144.4°	155.05°

3.3. Daylighting Performance Simulation Models in RELUX

The four different material alternative combinations of reference rooms are analyzing according to daylighting criteria of BREEAM by modeling phase in RELUX.

3.3.1.BREEAM Criteria

The daylighting issue of BREEAM is for university, colleges and higher education-occupied spaces building type. It has to provide 60% of the minimum area (m^2) to comply with at least 300 lux for 2000 hours per year or more for average daylight illuminance of entire space. According to BREAM, the reflectance value of the indoor environment is changing with the room depth, room width, and the window head height. For the maximum 3 meter room width, 5.4 meter room depth, and 2.5 meter window head height need to create 0.5 reflectance value for the indoor environment. These dimensions of the room are using for the reference room A and B in this study. However, the reflectance values are changing with the material alternatives. If the room depth is increasing to 6.8 meter which has 3 meter room width and 2.5 meter window head height at the same time, the reflectance value is calculated 0.6 for the interior. In other situation, if the room depth is decreasing to 4.5 meters and the room has 3 meter width and 2.5 meter window head height, the reflectance value is calculated 0.4 for the interior (BINC16 2017b).

3.3.2.Material Alternatives

The daylight, that comes from the window to the interior, is reflected between different indoor surfaces. The reflectance ability of surfaces provides this movement.

Table 3.7. Reflectance value for maximum room depths (m) and head heights (m).

Reflectance(RB)	**0.4**		**0.5**		**0.6**	
Room width (m)	**3**	10	**3**	10	**3**	10
Window head height (m)	**Room depth (m)**					
2.5	**4.5**	6.7	**5.4**	8.0	**6.8**	10.0
3.0	5.0	7.7	6.0	9.2	7.5	11.5
3.5	5.4	8.6	6.5	10.4	8.1	13.0

The daylight and the reflectance feature of different materials are working together in the indoor environment. The interior surfaces of reference rooms are floor, ceiling, and walls. Different materials and colors can apply to each of these surfaces. The important point is the reflectance value of them. Every material and color have a specific reflectance value. In addition, every surface of the interior has a reflectance value and they create an average reflectance value of the indoor environment.

$$r_{average} = \frac{(\text{floor m}^2 \text{ x } \text{r}_{\text{floor}}) + (\text{ceiling m}^2 \text{ x } \text{r}_{\text{ceiling}}) + (\text{wall m}^2 \text{ x } \text{r}_{\text{wall}})}{\text{m}^2 \text{ of total interior surfaces}}$$

The amount of reflection is directly related to the amount of light in the interior. The reflectance value of the interior affects the illuminance value of the interior. The value of the average reflectance can increase or decrease the amount of illuminance. If one of the interior surface material's reflectance value is low, the other materials can choose from higher reflectance values. By this way, the average value of reflectance is balanced.

In this study, there are four different material combinations. Each material combination alternative has its own average value of reflectance. The material combination of indoor environment shows the illuminance of interior changes.

The material alternative I (Table 3.2) was prepared with four different materials and colors. Mahogany wood parquet was applied for floor surface which has 0.147 reflectance value. Grey white color plaster (RAL 9002) was applied for the ceiling which has 0.66 reflectance value. Pure white color plaster (RAL 9010) was applied for a front wall which has a window and it has 0.84 reflectance value. Dark blue color plaster (RAL 5021) was applied for left and right walls which has 0.21 reflectance value. Grey white color plaster (RAL 9002) was applied for the back wall which has 0.66 reflectance value. According to these material selections, the reference room has 0.3762 as an average reflectance value.

Table 3.8. The material alternative I for reference room A and B.

Material Alternative I				
Surface	**Material**	**Reflectance**	**Average Reflectance A**	**Average Reflectance B**
Floor	Mahogany Wood Parquet	0.147	0.3762	0.3901
Ceiling	Plaster Grey White - RAL 9002	0.66		
Front Wall (Window Wall)	Plaster Pure White - RAL 9010	0.84		
Left Wall	Plaster Dark Blue - RAL 5021	0.21		
Right Wall	Plaster Dark Blue - RAL 5021	0.21		
Back Wall	Plaster Grey White - RAL 9002	0.66		

Material alternative II (Table 3.3) was prepared with four different materials and colors. Pinewood parquet was applied for floor surface which has 0.453 reflectance value. Dark blue color plaster (RAL 5021) was applied for the ceiling which has 0.21 reflectance value. Pure white color plaster (RAL 9010) was applied for a front wall which has a window and it has 0.84 reflectance value. Grey white color plaster (RAL 9002) was applied for left and right walls which has 0.66 reflectance value. Dark blue color plaster (RAL 5021) was applied for the back wall which has 0.21 reflectance value. According to these material selections, the reference room has 0.4738 as an average reflectance value.

Table 3.9. Material alternative II for reference room A and B.

Material Alternative II				
Surface	**Material**	**Reflectance**	**Average Reflectance A**	**Average Reflectance B**
Floor	Pine Wood Parquet	0.453	0.4738	0.4847
Ceiling	Plaster Dark Blue - RAL 5021	0.21		
Front Wall (Window Wall)	Plaster Pure White - RAL 9010	0.84		
Left Wall	Plaster Grey White - RAL 9002	0.66		
Right Wall	Plaster Grey White - RAL 9002	0.66		
Back Wall	Plaster Dark Blue - RAL 5021	0.21		

Material alternative III (Table 3.4) was prepared with four different materials and colors. The marble slab was applied for floor surface which has 0.715 reflectance value. Grey white color plaster (RAL 9002) was applied for the ceiling which has 0.66 reflectance value. Pure white color plaster (RAL 9010) was applied for a front wall which has a window and it has 0.84 reflectance value. Yellow color plaster (RAL 9002) was applied for left and right walls which has 0.53 reflectance value. Grey white color plaster (RAL 9002) was applied for the back wall which has 0.66 reflectance value. According to these material selections, the reference room has 0.6005 as an average reflectance value.

Table 3.10. Material alternative III for reference room A and B.

Material Alternative III				
Surface	**Material**	**Reflectance**	**Average Reflectance A**	**Average Reflectance B**
Floor	Marble Slab	0.715	0.6005	0.6355
Ceiling	Plaster Grey White - RAL 9002	0.66		
Front Wall (Window Wall)	Plaster Pure White - RAL 9010	0.84		
Left Wall	Plaster Yellow - RAL 1023	0.53		
Right Wall	Plaster Yellow - RAL 1023	0.53		
Back Wall	Plaster Grey White - RAL 9002	0.66		

Material alternative IV (Table 3.5) was prepared with four different materials and colors. The marble slab was applied for floor surface which has 0.59 reflectance value. Pure white color plaster (RAL 9010) was applied for the ceiling which has 0.84 reflectance value. Pure white color plaster (RAL 9010) was applied for a front wall which has a window and it has 0.84 reflectance value. Pure white color plaster (RAL 9010) was applied for left and right walls which has 0.84 reflectance value. Pure white color plaster (RAL 9010) was applied for the back wall which has 0.84 reflectance value. According to these material selections, the reference room has 0.7581 as an average reflectance value.

Table 3.11. Material alternative IV for reference room A and B.

Material Alternative IV				
Surface	**Material**	**Reflectance**	**Average Reflectance A**	**Average Reflectance B**
Floor	Marble Slab	0.59	0.7581	0.7606
Ceiling	Plaster Pure White - RAL 9010	0.84		
Front Wall (Window Wall)	Plaster Pure White - RAL 9010	0.84		
Left Wall	Plaster Pure White - RAL 9010	0.84		
Right Wall	Plaster Pure White - RAL 9010	0.84		
Back Wall	Plaster Pure White - RAL 9010	0.84		

3.3.3.RELUX Modeling

RELUX Desktop is a freeware lighting simulation tool which is developed by RELUX Informatik AG in Switzerland. It is possible to simulate daylight and artificial light (RELUX 2019). In addition, it provides to simulate architectural elements of building, materials, colors, and furnishings with their light diffusions (Yu, Su, and Chen 2014).

RELUX models were developed for the reference university, colleges and higher education-occupied spaces building type in the dimensions of reference room A and Bin order to make daylight analysis (Table 3.1). Two of the reference rooms have the same dimensions except for the window sizes. The virtual model of reference room A has a 3 meter width and 1.5 meter height glazing. The virtual model of reference room B has a 1.5 meter width and 1.5 meter height glazing. The purpose of changing the dimension of the window is creating a difference in the amount of daylight that comes from window to the indoor environment.

The interior surface materials of reference rooms have four different alternative combinations by using specific RAL colors and floor materials (Table 3.2, Table 3.3, Table 3.4, Table 3.5). The materials and colors are located in the raytracer material library. The real reflectance value of every material is applied in the simulation tool. Because of this, the surfaces reflect the real daylight illuminance in the indoor environment. The aim of this is to generate different average reflectance value of the indoor environment.

The geographical locations and time zonings for London and İzmir are applied in the RELUX. The coordinates of the cities are uploaded to the simulation tool. London is in the time zone UTC+0 and it is located in -0.1 longitudes and 51.5 latitudes. In addition, İzmir is in the time zone UTC+3 and it is located in 27.1 longitudes and 38.4 latitudes. Each version of the reference room is prepared and calculated once for London and once for İzmir. In order to calculate an average level of the interior illuminance value four different days are selected which are 21st March, 21st June, 21st September, and 21st December. The simulation tool is activated for these four dates in the same hour which is 12:30 pm. The sun position of these dates and locations are calculated automatically in the simulation tool. Moreover, each day is calculated in CIE clear sky (CLR) condition and CIE overcast sky (OVC) condition separately.

In the final, the reference room A has 64 different simulation results that give information about the illuminance value of the indoor environment (Table 3.6). The reference room B has also the same number of simulation outcomes (Table 3.7). These 128 simulation results evaluate the visual performance of the reference rooms which

Table 3.12. The number of a simulation model for reference room A.

12:30		Reference Room A							
		I		II		III		IV	
		London	İzmir	London	İzmir	London	İzmir	London	İzmir
21st March	**CLR**	1	1	1	1	1	1	1	1
	OVC	1	1	1	1	1	1	1	1
21st June	**CLR**	1	1	1	1	1	1	1	1
	OVC	1	1	1	1	1	1	1	1
21st September	**CLR**	1	1	1	1	1	1	1	1
	OVC	1	1	1	1	1	1	1	1
21st December	**CLR**	1	1	1	1	1	1	1	1
	OVC	1	1	1	1	1	1	1	1
Total		**64 simulations**							

Table 3.13. The number of a simulation model for reference room B.

12:30		Reference Room B							
		I		II		III		IV	
		London	İzmir	London	İzmir	London	İzmir	London	İzmir
21 March	**CLR**	1	1	1	1	1	1	1	1
	OVC	1	1	1	1	1	1	1	1
21 June	**CLR**	1	1	1	1	1	1	1	1
	OVC	1	1	1	1	1	1	1	1
21 September	**CLR**	1	1	1	1	1	1	1	1
	OVC	1	1	1	1	1	1	1	1
21 December	**CLR**	1	1	1	1	1	1	1	1
	OVC	1	1	1	1	1	1	1	1
Total		**64 simulations**							

depend on the illuminance based analysis. They are applied to find out how room and window design parameters change could make a difference in the daylight performance.

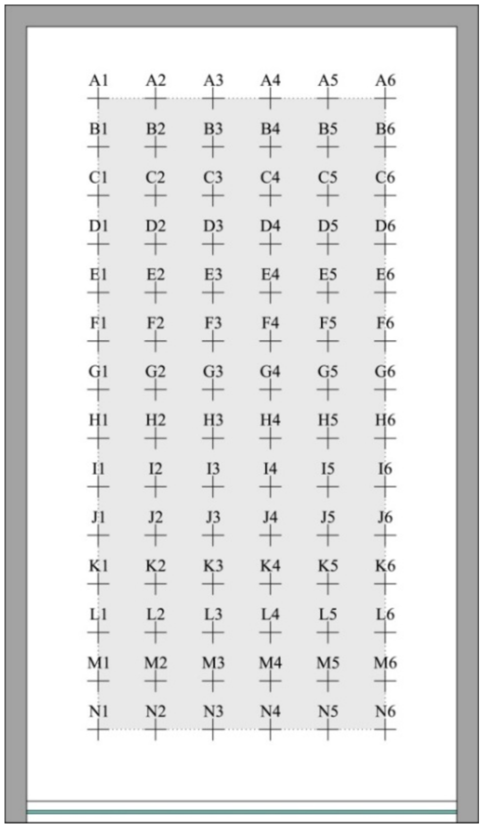


Figure 3.3. Horizontal reference plane and the calculation (84 calculation points) points of the reference room A and B.

In the simulation of the reference rooms, there is a horizontal reference plane which has points on it. This reference plane height is 0.75 meter from floor level and it has 84 calculation points on it (Figure 3.3). The simulation tool measures horizontal illuminance value (lux) of these reference points. Each point has a specific illuminance value. According to the BREEAM criteria, 60% of these points have to be measured equal to or higher than 300 lux. As a result of this, the reference room can take 1 credit from daylighting section of BREEAM (BINC16 2017b).

CHAPTER 4

RESEARCH FINDINGS

This chapter involves four subsections which are four different indoor environment material alternatives. They have different average reflectance value. RELUX simulation results show how the reference rooms provide daylight criteria of BREEAM. The simulations are evaluating according to BREEAM criteria because of this, the simulations are run in every season at 12:30 pm.

4.1. Material Alternative I

Results according to reference room A and B and material alternative I is explained in this section. The average reflectance value of material alternative I is 0.3762 for reference room A. Geometrical properties of the reference room A is given in Table 3.1. Also, the material selections and reflectance values are shown in Table 3.8.

In spring, 21st March is selected for analysis (Table 4.1). 97.6% of the indoor area has at least 300 lux illuminance value in clear sky condition and 54.7% of the indoor area has at least 300 lux illuminance value in overcast sky condition for London.66.6% of the indoor area has at least 300 lux illuminance value in clear sky condition and 57.1% of the indoor area has at least 300 lux illuminance value in overcast sky condition for İzmir. Clear sky condition of London and İzmir are providing BREEAM's daylight criteria with 300 lux over 60% of the indoor environment. However, in the overcast sky condition, London and İzmir are not provide BREEAM's daylight criteria.

According to simulation results in summer, 21st June is selected for analysis (Table 4.1). 63% of the indoor area in clear sky condition and 69% of the indoor area in overcast sky condition for London have at least 300 lux illuminance value. Two of the sky conditions are providing BREEAM's daylight criteria. In addition, 48.8% of the indoor area in clear sky condition and 70.2% of the indoor area in overcast sky condition for İzmir have at least 300 lux illuminance value. However, only overcast sky condition is provided BREEAM's daylight criteria.

In autumn 21st September is selected for analysis. 98.8% of the indoor area in clear sky condition and 55.9% of the indoor area in overcast sky condition have at least 300 lux illuminance value for London (Table 4.2). 69% of the indoor area in clear sky condition and 61.9% of the indoor area in overcast sky condition have at least 300 lux illuminance value for İzmir (Table 4.2). All the simulations in autumn are providing BREEAM's daylight criteria except overcast sky condition in London. The material alternative I's average reflectance value is 0.3762. However, for this size room, BREEAM specifies 0.5 reflectance value in order to provide daylight criteria. Because of this, it is a normal result for London in the overcast sky condition.

In Table 4.2, 21st December is selected for the winter season. In London,100% of the indoor area clear sky condition and 26.1% of the indoor area in overcast sky condition have at least 300 lux illuminance value. In İzmir, 100% of the indoor area in clear sky condition and 42.8% of the indoor area in overcast sky condition have at least 300 lux illuminance value. Both of the locations, only clear sky condition is providing BREEAM's daylight criteria.

Regarding reference room B, all the geometrical properties are same with reference room A except window width. The window head height is stable but the window width decreasing from 3 meters to 1.5 meters (Table 3.1). BREEAM does not have any criteria about window width. However, the window width affects the amount of daylight that comes into the interior. The aim of this to see the effect of window width to illuminance value of the interior.

Findings according to reference room B and material alternative I is clarified. 0.3901 is the average reflectance value of material alternative I for reference room B, it is explained in Table 3.8. The simulations are run in every season at 12:30 pm same as reference room A.

According to simulation findings in spring, 58.3% of the indoor in clear sky condition and 32.1% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. In addition, 40.4% of the indoor area in clear sky condition and 35.7% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. None of the simulation results in spring are above 60%. These results are expected because the geometrical properties and the reflectance value of the room are shown in Table 3.7. According to Table 3.7, the room has to have 0.5

Table 4.1. Reference room A, material alternative I, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st March and 21st June at 12:00 pm.

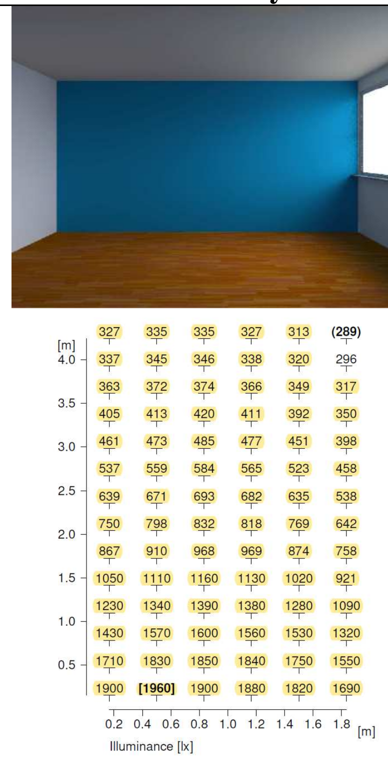
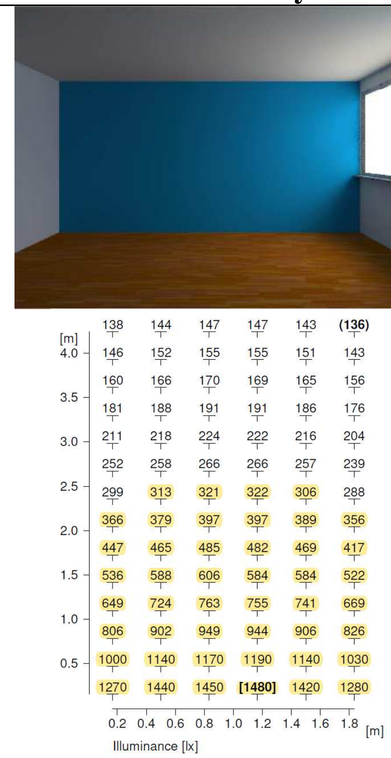
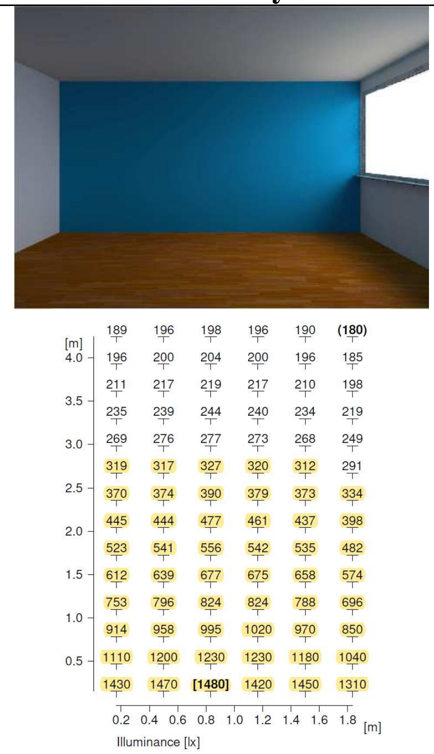
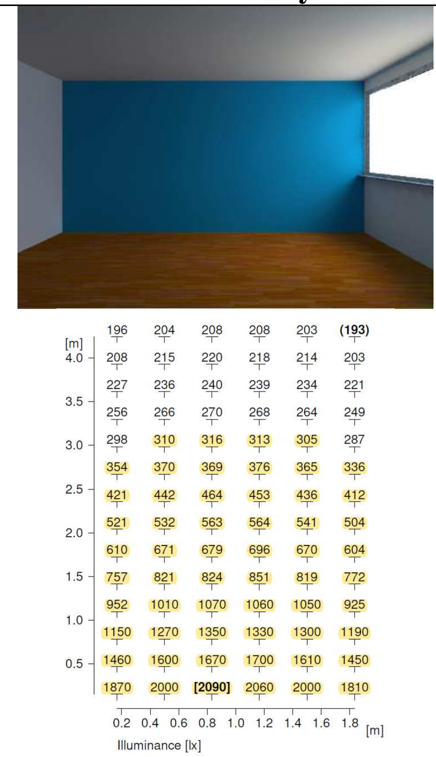
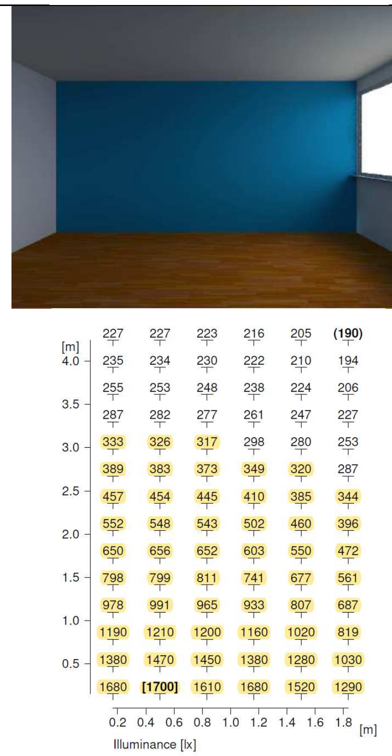
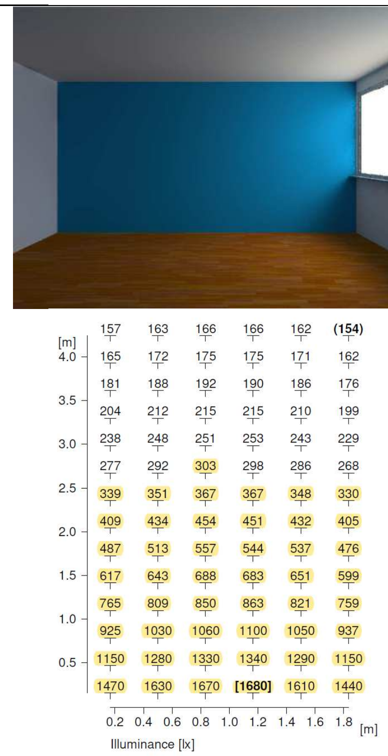
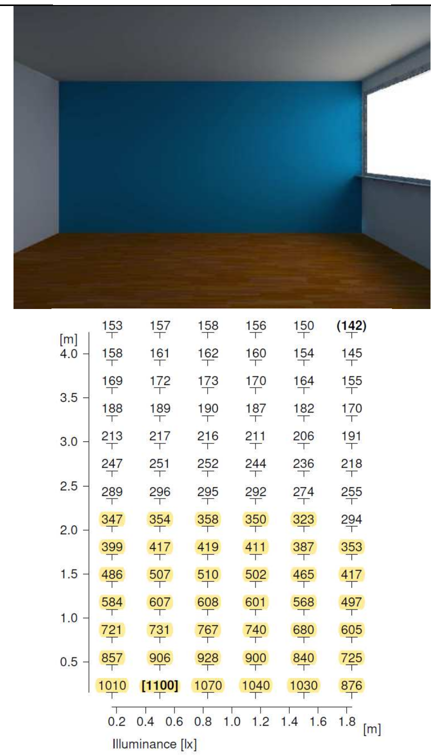
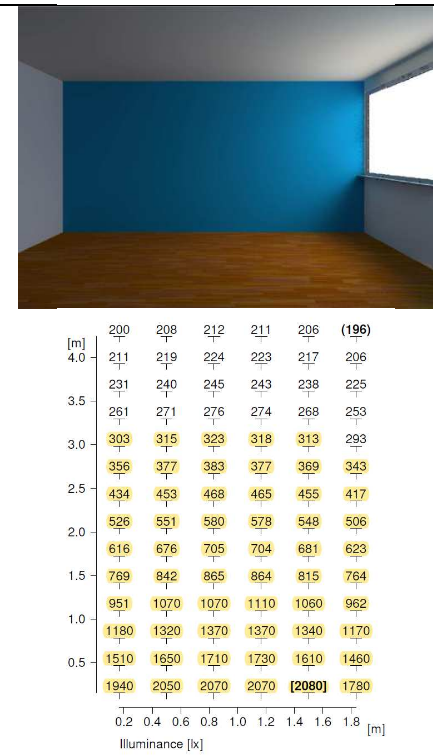
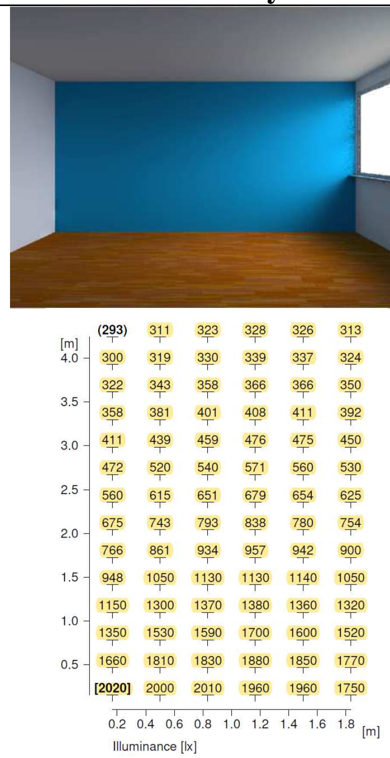
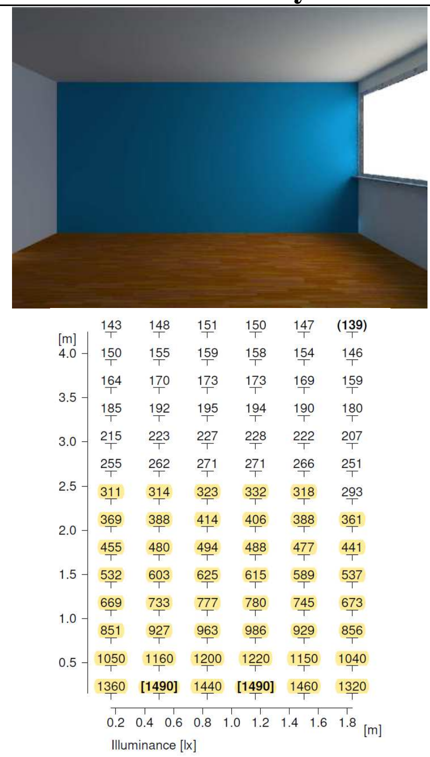
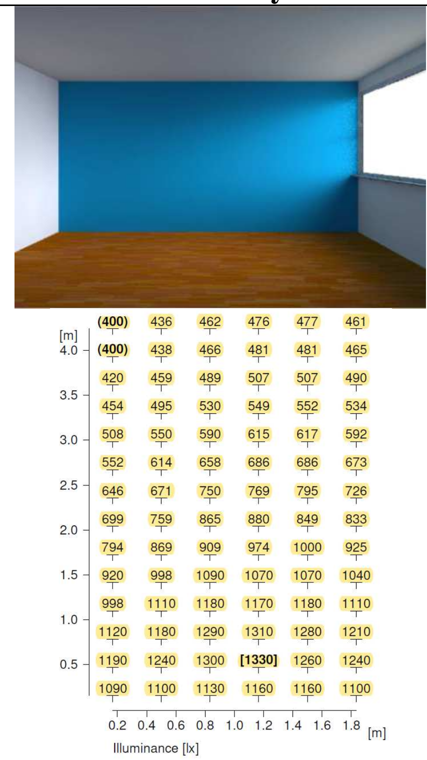
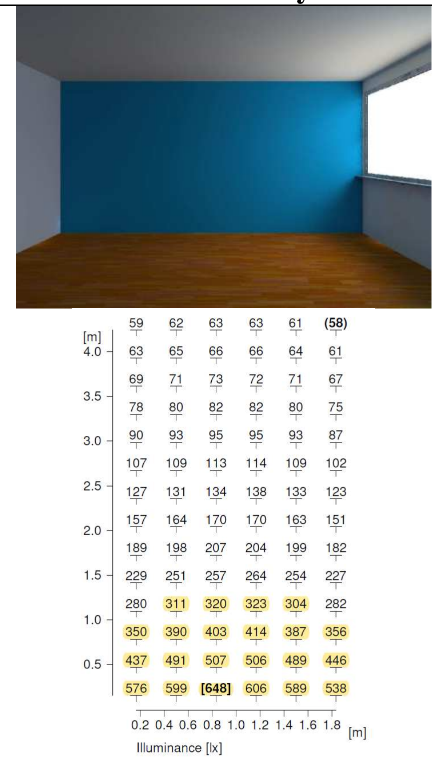
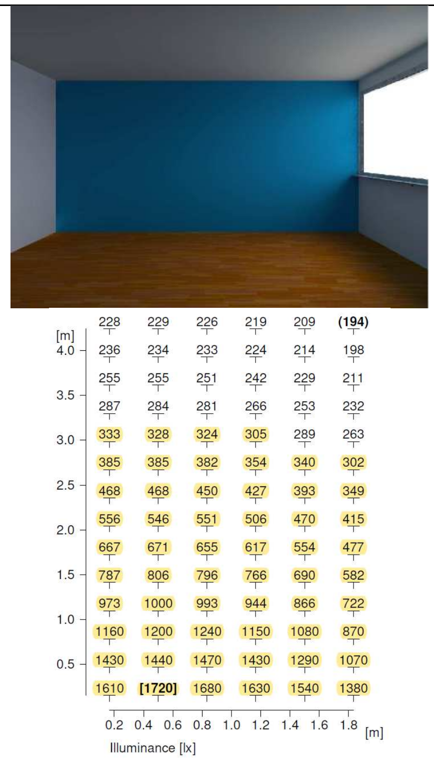
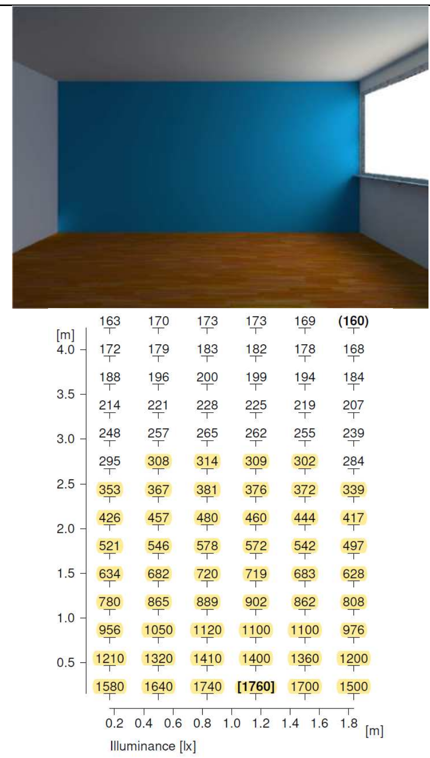
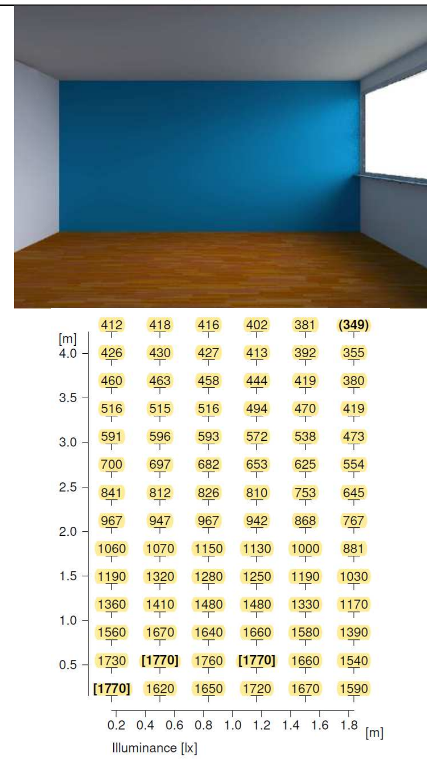
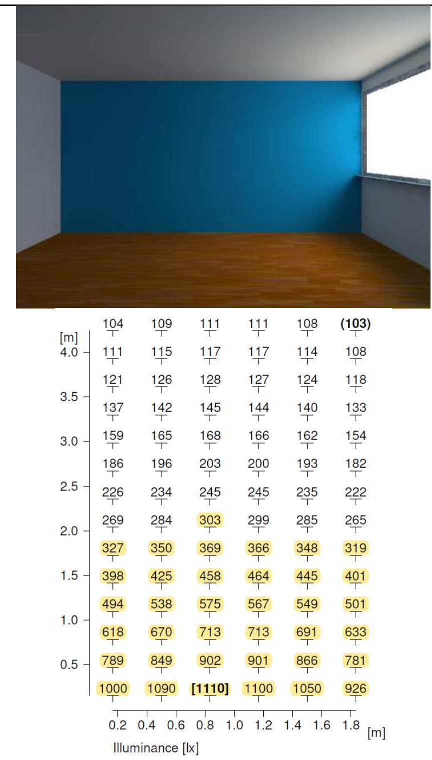
Room A- Material Alternative I at 12:00 pm	21st March		21st June	
	Clear Sky	Overcast Sky	Clear Sky	Overcast Sky
London				
İzmir				

Table 4.2. Reference room A, material alternative I, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st September and 21st December at 12:00 pm.

