EVALUATING THE EFFECTS OF TINTED AND CLEAR GLAZING ON INDOOR ENVIRONMENT PERCEPTION, VISUAL COMFORT, AND VIEW QUALITY

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ABSTRACT

EVALUATING THE EFFECTS OF TINTED AND CLEAR GLAZING ON INDOOR ENVIRONMENT PERCEPTION, VISUAL COMFORT, AND VIEW QUALITY

Indoors are essential in people's lives because most of the time is spent here. Therefore, indoor quality and comfort should be provided. One parameter affecting this quality and comfort is lighting. Although the importance of natural lighting comes to the forefront in sustainability studies, many variables must be taken into account while providing successful lighting conditions.

This thesis investigates the effects of glazing transmittance, colors, and view types on visual comfort and occupants' indoor perception and impact of the specified glazing parameters on the view quality. Room types combined with various glazing and view types were modeled and asked people through a questionnaire about how interesting, pleasant, and bright the rooms and pleasantness of the view are perceived by people. While subjective opinions were analyzed with statistical methods, calculated illuminance and luminance values of the rooms were compared with survey results.

In the results, it was found that the glazing color has a significant impact on the perception of the interior. While the yellow glazing offers an interesting experience to the occupants, these rooms were not found pleasant. Yellow glazing combined with the street view was the most unpleasant interior. Medium-transmittance glazing type and the nature view was evaluated as the most pleasant room. Although the glass with the highest transmittance causes very high illuminance values in the rooms, it is most preferred room for brightness. As a result, perceptions change according to the characteristics of the interior, and they should be taken into account when designing these spaces.

ÖZET

RENKLİ VE ŞEFFAF CAMLARIN İÇ ORTAM ALGISI, GÖRSEL KONFOR VE MANZARA KALİTESİ ÜZERİNDEKİ ETKİLERİNİN DEĞERLENDİRİLMESİ

İç mekanlar, insanların hayatında önemli bir yere sahiptir çünkü günlük zamanın büyük bir çoğunluğu burada geçirilir. Bu yüzden iç mekan kalitesi ve insanların konforunun iyi bir seviyede olması sağlanmalıdır. Bu kalite ve konforu etkileyen en önemli parametrelerden biri de aydınlatmadır. Doğal aydınlatmanın önemi sürdürülebilirlik odaklı çalışmalar sayesinde ön plana çıkmış olsa da, bu aydınlatma sağlanırken aynı anda göz önünde bulundurulması gereken pek çok değişken vardır.

Bu tezde doğal aydınlatma aracı olan pencere camlarının geçirgenlik değerleri, renkleri ve pencere aracılığıyla gözlemlenen manzara türlerinin görsel konfor ve iç mekan algısı üzerindeki etkileri aynı zamanda belirtilen cam parametrelerinin manzara kalitesi üzerindeki etkileri birlikte ele alınmıştır. Çeşitli cam ve manzara tiplerinin birleştirildiği oda tipleri sanal ortamda oluşturulup anket aracılığıyla katılımcıların oylamasına sunulmuştur. Oylama odaların kullanıcılar tarafından ilginçlik, hoşluk ve parlaklık açısından; manzaralarınsa hoşluk açısından değerlendirilmesine yöneliktir. Anket aracılığıyla kişisel beğeniler istatistik analiz yöntemleriyle ölçülürken, odaların aydınlatma değerleri hesaplanarak karşılaştırmalar yapılmıştır.

Sonuçlarda, cam renginin iç mekan algısı üzerinde oldukça büyük bir etkisi olduğu bulunmuştur. Sarı cam insanlara ilginç bir deneyim sunarken, bu odalar hoş bulunmamıştır. Sarı cam sokak manzarası ile birleştiğindeyse en hoş olmayan mekan olarak belirlenmiştir. Orta geçirgenlikteki cam çeşidi ve doğa manzarasıysa en hoş oda olarak değerlendirilmiştir. Geçirgenlik değeri en yüksek olan cam, odalarda oldukça yüksek aydınlık değerlerine sebep olsa da, parlaklık açısından en çok tercih edilen oda olmuştur. Manzara kalitesi açısından en beğenilen oda en düşük geçirgenlikteki cama sahip doğa manzaralı odadır. Sonuç olarak, beğeniler ve algılar mekanın özelliklerine göre değişmektedir ve bu mekanlar tasarlanırken kullanıcı odaklı yaklaşımlar öne çıkmalıdır.

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CHAPTER 1

INTRODUCTION

1.1. Daylight and Human Perception

Daylight is the primary light source and plays a significant role in our lives. In order to create quality and comfortable environments for humans, proper and effective use of daylight should be achieved (Fakhari and Fayaz 2023; Dutta 2023). The major importance of daylight is that it closely matches human visual response as opposed to artificial lighting, making it the ideal light source for realistic color rendering. Besides, it is the best option in terms of lighting quality, spectral color composition, and variability. Behalf of good illumination conditions, humans respond positively to daylight and have a sense of happiness (Alrubaih et al. 2013; Li and Lam 2001). Moreover, daylight enhances overall health and well-being, reduces stress, and increases satisfaction indoors. Both the physiology and psychology of humans are benefited from exposure to daylight, and it is beneficial for general and visual health (Turan et al. 2020; Plympton, Conway, and Epstein 2000).

People spend most of their daily lives indoors, and the quality of these indoor environments has significant importance. One of the factors that affect the indoors is the lighting of the space (Sarbu and Sebarchievici 2013). Improved lighting conditions create better indoor conditions. These indoor environments have impacts on people, such as health, comfort, etc., so they should be designed carefully. The importance of daylight on humans was mentioned previously; thus, indoors with daylight rather than artificial light will be discussed.

The transition of daylight for interiors is provided by the windows. Windows allow for natural light and ventilation, as well as direct access to the outside view. There are several parameters of the windows affecting the lighting conditions, such as shape, area of the window, etc. The glazing type is one of these parameters that influence penetrating daylight (Liu et al. 2021). Different glazing systems, with varied colors (Chinazzo, Wienold, and Andersen 2021) or transmittance (Pineault and Dubois

2013) of glazing change human perception and comfort in the indoor environment. The glazing color has effects on such parameters as visual comfort, pleasantness, and light level. Moreover, the glazing transmittance affects the pleasantness, light level, beauty, and precision in the room.

Since windows are the gates that open to the outside, they are able to give information about such as weather conditions, time of the day, or view outside (Matusiak and Klöckner 2015). View types that are preferable by people can lead decrease in the discomfort glare, according to a study (Tuaycharoen, Barch, and Mcibse Ceng 2007). How the combination of glazing types and views would alter users' perception of the indoor environment and visual comfort is a significant topic for researchers.

1.2. Problem Statement

A key factor that affects a person's overall comfort, health, and productivity in an indoor environment is visual comfort (Mujan et al. 2019). Providing adequate daylight for interior spaces is an incontrovertible parameter in indoor environment quality. The way indoors are getting light is quite substantial for occupants. Complex parameters such as the hormone patterns, concentration, performance, and alertness of people are affected by the lack of daylight conditions and cause problems such as tension, anxiety, and negativity inside the buildings (Canazei et al. 2017; Küller and Lindsten 1992; Boubekri et al. 2014). Nonetheless, the high amounts of penetrating daylight give rise to glare issues and uncontrollable illuminance, which are visual comfort problems for occupants (Liu et al. 2021; Z. Li, Ju, and Xu 2015). A balanced daylight transition through the glazing needs to be ensured indoor environments.

There are many attempts to provide preferable indoor lighting conditions by researchers. Glazing and window types are substantial in creating intended indoor conditions (Moscoso et al. 2020). Smart window technologies have considerable value for achieving glazing and window variety since they have the ability to change if necessary (Casini 2018). People are satisfied in the cases when they can control glazing conditions by this means the glare and visual comfort conditions; however, the distorted colored conditions caused by color changes in the glazing cause displeasure on people (Jianxin 2021). Besides, darker glazing variations cause less natural light transmission indoors (Garg 2007). Thus, no conclusion regarding the optimum type of glazing color and transmittance could be reached.

Desirable view quality seen through windows has impacts on occupants, such as life satisfaction, well-being, improved mood, lower stress levels, and higher levels of productivity (Heerwagen 1986; Elsadek, Liu, and Xie 2020; Kaplan 2001). The comparison between green, nature views, and city or building views showed that occupants are more intended to choose the first one since it has more positive effects (Benfield et al. 2015). However, unnatural color rendering of tinted glazing to the outdoor views and their quality perceived by humans is another problem for view quality (Jianxin 2021).

The combination of preferred glazing transmittance, color, and view type hasn’t been considered from the occupants' point of view at once. When view types and glazing types that enhance visual comfort and provide indoor environment quality are investigated at the same time, both objective lighting conditions and subjective criteria can be satisfied. However, there is missing literature in this direction. Thus, the glazing production technology and its optical properties that are designed considering color and transmittance characteristics together should be developed in accordance with the human-oriented design. Because people’s visual comfort, overall health, and pleasures have started to appear with new lighting concepts in recent years.

1.3. Purpose of Study

Understanding human perception can be complex but a significant issue for quality living environments. The way people perceive their environment and satisfy with the conditions should be a key element in the design of interiors. Therefore, aspects should be understood and considered.

The objective of this study is to explore the appropriate colors and transmittance of glazing to control daylight for better indoor environments, provide visual comfort, quality view, and understanding of human perception. Since evaluation in real environments has too many complex parameters, such as weather or sky conditions which can change over time, the study is conducted with visual data via

Relux to explore the impact of tinted glass and the transmittance of window glazing. Thus, optimum glazing can be selected for users during the design phase, or environments where users can make changes through new technologies can be created.

The research questions of this study are summarized below;

- Do the color and transmittance of the glazing and the type of view have an effect on finding the place interesting, pleasant, or bright?

- Do the color and transmittance of the glazing have any effect on finding the view more quality?

- Which type of glazing is more effective in terms of providing preferable indoor environments and view quality?

1.4. Limitations

There are some limitations in the study. The spaces created in a virtual environment are used in the survey. Firstly, the virtual environment conditions do not fully overlap with the real environment. During the research, Relux was used both for objective lighting calculations and 3D renders of the rooms. However, evaluating the survey results when participants are in a real room may provide different results than looking at the images on a computer/phone/tablet screen. Various parameters, such as the model of the electronic device used by the participants, screen brightness, and the environment in which they participated in the survey, can affect the survey results. The limitation is caused by the method, which uses the simulated room renders instead of a real environment.

1.5. Structure of the Thesis

The second chapter consists of a literature review and starts with the theory of daylight and daylighting. The definitions of these terminations are explained. The main advantages and disadvantages of daylight are mentioned afterward. Then, the history and general function of windows are explained. To understand the features of the glazing, studies that worked on the transmittance and color of the glazing are investigated. Moreover, the studies that include view quality evaluation are explained. Since the human response to tinted glazing, transparency variation, and view quality is aimed to be found out, studies about human perception are focused on under 2.2.

In the third chapter, the method of the study is detailly explained. The simulation stages of the virtual room where the experiment will be conducted are summarized. To understand human perception better, the experiment contains a survey, and information about this survey is given. The participants of the survey are shortly mentioned, and the statistical methods used while evaluating this survey are explained.

Finally, the results of the survey are analyzed statistically, and objective calculations of the room are given in the fourth chapter. The results are explained in detail in this chapter. In the end, the discussion and conclusion of the study are summarized.

CHAPTER 2

LITERATURE REVIEW

In this chapter, daylight and human perception of it are explained in two sections which are specialized according to sub-section definitions.

2.1. Theory of Daylight and Daylighting

Baker et al. define daylight shortly as "The combination of the diffuse light from the sky and sunshine" (Baker and Steemers 2002). In addition to Baker’s definition, in Reinhard’s book, some information and definitions are given to help understand daylight clearly. First of all, the origin of all daylight is the sun. Under that, direct sunlight means solar radiation from the sun, which can directly arrive at a location through the earth’s atmosphere without scattering. On the contrary, diffuse daylight term means the light that is being scattered in the earth’s atmosphere. Daylight is the visible section of sun's spectrum between approximately 380 and 780 nanometers (Reinhart 2014).

Daylight passed through many stages in history before reaching its clear definitions today. The needs of pre-industrial humans were different from those of the present. There wasn’t any significant activity that required specific daylight conditions in early types of indoors, such as shelters. The first designs of daylight started with religious buildings. Later, the development of the window was significantly affected by the production of glass since it allowed the reach the view outside and daylight while separating the indoor climate from the outdoor. The Industrial Revolution created significant changes in daylight necessities and solutions, and glazing technology gradually developed. With the help of decreasing costs and increasing technology, glass manufacturing became more common (Baker, Fanchiotti, and Steemers 2015).

To understand the use of daylight, it is necessary to be informed about daylighting. Daylighting is defined by Reinhart as “the controlled use of natural light in and around buildings," and the term is explained as "a derivative of the noun daylight and implies a process by which direct sunlight and diffuse daylight and reflected, scattered, admitted and/or blocked to achieve a desired lighting effect." Also, the author explained that for an area to be referred to as being daylit, there must be a distinct amount of available daylight for that activity. However, each person's definition of good lighting or a well-daylit environment is unique and changes over time and in a particular cultural environment (Reinhart 2014). Daylighting is an effective and convenient method for providing energy efficiency and sustainability for buildings. Together with its environmental aspects, it is a prospering approach for better visual comfort.

Additively to these definitions, their design should be explained for a better comprehension of daylight. Lighting design includes the composition of brightness and color in the entire visual field rather than window design or determining the luminaires. It is used to provide information, and its purpose is to help occupants to understand the indoor environment. The way a space is perceived or a visual task is completed changes with not only lighting but also how it interacts with the room's shape, surface colors, patterns, etc. That is the reason why the success of the lighting scheme depends on some variables. Lighting design may be complex; however, it is a necessary component of the entire architectural design (Tregenza and Loe 2013).

2.1.1. Daylight and Windows

Definitions of daylight and detailed information about windows are explained in two sections which are specialized according to sub-section definitions.

2.1.1.1. Advantages and Disadvantages of Daylight

Daylight can be evaluated as the best source of light for accurate color rendering, and it's the only light source that most closely matches human visual response rather than artificial lighting. In addition, daylight has importance for quality lighting, spectral composition, and variability. Also, it is beneficial for creating high illuminance. People respond positively to daylight because it gives them a sense of happiness and good illumination conditions. Thus, better natural lighting contributes to creating enjoyable and inviting indoor environments (Alrubaih et al. 2013; Ruck et al. 2001). Besides, the aware use of natural light in buildings increases energy efficiency by reducing lighting and thermal loads since there are increasing concerns about global warming, sustainability, etc. (Ruck et al. 2001).

Since earlier times, daylight has been seen as a need for people. The positive effects of daylight, such as better health and well-being on humans, have long been appreciated. Much as environmental factors impact human health, people benefit physiologically and psychologically from exposure to natural light. Thereby, daylight is one of the main issues in architectural spaces while designing, and it should be considered during the design phase for better building results (Turan et al. 2020). Providing better conditions to these occupants for their psychological and physiological well-being is a priority. Adequately designed and used daylighting systems can provide building occupants with many benefits, such as better health, productivity, etc. (Edwards and Torcellini 2002).