Room A- Material Alternative I at 12:00 pm	21stSeptember		21stDecember	
	Clear Sky	Overcast Sky	Clear Sky	Overcast Sky
London				
İzmir				

reflectance value however, in this situation reference room B has 0.3901 reflectance value. This is the main reason that is not providing BREEAM's daylight criteria.

In Table 4.3, the simulation results of reference room B are shown for the summer season.38% of the indoor area in clear sky condition and 45.2% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.25% of the indoor area in clear sky condition and 46,4% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. These conditions do not provide BREEAM's daylight criteria. Geographical location differences between London and İzmir do not affect the results, both of them have resulted under 60% value.

In autumn, 55.9% of the indoor area in clear sky condition and 33.3% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.41.6% of the indoor area in clear sky condition and 39.2% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir.

Regarding findings in winter, 67.8% of the indoor area in clear sky condition and 7.1% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. In addition, 64.2% of the indoor area in clear sky condition and 25% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. In winter, the clear sky condition is providing BREEAM's daylight criteria for different locations which are London and İzmir.

Table 4.3.Reference room A and B, the material alternative I, yearly daylight illuminance comparison under clear and overcast sky conditions for London and İzmir.

Alternative I		21st March		21st June		21st September		21st December	
At least 300 Lux		CLR	OVC	CLR	OVC	CLR	OVC	CLR	OVC
Room A	London	97.6%	54.7%	63.0%	69.0%	98.8%	55.9%	100.0%	26.1%
	İzmir	66.6%	57.1%	48.8%	70.2%	69.0%	61.9%	100.0%	42.8%
Room B	London	58.3%	32.1%	38.0%	45.2%	55.9%	33.3%	67.8%	7.1%
	İzmir	40.4%	35.7%	25.0%	46.4%	41.6%	39.2%	64.2%	25.0%

The general view of simulation results for reference room A and B in the material alternative I condition are shown in Table 4.3. Geometrical properties of the reference rooms are matching with 0.5 reflectance value according to BREEAM's criteria (Table 3.7). However, the rooms have the average reflectance values which are under 0.5 reflectance value. In the view of this criteria, the reference rooms should not provide BREEAM's daylight criteria. In the view of simulations, according to reference room A, clear sky condition is provided at least 300 lux illuminance in 60% of the interior in London. This is the expected result because BREEAM is an assessment tool which was launched in the UK, it is about geographical location similarities. Despite the fact that London has 1460 hours and İzmir has 3008 hours average sunlight per year (Table 3.4), İzmir does not have at least 300 lux illuminance in 60% of the interior in the summer season. According to reference room B, only the winter season provides at least 300 lux illuminance in 60% of the interior in both cities. The reason for this can be the altitude angles of these two locations that are shown in Table 3.3andTable 3.6. They are the lowest angles and the most horizontal angles that sunlight reaches into the interior. In the view of these findings, reference room A provides BREEAM's daylight criteria in summer season in London and in autumn season in İzmir in both sky conditions.

4.2. Material Alternative II

Material alternative II is explained in this section according to reference room A and B simulation results. Reference room A has 0.4738 the average reflectance value, it is shown in Table 3.9which is under 0.5 similar to a material alternative I.

According to simulation findings in spring, the illuminance values of results are shown in Table 4.4for London and İzmir. 92.8% of the indoor area clear sky condition and 57.1% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. 72.6% of the indoor area in clear sky condition and 60.7% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. Only overcast sky condition in London does not provide the BREEAM's daylight criteria.

In the summer season, 64.2% of the indoor area in clear sky condition and 71.4% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. In both sky conditions, London provides BREEAM's daylight criteria. In İzmir, 54.7% of the indoor area in clear sky condition and 71.4% of the indoor area in overcast sky condition have at least 300 lux illuminance value. The clear sky condition is not provided proper indoor illuminance value in İzmir, in the summer season.

In Table 4.5, the simulation results of reference room A are shown for the autumn season. 92.8% of the indoor area in clear sky condition and 57.1% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. Only the clear sky condition provide at least 300 lux illuminance value for London. However, İzmir provides condition in both sky situations. 72.6% of the indoor area in clear sky condition and 64.2% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir.

In winter, 100% of the indoor area in clear sky condition and 28.5% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. In addition, 100% of the indoor area in clear sky condition and 47.6% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. The clear sky condition provides BREEAM's daylight criteria in both locations.

According to reference room B and material alternative II, the average reflectance value is shown in Table 3.9 as 0.4847 reflectance value.

In the spring season, London has 59.5% of the indoor area in clear sky condition and 33.3% of the indoor area in overcast sky condition have at least 300 lux illuminance value. In both sky conditions, London does not provide enough illuminance for BREEAM's daylight criteria. Moreover, İzmir has 42.8% of the indoor area in clear sky condition and 38% of the indoor area have at least 300 lux illuminance value. These simulation findings are normal because according to Table 3.7 the reflectance value of the room should be 0.5 in order to have enough illuminance for BREEAM.

According to simulation results in summer, 40.4% of the indoor area in clear sky condition and 45.2% of the indoor in overcast sky condition area have at least 300 lux illuminance value in London. Also, 27.3% of the indoor area value in clear sky condition and 46.4% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. The results are similar to the spring season, none of the simulation findings provide BREEAM's daylight criteria.

In Table 4.5, the simulation results of reference room B are shown for the autumn season.63% of the indoor area in clear sky condition and 33.3% of the indoor

Table 4.4. Reference room A, material alternative II, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st March and 21st June at 12:00 pm.

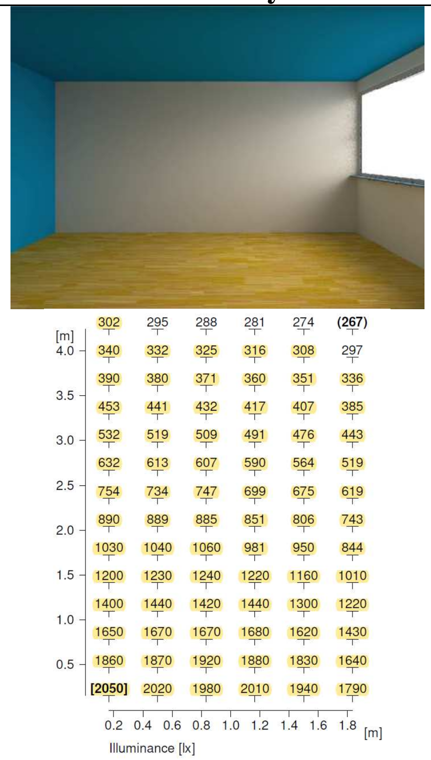
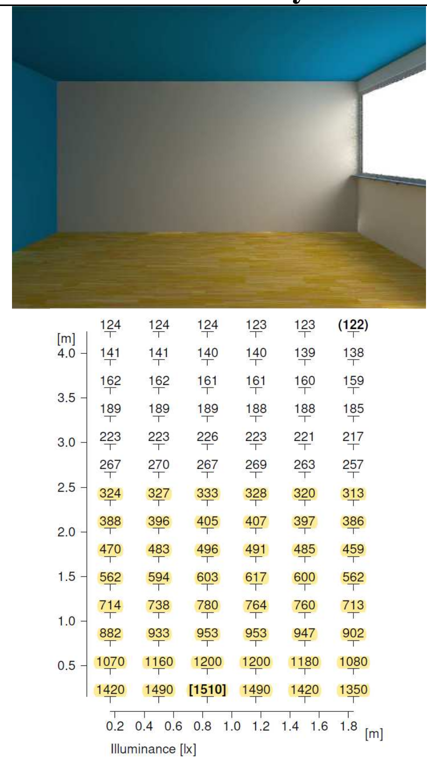
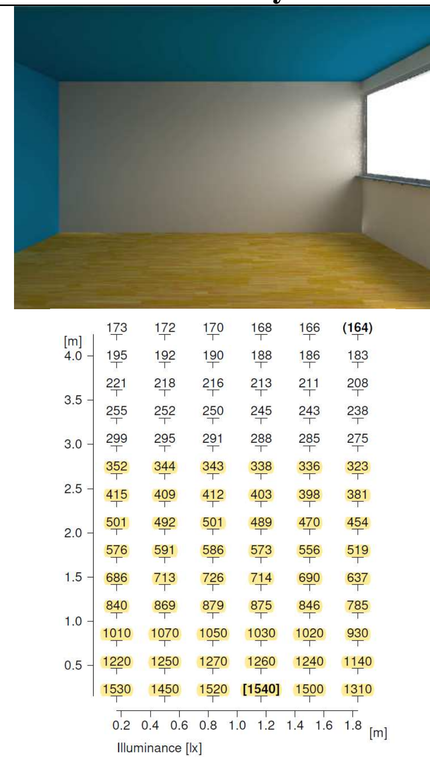
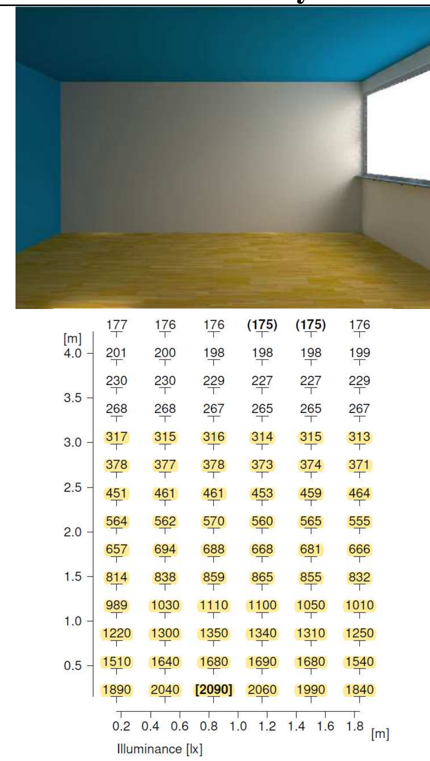
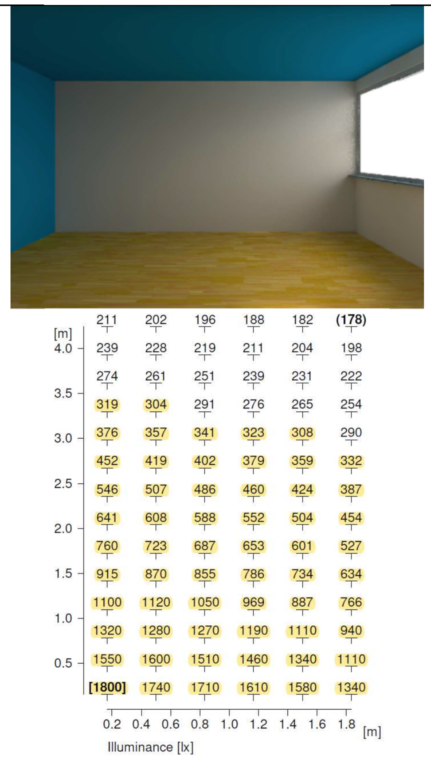
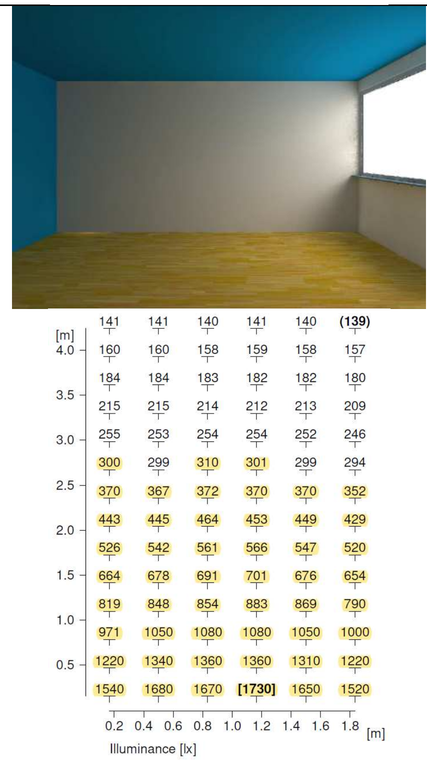
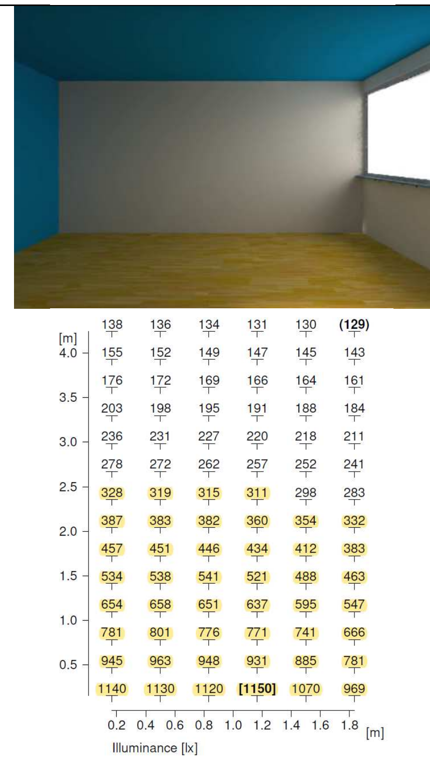
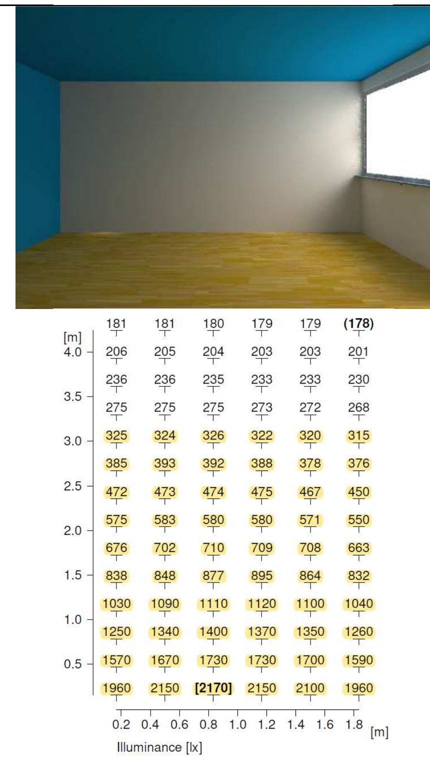
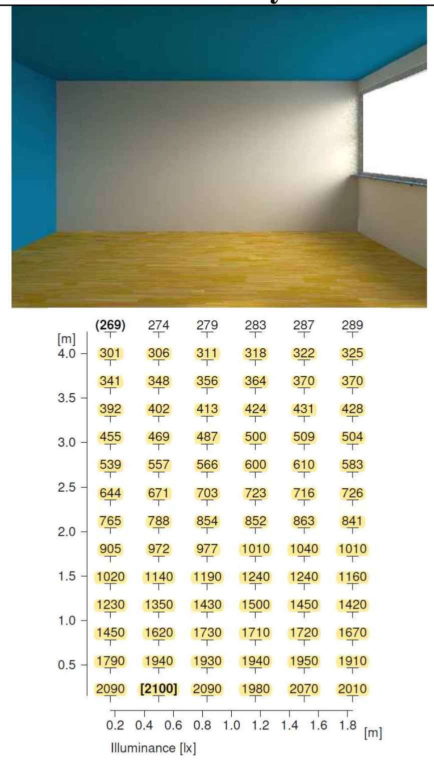
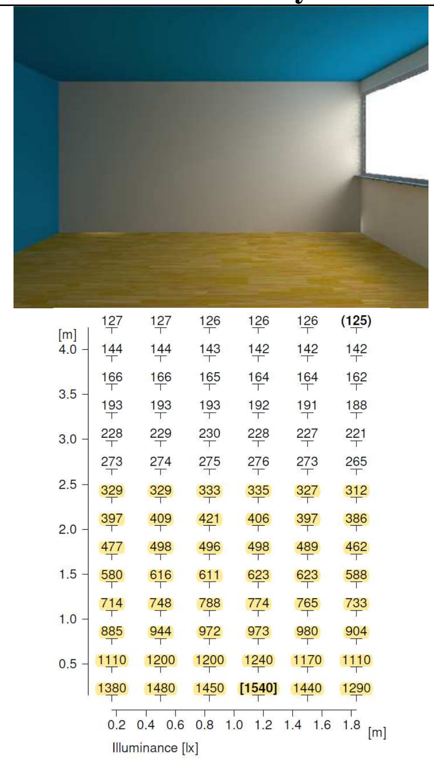
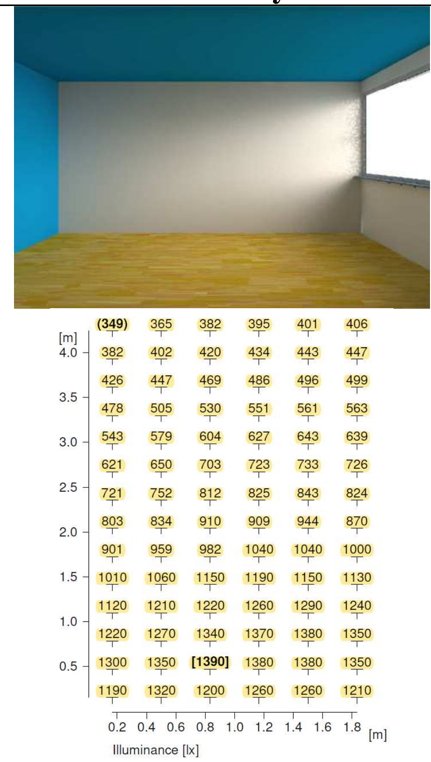
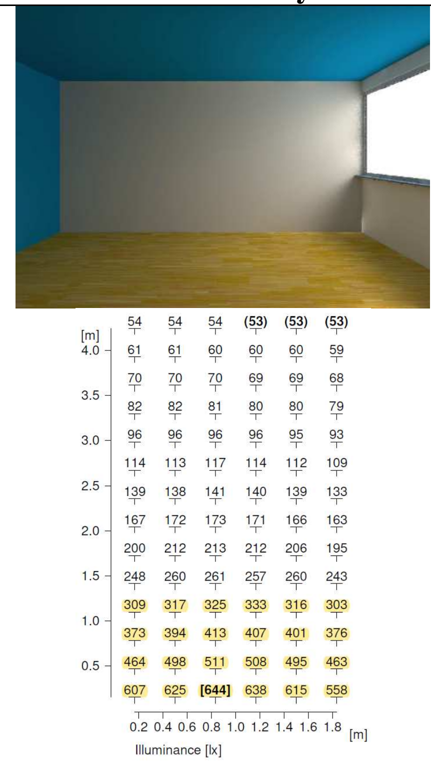
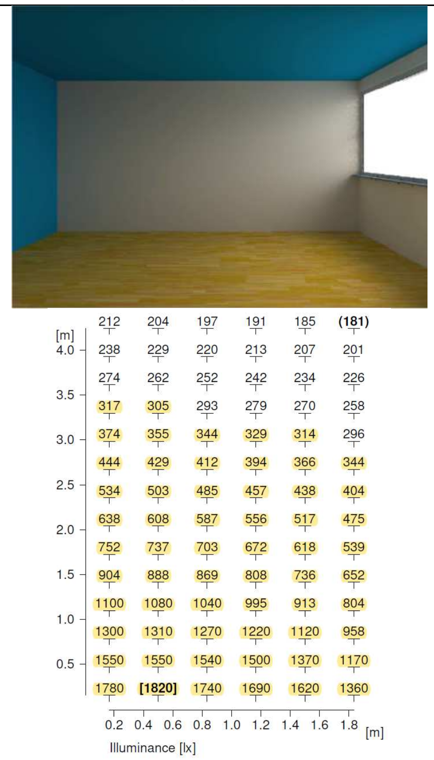
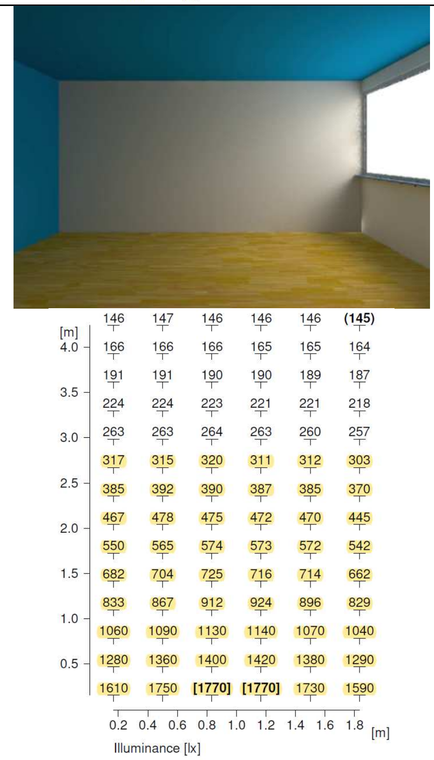
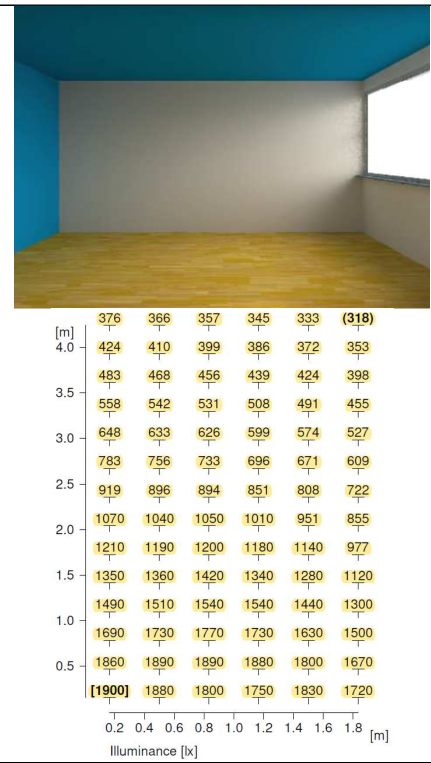
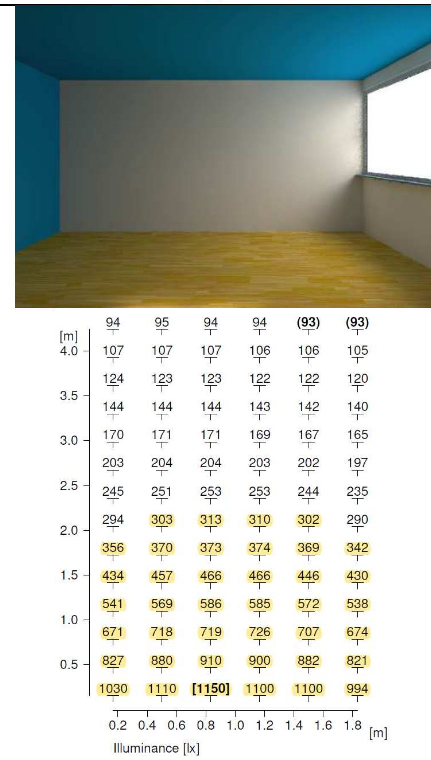
Room A- Material Alternative II at 12:00 pm	21st March		21st June	
	Clear Sky	Overcast Sky	Clear Sky	Overcast Sky
London				
İzmir				

Table 4.5. Reference room A, material alternative II, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st September and 21st December at 12:00 pm.

Room A - Material Alternative II at 12:00 pm	21st September		21st December	
	Clear Sky	Overcast Sky	Clear Sky	Overcast Sky
London				
İzmir				

area have at least 300 lux illuminance value in London. 42.8% of the indoor area in clear sky condition and 40.4% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. In these different locations and sky conditions, only London provide BREEAM's daylight criteria in clear sky condition.

Regarding findings in the winter season, 72.6% of the indoor area in clear sky condition and 7.1% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. 70.2% of the indoor area in clear sky condition and 26.1% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. In both of the locations provide BREEAM's minimum illuminance value in clear sky conditions.

Table 4.6.Reference room A and B, material alternative II, yearly daylight illuminance comparison under clear and overcast sky conditions for London and İzmir.

Alternative II		21st March		21st June		21st September		21st December	
At least 300 Lux		CLR	OVC	CLR	OVC	CLR	OVC	CLR	OVC
Room A	London	92.8%	57.1%	64.2%	71.4%	92.8%	57.1%	100.0%	28.5%
	İzmir	72.6%	60.7%	54.7%	71.4%	72.6%	64.2%	100.0%	47,6%
Room B	London	59.5%	33.3%	40.4%	45.2%	63.0%	33.3%	72.6%	7.1%
	İzmir	42.8%	38.0%	27.3%	46.4%	42.8%	40.4%	70.2%	26.1%

The general view of simulation findings for both reference rooms and locations are shown in Table 4.6. According to the dimensions of the reference rooms, the reflectance value should be 0.5 that is shown in Table 3.7. However, the average reflectance values of reference rooms are under 0.5 (Table 3.9). Because of this situation, it is acceptable, if the simulations do not provide 60% of the room at least 300 lux illuminance. However, according to reference room A results, all of the seasons provide BREEAM's daylight criteria in clear sky conditions except summer season in İzmir. But there is a contrast between this situation and İzmir's sunny weather in summer. İzmir has approximately two times more average sunlight per year than London that is shown in Table 3.4. According to reference room B, London and İzmir provide 60% illuminance criteria in clear sky condition, in winter. In winter, sunrays come from the sky more horizontally in reference to altitude angles that are shown in

Table 3.3andTable 3.6. In clear sky condition, more sunray reaches the interior. Also, London has enough illuminance percentage in autumn, in clear sky condition.

4.3. Material Alternative III

Results according to reference room A and B and material alternative III is explained in this section. The average reflectance value of material alternative III is 0.6005 for reference room A. It is explained in Table 3.10. According to the dimensions of the room, it should have 0.5 reflectance (Table 3.7). However, it has an average reflectance value above 0.5 (Table 3.10).

According to simulation findings in spring, The illuminance values of results are shown in Table 4.7for London and İzmir.100% of the indoor area in clear sky condition and 84.5% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.100% of the indoor area in clear sky condition and 100% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. All the locations and sky conditions provide BREEAM's daylight criteria. It is an expected situation because the average reflection value is above 0.5.

In Table 4.7, in the summer season, 100% of the indoor area in clear sky condition and 100% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. 78.5% of the indoor area in clear sky condition and 100% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. In the autumn season,100% of the indoor area in clear sky condition and 85.7% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. 100% of the indoor area in clear sky condition and 100% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. In both seasons provide BREEAM's daylight conditions in each location and sky conditions.

Regarding findings in winter (Table 4.8), 100% of the indoor area in clear sky condition and 35.7% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. 100% of the indoor area in clear sky condition and 63% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. BREEAM was launched in the UK but in this situation, overcast sky condition in London does not provide daylight criteria.

Table 4.7. Reference room A, material alternative III, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st March and 21st June at 12:00 pm.