Some of the building facilities have been investigated regarding proper daylighting conditions. Firstly, in office environments, visual comfort and productivity increase, and stress levels decrease with the help of appropriate lighting conditions (Liu et al. 2021; Woo et al. 2021; Boubekri et al. 2020). Another building type, classrooms, are quite important places for student learning activities. In the classrooms, daylight may have effects on satisfying the visual, non-visual, and perceptual needs of students and instructors and developing health and performance. Studies showed that proper daylight conditions helped students with improved vision and perception, better health conditions, comfort, and productivity (Namburu and Kumar 2013; Lo Verso et al. 2021; Rahman, Mozammel, and Tuhin 2019). Sales facilities such as shopping malls require quality lighting as well. The study about a shopping mall illuminated with daylight showed that with the help of natural lighting, better color rendering conditions occurred for the products that are being sold. Reaching daylight increased user satisfaction and mood; and made the place more attractive. Also, being able to see the outdoors through windows creates a preferable environment for both customers and staff (Pizarro 2019; Mayhoub and Rabboh 2022). Daylighting also benefits the recovery of patients in hospitals, decreased duration of hospital stays, quicker recovery, less need for pain relief, etc. In addition to the benefits of daylight for patients, hospital staff considers that daylight is helpful for their work in patients’ room and patients' health. That ends up with better results in healthcare spaces under daylit conditions (Strong et al. 2020; Alzubaidi et al. 2013). To sum up, daylighting has various advantages in various types of building facilities.

Besides the previously mentioned benefits, there are some drawbacks to being exposed to daylight. Due to daylight’s variability, intensity, and thermal component, it can cause major issues such as creating an uncomfortable amount of glare, causing visual discomfort, and reducing the desire for daylight among the occupants (Aries, Aarts, and Van Hoof 2013). With an increase in the window area, even though available daylight and visible outdoor view increase, glare and overheating may increase at the same time (Reinhart 2014). Therefore, windows are determining factors in whether daylight causes advantageous or disadvantaged situations. High incoming daylight levels in interior spaces can be uncomfortable in visual conditions as well. These daylight levels can be caused by the sky conditions, intensity, distribution, etc. Discomfort glare can be caused by the contrast between the source of daylight (windows) and the surroundings of it or a non-uniform luminance distribution in the viewpoint (Bellia et al. 2008). In addition to that, excessive heat gains and big amounts of cooling loads may occur due to daylight conditions (Galal 2019). Also, the other negative effects are uncomfortable solar glare and disturbing luminance conditions on screens. Therefore, the daylight design for buildings and its distribution is very important for indoor tasks of people. The design of daylight is supposed to start at the design's conceptual part while deciding the building's shape, proportions, and openings. Climate, surrounding buildings, and availability of natural light are some of the factors that affect daylight design (Ruck et al. 2001).

While evaluating daylight, it shouldn’t be seen as a single indoor lighting solution. Even though daylight has been seen as the primary source of light, the first use of artificial light was fire, at least ever since basic shelters were used by humans. Artificial lighting, however, was being used only during the nighttime. The availability of electric lighting increased near the end of the 19th century. The indoor air pollution and fire risks due to older light techniques have been decreased. With the industrialization of the world, especially in the previous 50 years, humans started spending their time mostly indoors, such as in offices, schools, and factories, with artificial light. These indoor activities using artificial lighting have become a concerning issue lately. There are two main reasons why these two issues have become important. The first is that people are not exposed to daylight during the daytime, and it may negatively affect them physiologically and psychologically. The other reason is the increase in energy use due to artificial lighting. This energy use also costs many expenses (Baker, Fanchiotti, and Steemers 2015). However, with the development of fluorescent lighting, lighting efficacy was increased, and costs were decreased. Thus designers started losing interest in daylight since large window glazing areas were already being accused of heat losses. Yet, with the abandonment of daylight, the quality of the indoor environment is reduced. Besides, with artificial lighting as a second common light source, energy consumption has increased.

Anyhow, with growing concerns about environmental issues, daylight became an issue again (Baker, Fanchiotti, and Steemers 2015). In addition to its environmental aspects, the human reaction should be taken into consideration. It is believed that working by daylight ends up with less stress and less discomfort, while working in artificial lighting conditions is harmful to human health (Ruck et al. 2001). A survey study investigated peoples' opinions about daylight and artificial lighting. Three of the questions out of 29 in the survey were about choices of artificial light and daylight. Results showed that most occupants preferred working in daylight alone, some chose a combination of daylight and artificial lighting, and a minority chose electric lighting. Thus, the study concluded that when more daylight is provided, there will be less need and desire for artificial lighting for the occupants (Roche, Dewey, and Littlefair 2000).

Daylight has been evaluated according to both advantages and disadvantages under this subtitle. By taking into consideration this information, comfortable and healthy use of daylight can emerge in indoor environments.

2.1.1.2. General Aspect to Windows

In the history of architecture, windows were the vehicles that allowed the transition of light, air, and heat between indoor and outdoor spaces. Their types have changed and developed over time. However, their main purpose, which is letting the daylight in, has never changed. Even though the glass was discovered in 3000 BC, using them as glazing in window openings was not known until the Roman period. Before that time, different materials were used, such as thin layers of marble, mica, or oiled paper. After new construction methods in England during the modern movement in the 1930s, window and glazing options developed a lot, and it was possible to use glass at the corners of the structure and create a relationship between indoors and outdoors (Phillips and Gardner 2012). The thermal performance of windows was not an issue for designers or manufacturers until the 1970s. Since that time, the research and production of windows became necessary, and heat and light transfer properties, energy performance, and positive effects on buildings started progressing (Arasteh 1994). With the developments in technology, new types of glazing have emerged to improve glazing performance in buildings. These technologies include both static and dynamic coating applications. Static coatings include glazing types such as anti-reflective, self-cleaning, low emissivity, electrothermal, and photothermal meanwhile, dynamic coatings include thermochromic, photochromic, electrochromic, gasochromic, and hydrogels (Khaled and Berardi 2021).

Windows are critical since they are the connection between the outside view and the indoor environment (Ruck et al. 2001). Their main functions have been defined as admitting the daylight and showing the outdoor view in the book Daylight in Architecture. Thus, windows have crucial importance for architectural spaces. Since the windows present a view outside, outdoor air, daylight, etc., humans feel more safety indoors with windows (Knoop et al. 2020). A building without windows is not a preferable option in terms of the visual and biological effects of daylight (Hee et al. 2015). A study that was conducted in classrooms without windows showed that without daylight, basic hormone patterns might have problems. This results in loss of children’s concentration or co-operates and even problems with body growth (Küller and Lindsten 1992). A similar study was carried out in office environments with and without windows. At the end of the research, workers in a windowless office environment could sleep less than the ones in offices with windows. Therefore, due to lack of daylight and poor-quality sleep conditions, workers started having health issues such as higher levels of cortisol in the evening, high levels of fatigue, lower performance, alertness, concentration, etc. (Boubekri et al. 2014). These studies show that windowless spaces with no daylight have major negativity on occupants.

Earlier studies proved the significance of windows for the indoors; however, a successful window design and its features must be considered for the quality of daylight and the indoor environment. In 2021, Liu et al. conducted a study about different windows for comfortable lighting. According to the findings of the various window shapes with the same area, rectangular windows create the highest amount of glare, while circular and square windows create slightly less glare than rectangular ones. Also, circular and arched ones create less glare, so that they might be used for the reduction of glare. The same study revealed that when the transmittance value increases, the glare, and indoor illumination reach higher values (Liu et al. 2021). Another current study investigated the relationship between window sizes and room perception. The results revealed that medium to large windows was preferred in order to create a more pleasant, interesting, bright, and adequate amount of view for the occupants. It was emphasized how significant window size is for users to assess places (Moscoso et al. 2020). Therefore, it is not enough for indoors to have a window, but they should have the appropriate features for the indoors.

2.1.2. Parameters of Glazing

The glass material is accepted as neither liquid nor solid. The use of this material in the buildings is under the transparent materials group. Due to this transparency, the interaction with light might be considered (Elkadi 2016) since glazing properties have a vital role in daylight penetration indoors. Clear, colorless glazing allows the highest amount of daylight to pass through and offers an unobstructed view of the sky. However, this type of glazing also allows direct sunlight to enter the building, which can be intense and potentially problematic (Baker, Fanchiotti, and Steemers 2015). Thus, color and transmittance features and options should be evaluated. The sub-titles will explain the transmittance and color properties of the building glazing element.

2.1.2.1. Light Transmittance of Glazing

Sunlight coming through the window can be reflected, transmitted, or absorbed. In this section, the transmittance of the glazing will be investigated. The definition of transmittance in the Merriam-webster dictionary is “the fraction of radiant energy that having entered a layer of absorbing matter reaches its farther boundary” and the light transmittance definition is “the ratio of luminous flux transmitted through an area of material to that incident on it” in the Dictionary and Architecture and Building Construction Book. The symbol of the transmission is shown by the symbol with “τ” (the Greek letter tau) (*Merriam-Webster.com Dictionary*; Davies and Jokiniemi 2008). The visible light transmittance factor is a measurement of the percentage of visible light that passes through a window. The visible light transmittance typically ranges from 60 to 80 percent for clear glass (Elkadi 2016). The higher transmittance values allow more natural light to come inside; however, it may cause glare for occupants. As can be seen in Table 2.1, there are various glazing types with different transmittance values. These examples of glazing may have different uses in buildings in terms of their aim. A range of glass types has been created due to the nature of light and the way different materials absorb or transmit it. These glass types vary in their capabilities and applications because of their ability to selectively transmit ultraviolet, visible light, and near-infrared wavelengths. The visual features and performance of glass are determined by its ability to filter or allow these specific wavebands of light from the sun (Elkadi 2016).

Buildings often have glazing with lower transmittance than clear glass to reduce solar heat gain, but this can also reduce natural daylight and increase energy use for heating and lighting. In locations where cooling needs outweigh heating needs, using low-transmittance glazing can be beneficial. However, there is a limit to how low the transmittance can be before the glazing becomes opaque and fails to serve its intended purpose of providing daylight and views as a window. According to Boyce’s study, this minimum acceptable transmittance is determined in the range between 25% to 38% (Boyce et al. 1995).

Table 2.1. Examples of Guardian Glass Products (clear glazing)
(Source: Guardian Glass, Digital Foldout)

			Visible Light					
Glazing	Layer	Color	Transmission (%)	Reflection Outside	Reflection Inside	CRI	Solar factor	U-Value
SNX 60	Double	Clear/Neutral	60	13	13	93	29	1
SNX 60	Triple	Clear/Neutral	54	15	16	92	27	0,5
SN 70S	Double	Clear/Neutral	70	11	13	95	39	1
SN 75	Triple	Clear/Neutral	66	14	16	95	37	0,5
HPNeutral 41/33	Double	Neutral	41	22	12	91	33	1,40

2.1.2.2. Tinted Glazing

Tinted glass is made by adding metal oxides to molten glass, resulting in a variety of colors. Some colorant examples are iron for green, brown, and blue; gold for red; manganese for purple; etc. This type of glass has filtering properties that can reduce eye strain caused by bright light, as well as absorption properties that can decrease the amount of solar energy transmitted through it when exposed to sunlight. For example, green-tinted glass allows more visible light to pass through while blocking infrared radiation. The level of tint can vary depending on the thickness of the glass, which affects its ability to transmit light and solar radiation. Darker tints can decrease the heat transmitted into a building, but they also reduce the amount of natural light that passes through (Garg 2007).

The most commonly used tint colors for windows are grey and bronze. These tints have the same effect of reducing the amount of light and heat that enter buildings. Compared to other colors of tint, blue and green-tinted windows allow more visible light to penetrate while still providing some reduction in heat transfer. Therefore, these tints have a slightly better balance between light and heat reduction compared to other colors of tint (Elkadi 2016). Some examples of varied colored glazing and their transmission values have given in Table 2.2.

Table 2.2. Examples of Guardian Glass Products (tinted glazing)
(Source: Guardian Glass, Digital Foldout)

			Visible Light					
Glazing	Layer	Color	Transmission (%)	Reflection Outside	Reflection Inside	CRI	Solar factor	U-Value
SN 70/35	Double	Neutral Blue	70	14	16	94	35	1
HP Royal Blue 41/29	Double	Deep Blue	40	27	27	95	29	1,1
HP Bronze 40/27	Double	Bronze	40	15	26	90	27	1,10
HP Light Blue 62/52	Triple	Neutral Blue	56	18	15	95	42	0,7
HP Amber 41/29	Triple	Bronze	37	26	20	87	26	0,60
Solar Gold 20	Double	Gold	21	24	12	93	18	1,1
HD Light Blue 52	Double	Neutral Blue	47	19	20	98	39	1,10

2.1.3. View through Windows

While windows provide air, light, and heat between indoor and outdoor environments, they make the outside view available for indoor occupants. This visual contact that the windows and its benefits and characteristics will be evaluated in further sub-titles. These characteristics include components of movement, horizontal stratification, design, dynamic changes in views based on observer-related parameters, and view quantity. They also include content-related criteria such as naturalness, movement elements, and view quantity (Abd-Alhamid, Kent, and Wu 2023). All these characteristics of view make indoor occupants get in touch with the outdoor views and have some impact on them.

2.1.3.1. View Quality and Assessment

The content of the view and how it is supposed to be analyzed have been explained by Markus according to its layers (Figure 2.1). The first layer is defined as the sky, which helps people follow the weather, time of the day, and seasonal variations. The second one is mainly the horizontal view of the city or landscape. These views inform people about the environment in detail. The last layer is the living activities below, such as humans, cars, etc. (Markus 1967). Later on, other studies about view quality assessment emerged in the literature. According to a survey study that evaluated the determinant factors of view quality were defined as the view distance, amount of view layers, the quality of landscape/elements, and the arrangement of the view. However, some parameters stayed out of these factors, such as the width of the view, including vegetation, and green area, the existence of water elements, etc. (Matusiak and Klöckner 2015). Recently, the importance and the assessment of window view quality were discussed in another study, and three main components were identified as content, access, and clarity. The first one included nature views, human-made views, and movement in the views. These are the components that a view can include, and these components affect the satisfaction of occupants on view. The access parameter focuses on the factors that affect the amount of view, such as angles of view, indoor layouts, furniture arrangements, or observer location available for occupants. The last one, clarity, investigates the role of façade materials, façade controls for glare, privacy, etc., on the appearance of view content. The study also explained the methods to evaluate the view quality, including laboratory studies, image-based, and simulations (Ko et al. 2022).

Figure 2.1. Layers of a view
(Source: Markus 1967; Matusiak and Klöckner 2015)

Recently, in the LEED for Building Design and Construction Handbook, the definition and requirements of the quality views have been explained in detail. The first requirement was given as the 75% of the indoor area should be able to directly see the outdoors from the windows. The glazing of this window should be clear glazing without any distortion as tints, patterns, etc. In addition to these, at least two of the given parameters should be provided in 75% of the indoor area:

a. having more than one glazing which is located at least 90° apart from each other

b. having at least two of the given: vegetation, animals, or sky; movement; and elements that are a minimum of 7.62 meters away from the glazing

c. unrestricted views that are within three times the head height of the glazing

d. views with a view factor of at least three (LEED 2019)

Overall, the importance of considering the window view quality in building and interior design is essential. Varied components and assessment factors were taken into consideration during the early years. However, the standards and human preferences should meet at a common point to create more quality views.