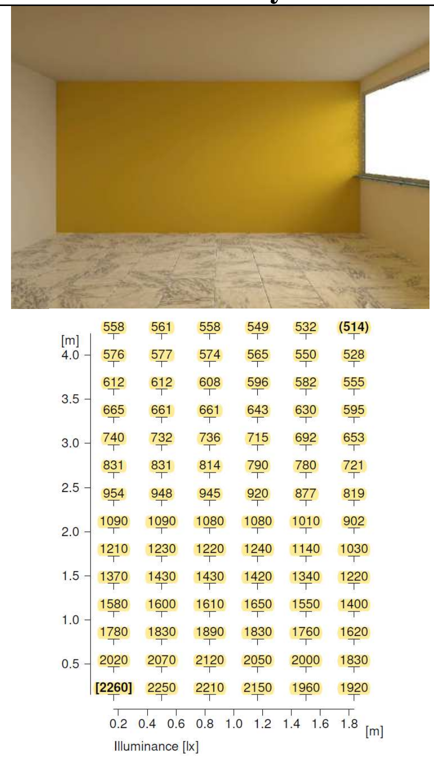
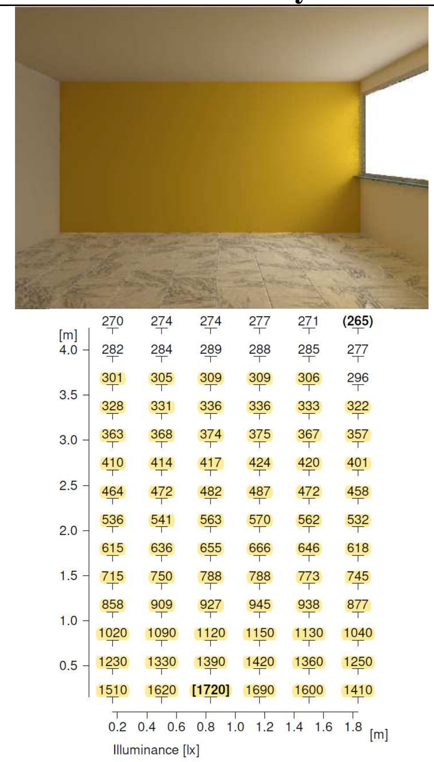
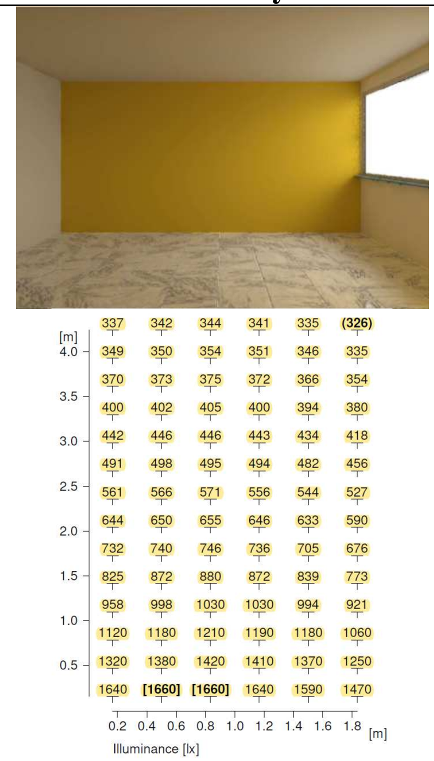
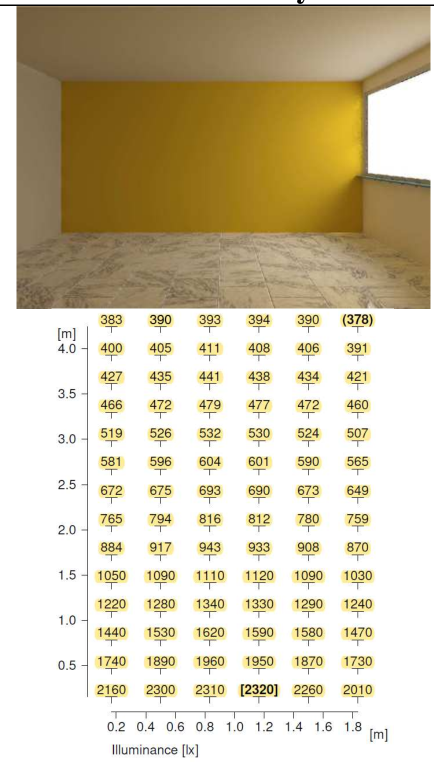
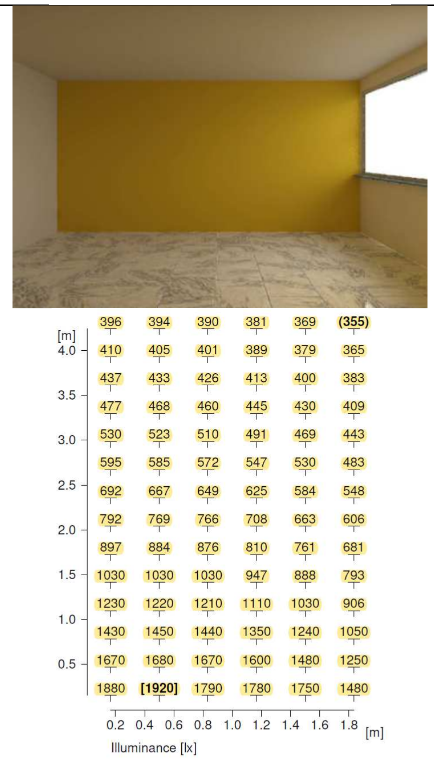
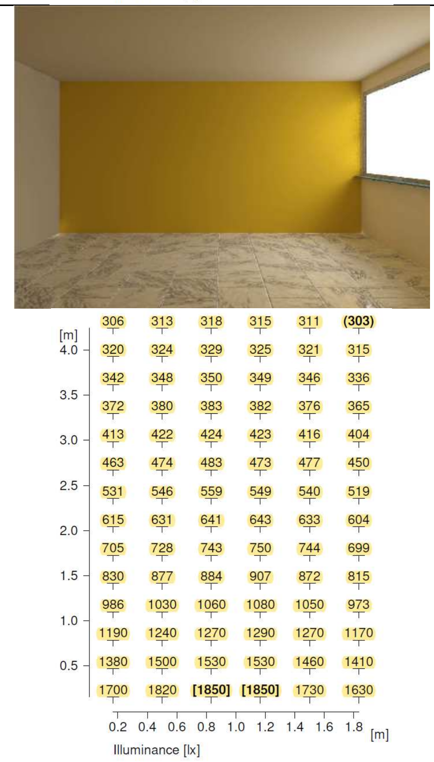
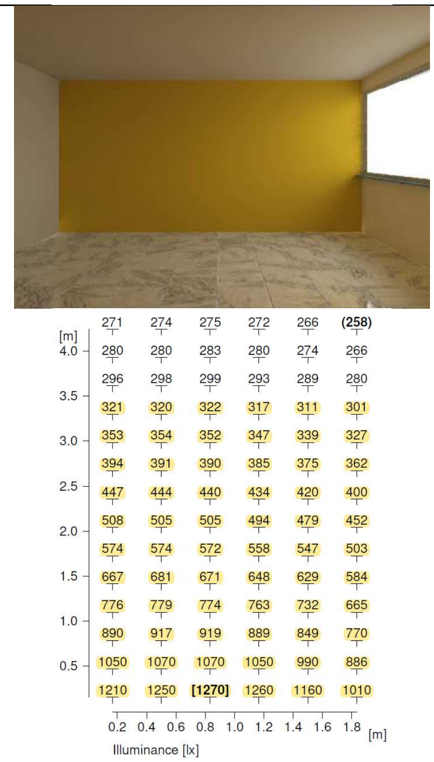
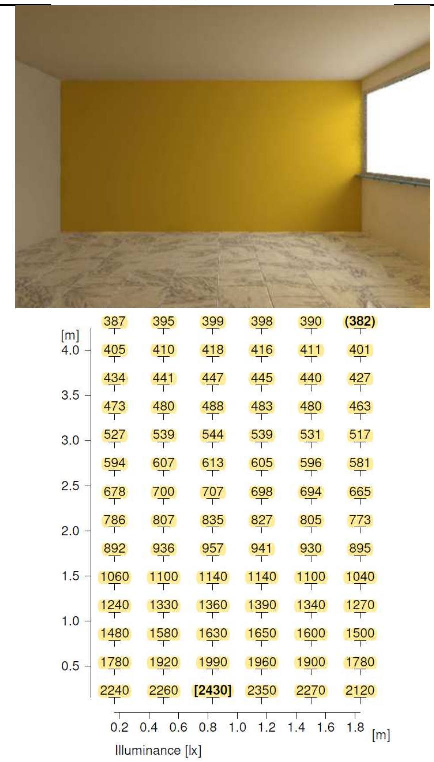
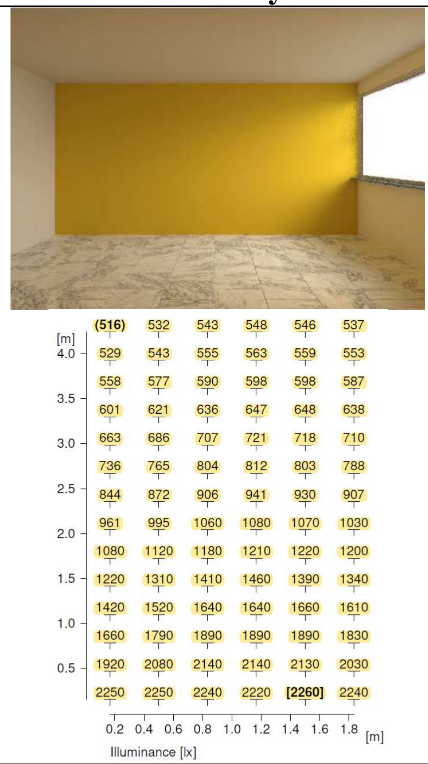
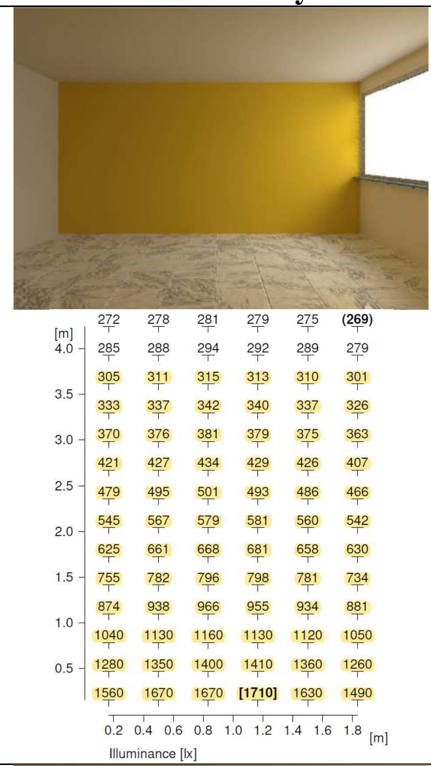
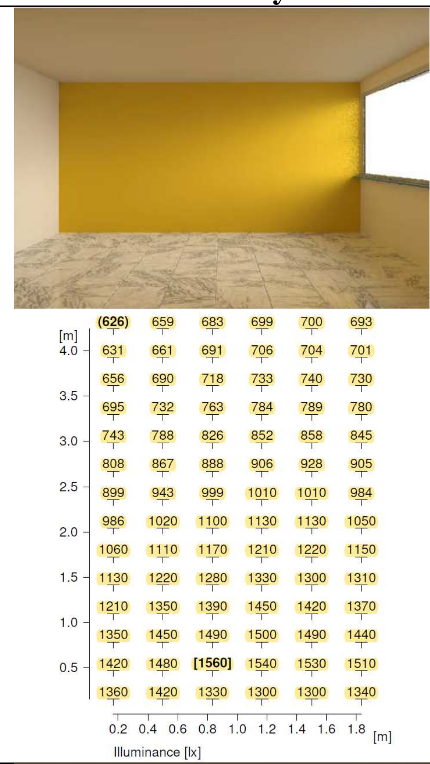
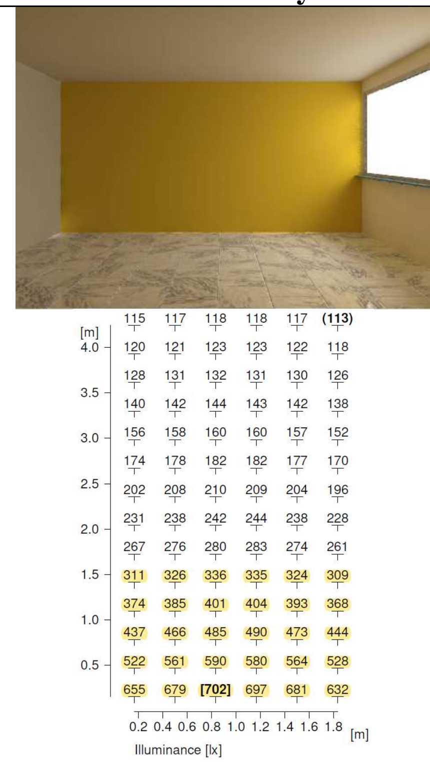
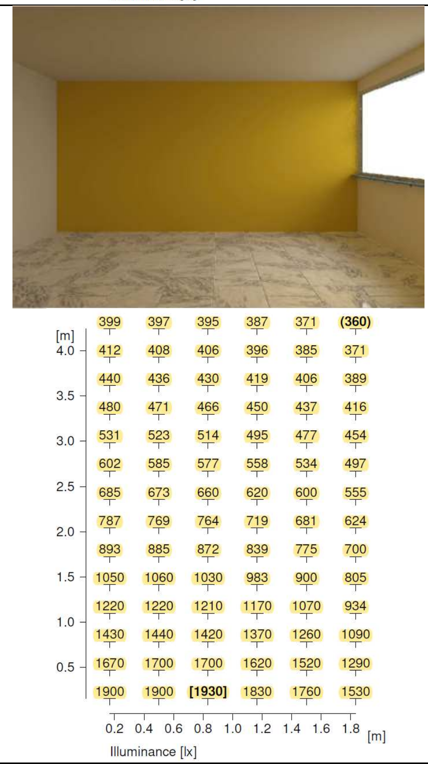
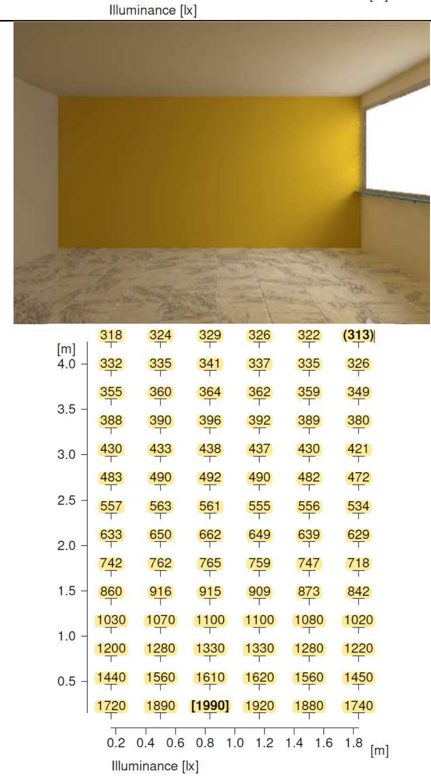
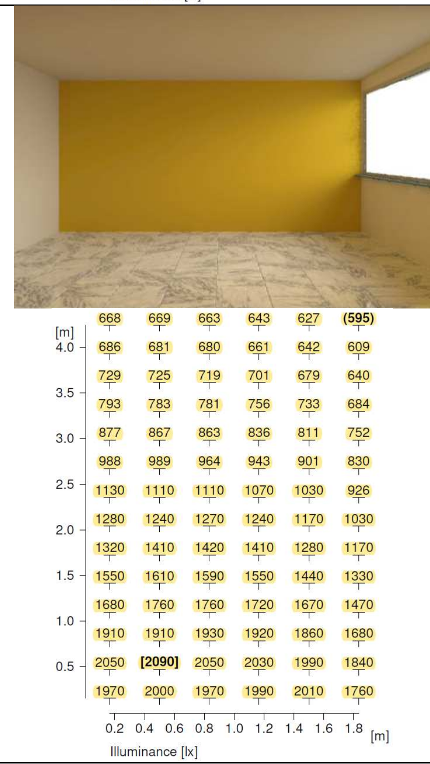
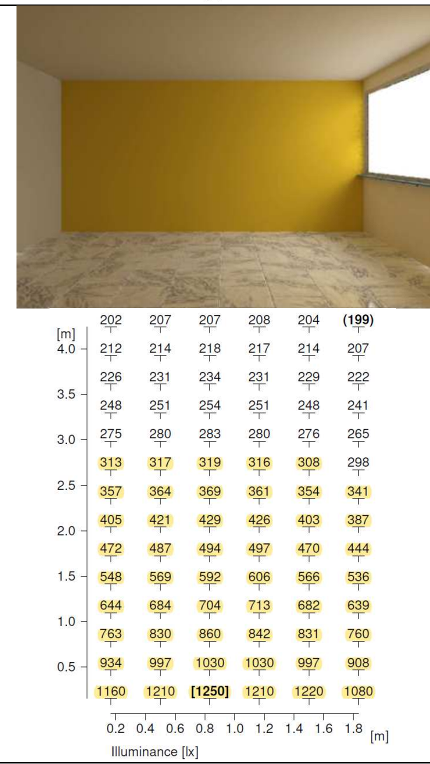
Room A - Material Alternative III at 12:00 pm	21st March		21st June	
	Clear Sky	Overcast Sky	Clear Sky	Overcast Sky
London				
İzmir				

Table 4.8. Reference room A, material alternative III, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st September and 21st December at 12:00 pm.

<table>
<tr><th rowspan="2">Room A - Material Alternative III at 12:00 pm</th><th colspan="2">21st September</th><th colspan="2">21st December</th></tr>
<tr><th>Clear Sky</th><th>Overcast Sky</th><th>Clear Sky</th><th>Overcast Sky</th></tr>
<tr><td>London</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
<tr><td>İzmir</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
</table>

According to reference room B and material alternative III, the average reflectance value is shown in Table 3.10as 0.6355 reflectance value. It is above 0.5 reflectance value that specified in Table 3.7.

In the spring season, 83.3% of the indoor area in clear sky condition and 46.4% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. The clear sky condition supply BREEAM's daylight criteria. 57.1% of the indoor area in clear sky condition and 50% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir.

According to simulation findings in summer, 52.3% of the indoor area in clear sky condition and 63% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.38% of the indoor area in clear sky condition and 64.2% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir.

Regarding findings in autumn,84.5% of the indoor area in clear sky condition and 46.4% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.58.3% of the indoor area in clear sky condition and 50% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. According to the results, only London provide enough percentage of illuminance in clear sky conditions.

In winter season, 100% of the indoor area in clear sky condition and 10.7% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.100% of the indoor area in clear sky condition and 33.3% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. Clear sky condition is providing enough percentage of illuminance for London and İzmir.

The general view of material alternative III simulation findings is shown in Table 4.9. For the reference room dimension, 0.5 reflectance is given by BREEAM (Table 3.7). However, the average reflectance values of the reference room A and B are above 0.5 which are approximately 0.6reflectance. This situation is explaining most of the 100% percentage illuminance. Because in Table 3.7, 0.6 reflectance needs 6.8 meter room depth but the reference rooms have 5.4 meter depth. According to reference room B, London has at least 300 lux illuminance in 60% of the room in one of the sky conditions. However, İzmir provides this situation in summer and winter.

Table 4.9. Reference room A and B, material alternative III, yearly daylight illuminance comparison under clear and overcast sky conditions for London and İzmir.

Alternative III		21st March		21st June		21st September		21st December	
At least 300 Lux		CLR	OVC	CLR	OVC	CLR	OVC	CLR	OVC
Room A	London	100.0%	84.5%	100.0%	100.0%	100.0%	85.7%	100.0%	35.7%
	İzmir	100.0%	100.0%	78.5%	100.0%	100.0%	100.0%	100.0%	63.0%
Room B	London	83.3%	46.4%	52.3%	63.0%	84.5%	46.4%	100.0%	10.7%
	İzmir	57.1%	50.0%	38.0%	64.2%	58.3%	50.0%	100.0%	33.3%

4.4. Material Alternative IV

Material alternative IV is explained in this section according to simulation findings of reference room A and B. Material alternative IV has 0.7581 reflectance for reference room A which is shown in

Table 3.11. It is above 0.5 which is specified by BREEAM criteria in Table 3.7.

Results according to spring, summer and autumn seasons, 100% of the indoor area in clear sky condition and 100% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.100% of the indoor area in clear sky condition and 100% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir.

In winter, 100% of the indoor area in clear sky condition and 54.7% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.100% of the indoor area in clear sky condition and 100% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. BREEAM is a UK based environmental assessment tool but, in these conditions, İzmir provides criteria better than London.

Table 4.10. Reference room A, material alternative IV, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st March and 21st June at 12:00 pm.

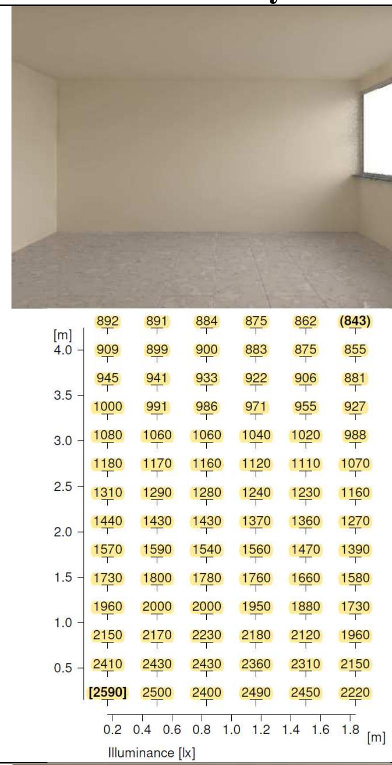
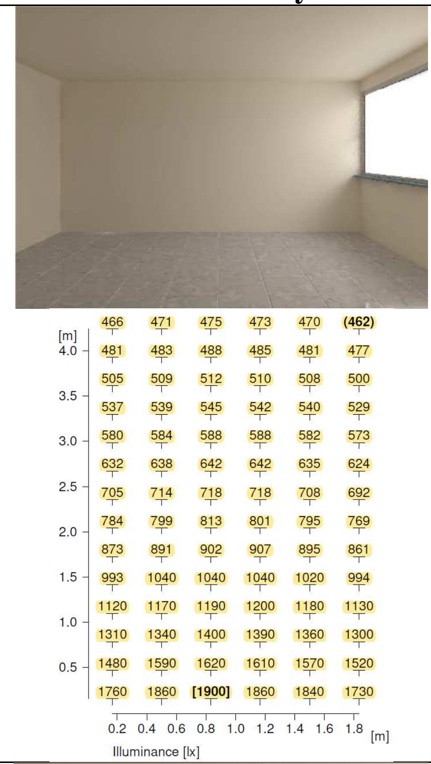
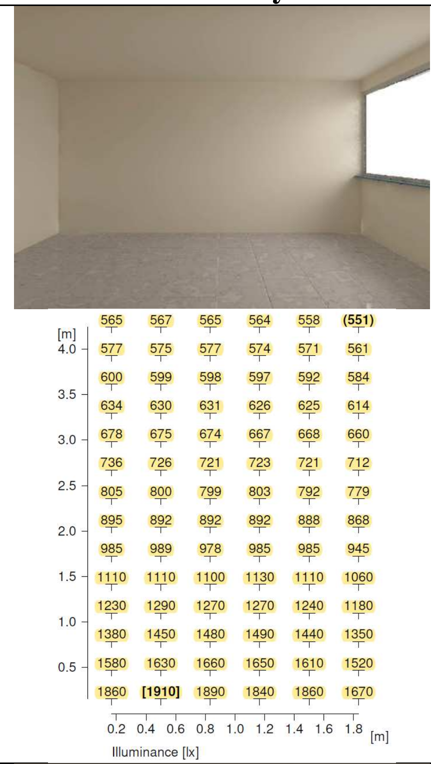
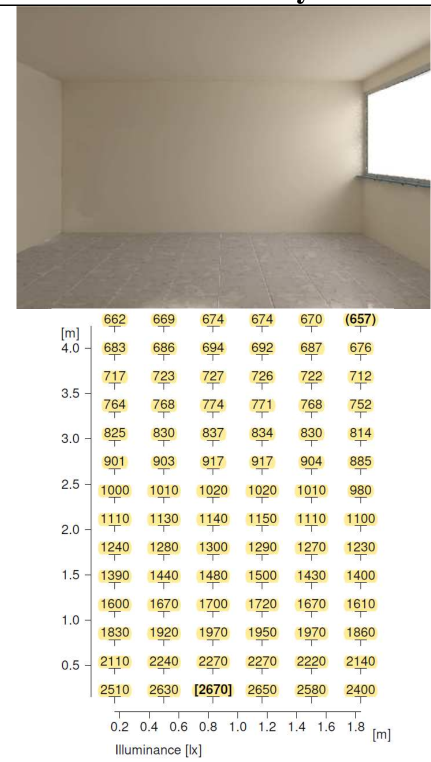
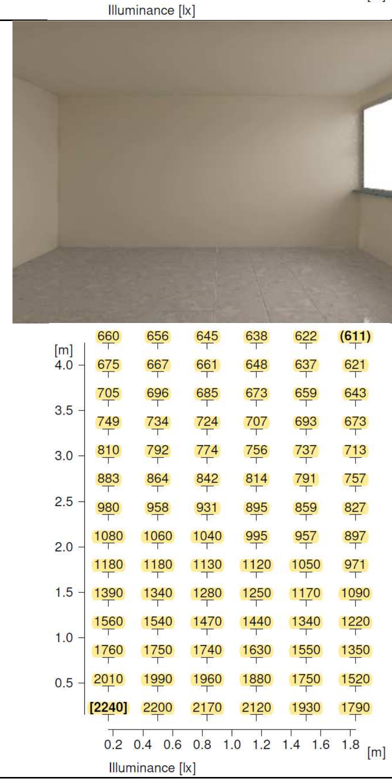
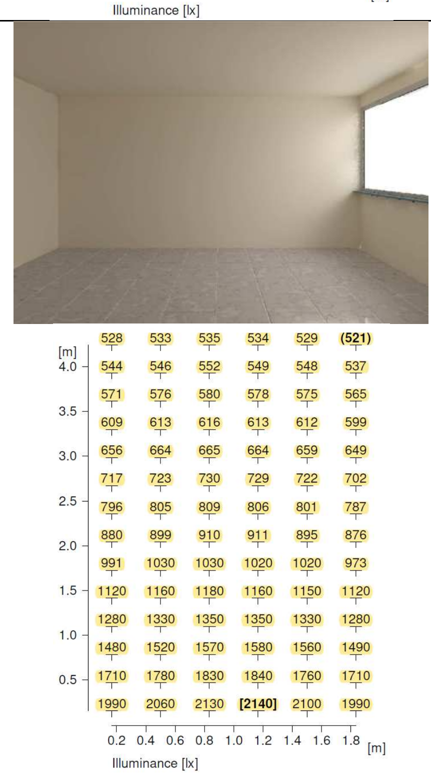
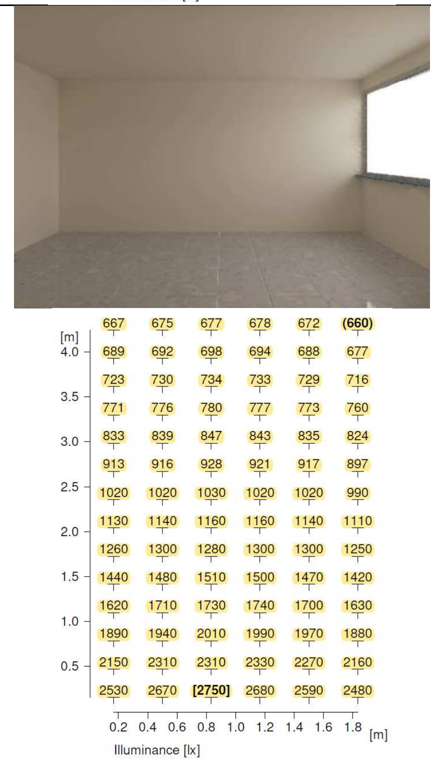
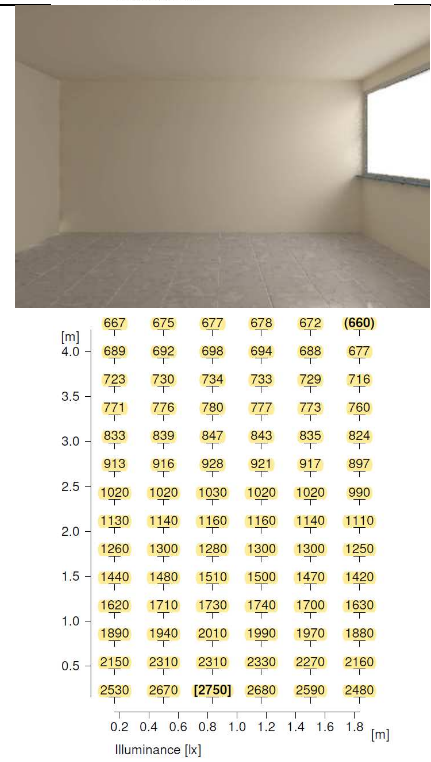
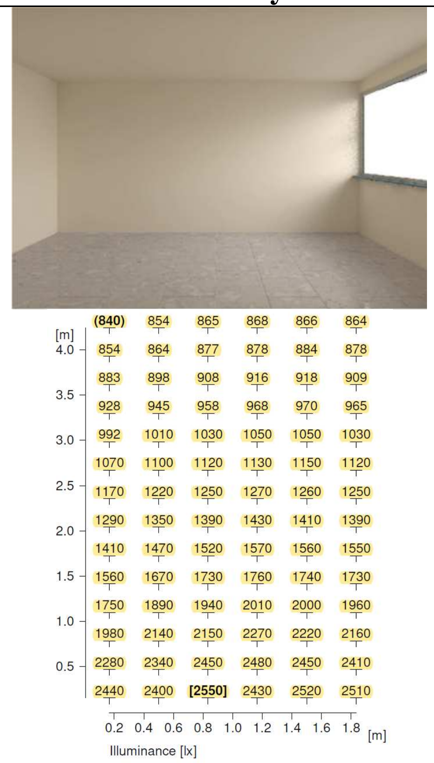
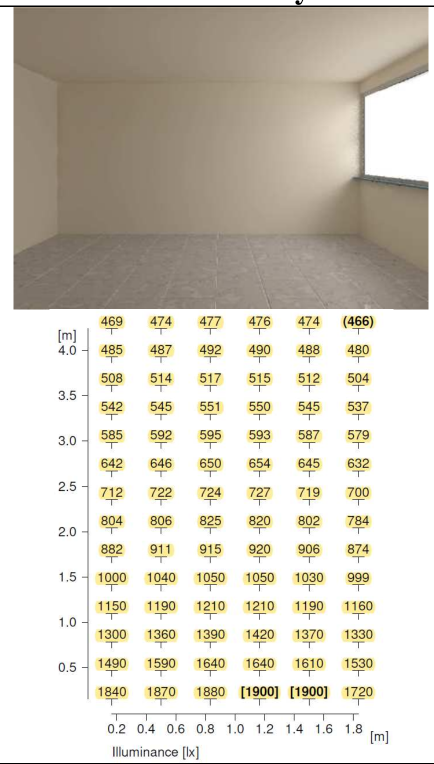
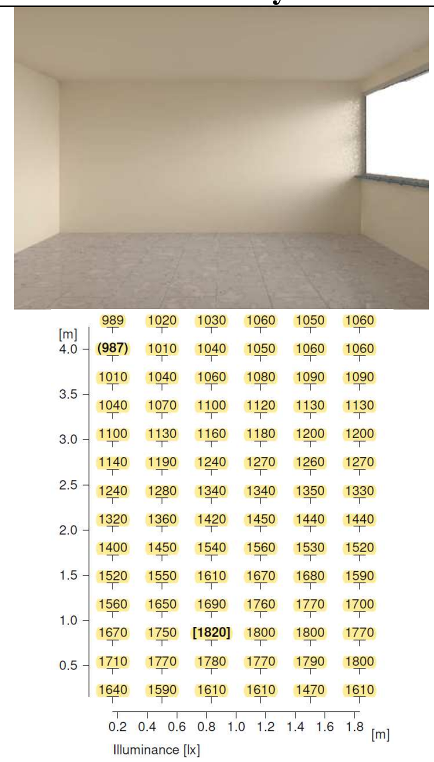
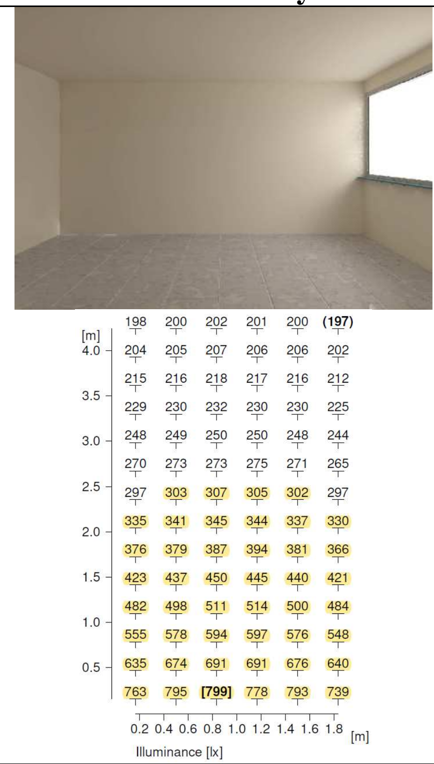
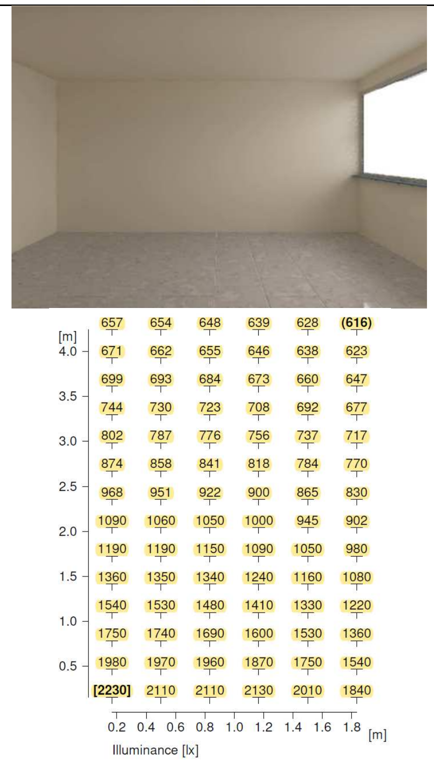
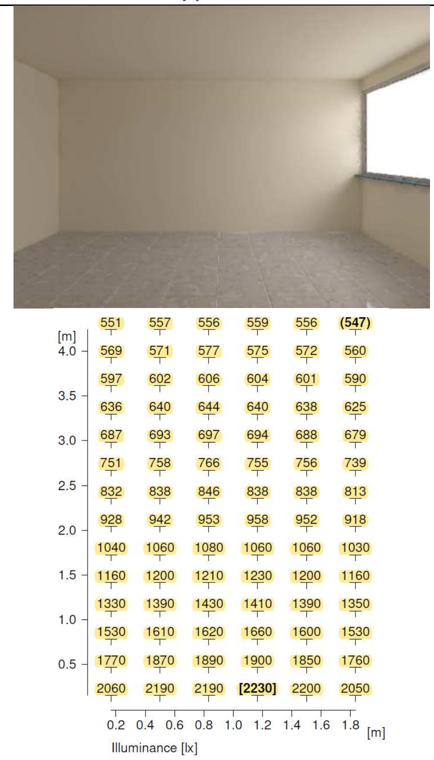
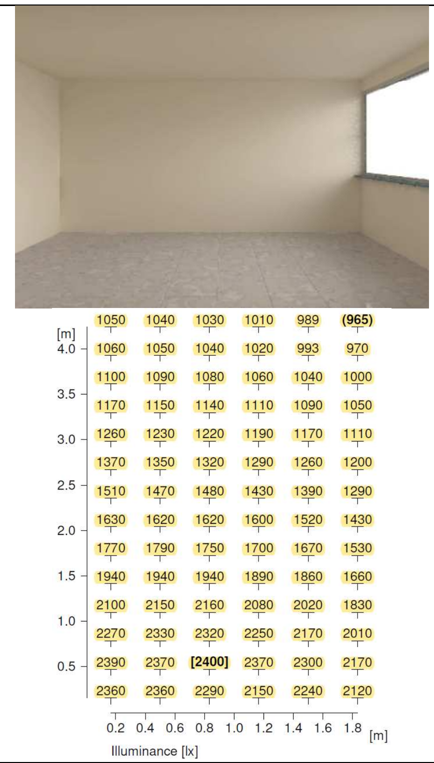
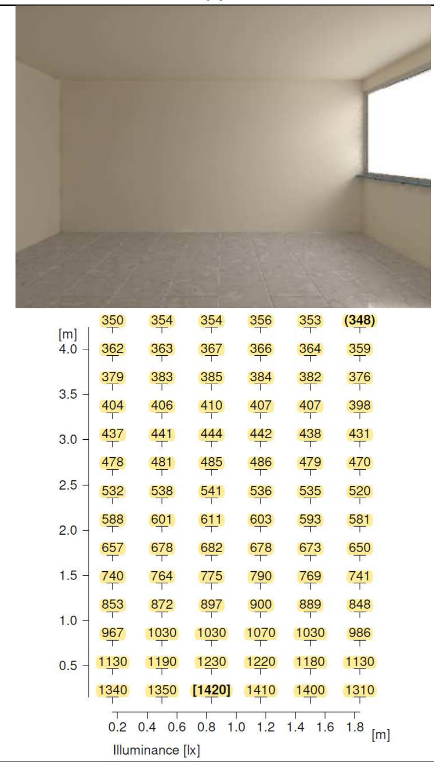
<table>
<tr><th rowspan="2">Room A - Material Alternative IV at 12:00 pm</th><th colspan="2">21st March</th><th colspan="2">21st June</th></tr>
<tr><th>Clear Sky</th><th>Overcast Sky</th><th>Clear Sky</th><th>Overcast Sky</th></tr>
<tr><td>London</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
<tr><td>İzmir</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
</table>

Table 4.11. Reference room A, material alternative IV, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st September and 21st December at 12:00 pm.

<table>
<tr><th rowspan="2">Room A - Material Alternative IV at 12:00 pm</th><th colspan="2">21st September</th><th colspan="2">21st December</th></tr>
<tr><th>Clear Sky</th><th>Overcast Sky</th><th>Clear Sky</th><th>Overcast Sky</th></tr>
<tr><td>London</td>
<td></td>
<td></td>
<td></td>
<td></td></tr>
<tr><td>İzmir</td>
<td></td>
<td></td>
<td></td>
<td></td></tr>
</table>

According to reference room B and material alternative IV, the average reflectance value is shown in

Table 3.11as 0.7606 reflectance value. It is above 0.5 reflectance value that specified in Table 3.7.

In the spring season, 100% of the indoor area in clear sky condition and 70.2% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London. 100% of the indoor area in clear sky condition and 82.1% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. All the simulation findings in spring supply BREEAM's daylight criteria.

Regarding findings in summer,84.7% of the indoor area in clear sky condition and 100% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.63% of the indoor area in clear sky condition and 100% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. According to results, London and İzmir provide enough percentage of illuminance in each sky conditions.

In autumn, 100% of the indoor area in clear sky condition and 71.4% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.100% of the indoor area in clear sky condition and 85.7% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. The autumn season has enough percentage of illuminance in order to BREEAM. However, İzmir has more percentage than London in overcast sky conditions. It can be related to cloudy daylight hours. London has more cloudy weather. In Table 3.4, London has 66.7% of the daylight hours cloudy but İzmir has 31.4% of the daylight hours cloudy.

According to winter season, 100% of the indoor area in clear sky condition and 19% of the indoor area in overcast sky condition have at least 300 lux illuminance value in London.100% of the indoor area in clear sky condition and 50% of the indoor area in overcast sky condition have at least 300 lux illuminance value in İzmir. The overcast sky conditions do not provide enough illuminance in the interior.

According to the daylight simulation results, they are compared and contrasted with their percentage of illuminance in Table 4.9. The proper reflectance value for the reference room is given as 0.5 in Table 3.7. However, reference room A and B have reflectance value 0.7581 and 0.7606. Material alternative IV has more than enough reflectance value. Because of this, the illuminance percentage of the interior is 100% in many results. All of the simulation findings in each reference room, location, season,

Table 4.12. Reference room A and B, material alternative IV, yearly daylight illuminance comparison under clear and overcast sky conditions for London and İzmir.

Alternative IV		21st March		21st June		21st September		21st December	
At least 300 Lux		CLR	OVC	CLR	OVC	CLR	OVC	CLR	OVC
Room A	London	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	54.7%
	İzmir	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Room B	London	100.0%	70.2%	85.7%	100.0%	100.0%	71.4%	100.0%	19.0%
	İzmir	100.0%	82.1%	63.0%	100.0%	100.0%	85.7%	100.0%	50.0%

and sky condition provide BREEAM's daylight criteria except winter season in overcast sky condition. In overcast sky condition, reference room A has at least 300 lux in 60%of the interior only in İzmir location. Table 3.4shows that İzmir has 31.4% cloudy daylight hours and London has 66.7% cloudy daylight hours. It can be the reason for İzmir that has more illuminance value percentage than London. Reference room B does not provide enough illuminance in overcast sky condition in each location. The only physical difference between reference room A and B is window width. In that point, window width can affect the illuminance percentage in an indoor environment.

CHAPTER 5

DISCUSSION

The aim of this thesis was to test daylighting performance in the view of room and window design parameters within the frame of BREEAM assessment criteria for London and İzmir. In addition, the author prepared RELUX models in order to evaluate daylight illuminance for reference rooms in different locations.

BREEAM is an environmental assessment tool that prepared in the United Kingdom. Firstly, the criteria of BREEAM is proper for London as its location. The RELUX simulation findings showed how daylighting criteria of BREEAM is proper or not proper for İzmir. In addition, the simulation results guided to understand the effect of material selection to illuminance value of the interior. Also, the simulations run in every season at noon to see results yearly due to BREEAM. In the view of these simulation findings, differences and similarities due to locations were shown for the same conditions.

Material alternatives and their average reflectance values strongly affect the illuminance percentage of the room. If average reflectance value is increasing at the same time the illuminance percentage of the room is also increasing. With reference to simulation results, the reflectance value of materials had an impact on the illuminance value of the interior.

Window width was not a parameter for BREEAM in daylighting criteria. However, a narrow window was modeled as reference room B. All the simulation findings showed that reference room B illuminance percentage was less than reference room A under the same conditions. They were shown in Table 4.3, Table 4.6, Table 4.9, and Table 4.12.According to daylight simulation findings, window width was a parameter that affects the illuminance of the indoor environment.

In Table 4.3, the adequate illuminance value percentages were shown. Although lower average reflectance value ($\rho=0.38$) than the one for BREEAM reference room with 5,4m depth($\rho=0.5$) was applied in Material Alternative I, a total of 5 different situations satisfies the criteria of at least 300 lux illuminance in 60% of the interior both London and İzmir simultaneously. These five situations were applicable for İzmir as providing BREEAM criteria. However, the other situations did not provide the terms of BREEAM to practice the assessment tool in İzmir.

In every alternative material conditions, 21st December in clear sky condition provided enough illuminance for BREEAM criteria. The lowest sun angles throughout the year can reach inside the room deeper. That's why the illuminance values can be counted in the satisfying condition.

Regarding findings of Material Alternative II which corresponds to the proposed reflectance value in BREEAM, there were two results that İzmir got one step forward from London. Table 4.6, reference room A had enough illuminance percentage for BREEAM in 21st March and 21st September overcast sky condition in İzmir and not in London. That is also a result of locating close to the equator for İzmir. Indicating the higher cloudy daylight hours in London than İzmir, it satisfies the daylight performance except for the winter season, according to BREEAM when 5.4m depth room with the required WWR was constructed. Even this criterion is more suitable for İzmir since almost 50 % of the floor area can benefit from daylight. Dominating clear sky conditions in İzmir, satisfying but lower illuminance percentages show us the impact of location on daylight benefit.

In material I and II simulation findings, reference room A provided daylight criteria of BREEAM in 21st March and 21st September in clear sky condition however they did not provide it in overcast sky condition in London. In Table 3.3, the altitude degrees of London were shown for selected dates. London had 38.62° altitude in 21st March and 38.52° altitude in 21st September. The altitude angles were too near to each other and the daylight simulations were also similar to each other in those two selected dates. That is another quantitative indicator of the strong impact of location and sun angles on daylight performance.

Regarding Material alternatives III and IV, in general, it was obvious to mention that higher reflectance values than the one (ρ=0.5) in BREEAM criteria for 5.4 m-depth-room lead to highly and strongly daylight benefit. The significant impact of reflectance makes the room fully daylit. Almost the whole floor area receives adequate daylight, even involving excessive illuminance values (more than 2000 lux) partly. That shows us the significant effect of surface reflectance on illuminance clearly.

CHAPTER 6

CONCLUSION

This study aimed to tests room and window design parameters for daylight performance according to BREEAM assessment criteria in the cases of London and İzmir. The daylight performance simulation models were prepared in RELUX and the findings were compared and contrasted according to their geographical location, material alternatives, and window size. The simulations were run on four different dates in order to see the changes in yearly. The specifications about the reference room were taken for the educational buildings which are universities, colleges, and higher education-occupied spaces. Moreover, the dimensions of the reference rooms were taken from criteria of BREEAM. Floor, ceiling, and wall materials have their reflectance values and all of them create an average reflectance value of the indoor environment. If the average reflectance value is increasing, the daylight illuminance value of the indoor environment is also increasing respectively. It is once again evaluated in this study that window geometry and geographical location affect the illuminance value, although the window width and altitudes are not separately involved in BREEAM criteria. Findings in Reference room A and B show such differences of illuminance value due to window width.

The window width is not a criterion in BREEAM unlike window height, however, it directly affects the illuminance value of the indoor environment. Also, we observed that the average reflectance of indoor materials show significant impact on the illuminance value of the interior.

In general, we can conclude that BREEAM daylighting criteria which are based on location and weather conditions of London (United Kingdom) can be applied for the cases in İzmir. Though satisfying the required values of BREEAM, even, reflectance value of 0.5 for 5.4 m depth room in İzmir case can be 20% higher, -that is 0.6-, to reach the daylight illuminance percentages in London case.

The significance of this research is based on this experimental approach to expose how the surface covering material variation modifies the daylight distribution over the horizontal work plane according to BREEAM. As it is an environmental assessment tool, it defines and evaluates the contribution of daylight in sustainable building design. The question in our case was whether it is applicable in a lower latitude location when clear sky conditions are dominant unlike the city of London. Despite of these variations, the regular large window (Room A) satisfied the daylight performance criteria mostly unlike the smaller window case (Room B) when 0.37 reflectance value (lower than BREEAM recommendations) was applied.

The small window width could initially and only provide adequate daylight penetration when reflectance value is 0.76 for both locations. This case is successful in summer under overcast sky and in winter clear sky conditions for both London and İzmir. That corresponds to a rarely observed situation when we have knowledge about days of dominantly having clear skies in summer in İzmir and days of dominantly having overcast skies in winter in London. So, this case cannot be recommended as a design alternative.

Consequently, observing the strong effect of window width on daylight performance, the requirements of BREEAM proposing the room width are suitable to be taken into consideration in architectural designs for the city of İzmir, even when lower reflectance values would be applicable. Findings would provide a wide variation of design alternatives as the feedback information for architects and lighting designers.

REFERENCES

Acosta, Ignacio, Miguel Ángel Campano, and Juan Francisco Molina. 2016. "Window Design in Architecture: Analysis of Energy Savings for Lighting and Visual Comfort in Residential Spaces." *Applied Energy* 168 (April): 493–506.

Acosta, Ignacio, Carmen Munoz, Miguel Angel Campano, and Jaime Navarro. 2015. "Analysis of Daylight Factors and Energy Saving Allowed by Windows under Overcast Sky Conditions." *Renewable Energy* 77: 194–207.

Al-Khatatbeh, Baraa J, and Shouib Nouh Ma'bdeh. 2017. "Improving Visual Comfort and Energy Efficiency in Existing Classrooms Using Passive Daylighting Techniques." *Energy Procedia* 136: 102–8.

Altomonte, Sergio, Sara Saadouni, Michael G Kent, and Stefano Schiavon. 2017. "Satisfaction with Indoor Environmental Quality in BREEAM and Non-BREEAM Certified Office Buildings." *Architectural Science Review* 60 (4): 343–55.

"Average Temperatures in İzmir, Turkey." n.d. Accessed March 31, 2019. http://www.izmir.climatemps.com/temperatures.php.

"Average Temperatures in London, England, UK." n.d. Accessed March 31, 2019. http://www.london.climatemps.com/temperatures.php.

Awadh, Omair. 2017. "Sustainability and Green Building Rating Systems: LEED, BREEAM, GSAS and Estidama Critical Analysis." *Journal of Building Engineering* 11: 25–29.

BINC16 2017a, "BREEAM International New Construction 2016." 2017a. BREEAM Assessment Issues and Credits. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#03_scoringrating_all/ass_crdts.htm%3FTocPath%3D3.0%2520Scoring%2520and%2520rating%2520BREEAM%2520%2520assessed%2520buildings%7C_____4.

BINC16 2017b, "BREEAM International New Construction 2016." 2017b. Health and Wellbeing. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#05_health/health.htm%3FTocPath%3D6.0%2520Health%2520and%2520Wellbeing%7C_____0.

BINC16 ,"BREEAM International New Construction 2016." 2017c. Energy. 2017. htt2017c ps://www.breeam.com/BREEAMInt2016SchemeDocument/#06_energy/energy.htm%3FTocPath%3D7.0%2520Energy%7C_____0.

BINC16 2017d, "BREEAM International New Construction 2016." 2017d. Transport. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#07_transport/transport.htm%3FTocPath%3D8.0%2520Transport%7C_____0.

BINC16, "BREEAM International New Construction 2016." 2017e. Water. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#08_water/water.htm%3FTocPath%3D9.0%2520Water%7C_____0.

BINC16 2017f, "BREEAM International New Construction 2016." 2017f. Materials. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#09_material/material.htm%3FTocPath%3D10.0%2520Materials%7C_____0.

BINC16 2017g, "BREEAM International New Construction 2016." 2017g. Waste. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#10_waste/waste.htm%3FTocPath%3D11.0%2520Waste%7C_____0.

BINC16 2017h, "BREEAM International New Construction 2016." 2017h. Land Use and Ecology. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#11_landuse/landuse.htm%3FTocPath%3D12.0%2520Land%2520Use%2520and%2520Ecology%7C_____0.

BINC16 2017i, "BREEAM International New Construction 2016." 2017i. Pollution. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#12_pollution/pollution.htm%3FTocPath%3D13.0%2520Pollution%7C_____0.

BINC16 2017a, "BREEAM International New Construction 2016." 2017a. BREEAM Rating Benchmarks. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#03_scoringrating_all/rat_benmks_all.htm%3FTocPath%3D3.0%2520Scoring%2520and%2520rating%2520BREEAM%2520%2520assessed%2520buildings%7C_____1.

BINC16 2017b, "BREEAM International New Construction 2016." 2017b. Hea 01 Visual Comfort. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#05_health/hea_01_nc.htm%3FTocPath%3D6.0%2520Health%2520and%2520Wellbeing%7C_____1.

BINC16 2017c, "BREEAM International New Construction 2016." 2017c. Minimum Standards. 2017. https://www.breeam.com/BREEAMInt2016SchemeDocument/#03_scoringrating_all/min_stds_all.htm%3FTocPath%3D3.0%2520Scoring%2520and%2520rating%2520BREEAM%2520%2520assessed%2520buildings%7C_____2.

Chergia, Citra. 2012. "International Adoption Framework of Green Building Guidelines in Developing Countries." Fen Bilimleri Enstitüsü.

CIBSE. n.d. "1.1.1 Daylight." In . CIBSE. https://app.knovel.com/hotlink/pdf/id:kt00U1GSG2/lighting-guide-10-daylighting/daylight BT - Lighting Guide 10 - Daylighting and Window Design.

Diş, Muhammet Ömer, and Mehmet Canbaz. 2015. “YAŞAM DÖNGÜSÜ ANALİZİ UYGULAMASI: BREEAM MODELİ.” *Life Cycle Assessment, BREEAM Model, Eco- Label, Building Product, Natural Resources.* 11 (2): 1–9.

Doan, Dat Tien, Ali Ghaffarianhoseini, Nicola Naismith, Tongrui Zhang, Amirhosein Ghaffarianhoseini, and John Tookey. 2017. “A Critical Comparison of Green Building Rating Systems.” *Building and Environment* 123: 243–60.

Erlalelitepe, Ilknur, Duygu Aral, and Tuğçe Kazanasmaz. 2011. “Eğitim Yapılarının Doğal Aydınlatma Performansı Açısından Incelenmesi = Investigation of Educational Buildings in Terms of Daylighting Performance.” *Megaron* 6 (1): 39–51.

Fontenelle, Marília Ramalho, and Leopoldo Eurico Gonçalves Bastos. 2014. “The Multicriteria Approach in the Architecture Conception: Defining Windows for an Office Building in Rio de Janeiro.” *Building and Environment* 74 (April): 96–105.

Galatioto, A, and M Beccali. 2016. “Aspects and Issues of Daylighting Assessment: A Review Study.” *Renewable and Sustainable Energy Reviews* 66: 852–60.

Giarma, Christina, Katerina Tsikaloudaki, and Dimitris Aravantinos. 2017. “Daylighting and Visual Comfort in Buildings’ Environmental Performance Assessment Tools: A Critical Review.” *Procedia Environmental Sciences* 38: 522–29.

Goia, Francesco. 2016. “Search for the Optimal Window-to-Wall Ratio in Office Buildings in Different European Climates and the Implications on Total Energy Saving Potential.” *Solar Energy* 132 (July): 467–92.

Heschong, Lisa, Ihab Elzeyadi, and Carey Knecht. 2002. “Re-Analysis Report: Daylighting in Schools, Additional Analysis. Tasks 2.2.1 through 2.2.5.”

Heschong, Lisa, Roger L. Wright, and Stacia Okura. 2002. “Daylighting Impacts on Human Performance in School.” *Journal of the Illuminating Engineering Society* 31 (2): 101–14.

Hiyama, Kyosuke, and Liwei Wen. 2015. “Rapid Response Surface Creation Method to Optimize Window Geometry Using Dynamic Daylighting Simulation and Energy Simulation.” *Energy and Buildings* 107: 417–23.

Iyer-Raniga, Usha, and Kendra Wasiluk. 2007. “Sustainability Rating Tools - A Snapshot Study.” *Environment Design Guide*, 1–14.

“Izmir Climate & Temperature.” n.d. Accessed March 31, 2019. http://www.izmir.climatemps.com/.

Jafarian, Hoda, Claude M H Demers, Pierre Blanchet, and Veronic Laundry. 2018. “Effects of Interior Wood Finishes on the Lighting Ambiance and Materiality of Architectural Spaces.” *Indoor & Built Environment* 27 (6): 786.

Kazanasmaz, Tuğçe, Lars Oliver Grobe, Carsten Bauer, Marek Krehel, and Stephen Wittkopf. 2016. “Three Approaches to Optimize Optical Properties and Size of a South-Facing Window for Spatial Daylight Autonomy.” *Building and Environment* 102: 243–56.

Konis, Kyle. 2013. “Evaluating Daylighting Effectiveness and Occupant Visual Comfort in a Side-Lit Open-Plan Office Building in San Francisco, California.” *Building and Environment* 59 (January): 662–77.

Lachman, Beth E, Agnes Gereben Schaefer, Nidhi Kalra, Scott Hassell, Kimberly Curry Hall, Aimee E Curtright, and David E Mosher. 2013. “Buildings and Energy Trends.” In *Key Trends That Will Shape Army Installations of Tomorrow*, 111–70. RAND Corporation.

Lee, W L. 2013. “A Comprehensive Review of Metrics of Building Environmental Assessment Schemes.” *Energy and Buildings* 62: 403–13.

Leslie, R P. 2003. “Capturing the Daylight Dividend in Buildings: Why and How?” *Building and Environment* 38 (2): 381–85.

Li, D H W, S L Wong, C L Tsang, and Gary H W Cheung. 2006. “A Study of the Daylighting Performance and Energy Use in Heavily Obstructed Residential Buildings via Computer Simulation Techniques.” *Energy & Buildings* 38 (Energy and Environment of Residential Buildings in China): 1343–48.

“London, England Climate & Temperature.” n.d. Accessed March 31, 2019. http://www.london.climatemps.com/index.php.

Mardaljevic, J, and J Christoffersen. 2017. “‘Climate Connectivity’ in the Daylight Factor Basis of Building Standards.” *Building and Environment VO - 113*, 200.

Nguyen, Binh K, and Hasim Altan. 2011. “Comparative Review of Five Sustainable Rating Systems.” *Procedia Engineering* 21: 376–86.

Ochoa, Carlos E, Myriam B C Aries, Evert J van Loenen, and Jan L M Hensen. 2012. “Considerations on Design Optimization Criteria for Windows Providing Low Energy Consumption and High Visual Comfort.” *Applied Energy* 95 (July): 238–45.

Oral, Gül Koçlar, Alpin Köknel Yener, and Nurgün Tamer Bayazit. 2004. “Building Envelope Design with the Objective to Ensure Thermal, Visual and Acoustic Comfort Conditions.” *Building and Environment* 39 (January): 281–87.

Osterhaus, W K E. 2005. “Discomfort Glare Assessment and Prevention for Daylight Applications in Office Environments.” *Solar Energy* 79 (2): 140–58.

Piasecki, Michal, Mateusz Kozicki, Szymon Firlag, Anna Goljan, and Krystyna Kostyrko. 2018. “The Approach of Including TVOCs Concentration in the Indoor Environmental Quality Model (IEQ)-Case Studies of BREEAM Certified Office Buildings.” *SUSTAINABILITY*.

Plympton, Patricia, Susan Conway, Kyra Epstein, and National Renewable Energy Lab (DOE). 2000. “Daylighting in Schools: Improving Student Performance and Health at a Price Schools Can Afford.”

Reinhart, Christoph F, John Mardaljevic, and Zack Rogers. 2006. “Dynamic Daylight Performance Metrics for Sustainable Building Design.” *LEUKOS*.

Reinhart, Christoph, Alstan Jakubiec, and Diego Ibarra. 2013. “Definition of a Reference Office for Standardized Evaluations of Dynamic Façade and Lighting Technologies.” In *13th Conference of International Building Performance Simulation Association*, 3645–52. Chambery, France.

Reinhart, Christoph, and Stephen Selkowitz. 2006. “Daylighting—Light, Form, and People.” *Energy and Buildings* 38 (7): 715–17.

“RELUX.” 2019. 2019. Accessed March 31, 2019. https://relux.com/en/about-us.html.

Said, Fatma S, and FACULTY O F ARCHITECTURE CANKAYA UNIVERSITY. 2019. *A Research on Selecting the Green Building Certification System Suitable for Turkey*. Çankaya Üniversitesi.

Schmid, Aloísio Leoni, and Leticia Karine Seki Uehara. 2017. “Lighting Performance of Multifunctional PV Windows: A Numeric Simulation to Explain Illuminance Distribution and Glare Control in Offices.” *Energy & Buildings* 154 (November): 590–605.

Sinou, Maria, and Stella Kyvelou. 2006. “Present and Future of Building Performance Assessment Tools.” *Management of Environmental Quality: An International Journal* 17 (5): 570–86.

“Sun Position.” 2019. Accessed March 31, 2019. https://www.sunearthtools.com/dp/tools/pos_sun.php?lang=en.

“Sunshine & Daylight Hours in İzmir, Turkey.” n.d. Accessed March 31, 2019. http://www.izmir.climatemps.com/sunlight.php.

“Sunshine & Daylight Hours in London, England, UK.” n.d. Accessed March 31, 2019. http://www.london.climatemps.com/sunlight.php.

Suzer, Ozge. 2019. “Analyzing the Compliance and Correlation of LEED and BREEAM by Conducting a Criteria-Based Comparative Analysis and Evaluating Dual-Certified Projects.” *Building and Environment* 147: 158–70.

Todd, Joel Ann, Drury Crawley, Susanne Geissler, and Gail Lindsey. 2001. “Comparative Assessment of Environmental Performance Tools and the Role of the Green Building Challenge.” *Building Research & Information* 29 (5): 324–35.

Tsikra, P, and E Andreou. 2017. “Investigation of the Energy Saving Potential in

Existing School Buildings in Greece. The Role of Shading and Daylight Strategies in Visual Comfort and Energy Saving.” *Procedia Environmental Sciences* 38: 204–11.

Uyan, Faruk. 2010. *Binalarda Aydınlatma Sistemlerinin Sürdürülebilirliklerini Değerlendirme İlkeleri*. Fen Bilimleri Enstitüsü.

Winterbottom, Mark, and Arnold Wilkins. 2009. “Lighting and Discomfort in the Classroom.” *Journal of Environmental Psychology* 29 (1): 63–75.

Wu, Wei, and Edward Ng. 2003. “A Review of the Development of Daylighting in Schools.” *Lighting Research & Technology* 35 (2): 111–25.

Yener, Alpin Köknel. 2002. “Daylight Analysis in Classrooms with Solar Control.” *Architectural Science Review* 45 (4): 311–16.

Yener, Alpin Köknel, Rana Kutlu Güvenkaya, and Feride Sener. 2009. “İlköĞretim Dersliklerinin Görsel Konfor Açısından Incelenmesi ve Değerlendirilmesi.” *Investigation and Evaluation of Primary School Classrooms with Respect to Visual Comfort.* 8 (1): 105–16.

Yu, X, Y Su, and X Chen. 2014. “Application of RELUX Simulation to Investigate Energy Saving Potential from Daylighting in a New Educational Building in UK.” *Energy and Buildings* 74 (May): 191–202.

APPENDIX A

CALCULATION RESULTS OF RELUX SIMULATIONS; RENDERS, CALCULATION POINTS ANDTHEIR ILLUMINANCE VALUES

Table A.1. Reference room B, material alternative I, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st March and 21stJune at 12:00 pm.