2.1.3.2. View Types and Their Effects

Window views have various influences and benefits on people. Some of these effects are physical, and some are psychological effects on humans. There is extensive literature on these effects of views. This literature is examined under this sub-title and summarized according to focused points.

Firstly, the type and content of the view have variations, and these have different impacts on people. There are studies that mostly focus on green, nature views and their effects. One of the research summarizes the importance of nature views from windows in promoting well-being and improving indoor environments. The study found that nature views, especially green spaces, from windows can have positive effects on stress reduction, mood, and cognitive performance (Heerwagen 1986). Another study supports that access to nature views from windows may have positive impacts on well-being and relaxation. The survey investigates the relationship between window views of green spaces and the well-being of urban dwellers in high-rise estates. The questions were about the views from the residents' windows and their relaxation and well-being. The results showed that there was a positive correlation between viewing green space from a window and increased well-being and relaxation among residents (Elsadek, Liu, and Xie 2020). The literature supports that when people are exposed to more nature views through the windows, they report higher levels of life satisfaction than those with less exposure (Chang et al. 2020).

Houses have importance of being people's living spaces and are evaluated in terms of view-type conditions. A research study discusses the positive impact that view from a person's home window can have on their psychological well-being. It explores the several advantages, such as reducing stress levels, increasing life satisfaction, and enhancing mood, of having a nature view through windows at home. The study highlights that some characteristics of the view, such as the existence of water or vegetation, have benefits in determining the psychological well-being of occupants (Kaplan 2001). Other than houses, office environments are common indoors, where people spend their time quite often. The relationship between access to daylight and views and the physical and emotional well-being of office workers has been investigated in a study. Office workers were randomly assigned to two office environments, one with views and daylight and the other without. The participants were asked to rate their physical and emotional well-being before and after each workday using questionnaires. The study also collected objective data on light exposure, noise levels, and indoor air quality in the two office environments. The study found that workers who had access to daylight and views reported improved mood, lower stress levels, emotional well-being, and higher levels of productivity compared to those who did not have access to these environmental factors (Woo et al. 2021). Many studies support that providing office workers with a view of a green outdoor environment can significantly improve their job satisfaction (Shin 2007; Lottrup et al. 2015).

While studies worked on the landscape view, some of them investigated the effects of street, urban, or building views and compared the view types as well. A study investigated the relationship between office window characteristics, views, and physical and psychological discomfort. Participants completed a survey to assess their discomfort levels and perceptions. The collected data was analyzed, and it showed that views of nature and access to natural light were found to reduce discomfort, while an urban view which was defined as a poor view, increased discomfort. The study highlights the importance of considering these factors in office building design for better employee well-being (Aries, Veitch, and Newsham 2010). Another one explored stress recovery in high school students with two different views. The study participants were students who completed a stress induction task and were randomly assigned to sit in a room with either a nature view or a built view. The students' stress recovery was measured to investigate the relationship between view types and stress recovery in high school students. It was concluded that the high school students who had access to nature views from their classroom windows showed faster stress recovery compared to those who had built views (Chen 2015). The other literature, which focused on the impact of natural views on student performance and perceptions in college writing courses, compared identical classrooms, with one having a view of a natural setting and the other a view of a concrete retaining wall. Results showed that students in the natural view classrooms had more positive ratings of the course and higher grades compared to those in the classrooms with views of the retaining wall. The study suggests that incorporating natural views in educational settings could offer several advantages and lead to better student outcomes (Benfield et al. 2013).

All these studies show that view designs should prioritize access to views to enhance residents' overall satisfaction, well-being, and quality of life. Even though buildings such as offices have their own aim to create a working environment or classrooms are built to be educational places for students, these constructions have better performance with a preferred view by occupants.

2.2. Daylighting in Terms of Human Perception

Daylight, view and human interaction are explained under sub-sections of this part.

2.2.1. Visual Comfort of the User

One of the key factors that affect a person's overall comfort, health, and productivity in an indoor environment is visual comfort (Mujan et al. 2019). It is defined as a "subjective condition of visual well-being induced by the luminous environment'' in EN 12665 European Standard (EN 12665 2018). Indoor visual comfort is mainly associated with surface contrast and brightness variation caused by lighting (Nasrollahi and Shokri 2016). Thus, the optimum way to achieve visual comfort is through the proper use of daylight. Since daylighting is one of the primary purposes of windows, their design affects the penetration of daylight (Ruck et al. 2001; Liu et al. 2021). Windows should be designed carefully to get benefit from them in terms of visual comfort and improve indoor environment quality (Hellinga 2013). Varying illuminance values of the indoor environment, daylight glare, and luminance are identified as some of these metrics that help researchers investigate visual comfort (Bian and Luo 2017). However, there is no mutually acknowledged measurement of lighting quality that can guess how a luminous environment affects humans since visual comfort is highly complicated (Piccolo, Pennisi, and Simone 2009).

Preventing discomfort glare and controlling illuminance provide visually comfortable indoor environments for the occupants. Occupants' perception of discomfort glare may change under different glazing conditions. For example, in a situation in which blue-tinted and clear glazing in different transmittance values are compared, people perceive less glare under clear glazing conditions, according to research (Sneha Jain et al. 2023).

Figure 2.2. Blue tinted (left) and clear glazing(right) used for the experiment (Source: Jain et al. 2023)

Figure 2.3. Tinted glazing used for the experiment in Donna Land Port (Source: Luis et al. 2015)

Other studies conducted with survey and physical measurements support the idea that tinted glazing has positive impacts on glare control in indoor environments (Fernandes, Lee, and Thanachareonkit 2015) and removed over illumination without damaging decent daylight autonomy (Ajaji and André 2015); however, some experiments concluded despite the decreased levels of glare, fully tinted conditions resulted in very dark and uncomfortable environments (Fernandes et al. 2018). In addition to the given literature, color-coated glazing with colors of red, blue, and yellow and their combinations were used in the design of a study. According to the results, the utilization of multi-color glazing instead of no-coating, daylight glare probability, and useful daylight illuminance is improved (Matin, Eydgahi, and Matin 2022).

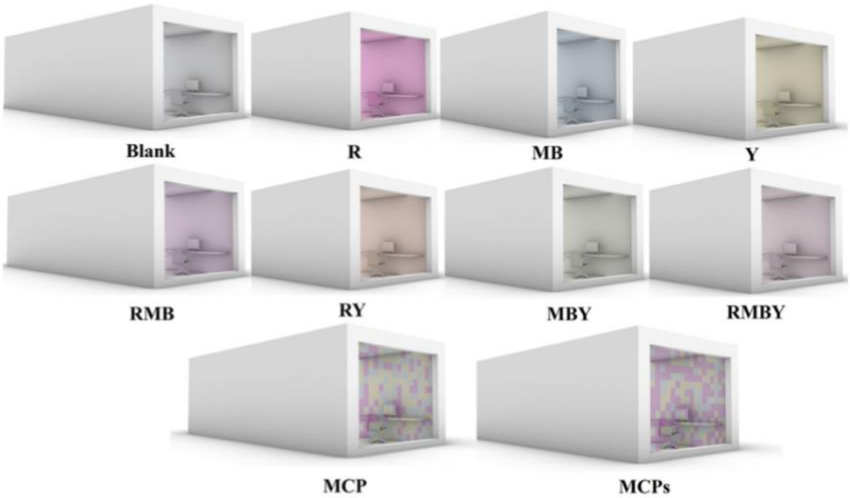


Figure 2.4. Multi-color glazing simulations
(Source: Matin, Eydgahi, and Matin 2022)

2.2.2. Effects of Glazing Type on the Room Perception

Creating an indoor environment by using various glazing types and exposing occupants to different types of views may have influences on the overall satisfaction of occupants and their perception of the indoor environment.

Glazing types are one determinant element in room perception of humans. An experimental study was performed in two identical rooms with office and bedroom furniture and different glazing (standard three-pane window with clear glass and super-insulated four-pane window with low-emittance coatings). The study concluded that the room with the four-pane window was perceived as more enclosed, and penetrating daylight into the room was seen as less clear. Also, color perception was affected, and they appeared as more subdued and dimmer (Bülow-Hübe 1995).

Color parameter of glazing can shape the indoor environment and cause visual improvements. Liang et al. conducted a study investigating the effects of thermochromic windows on visual comfort and performance. A test room of an office was designed and illuminated with blue-tinted and bronze-tinted glazing. A questionnaire was conducted with subjects, who preferred to work and stay under bronze glazing conditions compared to clear and blue glazing conditions. Researchers pointed out that subjects chose the bronze window since it provides a warm tint and natural rendering of indoors (Liang et al. 2019). Sometimes this integrated glazing may cause some unfavorable effects. One example can be given in the survey conducted in an office building with four transmittance levels (1%, 6%, 40%, 58%) of electrochromic glazing installed in the conference room. The occupants were satisfied with the glare control of these rooms, and they were visually comfortable; however, tinted glazing caused unnatural color rendering in both indoor and outdoor environments (Jianxin 2021). It is supported by some findings in the literature on color rendering properties of glazing, showing that the colors of the room elements are not perceived as natural. Therefore, the necessity for better color rendering improvements is expected by the occupants (S. Jain, Karmann, and Wienold 2021). These studies highlight the importance of the visual and perceptual impact of glazing on indoor spaces.

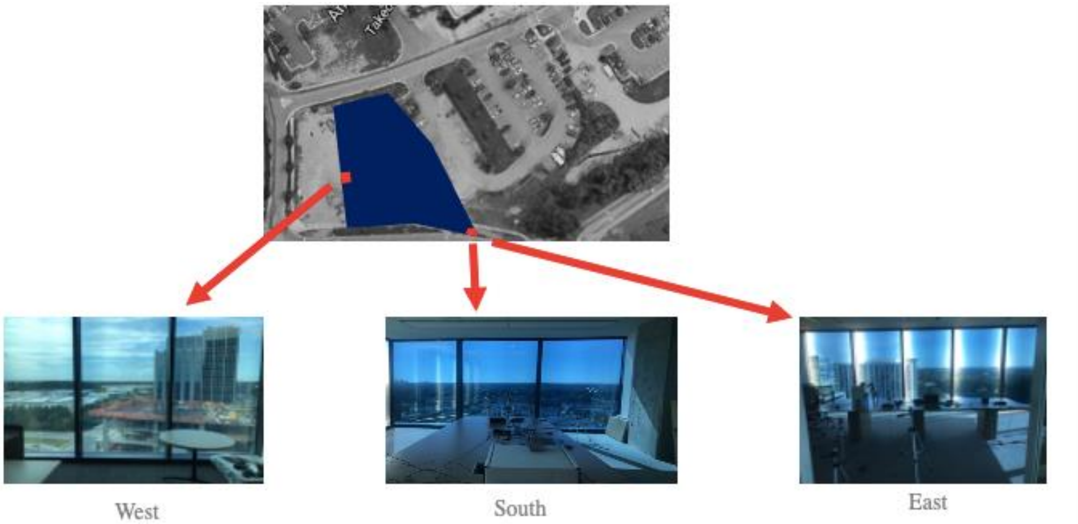


Figure 2.5. Glazing types used in the case study
(Source: Jianxin 2021)

2.2.3. Effects of View Type on the Room Perception

Along with the glazing types of a room, the view through the windows influences the occupant's perception of the room. Being exposed to better window views in building design can enhance the overall indoor environmental quality and improve the well-being of the occupants.

Room satisfaction at schools was evaluated in research that investigates the impact of window views on the perception of some parameters, such as spaciousness, brightness, and overall room satisfaction in a campus building. Interviews with 18 single-room occupants showed that rooms on the upper floors were perceived as bigger and brighter because of expanded open window views, while rooms on the low floors were perceived as darker. Findings showed that offices with more open and natural views received higher room satisfaction ratings, particularly during the winter months (Ozdemir 2010). Besides the schools, workspaces are also investigated since people spend their daily life. A study focused on the effects of window views and indoor plants on human responses in the workplace. A questionnaire is conducted on workers in two office buildings, one with window views of nature and indoor plants and one without. The participants completed a survey that included questions about their perceptions of their workplace environment, stress levels, and job satisfaction. The qualitative interviews revealed that workers in the window view and indoor plant group perceived their workplace as more visually appealing and calming compared to those in the other group, and they reported lower stress levels and higher job satisfaction (Chang and Chen 2005). Another study explored natural window views' impact on people's perceptions of indoor environmental quality. The study was conducted in a controlled laboratory setting. The participants were randomly assigned to a room with a natural window view or a room without a window view. The survey evaluated occupant perceptions of indoor environmental quality, including air quality, temperature, lighting, and overall satisfaction. The data was analyzed to find the effects of natural window views on participants' perceptions of indoor environmental quality. It concluded that natural window views positively affected participants' perceptions of indoor environmental quality. Participants with a natural window view rated their indoor air quality, temperature, and lighting higher than those without a window view. They also reported higher satisfaction levels with their indoor environment and a sense of well-being (Du et al. 2022).

The other indoor environments which have significance for humans are hospitals, and studies should be investigated to understand the perception there. The effect of window views in hospital rooms on patients' satisfaction and perceptions of the quality of care they receive was investigated in a study. Data about participants' previous hospital stay, their perception of the windows in their room, and their overall perception of the room, and care they received were collected. According to the occupants access to windows and views of green environment caused a higher rating of the hospital, room, and care received. The design of patient rooms, including the quality of window views, can play a significant role in shaping patients' experience and satisfaction during their stay (Mihandoust et al. 2021).

Perception of the view and indoor environment plays a role in the users' view preferences. In order to create preferred views, how users perceive them should be analyzed first. The perception of indoor occupants has been evaluated in previous studies, and the results indicated that individual opinions for window views vary greatly based on personal preferences, cultural background, and life experiences (Lin, Le, and Chan 2022).

2.2.4. Simulation and Real Environment Approach to Daylight and Human Interaction

The design and development of virtual environments is an important way of understanding human comfort and perception indoors. Several studies examine how various lighting and ventilation conditions affect occupant satisfaction and productivity. In one of these reviews, it was underlined how crucial virtual environments are becoming for exploring occupant comfort and behavior and how these tools need to be improved. Additionally, it highlighted the advantages and drawbacks of employing virtual environments in research, including their ability to simulate a wide range of environmental conditions and occupant behaviors and the challenges of creating accurate and realistic environments (Alamirah, Schweiker, and Azar 2022). Virtual reality studies on visual quality and illumination perception was the subject of another review study. A number of review studies that examined the methods used in virtual reality evaluations of visual quality and lighting perception have been looked investigated. The results highlighted the benefits of using virtual reality for this kind of study, including its ability to simulate different lighting conditions and to control factors that may affect the perception of humans. A few of the challenges are also mentioned in the evaluation, such as the need to ensure that the virtual environment accurately represents the real-world environment and that participants are fully immersed in the VR experience. Therefore, the potential of VR technology for evaluating visual quality and lighting perception is highlighted, as well as the necessity of further developing these tools and approaches. Researchers that are interested in human perception and behavior as well as professionals who are involved in developing and evaluating interior settings may find the findings to be relevant. (Bellazzi et al. 2022).