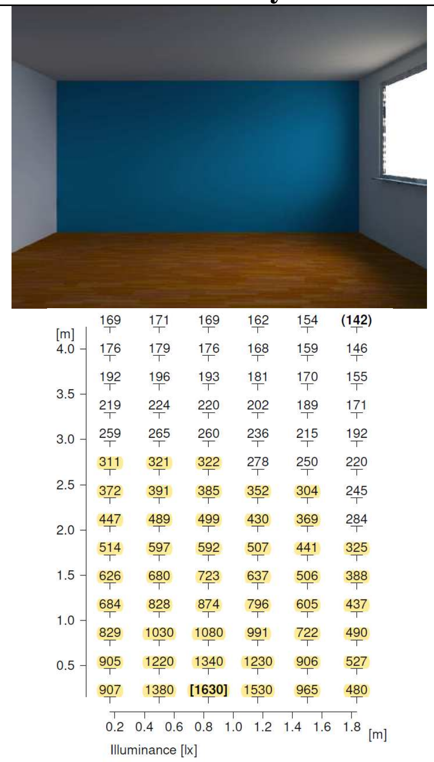
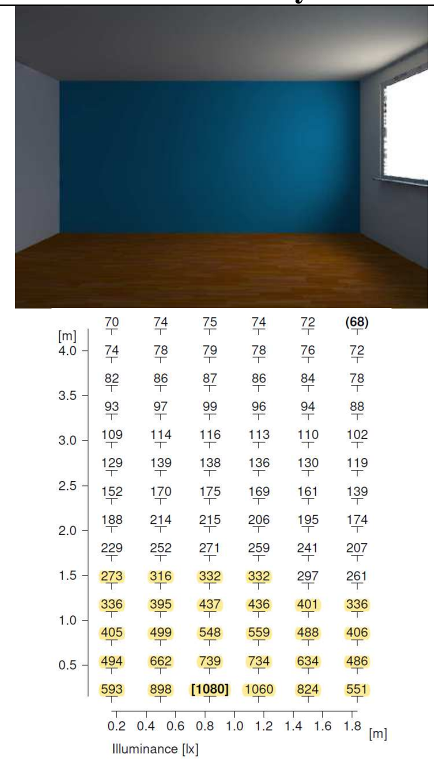
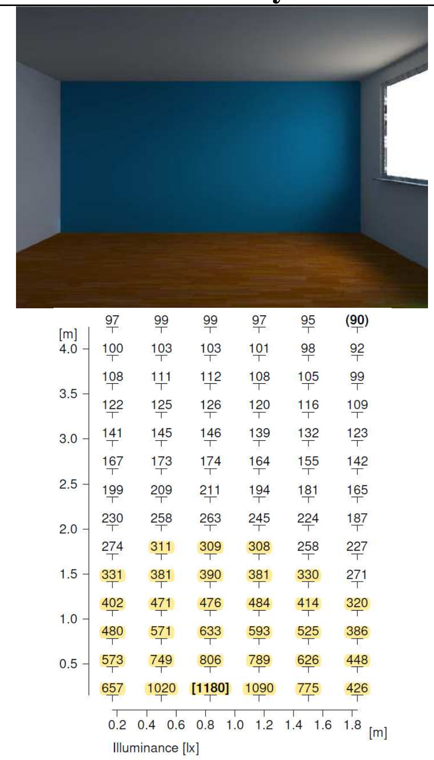
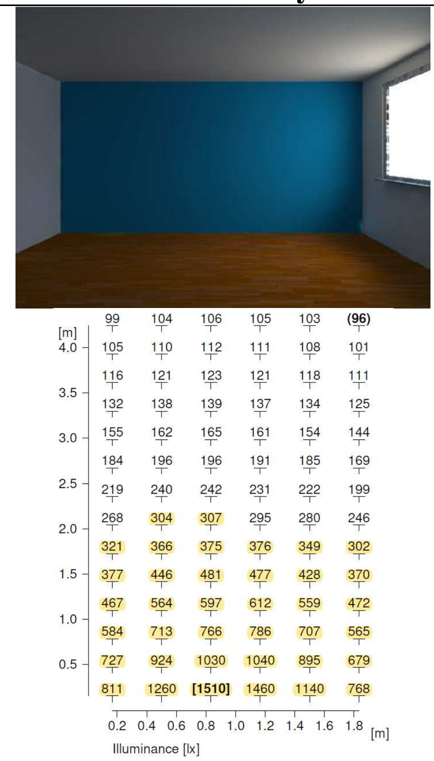
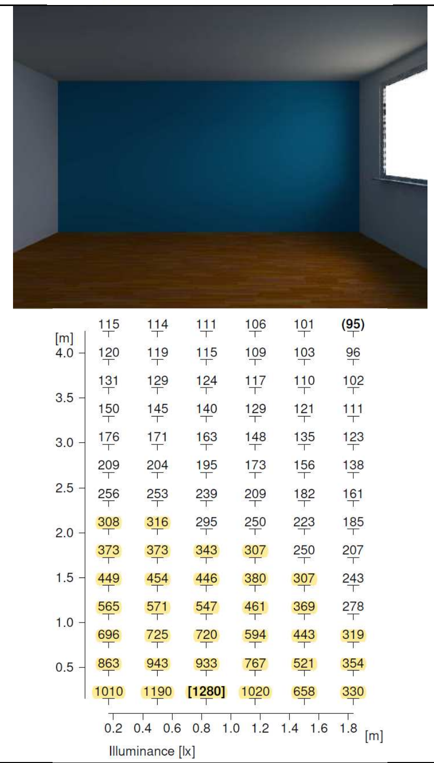
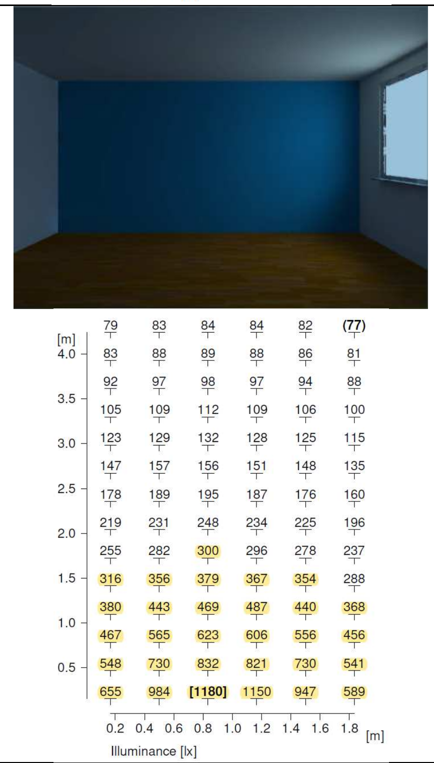
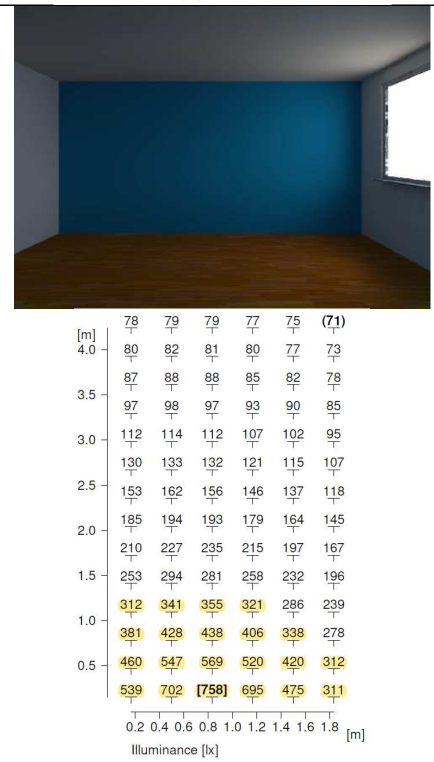
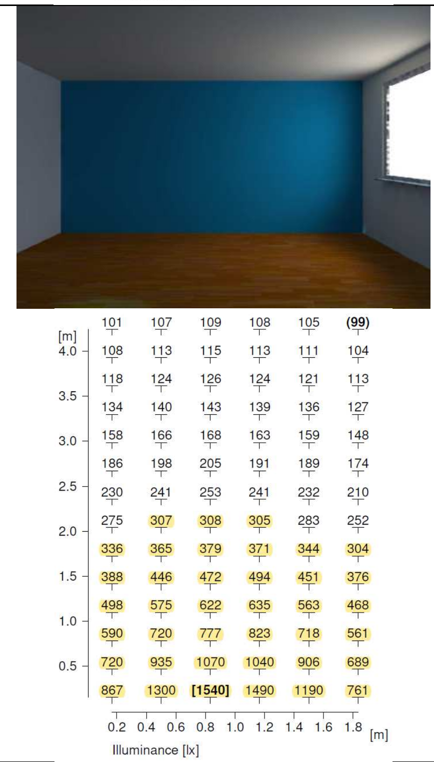
Room B - Material Alternative I at 12:00 pm	**21stMarch**		**21stJune**	
	Clear Sky	**Overcast Sky**	**Clear Sky**	**Overcast Sky**
London				
İzmir				

Table A.2. Reference room B, material alternative I, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st September and 21st December at 12:00 pm.

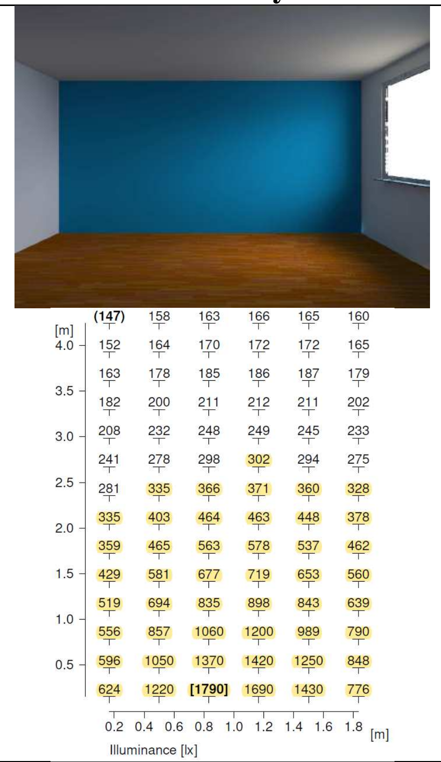
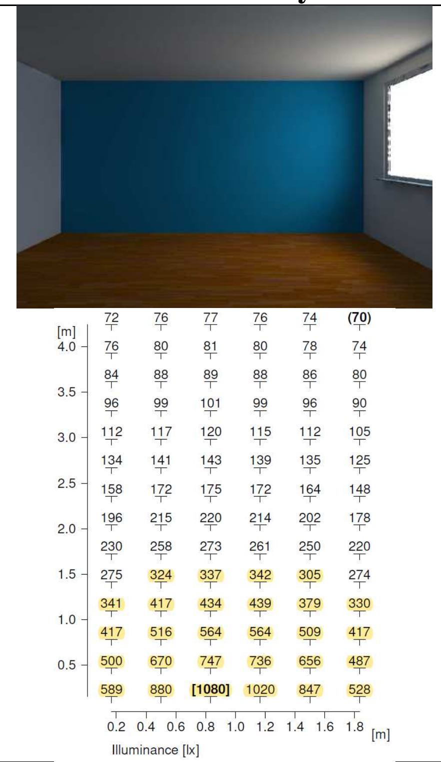
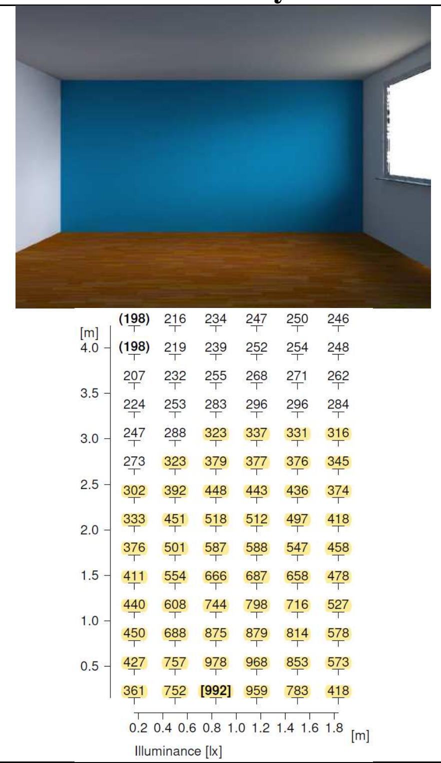
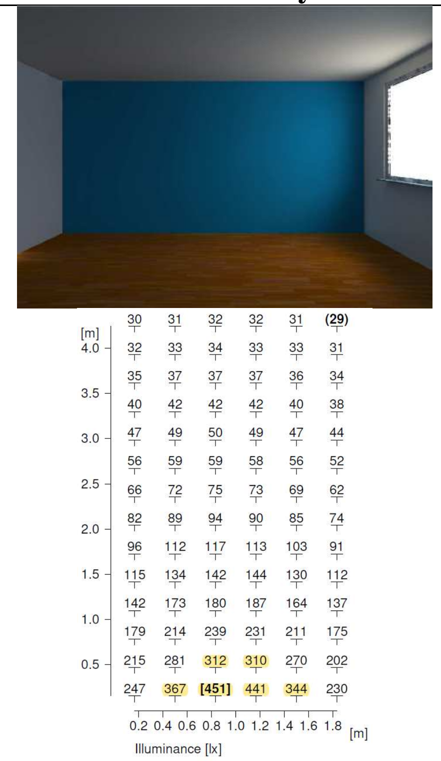
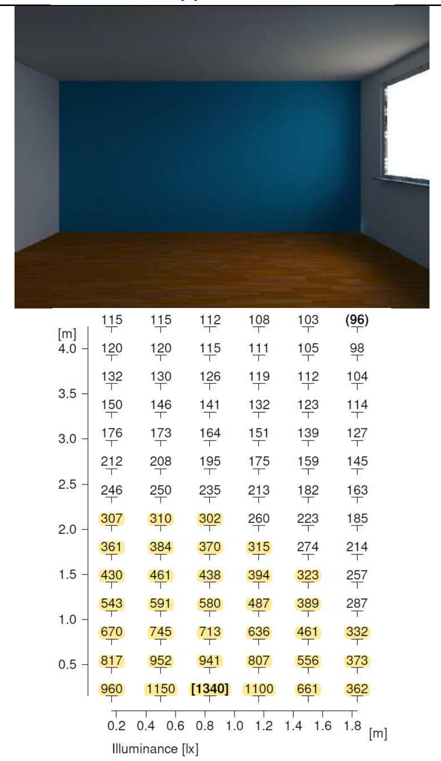
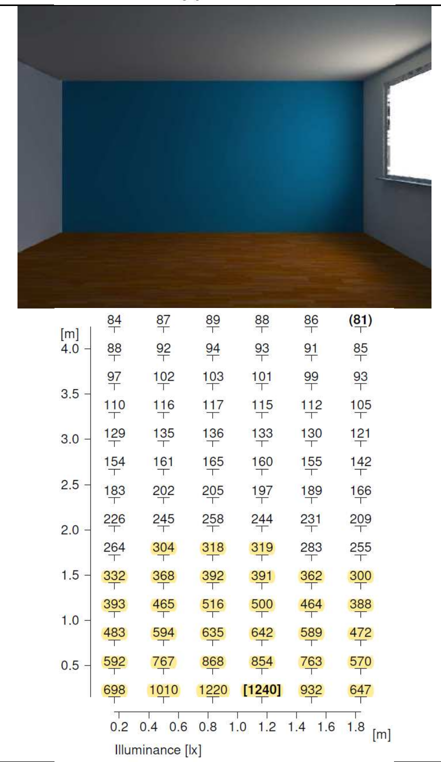
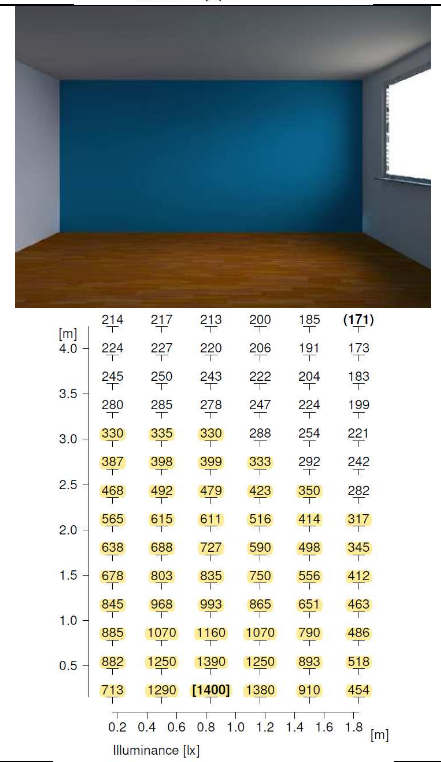
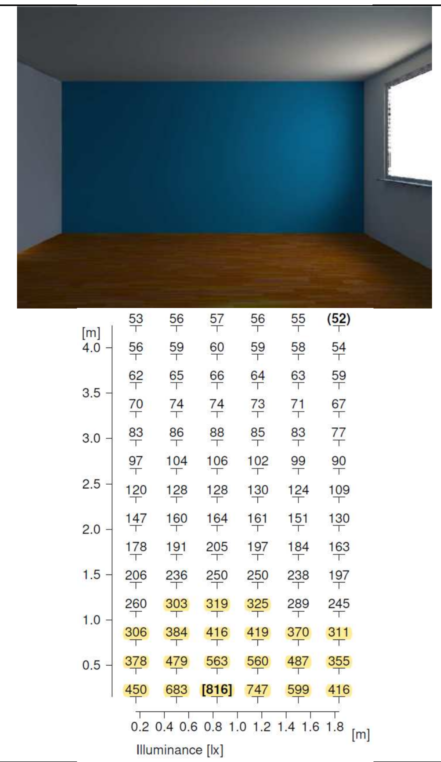
Room B - Material Alternative I at 12:00 pm	21st September		21st December	
	Clear Sky	**Overcast Sky**	**Clear Sky**	**Overcast Sky**
London				
İzmir				

Table A.3. Reference room B, material alternative II, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st March and 21stJune at 12:00 pm.

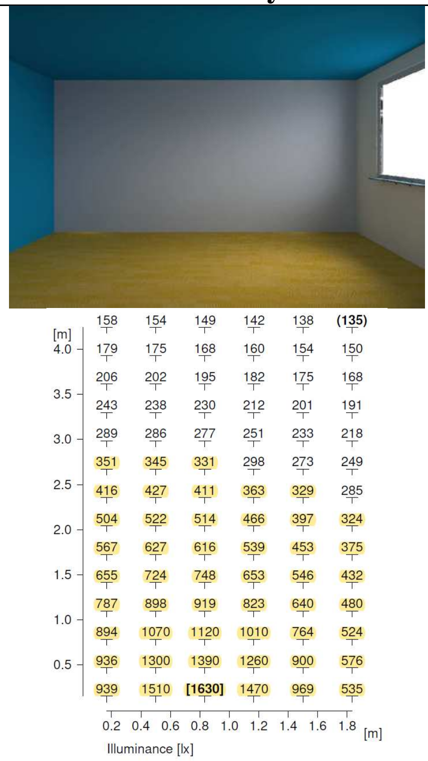
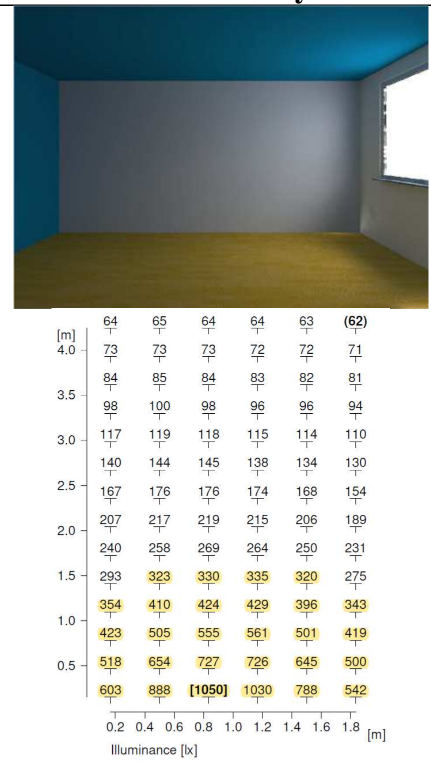
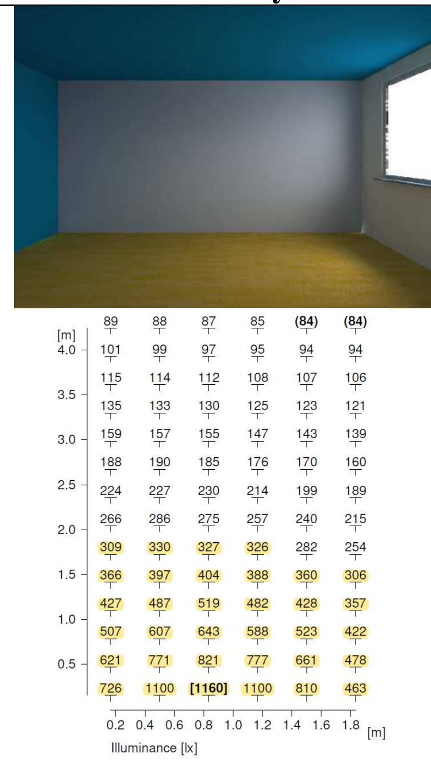
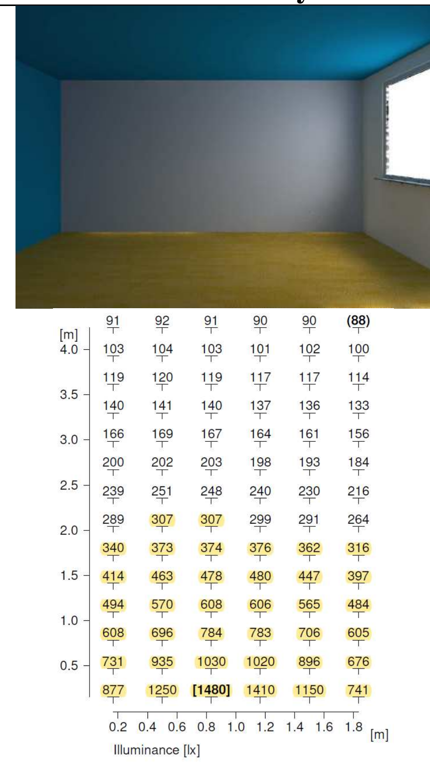
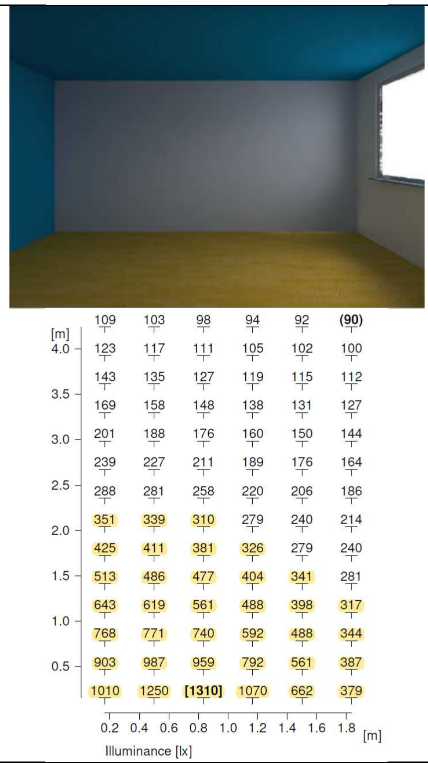
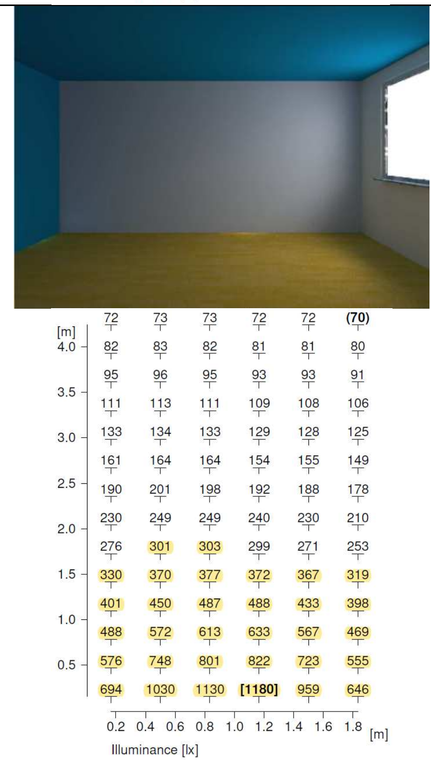
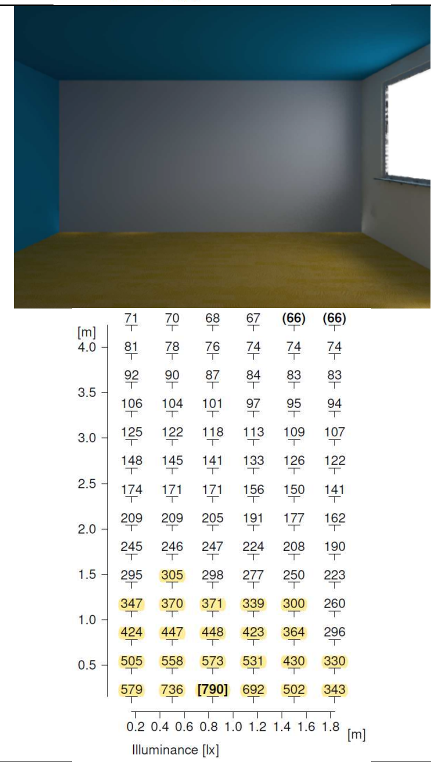
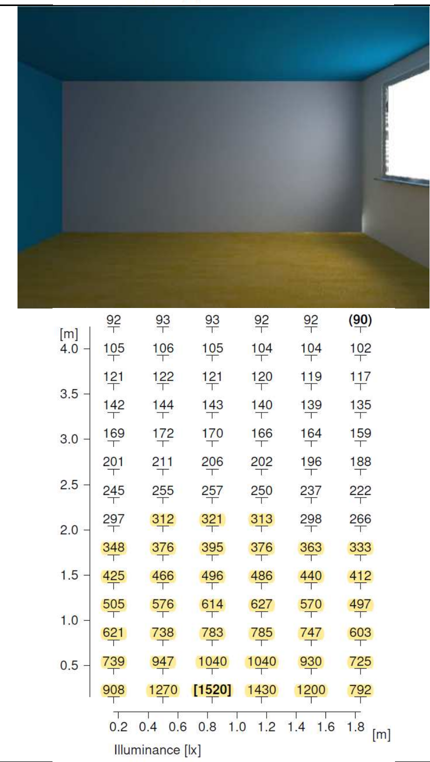
Room B - Material Alternative II at 12:00 pm	21st March		21st June	
	Clear Sky	Overcast Sky	Clear Sky	Overcast Sky
London				
İzmir				

Table A.4. Reference room B, material alternative II, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st September and 21st December at 12:00 pm.

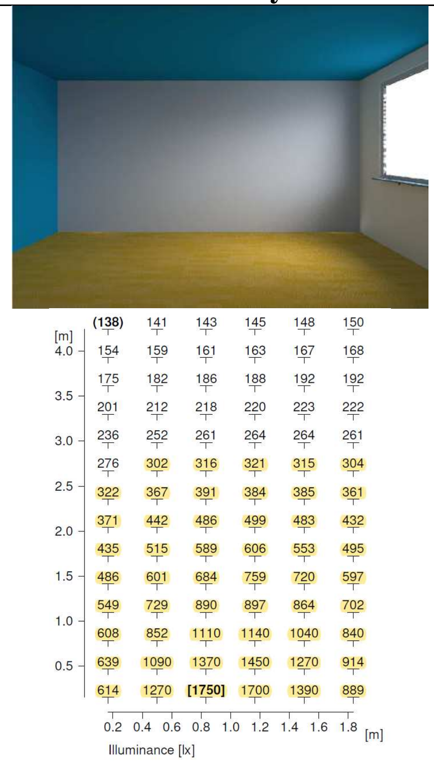
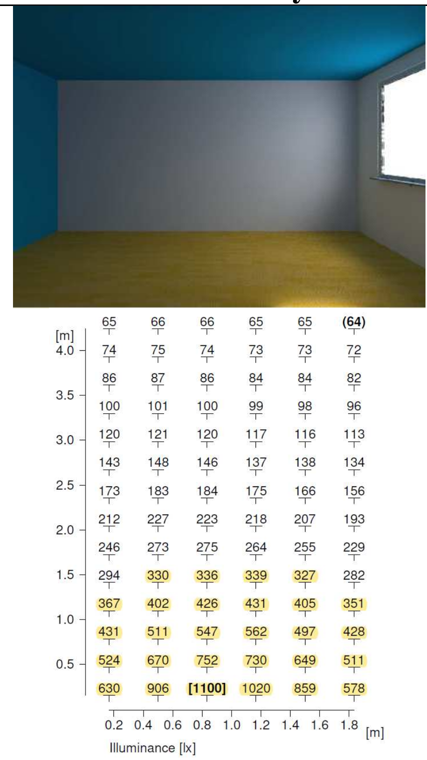
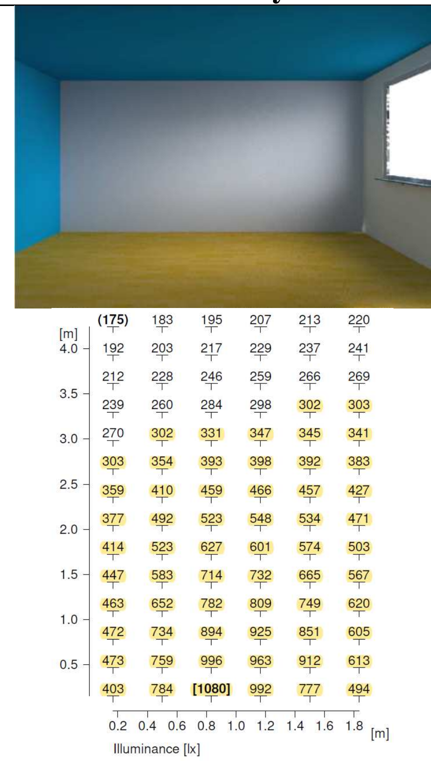
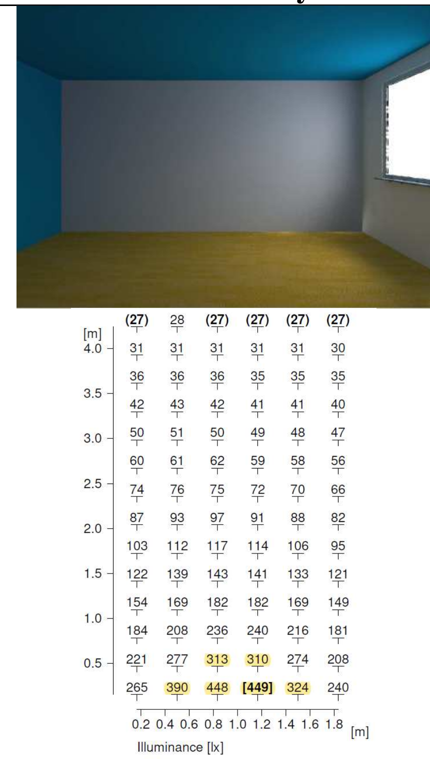
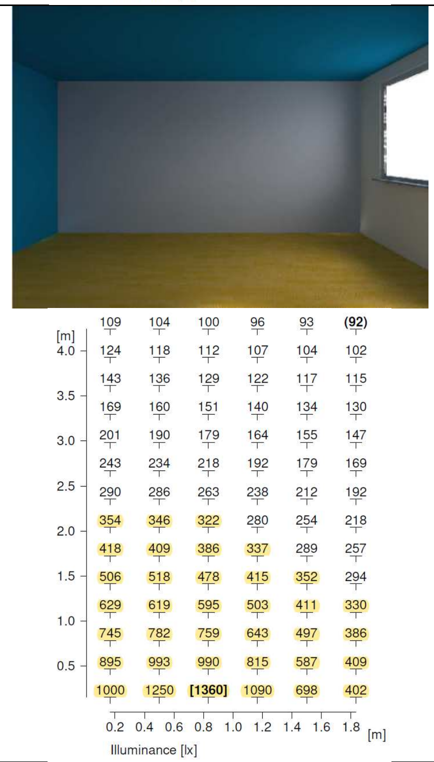
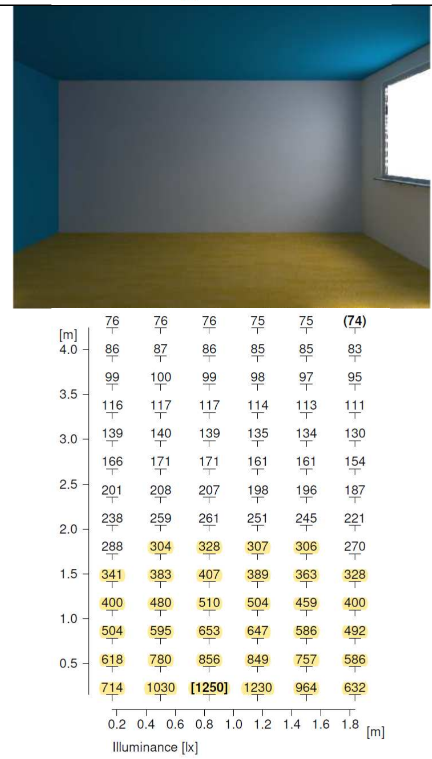
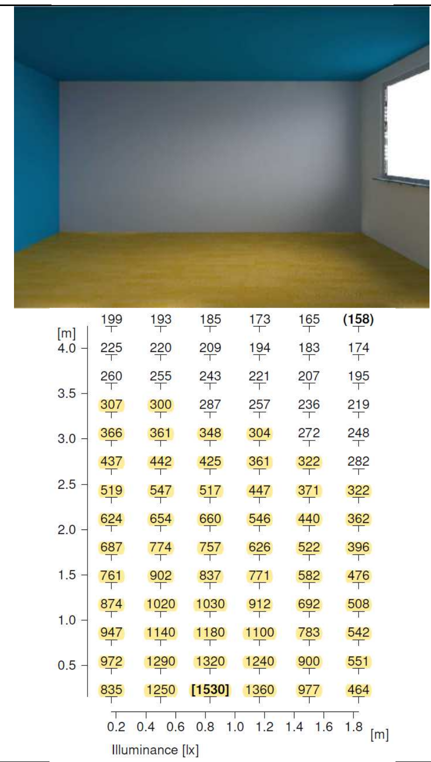
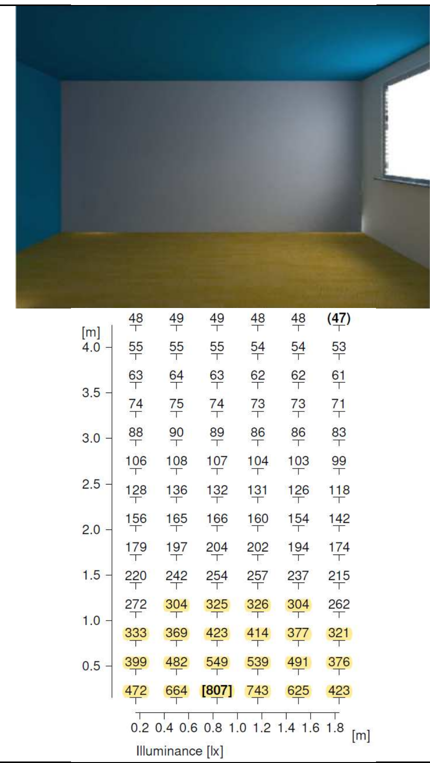
Room B - Material Alternative II at 12:00 pm	**21st September**		**21st December**	
	Clear Sky	**Overcast Sky**	**Clear Sky**	**Overcast Sky**
London				
İzmir				

Table A.5. Reference room B, material alternative III, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st March and 21st June at 12:00 pm.