The comparison between real and virtual environments can help designers and researchers in daylight studies and building design. This comparison demonstrated that virtual reality technology can simulate daylight brightness; however, there may be some differences in perception of them. A study evaluated how satisfied occupants were with the size of windows in real and virtual settings. The study looked at the relationship between window size and occupants' contentment with the indoor environment using both a real-world test room and a virtual reality simulation.

Based on a number of aspects related to window sizes, including the amount of daylight, the overall quality of the interior environment, and their ability to see the outside view, participants were asked to rate their satisfaction with the test room and the VR simulation. Participants in the study were more satisfied with larger windows, both in the real world and the virtual one. Participants' satisfaction with window size was higher in the real test room compared to the simulation. Thus, there may be some limitations on how accurately interior settings can be simulated with virtual reality. The study also emphasizes that since virtual reality simulations might not accurately represent the complexity of human perception, researchers should be careful when using this technology to evaluate occupant responses (Hong et al. 2019). Perceptions of daylit environments in both physical and virtual environments were compared in a research study. Participants evaluated both environments regarding the perceived quality of daylighting. The study's results revealed that participants' perceptions of daylighting quality were consistent in both real and virtual environments. Thus, virtual reality technology can create a realistic perception of daylit spaces and simulate daylighting conditions effectively. However, the study found that several elements of the virtual environment, such as the color and texture of surfaces, were perceived differently compared to the real environment. According to the study, these differences may be due to limitations of the technology used to create the virtual environment, and the simulations' accuracy should be increased in further research. The potential of virtual reality technology for evaluating daylighting in built environments is highlighted. The study suggests that additional research and development of tools may have significant benefits for architects, designers, and researchers working in the field of designing and evaluating built environments (Chamilothori, Wienold, and Andersen 2018).

Figure 2.6. Physical (right) and virtual (left) office spaces in comparison study (Source: Hong et al. 2019)

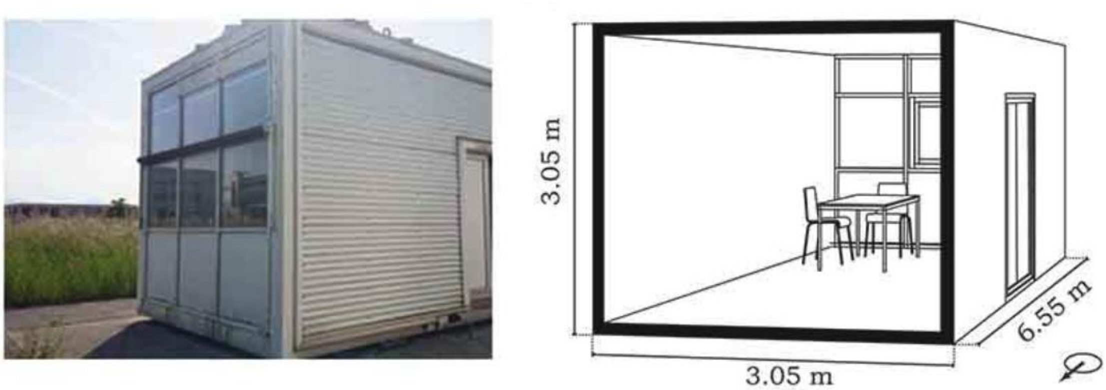


Figure 2.7. Physical (right) and illustrated (left) test rooms in comparison study (Source: Chamilothori, Wienold, and Andersen 2018)

In addition to comparison studies, a study that analyzed the effectiveness of dynamic window shades in reducing glare in office environments used both experimental and simulation methods. In the experimental part, participants were asked to rate the level of glare they perceived under different lighting and shading conditions in a mock office environment. A computer model was used in the simulation to achieve the same conditions as the real environment and evaluate the possible glare reduction. The study concluded that the simulation model was effective in predicting the level of glare reduction and using integrated simulation and measurement methodologies can be highly effective for mapping daylight glare probability (Konstantzos, Tzempelikos, and Chan 2015).

Many studies uses virtual environments to investigate daylit spaces and their influences, such as satisfaction, indoor impression, and perception of occupants, and subjective responses of occupants were evaluated (Karmann et al. 2021a; Omidfar Sawyer and Chamilothori 2019; Rockcastle, Chamilothori, and Andersen 2017; Hegazy, Yasufuku, and Abe 2022; Mahmoudzadeh, Afacan, and Adi 2021; Moscoso et al. 2021). The outcomes of these studies can provide opinions for architects, designers, and researchers in the field of built environment design and evaluation. They help to inform the development of more effective daylighting strategies in architectural design. Virtual reality has advantages and disadvantages, such as providing a controlled experimental environment that allows for precise measurements and evaluations while allowing for the manipulation of various factors that are difficult to control in real-world settings (Chamilothori, Wienold, and Andersen 2018). These studies confirm that the use of virtual reality technology in the study also shows its potential as a useful tool for evaluating environmental characteristics in building design.

CHAPTER 3

THE METHODOLOGY

3.1. Modelling the Visual Environment

The questionnaire method was used to determine the choices and evaluations of the participants. While preparing the survey questions, multiple sample images were prepared for the participants to evaluate. While preparing these images, Relux was used, and the images were turned into a questionnaire in MS Word to be sent to the users together with the prepared questions.

3.1.1. Room Characteristics

An artificial room environment was designed to find out how various glazing and view types impact the users' perception of the room and satisfaction with the interior spaces. The room, designed to understand the responses of the survey participants, was first modeled in 3D to make it more visually realistic. It was designed with specific dimensions of 6 m x 4 m, and the height is determined as 2.8 m. Window dimensions are 1.8 meters to 2.4 meters to provide occupants more daylight and a view for the experiment. It is located 0.80 m in height from the floor (Figure 3.1 and Figure 3.2).

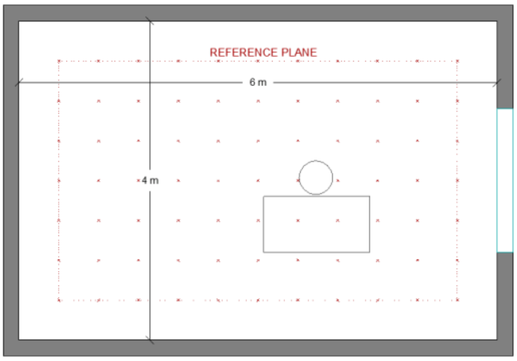


Figure 3.1. Simulated room plan

After generating the virtual scene, the following step is to choose glazing and view types. Glazing types were selected from different colors and transmittance values. Two of them were defined as colorful glazing, which is blue with 25% transmittance glazing and 66% transmittance glazing. In addition to colorful ones, three clear glazings were chosen according to their transmittance values. First, 20% of transmittance glazing was chosen to provide a less daylighted atmosphere. The second one was determined as 50% transmittance glazing, and the last one was the glazing with 90% transmittance for a lighter environment. So clear glazing was generated as a low, medium, and high transmittance to compare every lighting condition. Each of these five types of windows has two views; one of them is a street, and the other one is a landscape view from the city of Izmir. Glazing types and view types are combined to generate ten rooms with various glazing and views using the raytracing module in Relux.

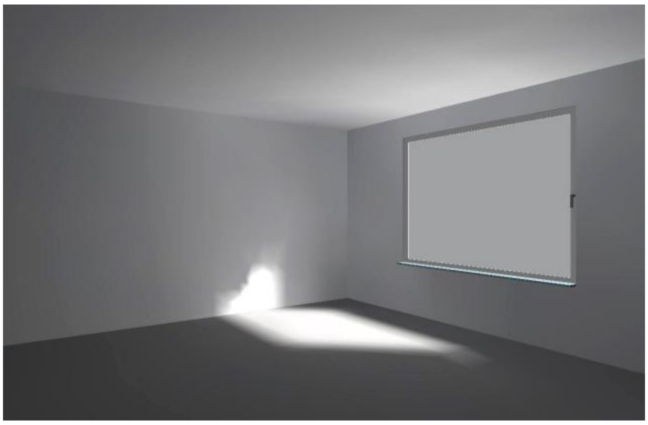


Figure 3.2. Isometric View of Simulated Room

By creating these combinations, it was aimed to find not only the glazing types and view's impacts on users but their combined versions' effects. Another factor that will affect the users' perspective is the reflectance of the surfaces in the room. Reflectance values of the floor, walls, and ceiling were determined as 20%, 75%, and 90%, respectively. While modeling the wall materials of the room, all of them were determined as 75% reflectance. In addition, the reflectance of the floor material was chosen as 20% reflectance and 90% for the ceiling (Table 3.1). Thus, created scenes were ready to be used in the survey.

Table 3.1. Room characteristics

Room dimensions	6 m x 4 m x 2.8 m
Window dimensions	1.8 m x 2.4 m
Window height from floor	0.80 m
Reflectance of ceiling	90%
Reflectance of walls	75%
Reflectance of floor	20%

3.1.2. Simulation Process

In the modeling process, the Relux was preferred in terms of being suitable for modeling in 3D, producing images that can be used as renders, and making detailed daylight analyses. While Relux is used to analyze lighting, it can also analyze according to a specific date, time zone, weather, and location. Providing adjustable parameters is important for the sake of a realistic experiment since variables such as date, location, and weather have an impact on lighting conditions. The location is the city of İzmir (38.4127 N; 27.1384 E), a city located West coast of Turkey. The weather is set to a clear sky with the sun. Daylight raytracing simulations were run on specific days as 21st March (equinox) and 21st June (the longest day in the northern hemisphere) at 11.00 am (Table 3.2). The renders used in the survey were chosen from the equinox day. To analyze the horizontal daylight distribution, the reference plane height is determined as 0.8 meters. It involves a total of 54 calculation points with 0.50 m spacing.

By using simulations, it was integrated both of these scenes and calculated horizontal daylight illuminance and 3D luminance values to test whether they meet the visual preferences of people.

Table 3.2. Simulated environment conditions

Reference Plane	0.80 m above the floor
Weather conditions	Clear sky with sun
Dates	21 March / 21 June at 11.00 am

3.2. Questionnaire

A two-part survey was prepared for evaluation of the renders achieved. The renders were grouped according to glazing types and views. In the first part of the questionnaire, visuals with five types of glazing (yellow, blue, 20%, 50%, and 90% transmittance clear glazing) and street view were used (Figure 3.3).

3.2.1. Questions and the Procedure

In order to evaluate the images, four questions were asked to participants. Thus, the first part of the questionnaire consisted of 20 questions. In the second part, the same five types of glazing were used, but the street view was replaced with a landscape view. In this part, the same four questions were asked. As a result, 40 questions were asked to a person in the survey, with the help of ten rendered scenes. Survey images were rendered via Relux; the questionnaire was prepared in MS Word and conducted online. The scenes were arranged as five of them on one page, and one of the four questions was asked for each scene. Appendix 1 presents the questionnaire.

The first question, which is "*How interesting is this space*?", aimed to understand how glazing type and view combinations affect the response to the interestingness of these simulated rooms (Table 3.3). This question was asked in each rendered scene. Participants were expected to answer using the Likert scale. The Likert scale was set between 0 to 5 throughout the whole questionnaire. 0 was determined as extremely uninteresting, and 5 was extremely interesting (Table 3.4). The second question, which is "*How pleasant is this space*?" was asked to measure how glazing and view types affect the pleasantness of the spaces according to users. When the glazing type changes, room brightness changes too; however, there is a view factor that might impact the user by the sense of brightness. That's why the third question, which is "*How satisfied are you with the brightness of the space?*" was asked to understand the effects of changing glazing types and views on users' perception of the room brightness. The last question, which is "*How pleasant is this view?*" aimed to compare street and landscape views' pleasantness for the occupants under different glazing-type conditions. All four questions were asked for each rendered scene.

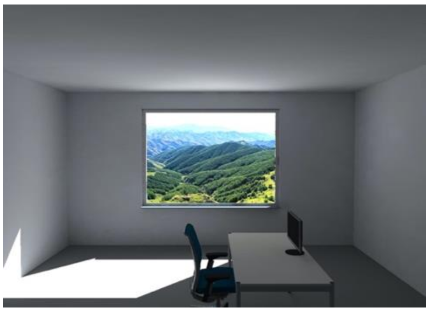
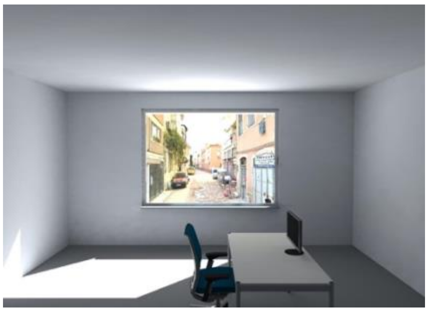
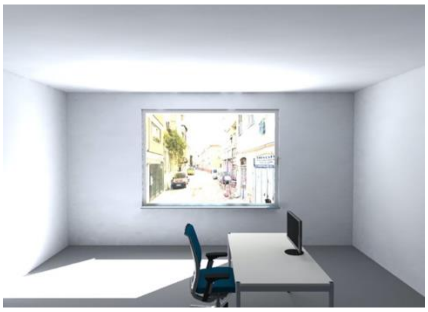
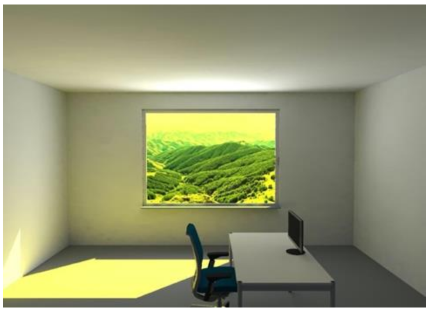
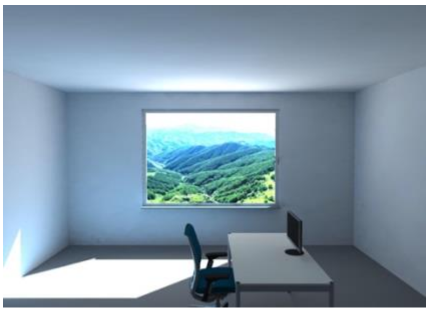
	Street View	Landscape View
Clear Glazing with 20% Transmittance (low)	 Room 1	 Room 6
Clear Glazing with 50% Transmittance (medium)	 Room 2	 Room 7
Clear Glazing with 90% Transmittance (high)	 Room 3	 Room 8
Yellow Glazing with 66% Transmittance	 Room 4	 Room 9
Blue Glazing with 25% Transmittance	 Room 5	 Room 10

Figure 3.3. The rendered scenes with glazing types and views

Table 3.3. Survey questions and answer scale

Questions	Answers (0-5)
"*how interesting is this space*?"	0 • 1 • 2 • 3 • 4 • 5 •
"*how pleasant is this space*?"	0 • 1 • 2 • 3 • 4 • 5 •
"*how satisfied are you with the brightness of the space?*"	0 • 1 • 2 • 3 • 4 • 5 •
"*how pleasant is this view?*"	0 • 1 • 2 • 3 • 4 • 5 •

Table 3.4. 6-Point Likert Scale

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
0	1	2	3	4	5

3.2.2. Participants

A total of forty random people were selected and participated in the survey. Twenty-six of the participants were women, and 14 of them were men. They were aged between 20 and 53. Participants were not selected from a specific group of people, age, or gender to be able to evaluate the survey objective.