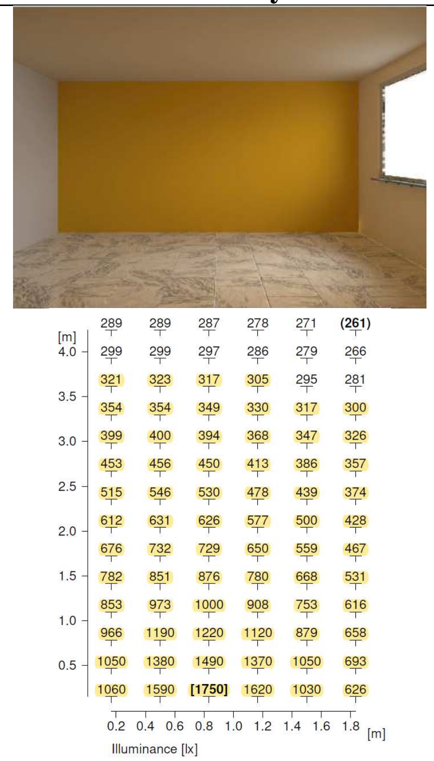
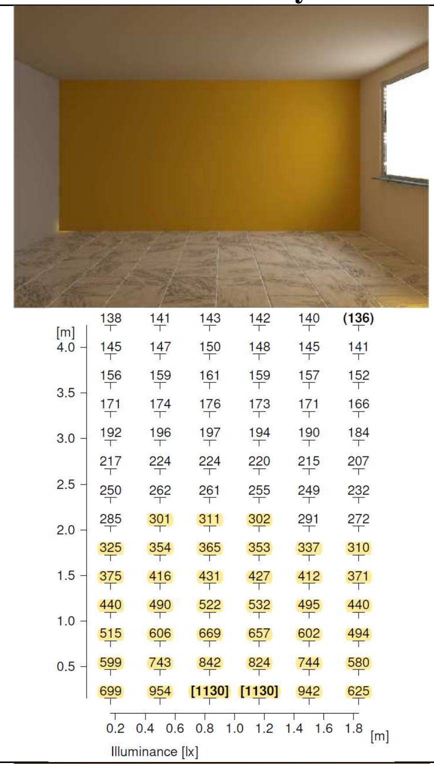
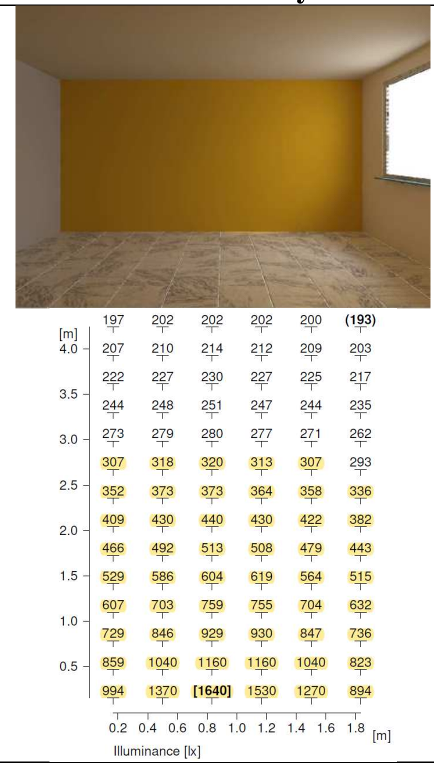
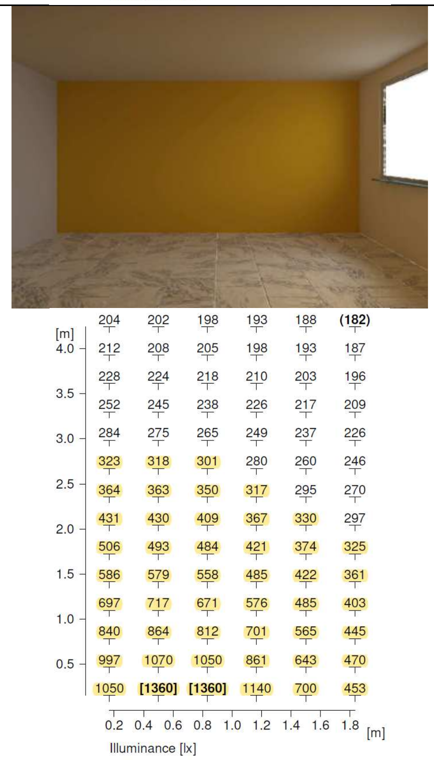
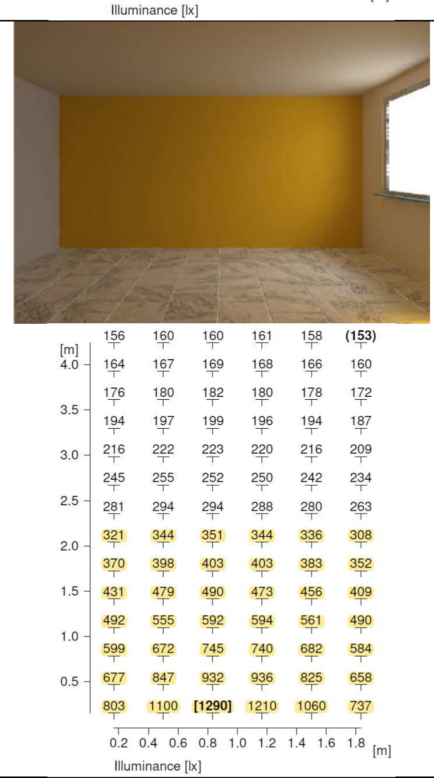
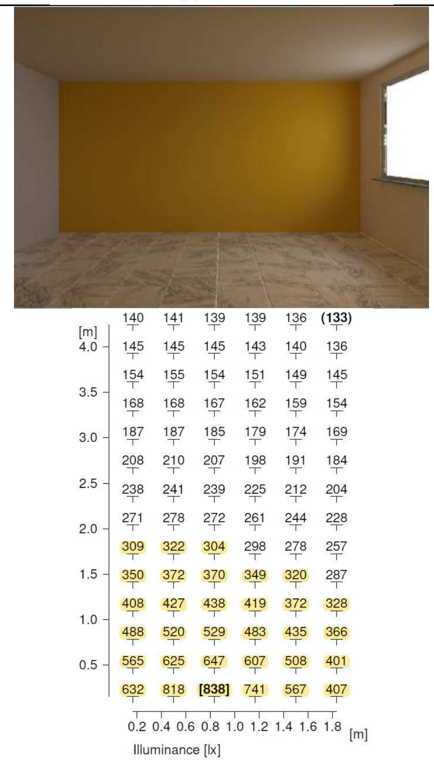
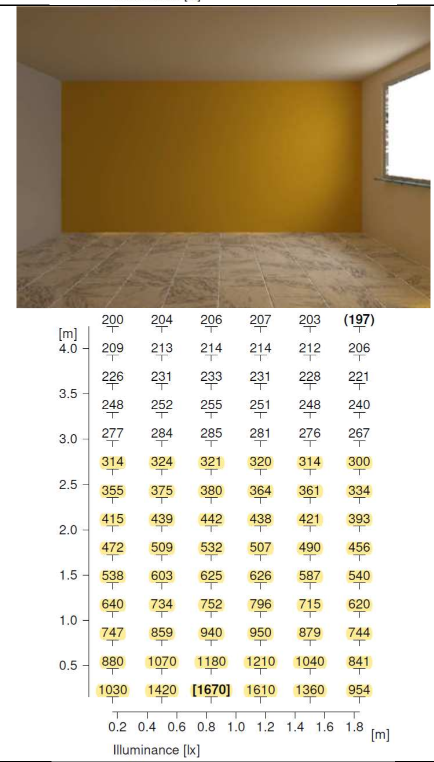
Room B - Material Alternative III at 12:00 pm	21st March		21st June	
	Clear Sky	Overcast Sky	Clear Sky	Overcast Sky
London				
İzmir				

Table A.6. Reference room B, material alternative III, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st September and 21st December at 12:00 pm.

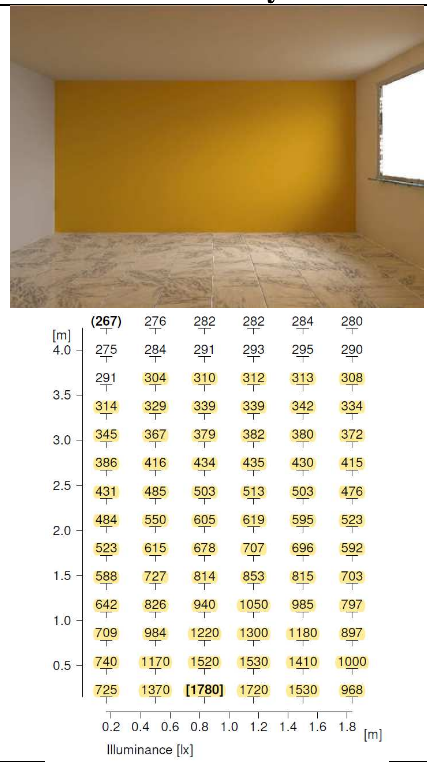
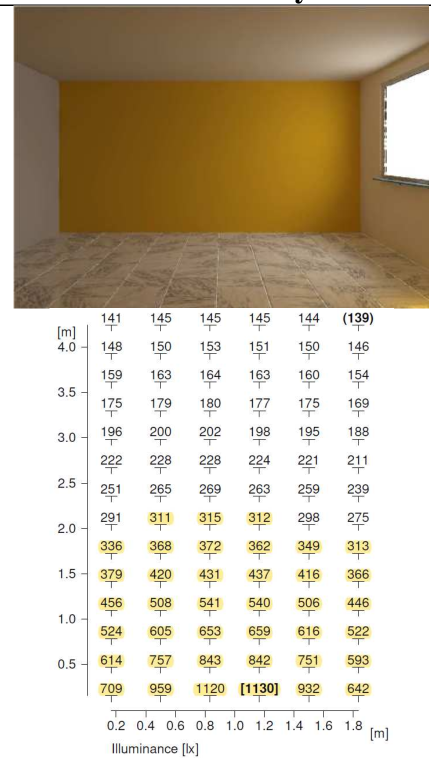
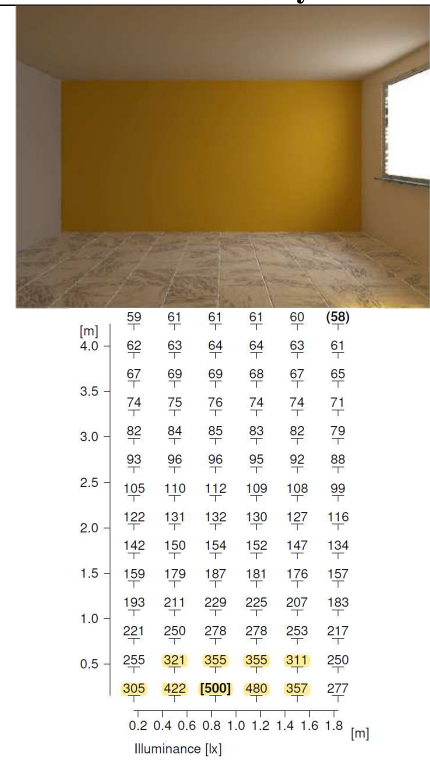
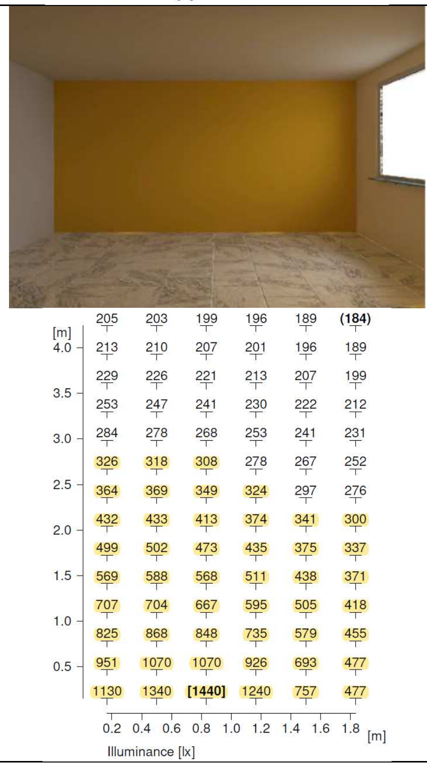
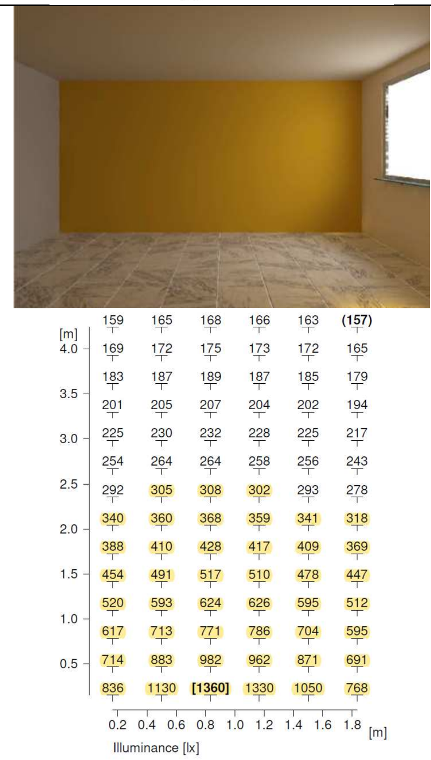
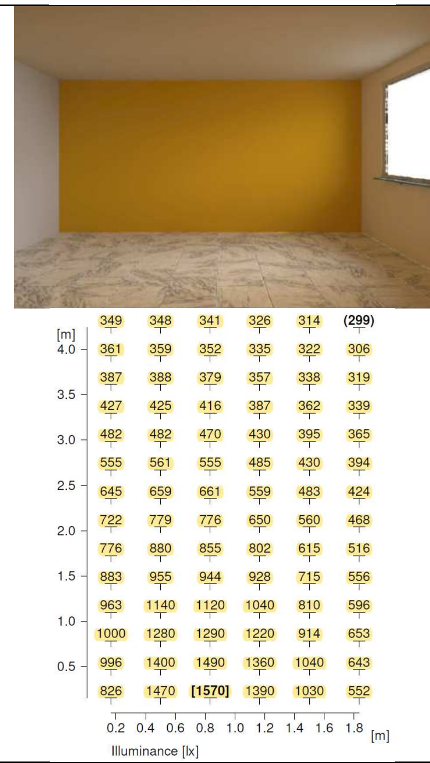
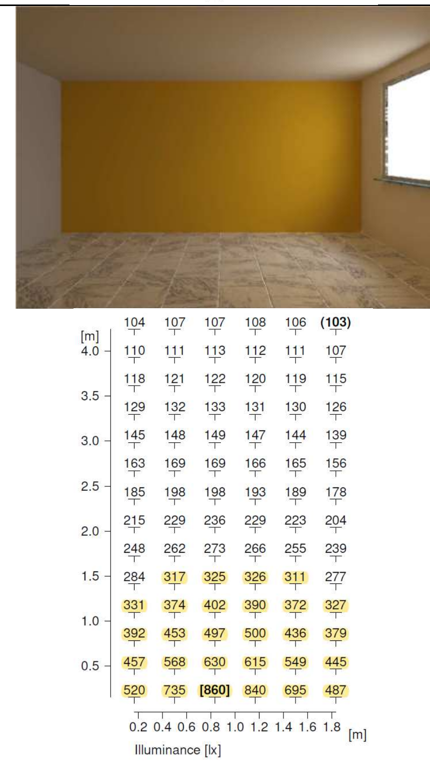
Room B - Material Alternative III at 12:00 pm	21st September		21st December	
	Clear Sky	Overcast Sky	Clear Sky	Overcast Sky
London				
İzmir				

Table A.7. Reference room B, material alternative IV, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st March and 21st June at 12:00 pm.

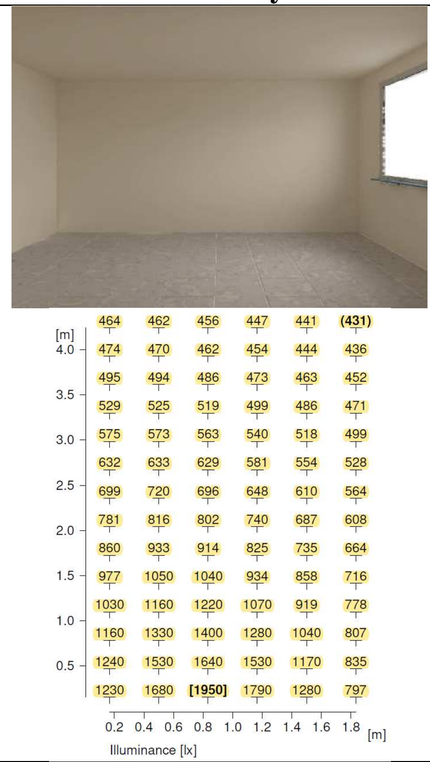
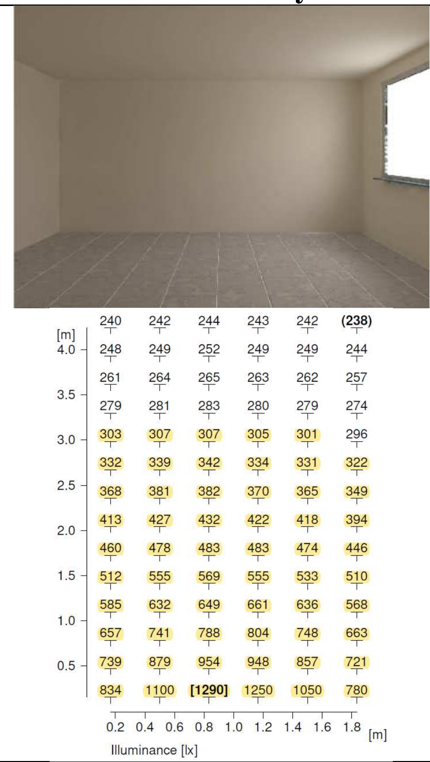
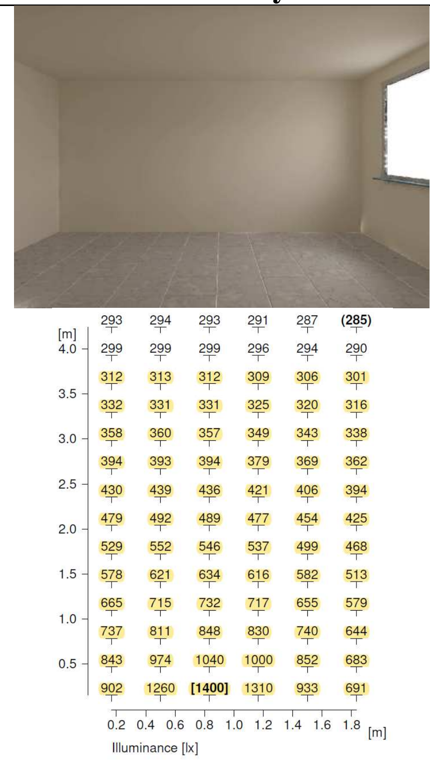
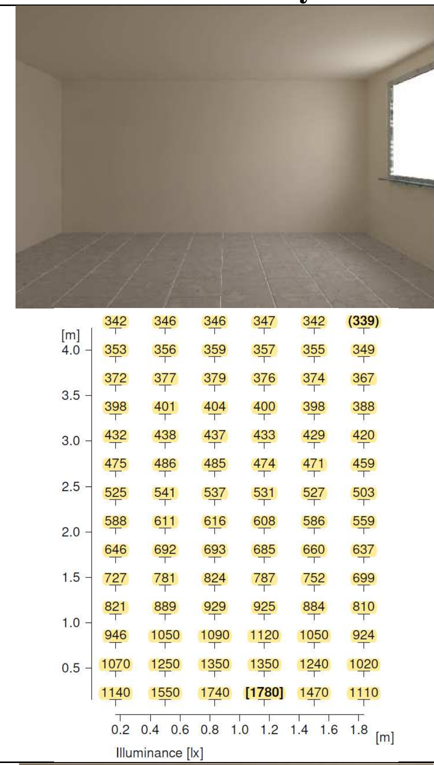
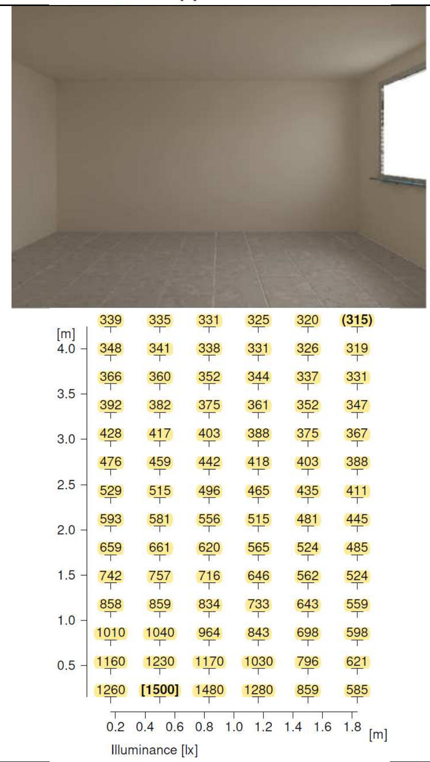
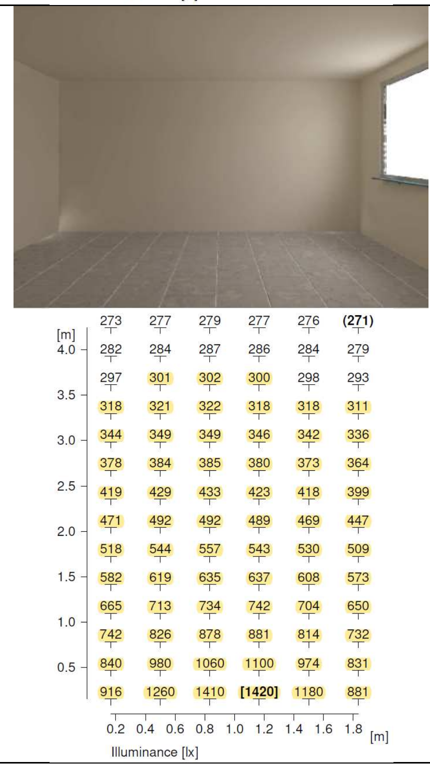
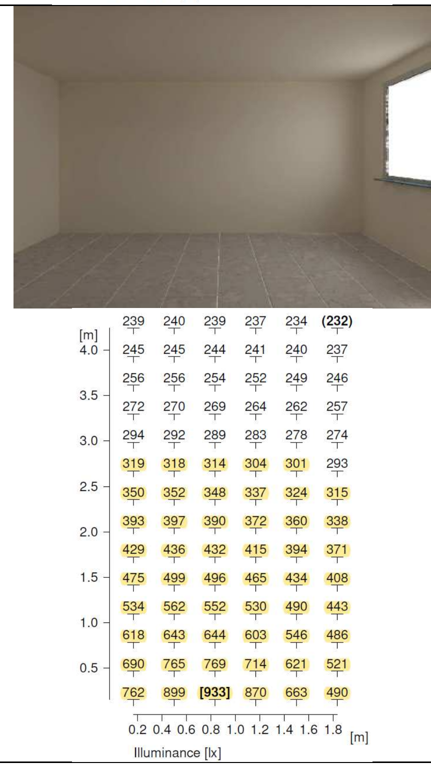
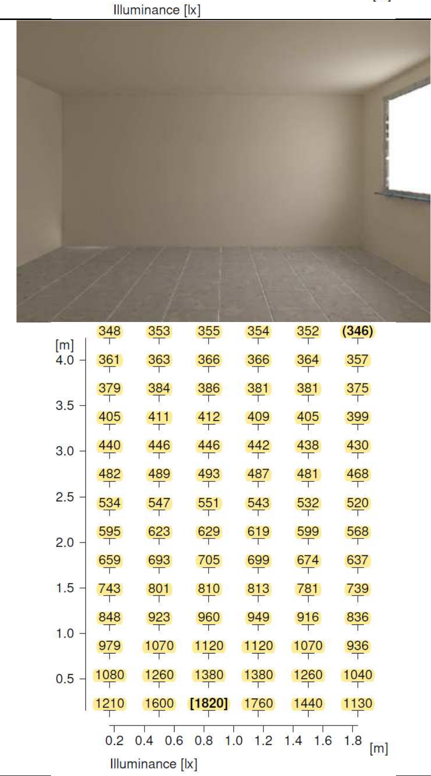
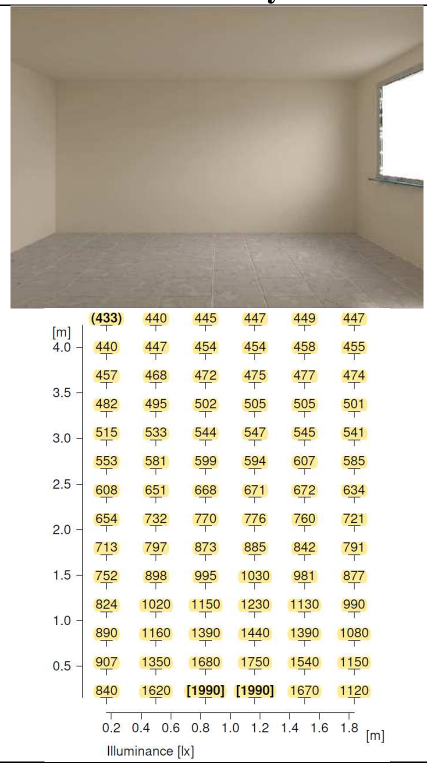
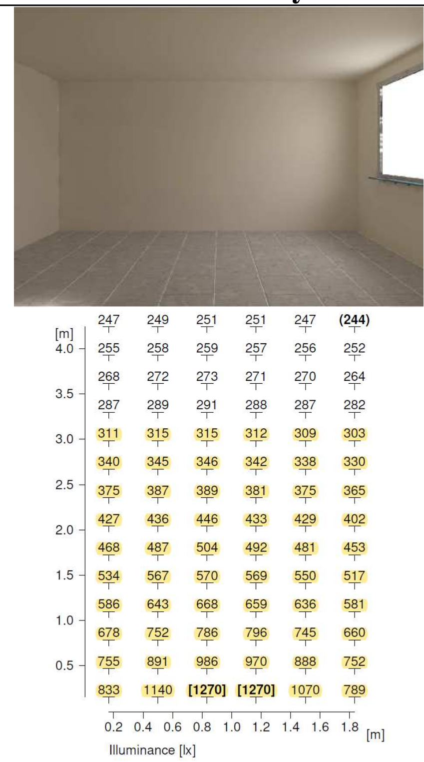
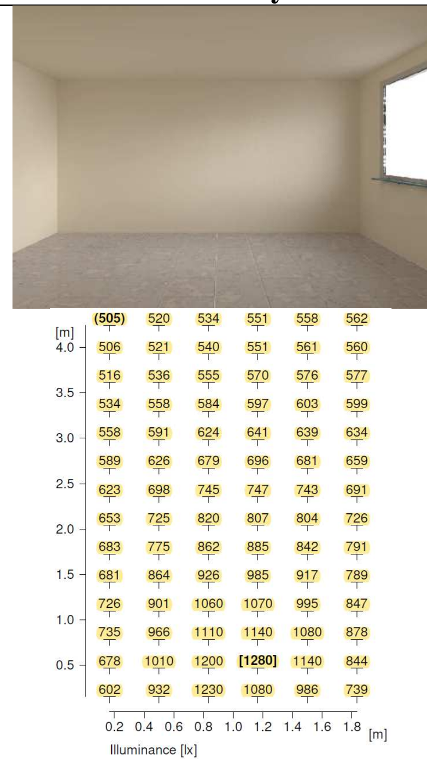
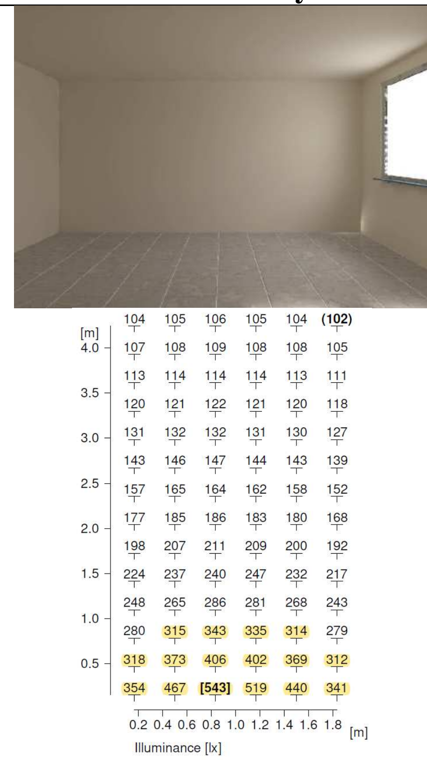
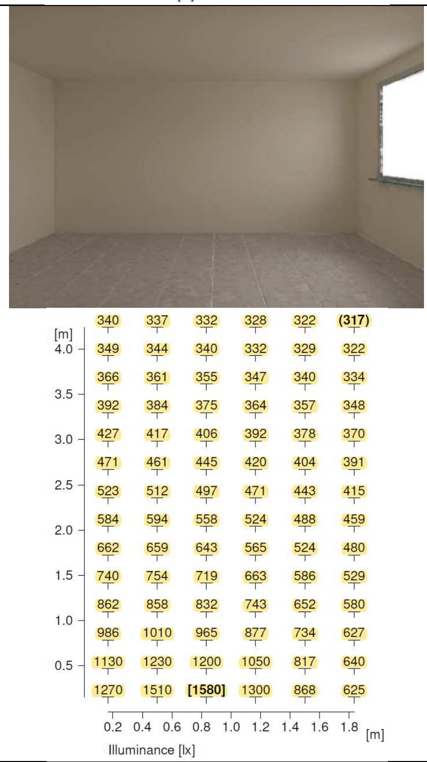
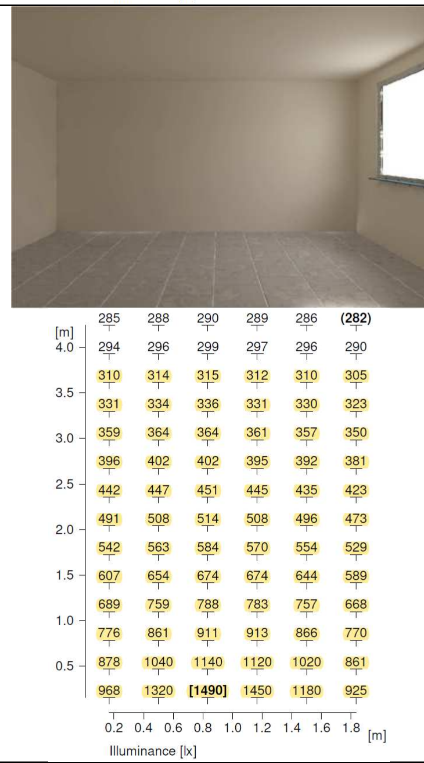
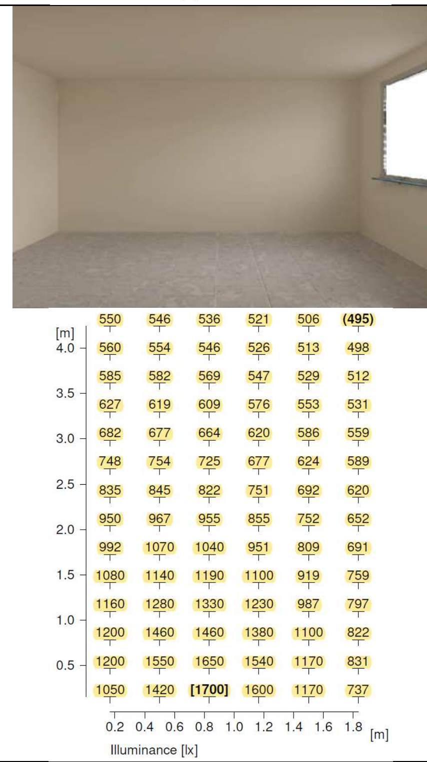
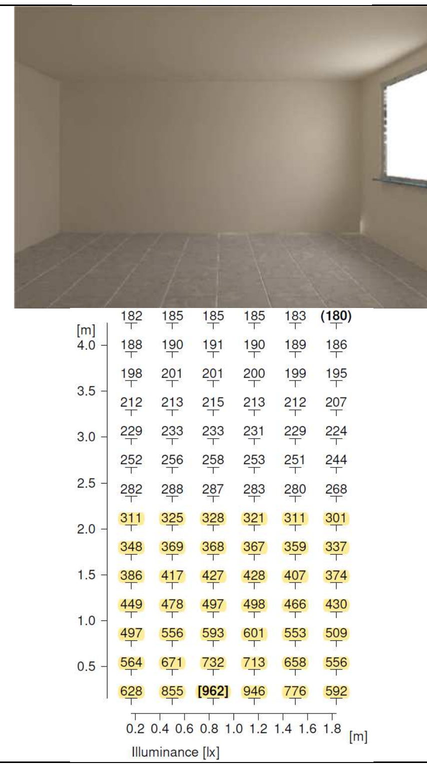
<table>
<tr><th rowspan="2">Room B - Material Alternative IV at 12:00 pm</th><th colspan="2">21st March</th><th colspan="2">21st June</th></tr>
<tr><th>Clear Sky</th><th>Overcast Sky</th><th>Clear Sky</th><th>Overcast Sky</th></tr>
<tr><td>London</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
<tr><td>İzmir</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
</table>

Table A.8. Reference room B, material alternative IV, clear sky and overcast sky RELUX simulation results for London and İzmir in 21st September and 21st December at 12:00 pm.