3.3. Statistical Analysis

OLS (ordinary least square), Heteroskedasticity White Test, and OLR (Ordinal/Ordered Logistic Regression) are applied on the data (White 1980), using Stata and E-views. OLS estimations are applied to identify the significance of the impacts of independent variables (Age, Gender, Landscape, Yellow, Blue, Transmittance) on the dependent variables (Interesting, Pleasant, View Quality, Brightness). Ordinal/Ordered Logistic Regressions are for the sake of robustness since the data is in discrete form, and the OLS regressions may not satisfy the standard assumptions of linear regressions under discrete data cases (McCullagh 1980; Winship and Mare 1984).

The results of the questionnaires were converted into variables, the details of which are explained in the tables below:

Table 3.5. Dependent variables

Variable Name	Definition	Measurement
Interesting	How interesting the participants find the simulated room	Questionnaire answers ranging between 0 and 5.
Pleasant	How pleasant the participants find the simulated room	Questionnaire answers ranging between 0 and 5.
Brightness	Are the participants satisfied with the brightness of simulated room	Questionnaire answers ranging between 0 and 5.
View Quality	How pleasant the participants find the view of the simulated room	Questionnaire answers ranging between 0 and 5.

Table 3.6. Independent variables

Variable Name	Definition	Measurement
Age	Age interval of survey participants	Between 20 and 53
Gender	Gender of survey participants	Consist of 26 female and 14 male
View	Outside view through windows	Street or Landscape
Yellow Glazing	Yellow-colored glazing with 66% transmittance	Colorful or Clear glazing
Blue Glazing	Blue-colored glazing with 25% transmittance	Colorful or Clear glazing
Glazing Transmittance	Three types of clear glazing with 20% , 50% and 90% transmittance	Low-Medium-High Transmittance

In regression analyses, it is considered the following 4 regression equations:

$$Interesting_i = \partial + \beta 1Age_i + \beta 2Gender + \beta 3Landscape_i + \beta 4Yellow_i + \beta 5Blue_i + \beta 6Transmittence_i + e_i$$

$$Pleasent_i = \partial + \beta 1Age_i + \beta 2Gender + \beta 3Landscape_i + \beta 4Yellow_i + \beta 5Blue_i + \beta 6Transmittence_i + e_i$$

$$Viewquality_i = \partial + \beta 1Age_i + \beta 2Gender + \beta 3Landscape_i + \beta 4Yellow_i + \beta 5Blue_i + \beta 6Transmittence_i + e_i$$

$$Brightness_i = \partial + \beta 1Age_i + \beta 2Gender + \beta 3Landscape_i + \beta 4Yellow_i + \beta 5Blue_i + \beta 6Transmittence_i + e_i$$

i : respondents, 1…..,40

CHAPTER 4

RESULTS AND ANALYSIS

4.1. Preferences of participants through scores and mean values

This section involves basic descriptive properties of the variables and participants' preferences based on these variables. Each question asked to participants is assessed according to its own unique variables. The scores for each question are graphed and evaluated. Results for the questions are analyzed statistically in this section.

For the first question, the study asked 40 participants to rate the degree how interesting they found each room. Participants answered survey questions based on renders that were created in Relux. The evaluation of the preferences has been made according to the 6-point Likert scale. The Likert scale encourages attendants to answer the question by giving scores that vary between 0-5. A score of 0 indicates that the participant found the room "extremely uninteresting," while a score of 5 indicates that the participant found the room "extremely interesting." Therefore, participants were allowed to choose any answer between 0 and 5. According to this range, 0 means extremely uninteresting, and 5 means extremely interesting. For the first question, which asked about overall interest in each room, participants' votes were collected, analyzed, and graphically shown (Figure 4.1). Results of the first question revealed that room 9 (yellow glazing with 66% transmittance and the landscape view, Figure 4.2) has been found as the most interesting one. 40% (16 out of 40 people) of the participants gave a score of 4, while 17.5% of them gave a score of 5. Overall, 57.5% of the participants agree or strongly agree that room 9 is interesting. In total, 28 out of 40 people (70%) voted as 3,4, or 5 (Figure 4.3), which means they chose a positive answer, and the mean value of these answers is 3,025. (Figure 4.13). This indicates that more than half of the attendants think that Room 9 is interesting.

On the contrary, Room 1 (clear glazing with %20 transmittance and street view, Figure 4.2) received the lowest scores and was deemed as the least interesting room. 31 out of 40 participants (77,5%) gave negative impressions by selecting scores of 0,1, or 2 (Figure 4.3), and 32% of them selected a score of 1. The mean value for Room 1 is 1,4. (Figure 4.13); thus, it is found as the least interesting room.

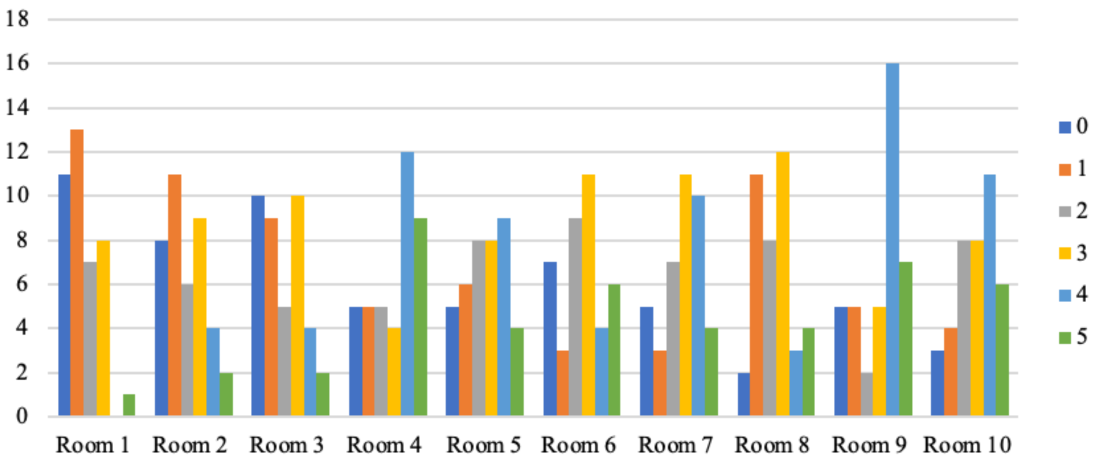
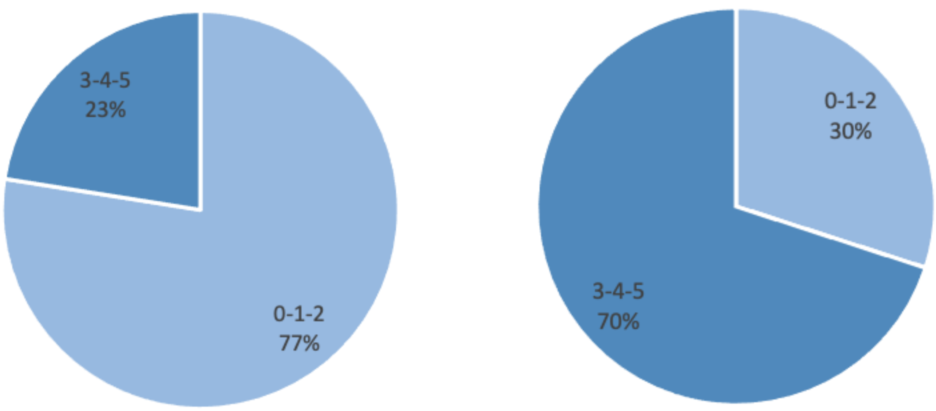


Figure 4.1. Graphical results of survey question 1 *"how interesting is this space?"*

Room 1 Room 9

Figure 4.2. Most (right) and least (left) interesting rooms



Room 1 Room 9

Figure 4.3. The vote percentages of the most (right) and least (left) interesting rooms

The second question is asked 40 participants with regard to the degree of the pleasantness of the room on a scale ranging from 0 to 5. Participants answered the questions through an online survey, similar to the first one, and they were expected to vote by evaluating the renders of the rooms. Afterward, the votes have been evaluated and graphically shown (Figure 4.4). According to survey results, participants find Room 7 (clear glazing with %50 transmittance and landscape view, Figure 4.5) to be the most pleasant one among the ten types of rooms. A total of 17 out of 40 participants decided on a score of 4, and 11 out of 40 chose a score of 5, indicating that they found the room extremely pleasant. In total, 38 of the 40 participants chose a score of 3, 4, or 5, and the mean value of the votes was found as 3,925. For Room 7, 95% of the attendees positively evaluated and find the room as the most pleasant one (Figure 4.6).

However, the least pleasant room was found to be room 4 (yellow glazing with 66% transmittance and a street view, Figure 4.5), based on the votes received for the second question. A total of 35 out of 40 participants (87.5%) gave a score of 0,1 or 2 for Room 4, and 24 of them (60% of the participants) gave a score of 0. With respect to these results, the mean value for room 4 is 0.825 (Figure 4.13), showing that it was the least pleasant room.

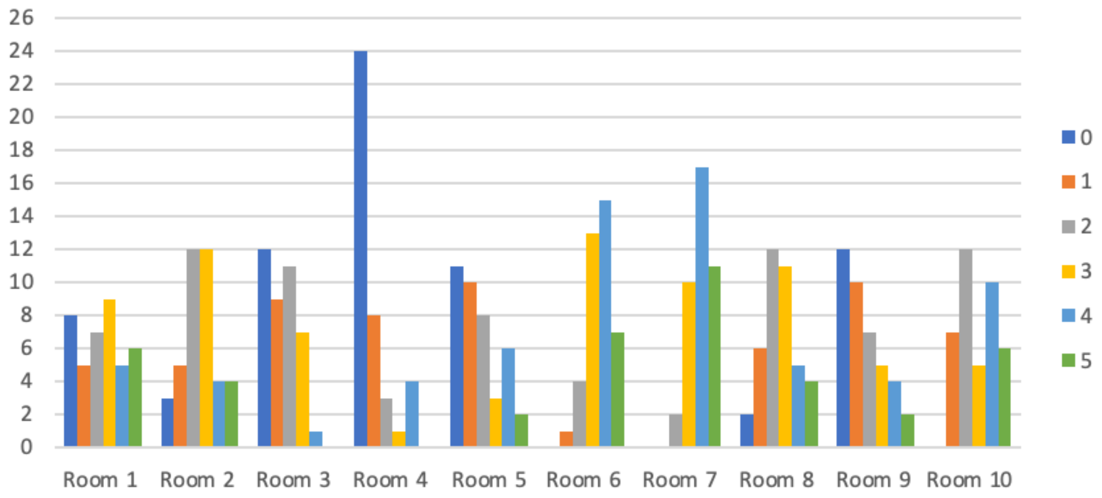
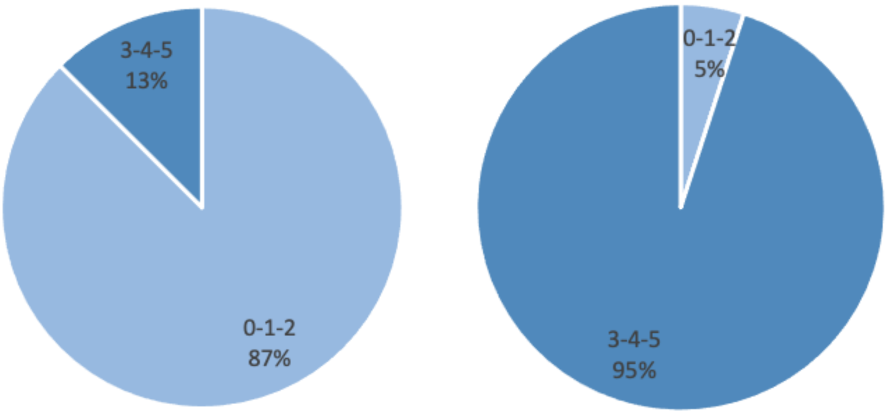


Figure 4.4. Graphical results of survey question 2 “*how pleasant is this space?*”

Room 4 Room 7

Figure 4.5. Most (right) and least (left) pleasant rooms



Room 4 Room 7

Figure 4.6. The vote percentages of the most (right) and least (left) pleasant rooms

In the third question, the effect of brightness on the users is investigated. The question is "how satisfied are you with the brightness of the space" and it is asked to 40 participants of the survey. They were expected to answer the questions by looking at rendered images on the online questionnaire. For room 3 (clear glazing with 90% transmittance and street view, Figure 4.8), participants are given positive votes according to the answers. Thirty-five of the participants, which means 87.5% of them, answered as 3,4, or 5 (Figure 4.9), and 17 out of 40 (42.5%) voted for 5 (Figure 4.7). The mean value of this room is 3.975 (Figure 4.13). It has been seen that room 8 has the same mean value as room 3, but the number of positive ratings for room 8 (32 out of 40) is lower than that of room 3. Therefore, among all the rooms, most of the participants were satisfied with the brightness of room 3.

On the other hand, room 4 (yellow glazing with 66% transmittance and a street view, Figure 4.8) received the lowest votes with a mean value of 1.775 (Figure 4.13) for the third question. According to the evaluation of the votes, 29 out of 40 participants, which means 72.5% voted for 0,1, or 2 (Figure 4.9). Thus, room 4 was evaluated as the room where participants were less satisfied with the room brightness.