<table>
<tr><th rowspan="2">Room B - Material Alternative IV at 12:00 pm</th><th colspan="2">21st September</th><th colspan="2">21st December</th></tr>
<tr><th>Clear Sky</th><th>Overcast Sky</th><th>Clear Sky</th><th>Overcast Sky</th></tr>
<tr><td>London</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
<tr><td>İzmir</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
</table>

APPENDIX B

CALCULATION RESULTS OF RELUX SIMULATIONS; AVERAGE, MINIMUM, AND MAXIMUM ILLUMINANCE VALUES

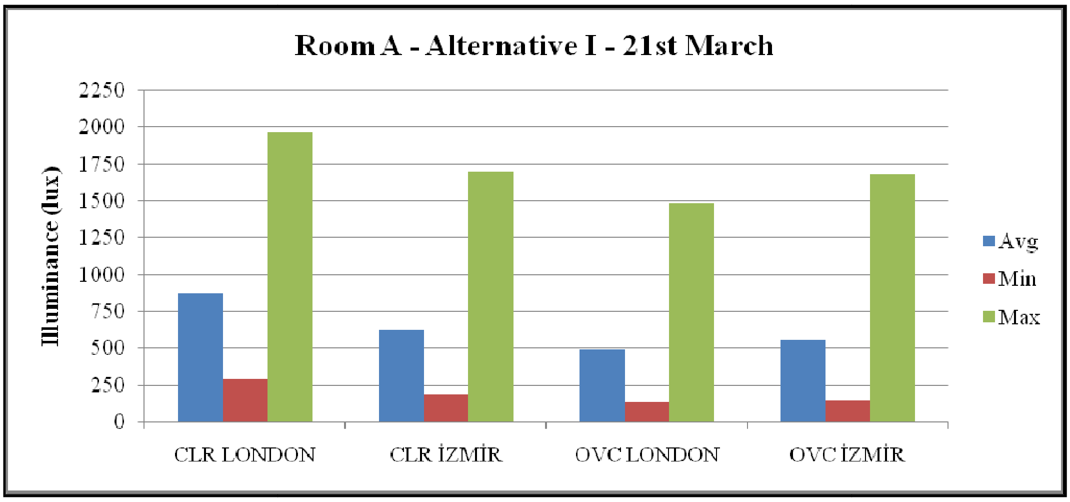


Figure B.1. Reference room A, material alternative I, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st March.

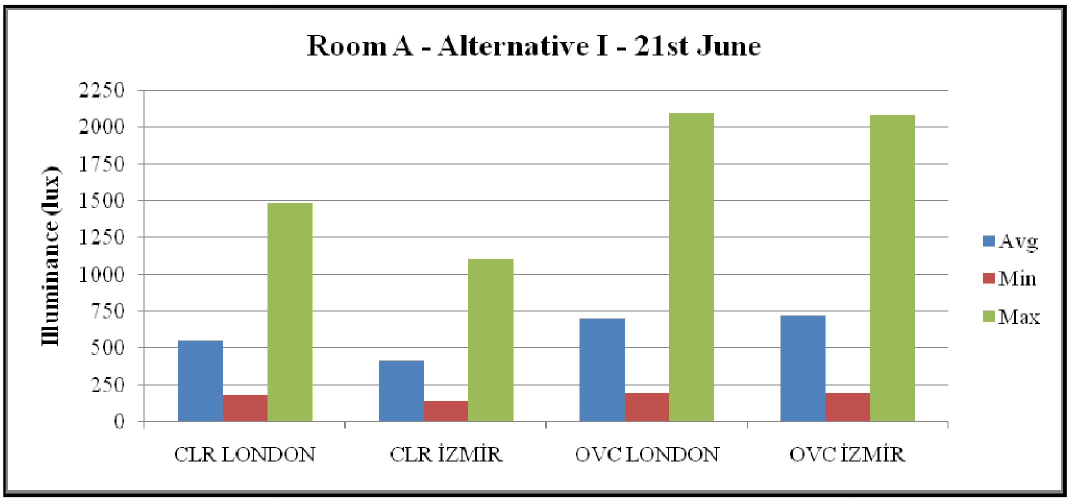


Figure B.2. Reference room A, material alternative I, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st June.

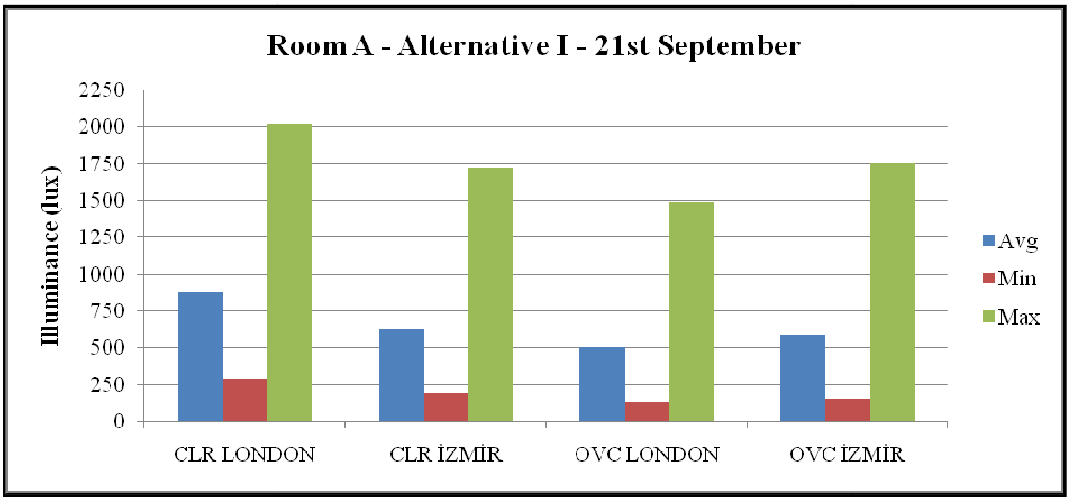


Figure B.3. Reference room A, material alternative I, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st September.

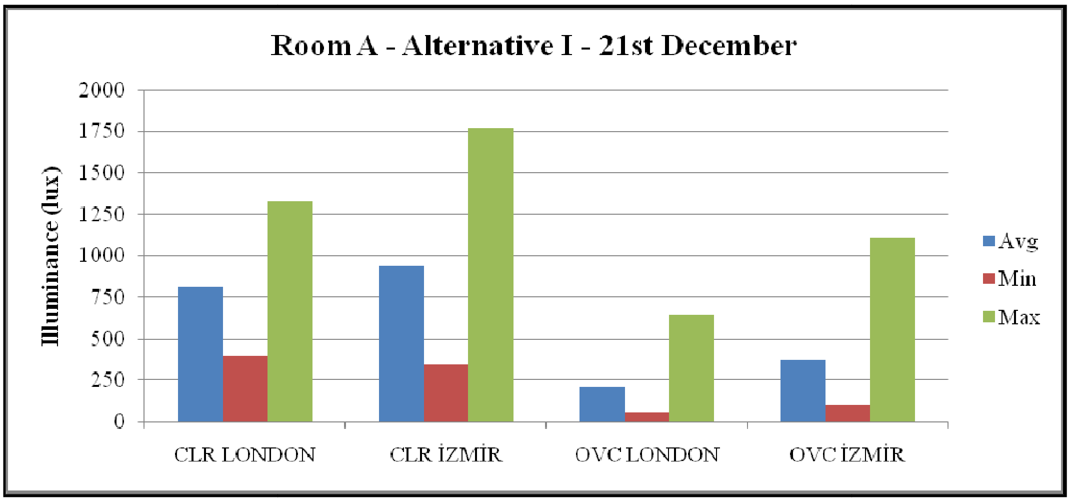


Figure B.4. Reference room A, material alternative I, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st December.

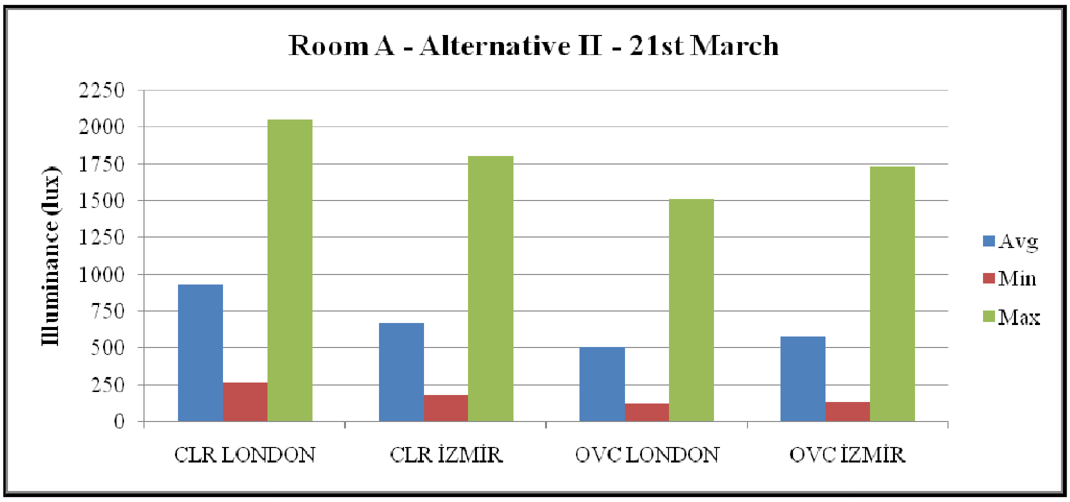


Figure B.5. Reference room A, material alternative II, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st March.

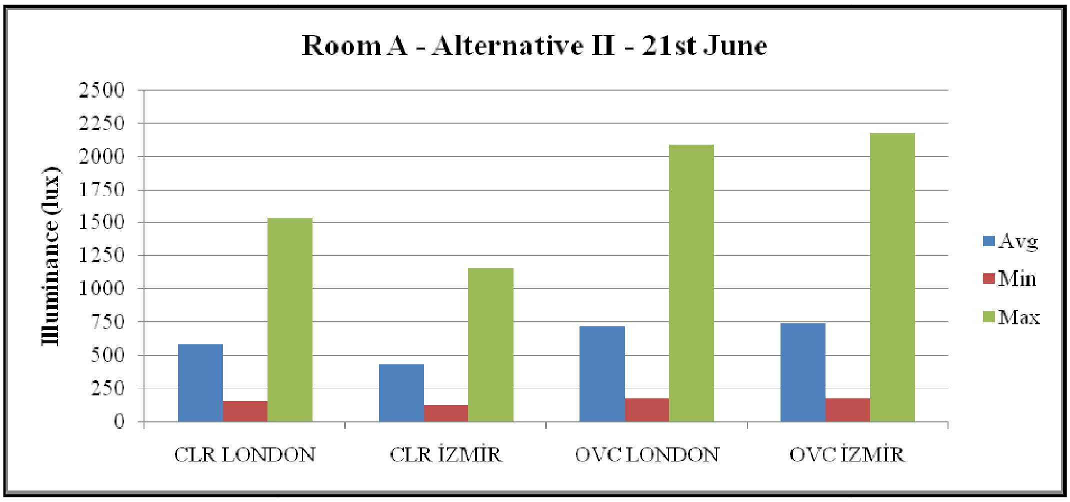


Figure B.6. Reference room A, material alternative II, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st June.

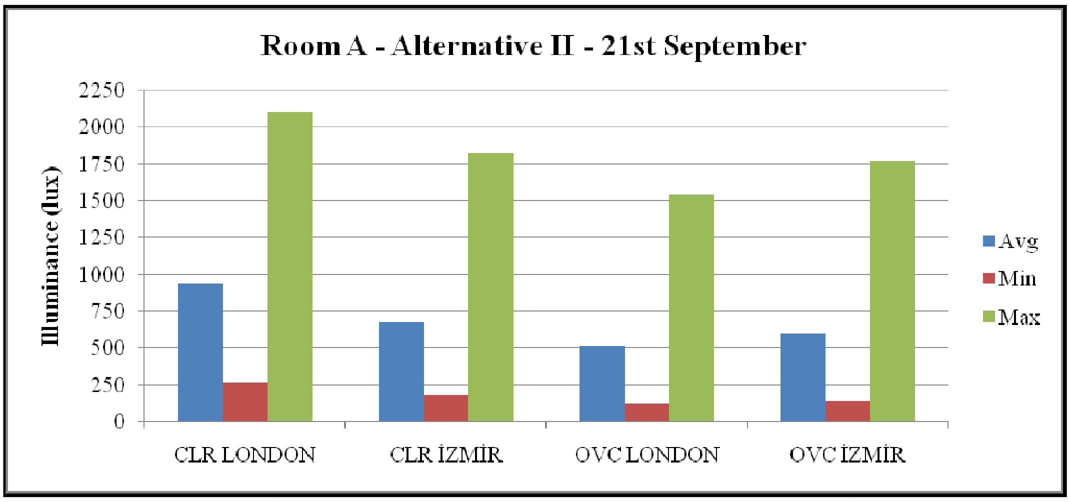


Figure B.7. Reference room A, material alternative II, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st September.

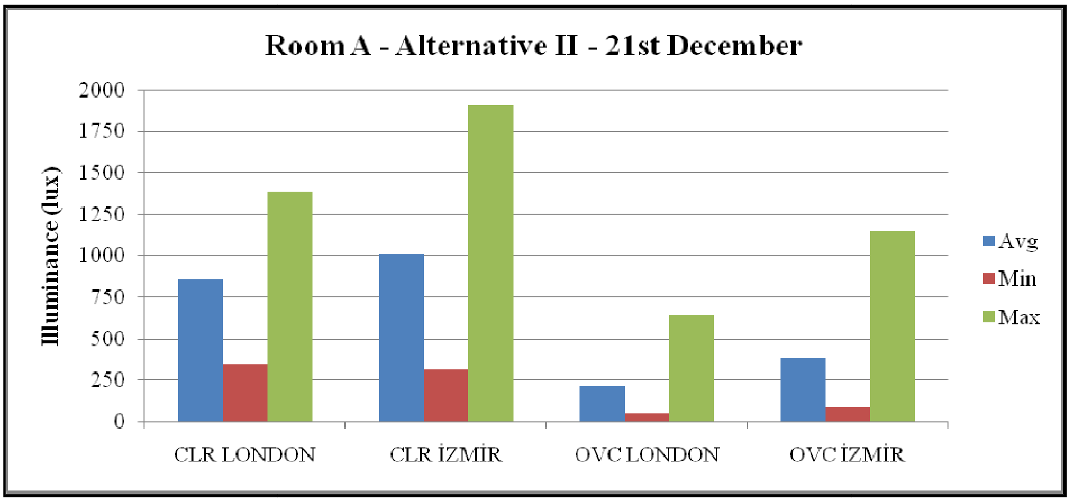


Figure B.8. Reference room A, material alternative II, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st December.

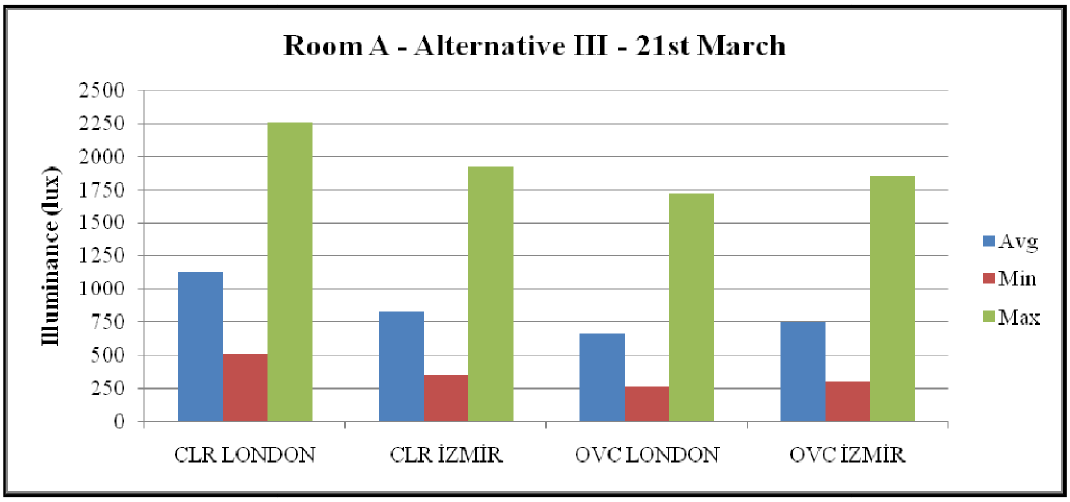


Figure B.9. Reference room A, material alternative III, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st March.

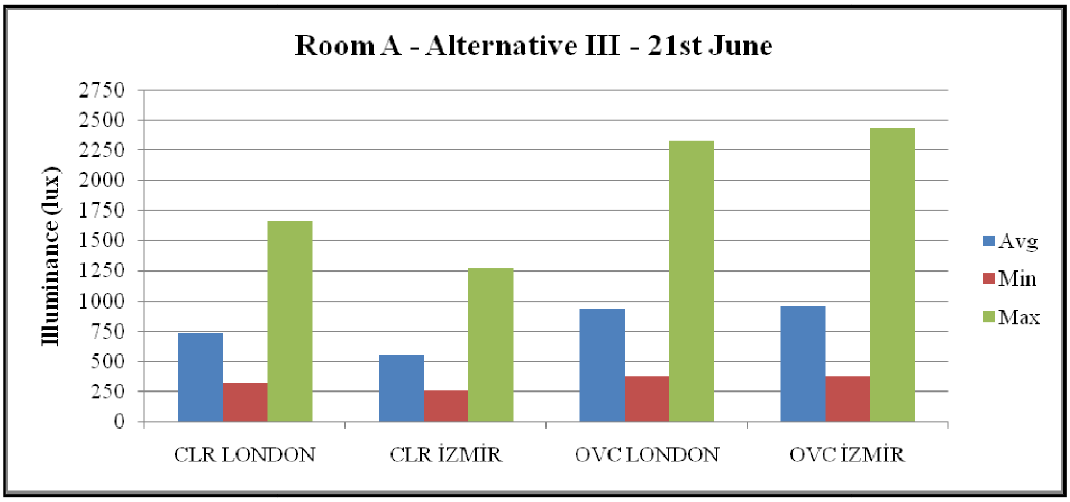


Figure B.10. Reference room A, material alternative III, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st June.

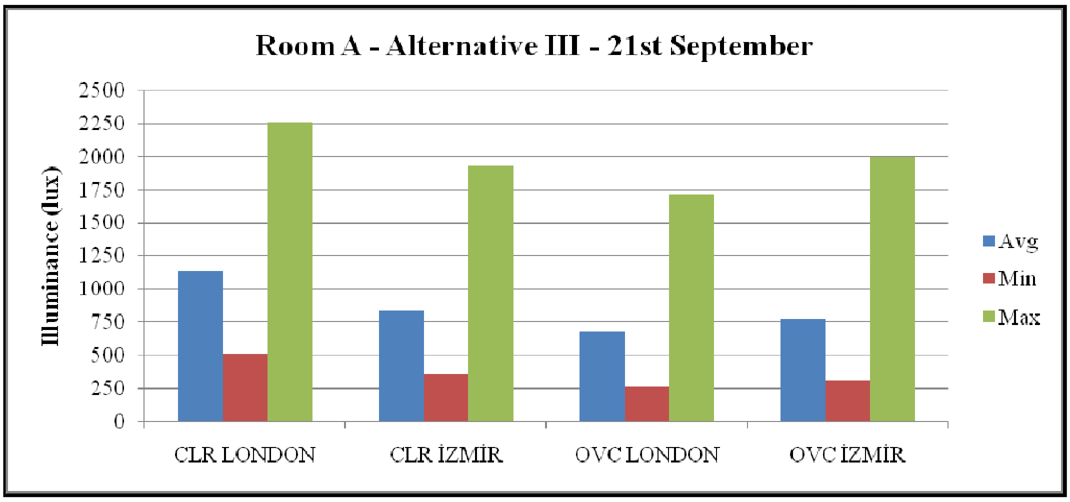


Figure B.11. Reference room A, material alternative III, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st September.

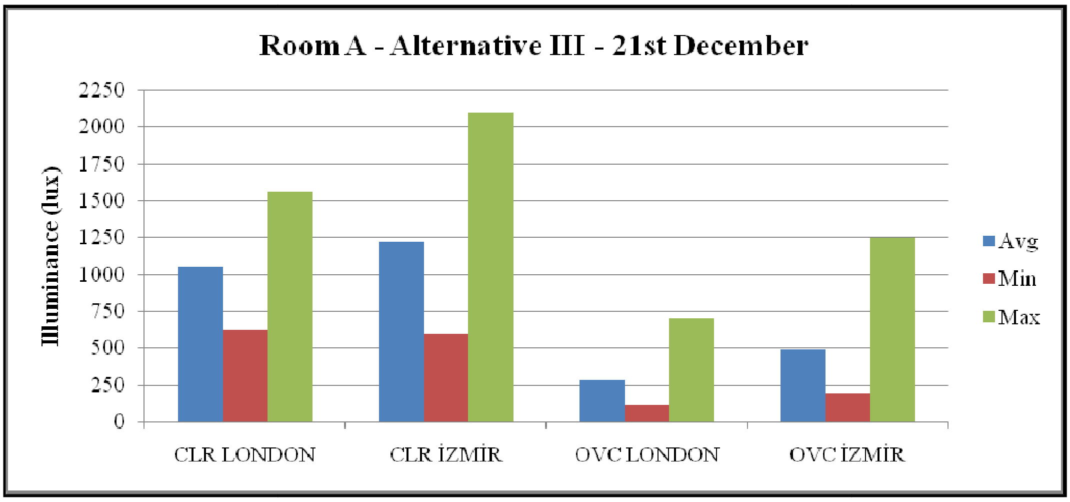


Figure B.12. Reference room A, material alternative III, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st December.

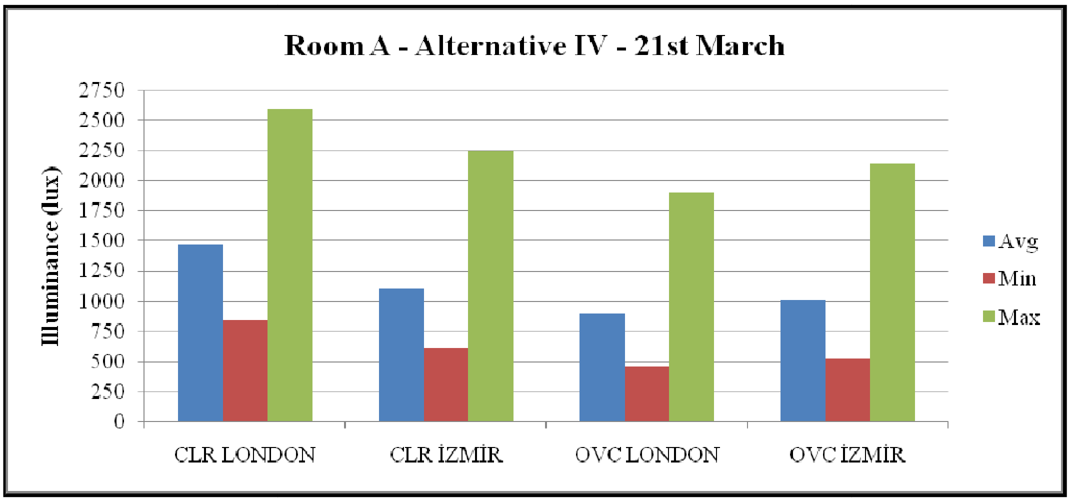


Figure B.13. Reference room A, material alternative IV, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st March.

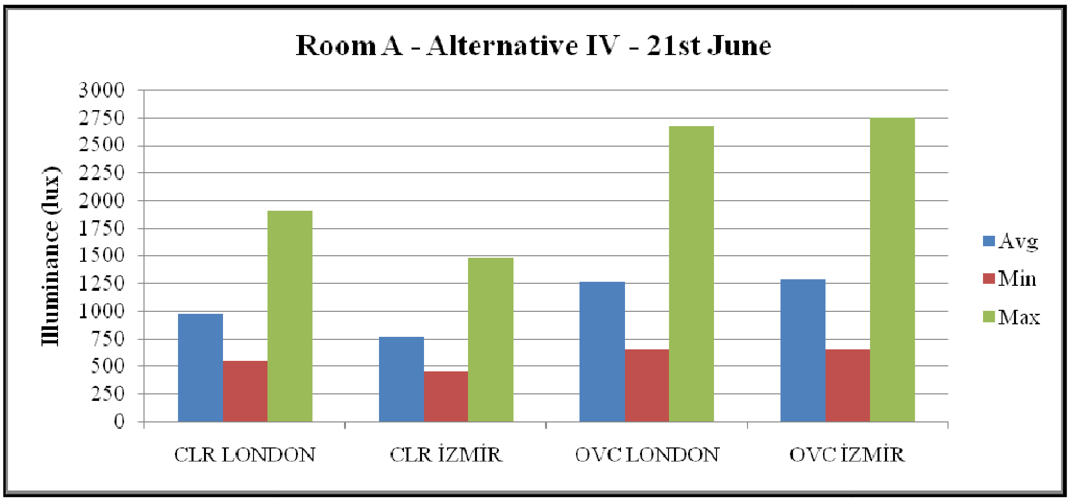


Figure B.14. Reference room A, material alternative IV, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st June.

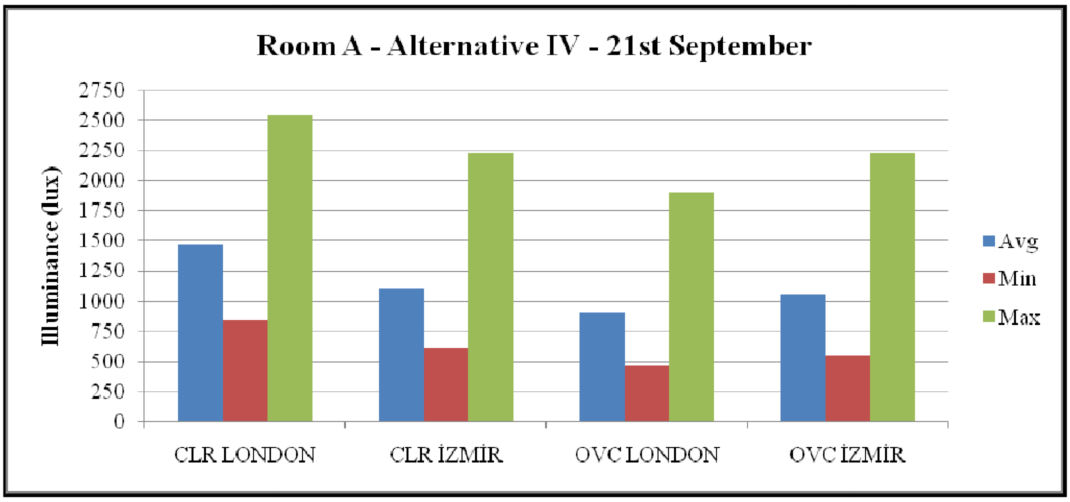


Figure B.15. Reference room A, material alternative IV, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st September.

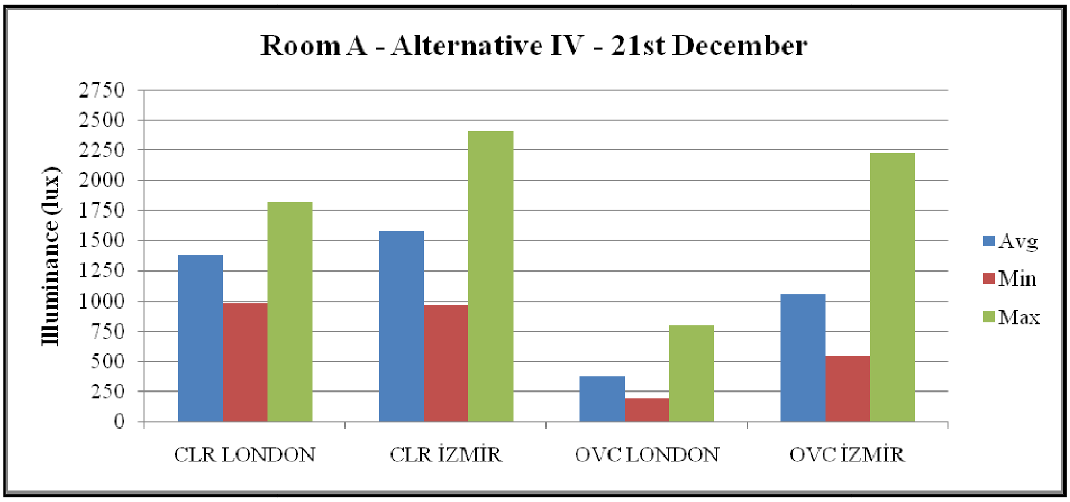


Figure B.16. Reference room A, material alternative IV, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st December.