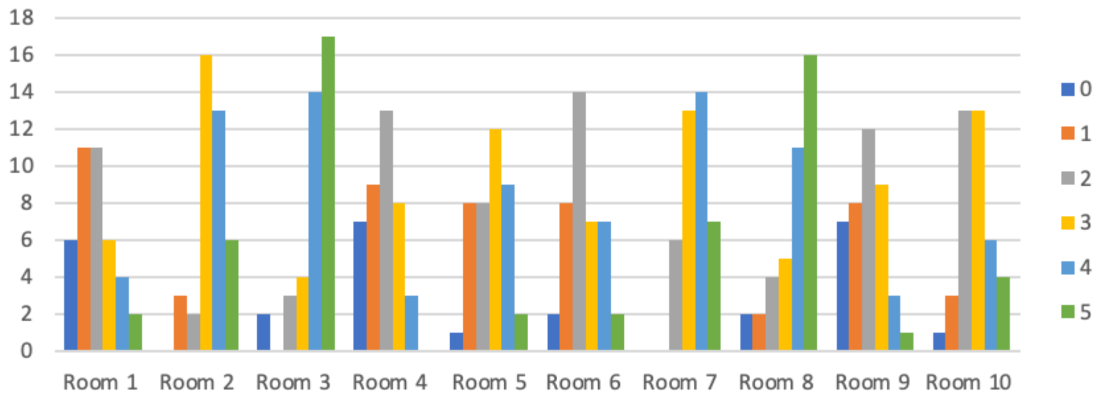
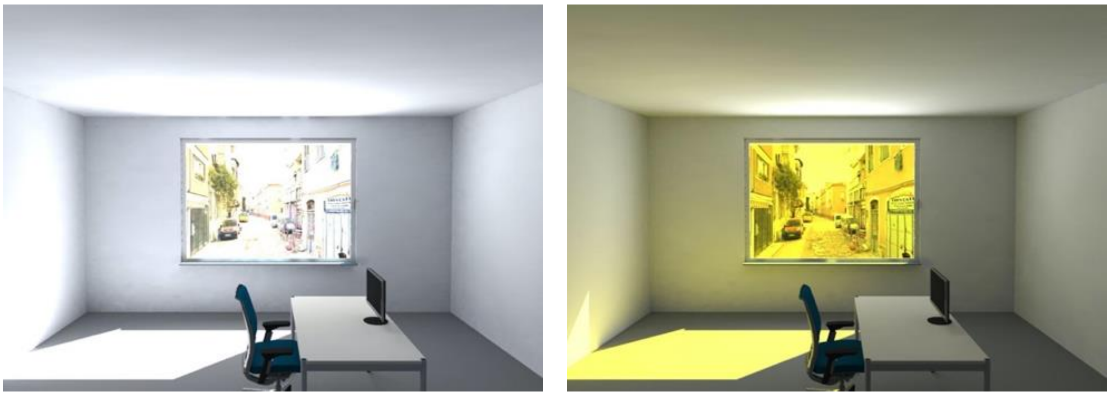
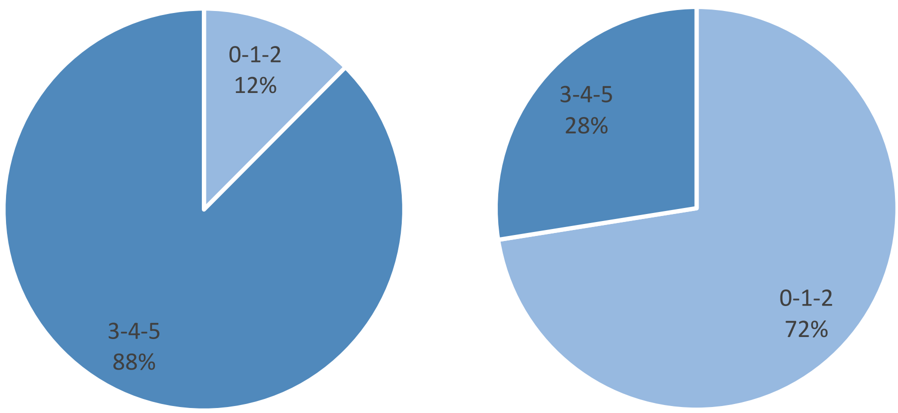


Figure 4.7. Graphical results of survey question 3 "*how satisfied are you with the brightness of the space?*"



Room 3 Room 4

Figure 4.8. Rooms with the most (left) and least (right) indoor brightness satisfaction



Room 3 Room 4

Figure 4.9. The vote percentages of the rooms of most (left) and least (right) indoor brightness satisfaction

The last question asks the same 40 participants to investigate how pleasant the view they see through the window is. The same ten-room pictures were used for this question as in the previous three questions. Participants were asked to determine the most pleasant view in changing glazing conditions for two types of views: street and landscape. For room 6 (clear glazing with 20% transmittance and landscape view, Figure 4.11) 38 of 40 people (95%) chose a score between 3,4, or 5, and 26 of 40 (65%) chose a score of 5 (Figure 4.12). The mean value for this room has been found to be 4.4 (Figure 4.13). Thus, room 6 has been found as the room with the most pleasant view.

On the contrary, room 3 (clear glazing with 90% transmittance and street view, Figure 4.11) has the lowest mean value, which is 0.825. 95% of the participants (38 out of 40) voted 0,1, or 2 on the survey (Figure 4.12). This means the view in room three was evaluated as the least pleasant one, according to participants. After room 3, room 4 has the second-lowest mean value, which is 0.925. 25 of the 40 (62.5%) participants choose 0 for room 4, which has yellow glazing with 66% transmittance and a street view.

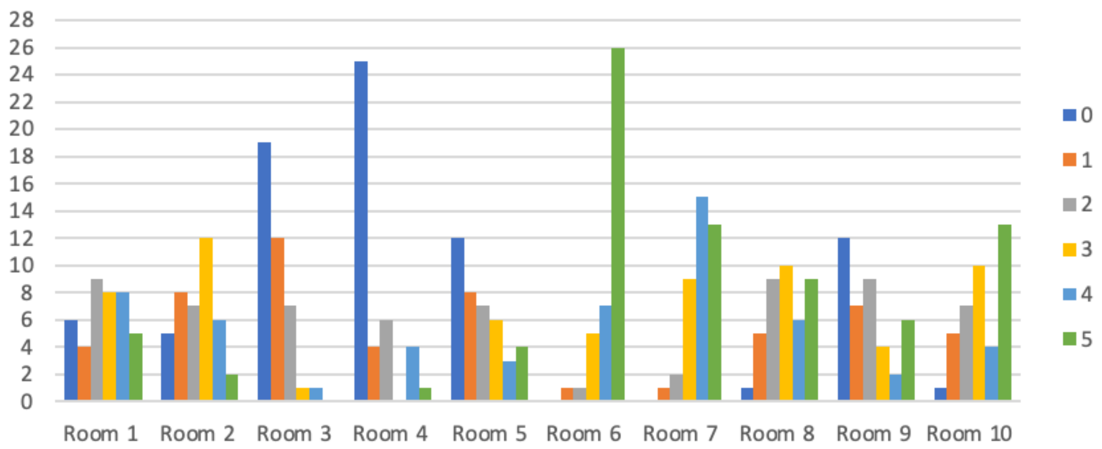
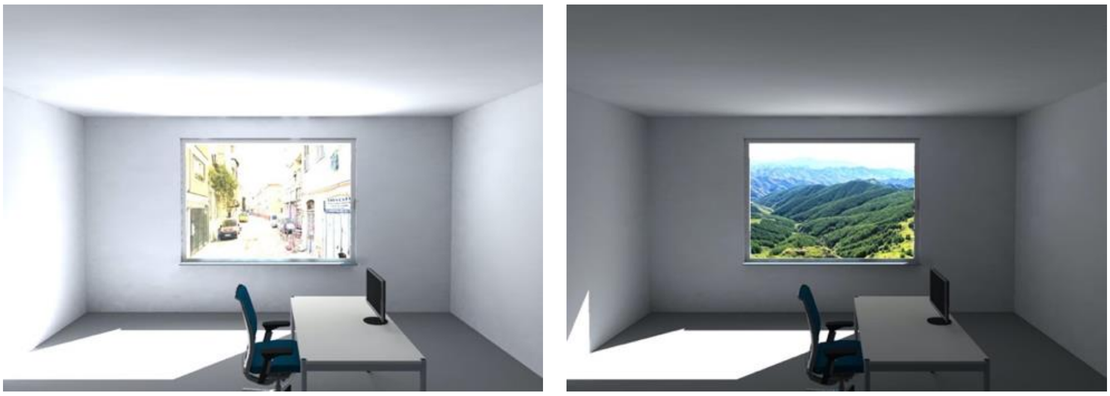
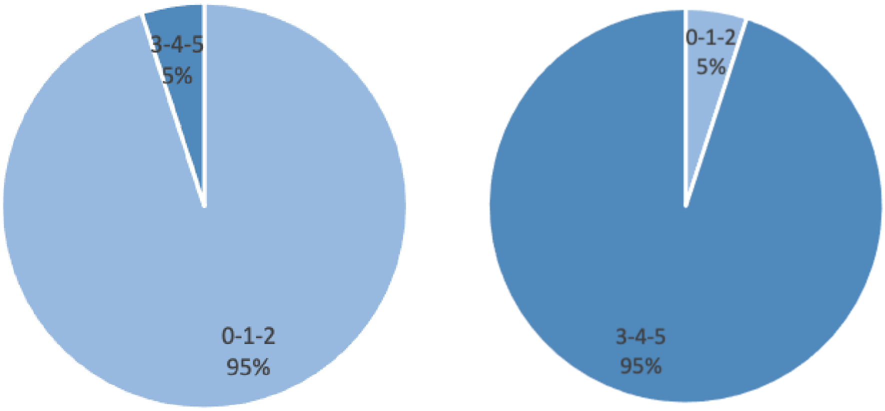


Figure 4.10. Graphical results of survey question 4 *"how pleasant is this view?"*



Room 3 Room 6

Figure 4.11. Rooms with the most (right) and least (left) pleasant view



Room 3 Room 4

Figure 4.12. The vote percentages of the rooms with the most (right) and least (left) pleasant view

Based on the statistical analysis results, it can be observed that looking at a landscape view instead of a street view from the window positively and significantly affects the users. Blue and yellow glazing, on the other hand, have a negative impact on the quality of the landscape view. In other words, users desire to view the landscapes through clear glazing, particularly with lower transmittance value. The results also indicate that the brightness increases as the transmittance value increases. Therefore, it can be concluded that as the brightness increases, view quality decreases. Considering the statistical analysis results, the view of the room does not have an effect on the degree of brightness. Rather than the view factor, when the transmittance value increases, the brightness of the room also increases, and blue or yellow glazing has a negative impact on the level of brightness satisfaction.

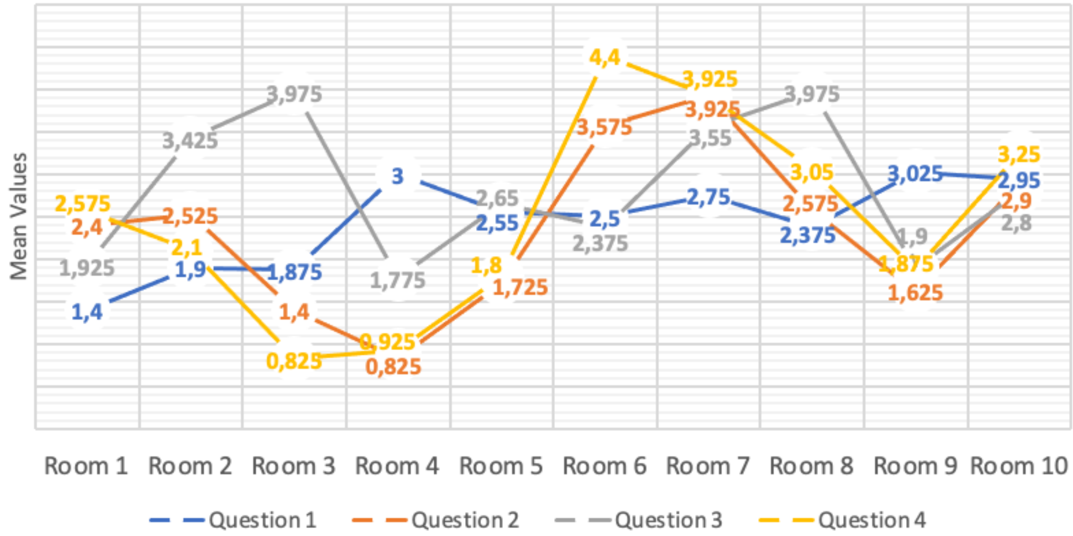


Figure 4.13. Mean values

4.2. Impacts of Glazing and View through Regression Analysis

Primarily, OLS regression results are presented in Table 4.1. The P-values (probability value) have been found to determine the level of statistical significance of the hypothesis. The coefficients in the regression analysis are the parameters that are used for understanding the effects of independent variables on dependent variables. The R^2 is the coefficient of determination, which is used to evaluate the goodness of fit of the OLS regression model (Gujarati Domadar N. 2010). In addition, the White test is applied to check if there is heteroscedasticity in the regression.

Age, as the first independent variable, has a positive and weakly significant impact on only view quality, which means older people have higher view quality compared to the younger ones (p=0,0894). The second variable is the gender. It has a significant impact on finding the room interesting and pleasant. In this case, male participants significantly found the simulated rooms more interesting and pleasant compared to female participants (p= 0,0517 and p=0,0209).

Analysis results of the view of the rooms indicated that in case there is a landscape view outside instead of a street view, it has a positive and significant impact on the degree of finding the place interesting, pleasant and higher view quality.

Yellow glazing has a negative and significant impact on the degree of finding the place pleasant (p=0), brightness (p=0), and higher view quality (p=0) of the room. However, it positively affects describing the room as interesting (p= 0,0001). Even though yellow glazing has a higher transmittance value than blue glazing, it has been perceived as less bright.

The second glazing color, blue, has a negative and significant impact on the degree of finding the place pleasant (p=0,0009) and view quality (p=0). However, it has a positive effect on defining the room as interesting, like yellow glazing but with less impact (p=0,0011).

The last factor, transmittance values of the glazing, were analyzed as 20%, 50%, and 90%. Transmittance has a significant impact on dependent variables. When the transmittance value increases from 20% to 90%, participants tend to find the room less pleasant (p=0) and poor view quality (p=0) but more bright (p=0).

Ordinal Logistic Regressions are applied in addition to OLS results and presented (Table 4.2). When this regression analysis is compared with the previous analysis, it can be seen that they overlap with each other. The coefficient and P-values of the variables are close to each other. In the comparison of the age variable, OLS results showed that it has a positive and weakly significant impact on only view quality (p=0,0894). That means older people have higher view quality compared to the younger ones. However, according to OLR results, age doesn't have any impact on dependent variables (p=0,18). This means there is no relationship between age and finding the room interesting, pleasant, bright, or better view quality.

Table 4.1. OLS regression analysis results (if p ≤ 0.05 statistically significant)

	Interesting		Pleasant		View Quality		Brightness	
	Coefficients	**P-values**	**Coefficients**	**P-values**	**Coefficients**	**P-values**	**Coefficients**	**P-values**
c	1,493136	0	2,508979	0	2,869296	0	1,549724	0
Age	0,004245	0,6813	0,012026	0,1275	0,014249*	0,0894	0,009479	0,179
Gender	0,323731*	0,0517	0,326308**	0,0209	0,104048	0,5255	0,033718	0,8023
Land-scape	0,585***	0,0001	1,145***	0	1,44***	0	0,125	0,3233
Yellow	0,877635***	0,0001	-1,31598***	0	-1,255***	0	-1,620169***	0
Blue	0,676014***	0,0011	-0,851098***	0,0009	-1,0125***	0	0,236233	0,195
Transmittance	0,209459	0,4957	-1,518581***	0	-2***	0	2,363176***	0
R2	0,102776		0,317819		0,341173		0,259858	
White Test	1,550049*		2,454922***		1,848831**		1,072266**	
P-Value	0,0622		0,0005		0,0149		0,3767	

Table 4.2. OLR regression analysis results (if p ≤ 0.05 statistically significant)

	Interesting		Pleasant		View Quality		Brightness	
	Coefficients	**P-values**	**Coefficients**	**P-values**	**Coefficients**	**P-values**	**Coefficients**	**P-values**
Age	0,0035775	0,738	0,0126134	0,178	0,0139746	0,18	0,0157616	0,114
Gender	0,4617441**	0,023	0,4594896**	0,022	0,1286976	0,544	0,0175369	0,929
Land-scape	0,6786529***	0	1,464129***	0	1,74839***	0	0,1623792	0,36
Yellow	1,161144***	0	-1,890655***	0	-1,703538***	0	-2,405735***	0
Blue	0,8055711***	0,001	-1,095299***	0	-1,277378***	0	0,3625509	0,138
Transmittance	0,1946438	0,583	-1,879474***	0	-2,506824***	0	3,914368***	0
R2	0,0332		0,1062		0,117		0.0949	
Prob. (F)	0.0000		0.0000		0.0000		0.0000	

4.3. Regarding Calculation and Daylight Analysis

The room visuals, created by the simulation method, were first presented to survey study participants for subjective evaluation. The survey results were obtained on participants' preferences and then analyzed based on the number of votes and mean values in section 4.1. In the second part, the results were evaluated statistically. In this last section of the results, illuminance and luminance values, as well as light distributions in the rooms, were analyzed. The simulation carried out on March 21 was used as the basis of the survey study, but the objective calculation simulations conducted on both March 21 and June 21 were evaluated and compared.