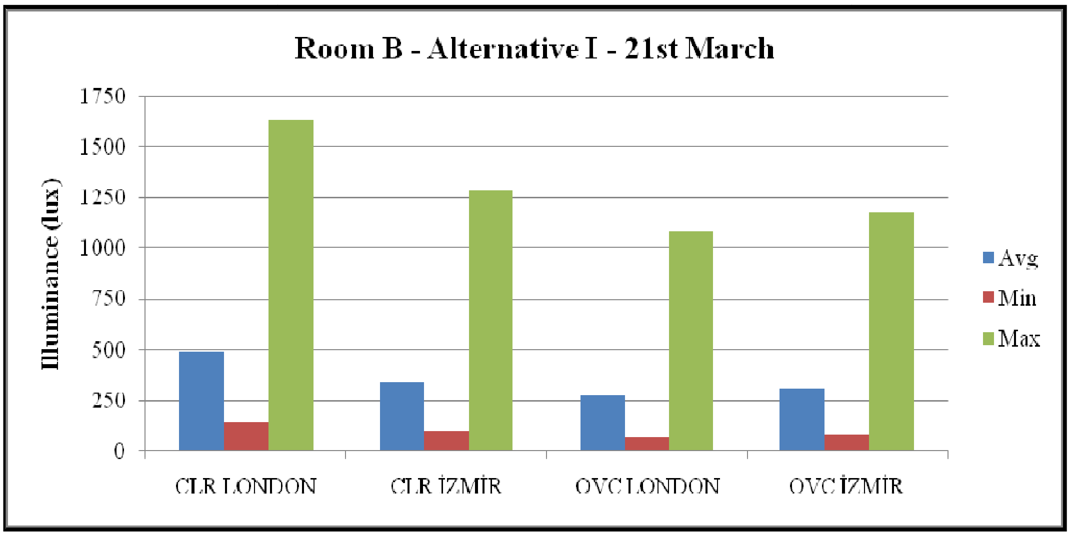


Figure B.17. Reference room B, material alternative I, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st March.

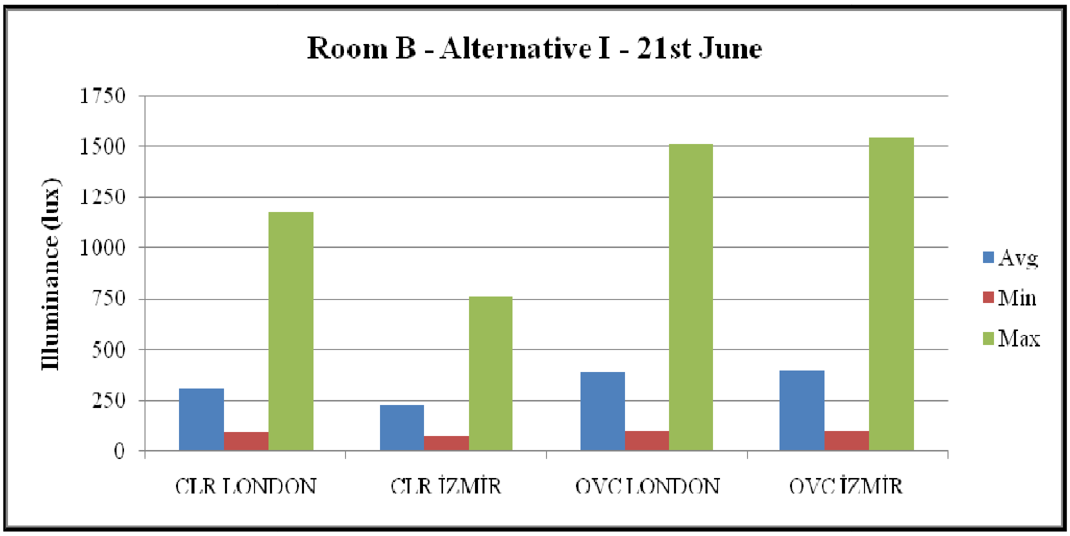


Figure B.18. Reference room B, material alternative I, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st June.

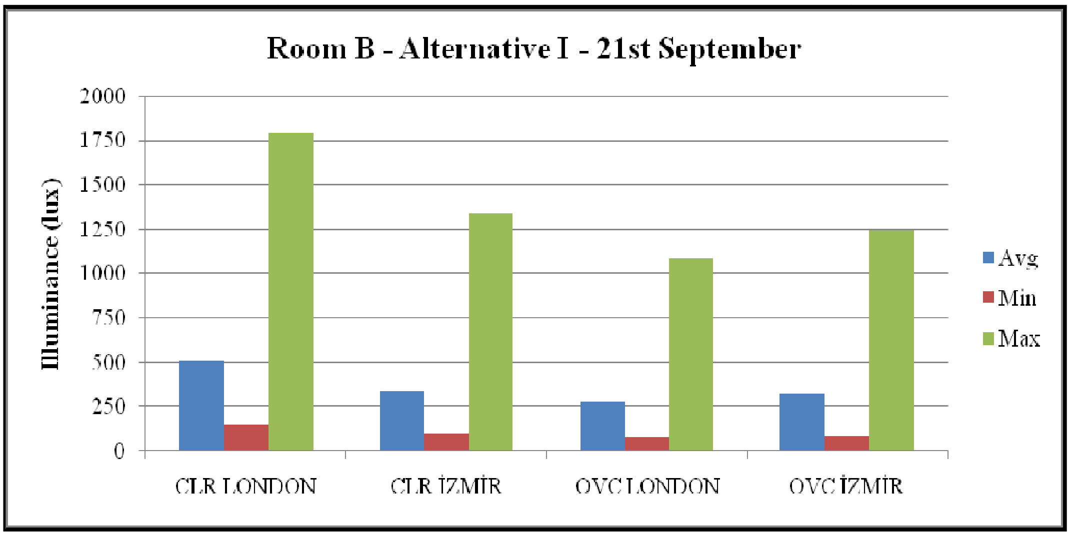


Figure B.19. Reference room B, material alternative I, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st September.

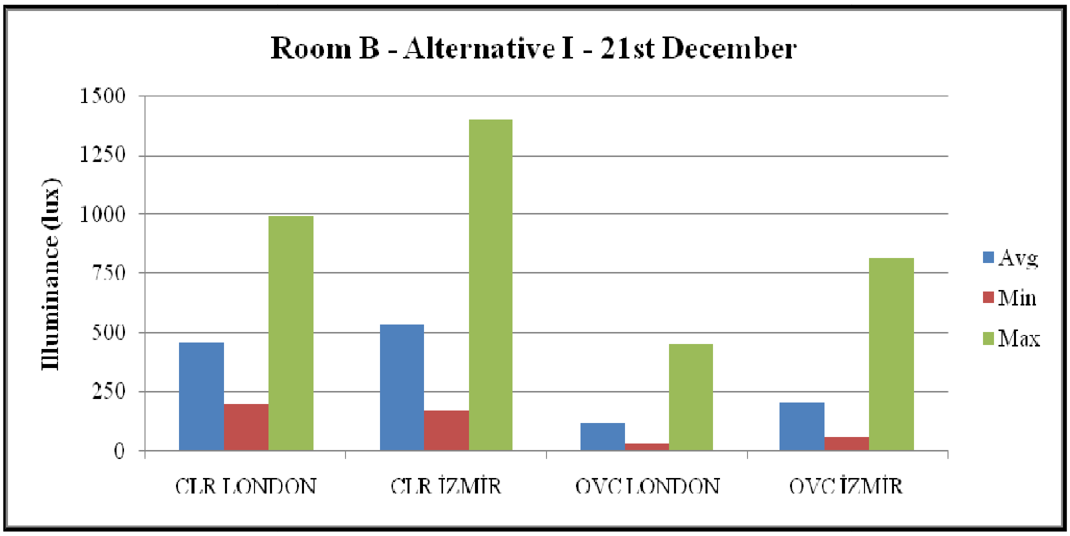


Figure B.20. Reference room B, material alternative I, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st December.

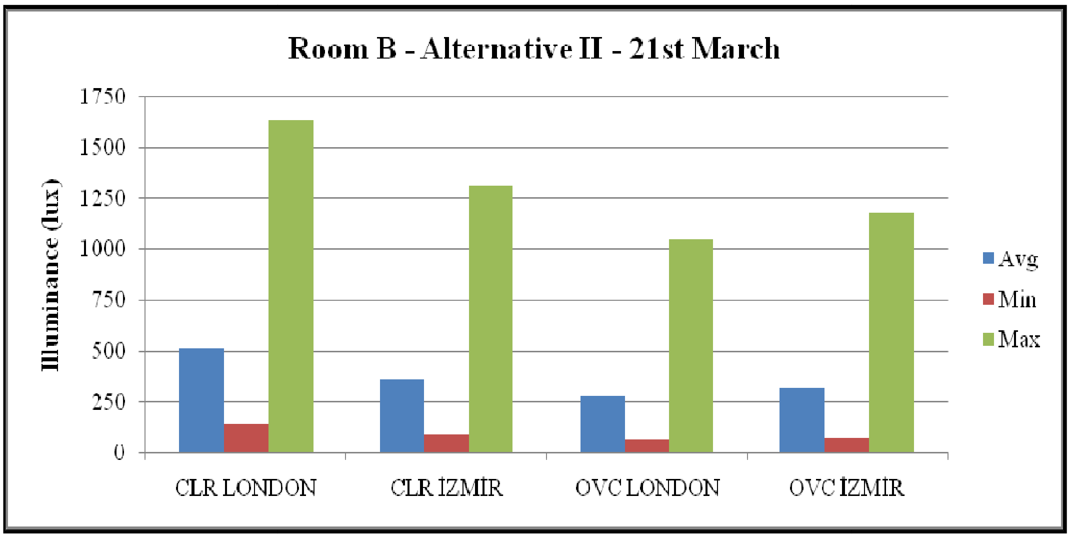


Figure B.21. Reference room B, material alternative II, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st March.

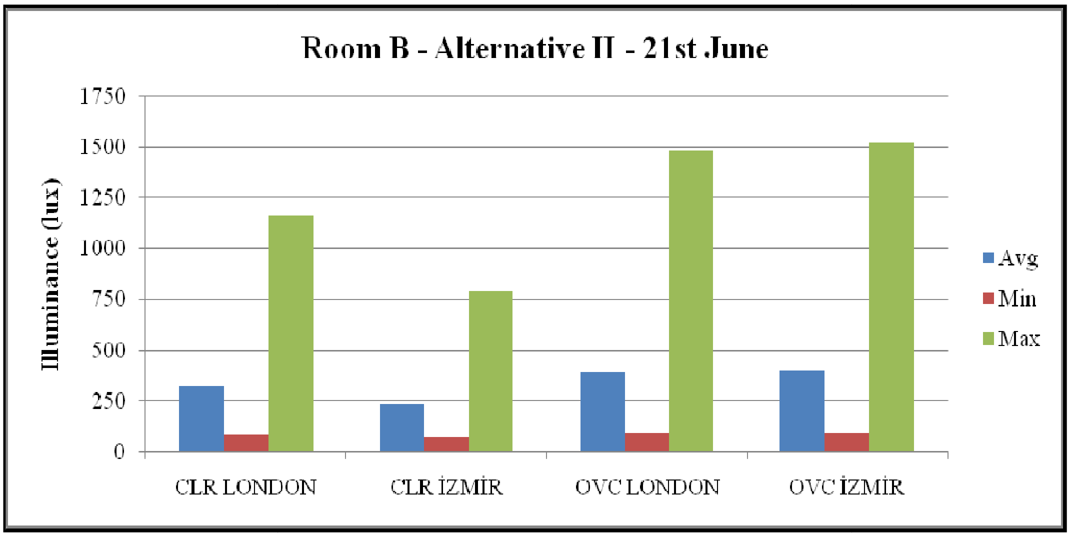


Figure B.22. Reference room B, material alternative II, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st June.

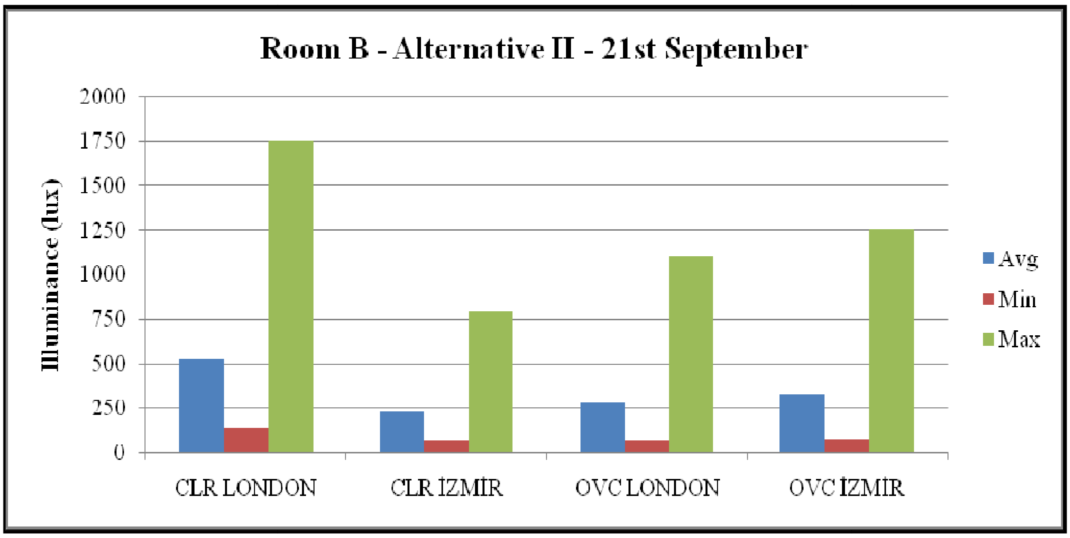


Figure B.23. Reference room B, material alternative II, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st September.

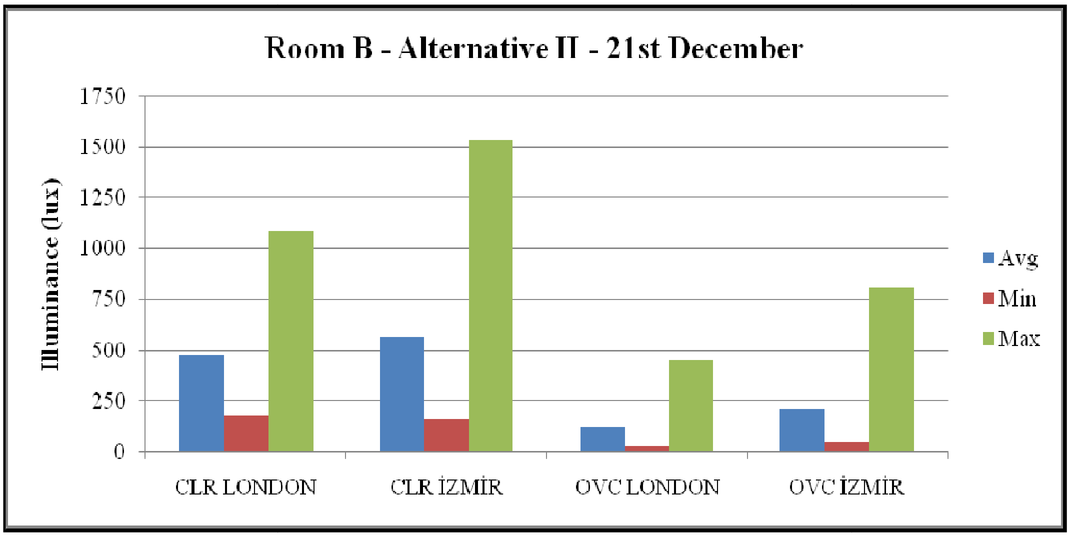


Figure B.24. Reference room B, material alternative II, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st December.

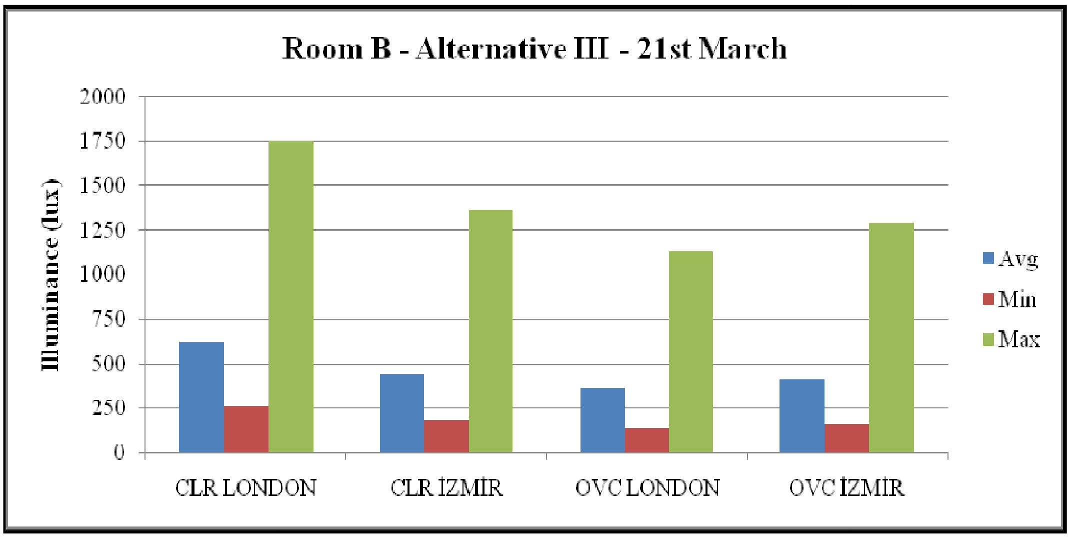


Figure B.25. Reference room B, material alternative III, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st March.

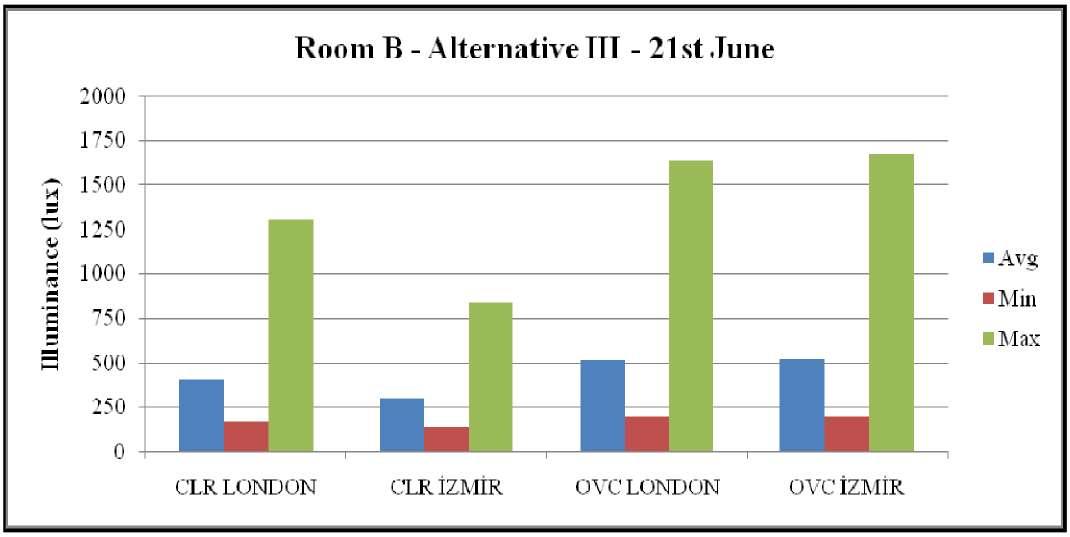


Figure B.26. Reference room B, material alternative III, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st June.

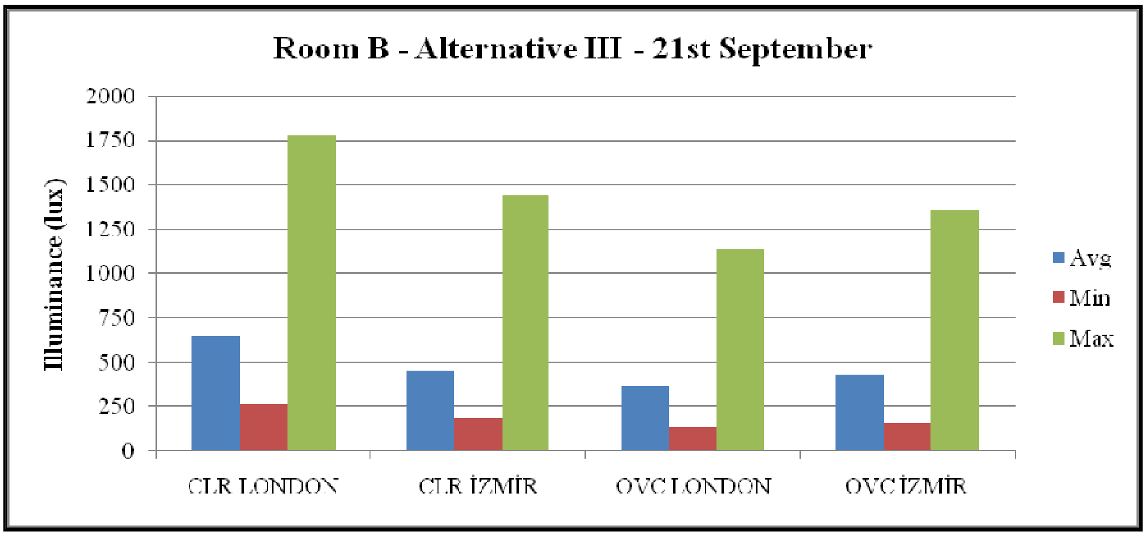


Figure B.27. Reference room B, material alternative III, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st September.

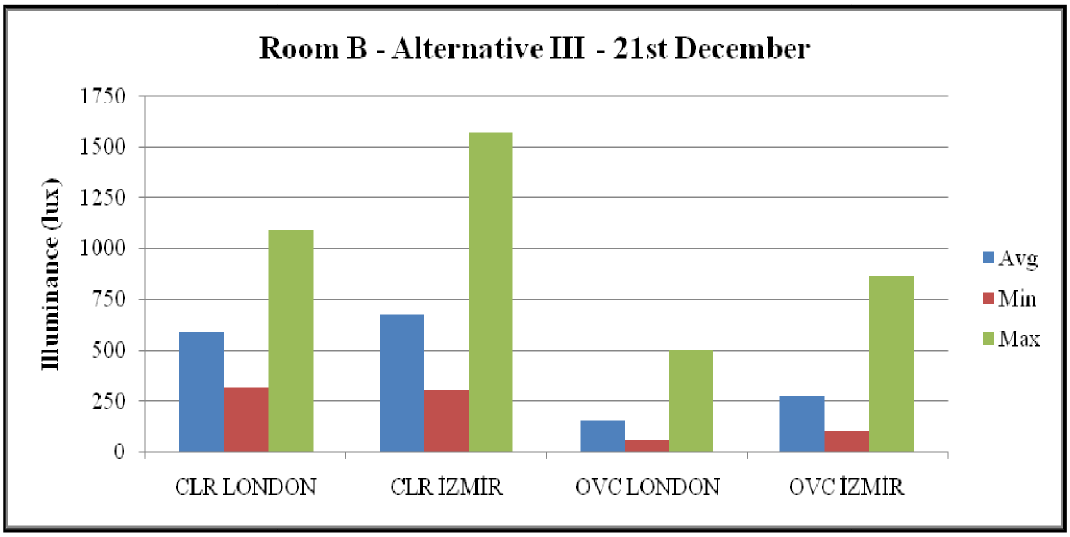


Figure B.28. Reference room B, material alternative III, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st December.

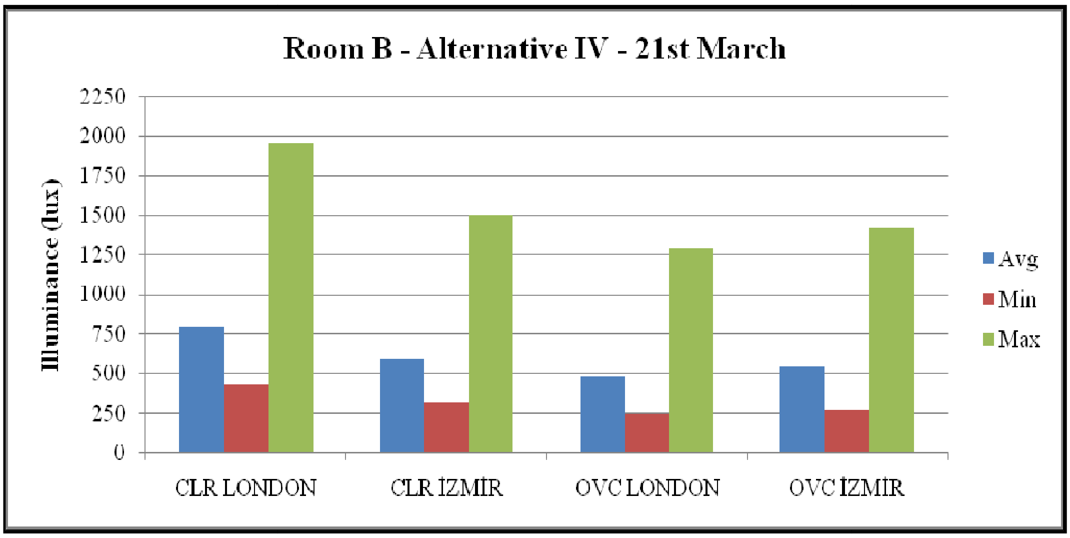


Figure B.29. Reference room B, material alternative IV, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st March.

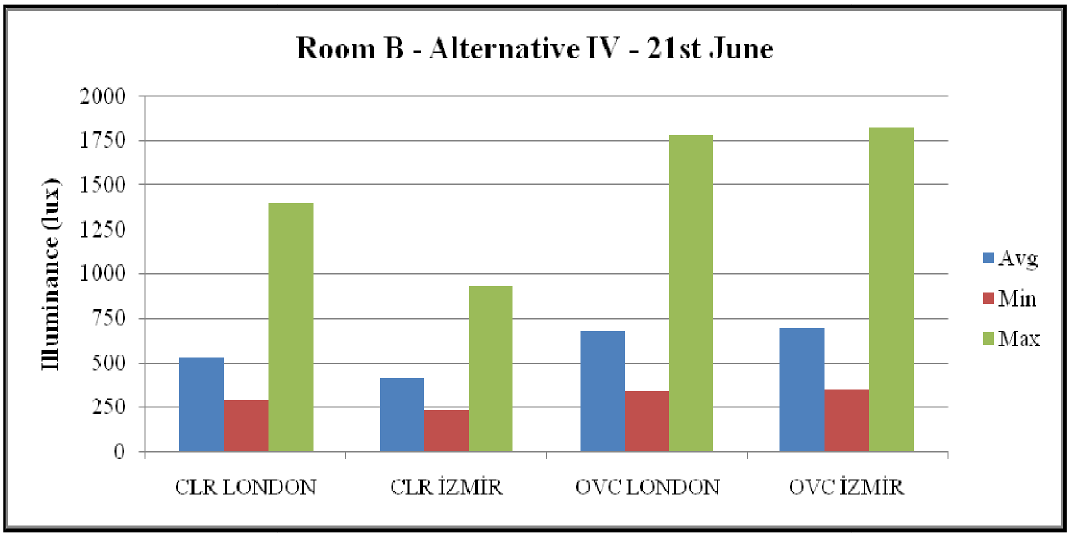


Figure B.30. Reference room B, material alternative IV, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st June.

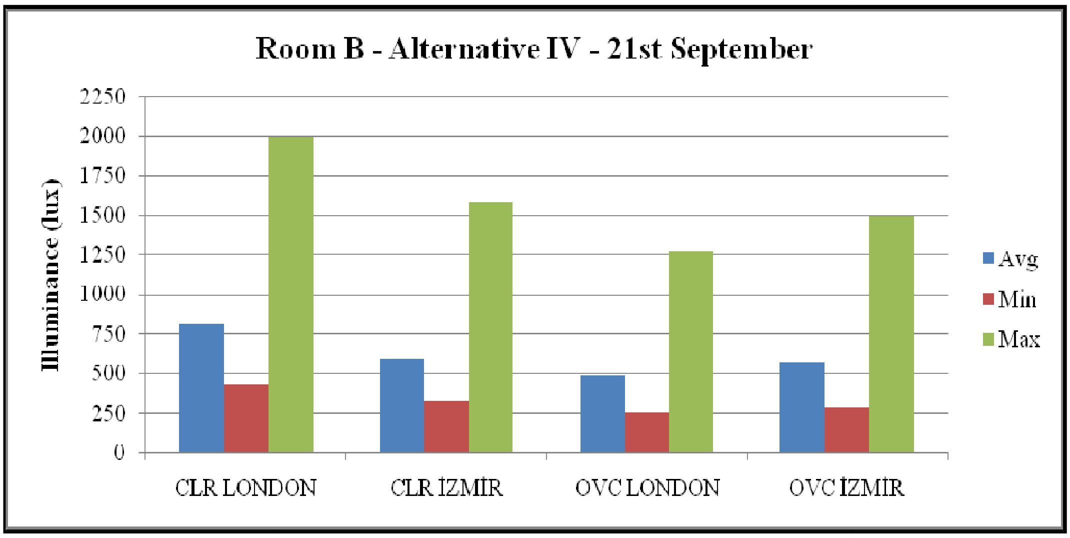


Figure B.31. Reference room B, material alternative IV, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st September.

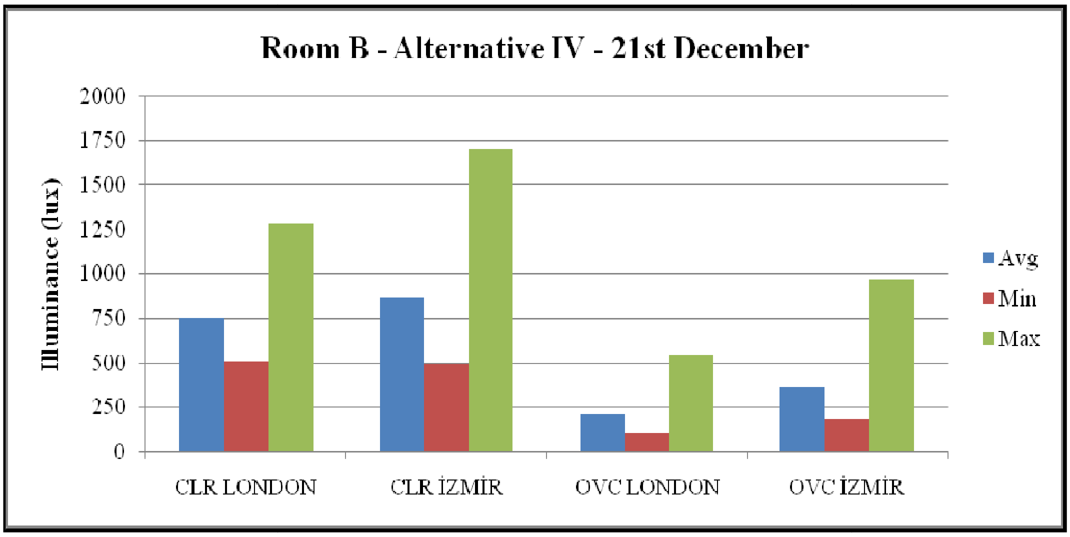


Figure B.32. Reference room B, material alternative IV, clear sky and overcast sky conditions for London and İzmir, average, minimum and maximum illuminance values in 21st December.