4.3.1. Illuminance

4.3.1.1. Illuminance values on March 21st

The first simulation date was identified as March 21st at 11.00, as it is the equinox. After setting the simulation date, daylight measurements were conducted using Relux. Based on these measurements, illuminance value distribution was shown in the plan views and on the charts for each rendered room (Figure 4.14). The illuminance values were evaluated, and it was observed that the illuminance in the room increased as the transmittance value increased. To evaluate this increase, the plan views of the rooms were compared. In plan view A, which stands for rooms 1 and 6 with 20% transmittance clear glazing, the dark red part covers a wide area in the room, while there is no in illuminance distribution plan view C (rooms 3 and 8 with 90% transmittance clear glazing). These dark red parts represent the areas of the room under a 300 lx illuminance threshold. As shown on the illuminance values plan of A, 74% of the room has illuminance values under 300 lx, while there is no point under 300 lx in plan of C. In the middle of these A and C outputs, the illuminance distribution plan and table of the B show that the illuminance values are in-between them. B represents rooms 2 and 7 with 50% transmittance clear glazing in the figure. The in-between value of the glazing transmittance caused illuminance values and distribution approximately average of A and C, concluding 29% of these rooms are under 300 lx. C and D stand for the tinted glazing and illuminance values in these rooms.

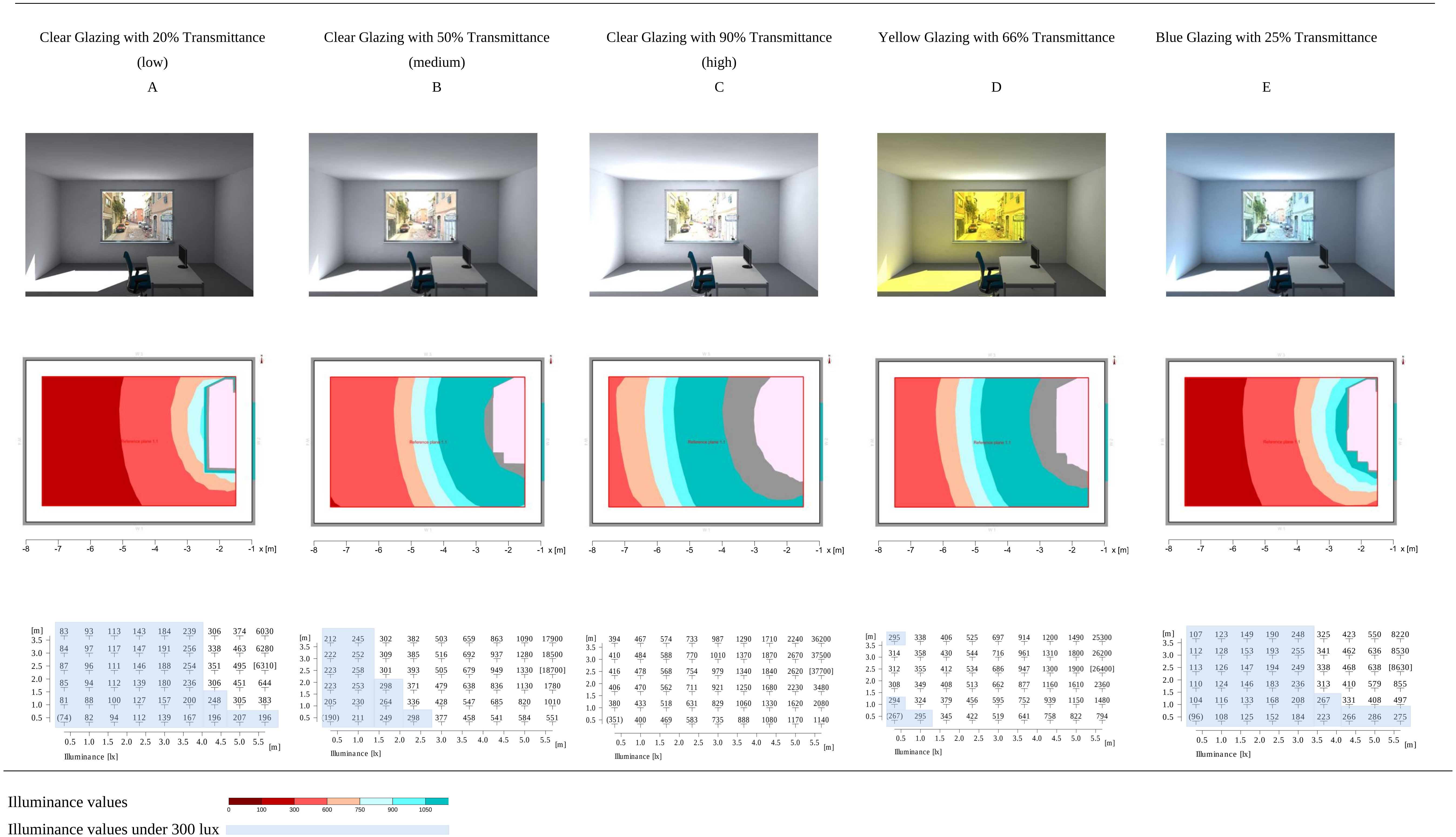


Figure 4.14. Renders of the rooms (first line), illuminance distribution (second line) and their values on plans of rooms (third line) (a) Room 1 and 6, (b) Room 2 and 7, (c) Room 3 and 8, (d) Room 4 and 9, (e) Room 5 and 10 at 11.00 on March 21st

When using 90% transmittance glazing, light bursts occur throughout most of the room, with a maximum illuminance value of 37700 lx and a minimum of 351 lx (Figure 4.15). Therefore, 16% of the room area has illuminance values over 3000 lx, leading to visual discomfort and glare (Mardaljevic et al. 2012). In contrast, in rooms with 20% clear glazing, the minimum illuminance value is 74 lx, and 74% of the room is under 300 lx, which might require artificial lighting for visual comfort (Mardaljevic et al. 2012). Only 5% of the room area is over 3000 lx value. Rooms with 50% transmittance have average illuminance values (minimum 190 lx and maximum 18700 lx) compared to those with 90% and 20%. Rooms with yellow glazing have illuminance values of a minimum 96 lx and maximum of 8630 lx, while the rooms with blue glazing have a minimum of 267 lx and maximum 26400 lx illuminance values (Figure 4.15).

In the rooms with yellow glazing, 64% of the area is under 300 lx, which is far from the window and might need artificial lighting. Meanwhile, very high illuminance values which lead to sun patches are seen in areas closer to the window and can be prevented with extra blinds or shadings. Blue glazing provides a brighter room since 93% of the room area is over 300 lx.

In terms of survey results, most of the attendants are satisfied with the brightness values in the rooms with higher transmittance values, such as room 3 or room 8 with 90% transmittance glazing, which has 3060 lx average illuminance values. However, survey participants are not very satisfied with the brightness of the rooms with 20% transmittance values, which have 533 lx average illuminance. Moreover, the satisfaction with the view changes the total opposite way, as people tend to like views when the illuminance values are lower, according to survey results. Even though the room with yellow glazing has 2150 lx average illuminance, people are not satisfied with the brightness. Therefore, glazing colors have unique effects on participants' perceptions.

Overall, the results in Relux on 21st March showed that the lowest illuminance values were in the room with the highest transmittance glazing (Figure 4.14). Despite this illuminance decrease, it was concluded that the room had a more pleasant environment and the view quality improved. However, the pleasantness rate and quality of view were negatively affected by the yellow glazing.

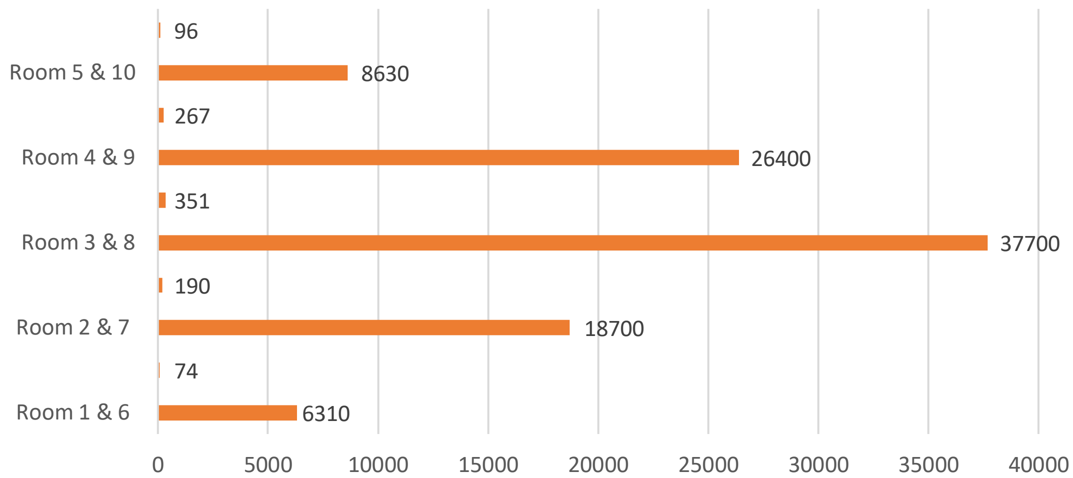


Figure 4.15.Maximum and minimum illuminance values on 21st March

4.3.1.2.Illuminance values on June 21st

The other calculations are performed on June 21 at 11.00. The illuminance values changed according to glazing transmittance, just as the calculations on March 21. However, this time, the illuminance values were much higher than the earlier calculations (Figure 4.17). The reason why the illuminance values are higher is the date parameter changing from March 21 to June 21. In the room with 20% transmittance values, the maximum illuminance value increased from 6310 lx to 8150 lx compared to March 21, and the minimum illuminance value increased from 74 to 92 lx (Figure 4.16). This maximum value reached 45400 lx in the room with 90% transmittance glazing. While 67% of the area of the rooms with clear glazing with 20% transmittance are under 300 lx, there is no point under 300 lx in 90% transmittance glazing. Even though all the points are over 300 lx, the lighting distribution is not accomplished since 11% of the room is over 3000 lx (Mardaljevic et al. 2012).

The rooms with colorful glazing have the same changes in illuminance values. The room with yellow glazing reached up to 11000 lx, and 52% of the room is under 300 lx which means half of the room might need artificial lighting. In the room with blue glazing, the maximum illuminance value was 26400 lx in March, and it increased to 32200 lx in June, and there is not any point under 300 lx. In both the rooms with yellow and blue glazing, the areas over 3000 lx are 7% (Figure 4.17).

The survey was conducted according to the simulation on March 21, so there is no comparison with human responses however, the calculation results indicate that in the summer months, it becomes more important to control sunlight for users to get comfortable indoor places due to high illuminance.

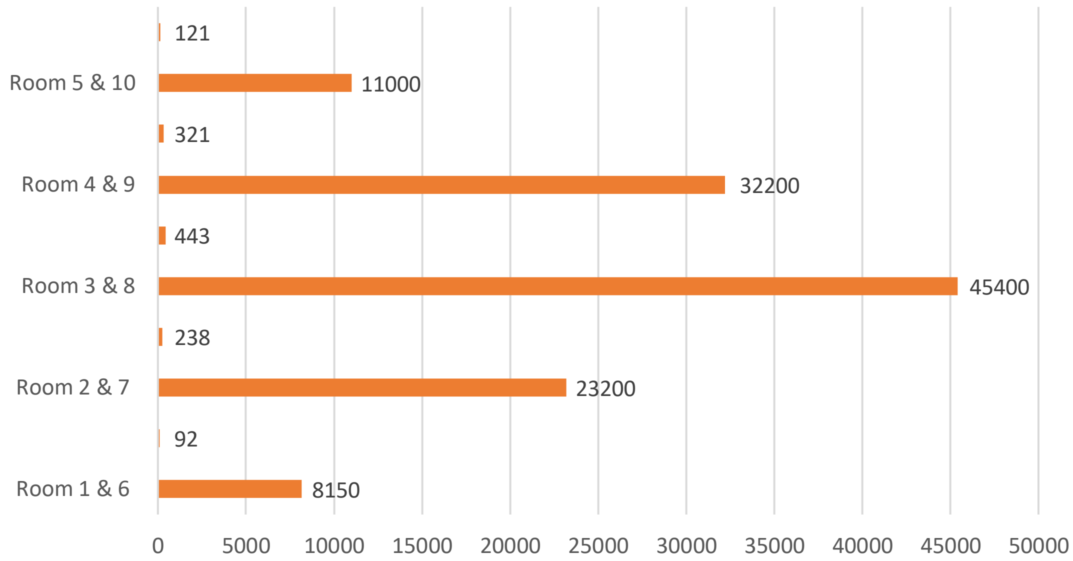


Figure 4.16.Maximum and minimum illuminance values on 21st June

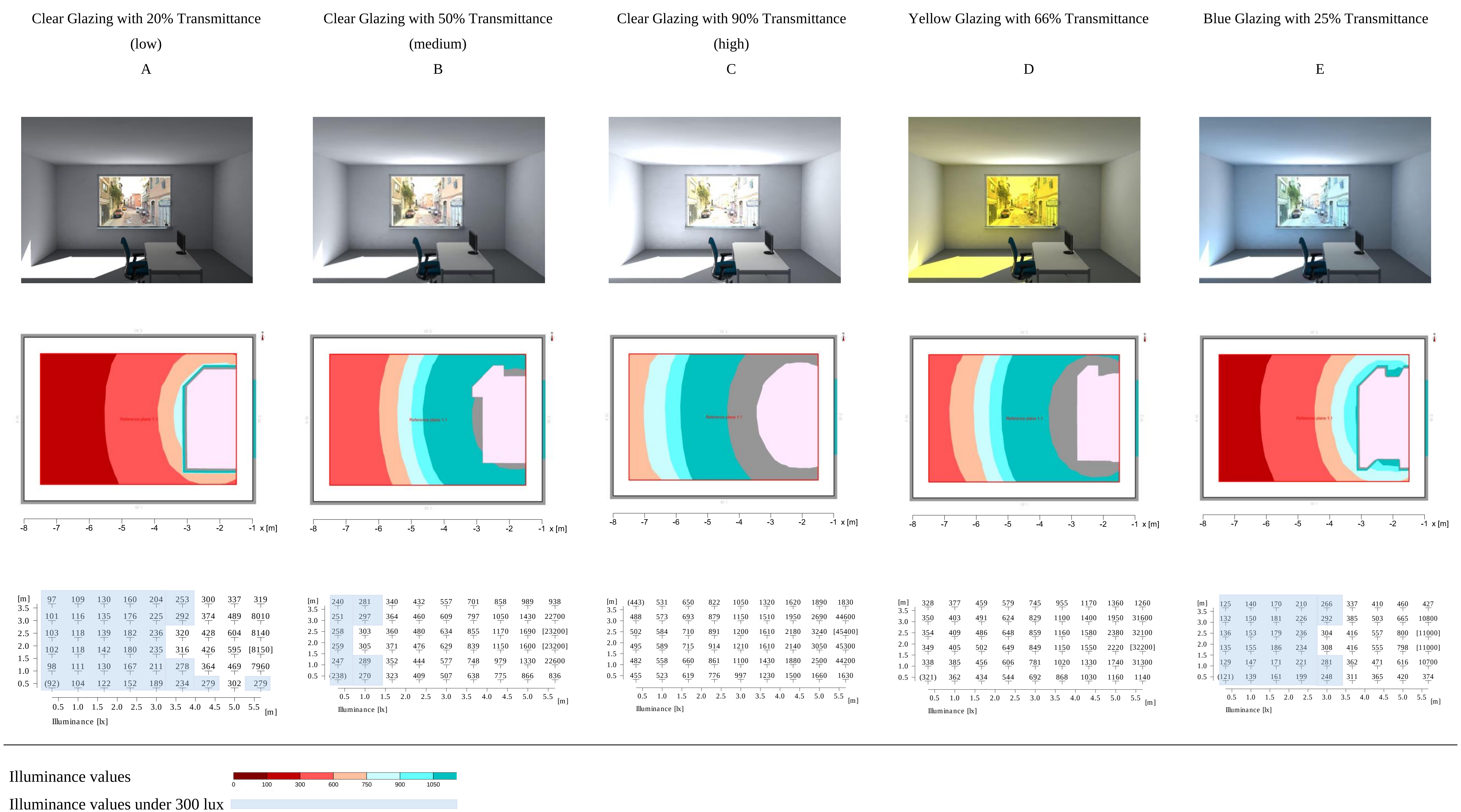


Figure 4.17. Renders of the rooms (first line), illuminance distribution (second line) and their values on plans of rooms (third line) (a) Room 1 and 6, (b) Room 2 and 7, (c) Room 3 and 8, (d) Room 4 and 9, (e) Room 5 and 10 at 11.00 on June 21

4.3.2. Luminance

To assess the uniformity and luminous conditions of the rooms, Relux provided 3D luminance false color distributions of rooms according to date, glazing transmittance, and color (Figure 4.18).

Studies that explored the connection between luminance and visual comfort suggested that recommended threshold value is 100 cd/ m2 based on subjective perception (Shi et al. 2021). These luminance values have various impacts on the visual comfort of the users in rooms. Earlier literature showed that undesirable luminous conditions caused blinding installment in the rooms (Van Den Wymelenberg and Inanici 2014), which is aimed to be replaced by the optimum glazing type. In the study, the luminance values are higher on June 21st than on March 21st. In the specific evaluation of March 21st, the windows have the highest luminance value in the room (+750 cd/m2) since they are the source of light. Luminous ratios are calculated to understand the uniformity or comfort conditions in the rooms. These ratios should adhere to certain rules to prevent glare. Each room has light patches on the floor, with rooms 1,5,6, and 10 having 400-500 cd/ m2 of luminance values in these light patches. The walls of rooms 1 and 6 have a luminance value of approximately 75 cd/ m2. Thus, the wall-to-window luminance ratio is 1:10 and causes a non-uniform indoor environment for the occupants (Garretón, Rodriguez, and Pattini 2015). In rooms 2 and 7, walls vary in brightness from 200 to 400 cd/m2, resulting in a ratio of 2.6:10 to 5.3:10 between the window and the walls is more consistent than in rooms with low transmittance glazing. The wall luminance in rooms 3 and 8 ranges from 250 to 650 cd/m2. The wall-to-window luminance ratios are between 3.3:10 and 8.6:10. Consequently, the distribution of sunlight in the rooms with higher transmittance glazing values is more even. The brightness values, however, can be excessive for the occupants. Even though the glazing colors are different, since the transmittance values of glazing are close, the values in rooms 4 and 9 are practically identical to those in rooms 2 and 7. The same situation applies to rooms 1 and 6, as well as rooms 5 and 10.

The luminance in the rooms is evaluated according to the luminance false color distribution of the rooms achieved by Relux.

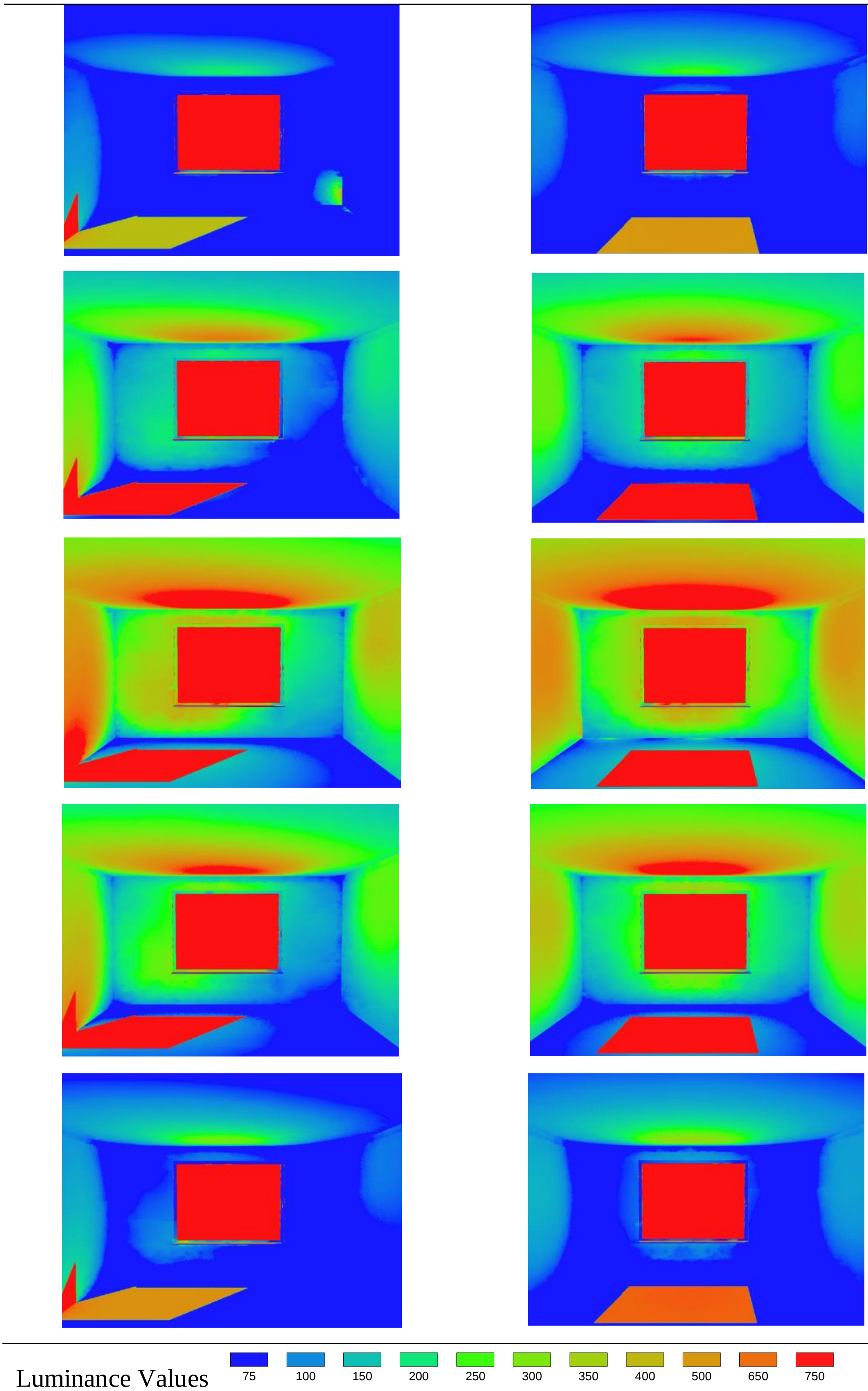


Figure 4.18. 3D Luminance false color distributions of rooms (a) 1 and 6, (b) 2 and 7, (c) 3 and 8, (d) 4 and 9, (e) 5 and 10 at 11.00 on March 21st and June 21st

CHAPTER 5

DISCUSSIONS

In this study, the effects of different types of glazing on the perception of indoor environments were evaluated.

One of the key findings of the study was that glazing color has a major impact on indoor perception. The most interesting indoor was found as Room 9, which featured yellow glazing with 66% transmittance and a landscape view. On the contrary, Room 1, which had clear glazing with 20% transmittance and a street view, was chosen as the least interesting room according to survey participants. Clear glazing is often used in typical indoor environments, so people are not accustomed to seeing colorful glazing; however, they are more likely to see indoor environments with clear glazing and a street view in their daily lives. Thus, participants voted the room with yellow glazing as the most interesting one.

The results showed that, although yellow glazing has been found to be interesting in indoor environments, room 4, which had yellow glazing with 66% transmittance and a street view, was perceived as the least pleasant. This may be due to the unfamiliarity with the yellow color. Besides, the yellow color on the window glazing caused an unnatural and distorted color indoors, so people started perceiving that as an unpleasant indoor environment. On the other hand, room 7, which had clear glazing with 50% transmittance and a landscape view, was rated as the most pleasant. Therefore, it seems that people prefer clear glazing with average transmittance and a landscape view when spending time indoors.

Another aspect that was evaluated was the perception of brightness in the rooms. Participants were most satisfied with the brightness in room 3, which had clear glazing with 90% transmittance and a street view. Even though Relux calculations indicated that this room had higher illuminance values and light patches in certain areas, participants still preferred it in terms of brightness. However, room 4, which had yellow glazing with 66% transmittance and a street view, was rated as less satisfactory in terms of brightness. This suggests that people prefer natural light over the changed illumination caused by yellow glazing. The results also showed that high illuminance on windows could create an uncomfortably bright view, as was the case in room 3. This highlights the importance of carefully controlling the amount of light that enters a space through glazing.

In terms of view preferences, room 6, which had clear glazing with 20% transmittance and a landscape view, was the most liked by participants. This is likely because people prefer the calming and refreshing effect of nature and green over a random street view. Room 3, which had clear glazing with 90% transmittance and a street view, had the most satisfactory levels of brightness but was rated as having a less pleasant view due to the high brightness levels on the windows. This suggests that a balance needs to be struck between the amount of light entering a space and the quality of the view. Besides, the views that are seen through colorful glazing were not preferred according to the results; both views were perceived as less pleasant in the rooms with tinted glazing.

All the rooms which were evaluated as having the most pleasant, most interesting, and best view quality have landscape view, which corresponds with the statistical result of the positive and significant impact of landscape view on interestingness, pleasantness, and better view quality in spaces. Although both blue and yellow glazing had negatively influenced the pleasantness, brightness, and view the quality of the indoors, blue glazing had less impact than yellow one on the votes of occupants. The reason may be the more intense yellow color of the used material compared to the soft color of blue material in Relux raytracing.

When the results achieved by the questionnaire and earlier studies in the literature are compared, it can be clearly seen that unlike the negative correlation between glazing transmittance values and pleasantness in this study, an earlier study (Arsenault, Hébert, and Dubois 2012) indicated that there is a positive correlation between transmittance values and pleasantness. However, both studies confirmed that when the glazing transmittance increase, the light level of the room increases, too. Also, the same study revealed that users prefer colored glazing (bronze) in terms of visual comfort, pleasantness, and light level, and blue glazing decreases arousal levels. On the contrary, yellow and blue glazing decreased the feeling of pleasantness in the room, and the view quality was not satisfactory for users in this study. Another study concluded that view quality has an effect on the perception of the room brightness and satisfaction with the indoor environment (Ko et al. 2020; Ozdemir 2010). Likewise, in this survey, results showed that people tend to find rooms with landscape view more interesting and pleasant.

Even though participants in the study prefer the landscape view in the rooms with glazing with 20% and 50% transmittance, these rooms have points under the threshold value of 300 lx. This means occupants might see a better and more satisfying view under these conditions however, they will need artificial lighting. Participants find the rooms more pleasant when there is glazing with 90% transmittance glazing. However, according to Relux calculation results, these rooms are very luminous and might have glare problems according to visual quality evaluations.

CHAPTER 6

CONCLUSIONS

Adjustable window glazing is very significant for human comfort in indoor spaces, as these changes can impact occupants' perception of the interior. In this study, a survey was conducted to evaluate the perception of humans with regard to the interestingness, brightness, and pleasantness of the room and the quality of the outside view. Participants evaluated the given rooms through renders on the computer. Answers to the survey are analyzed in varied methods. Furthermore, objective calculations on daylight values were conducted.

The survey involves two steps which include questions that ask to identify the significance of the impacts of independent variables (Age, Gender, Landscape, Yellow, Blue, Transmittance) on the dependent variables (Interesting, Pleasant, View Quality, Brightness). While the first part asks questions about the interestingness, pleasantness, brightness, and view quality of the room, in the second part, the same five types of glazing were used, but the street view was replaced with a landscape view.

Each variable in the study has different effects on user satisfaction and perception of the environment. While yellow glazing is more preferred for a room that is designed to be interesting, it negatively affects the view quality and a pleasant indoor environment. When the glazing transmittance decreases, illuminance values will also decrease, and the room will end up being darker. Under these circumstances, users start to see the outdoor view better. So for a better view for the occupants, landscape through the glazing with low transmittance should be chosen. However, this may end up in a dark room. It is better to evaluate each condition not from a single point of view but from many alternative concerns and thoughts. Thus, the use of glazing types, artificial light for dark indoors, or preservation from over-illumination should be provided.

Even though there are earlier studies on glazing types and view types, this study focused on combinations of glazing type, color, and the view from the occupants' point of view. The significance of this study is that a simultaneous study on indoor environments and occupants' perceptions with regard to glazing and view types. In addition to the perception evaluations of occupants, the simulated room illuminance and luminance values have been calculated. Thus, both objective lighting conditions and subjective criteria were investigated together. In further designs, the aim should be to re-think indoor environments and adjustable window use, including optical parameters, and human-centric design should be taken into consideration. Innovations in glazing technologies should be continued in response to occupants' desire to control environmental conditions and adjust these conditions according to their needs and requests. To maintain the development of these technologies, their impacts on penetrating daylight should be more preferable to other tools for window and glazing control.

Overall, the study concluded that glazing and view types are significant for indoor quality and occupants' comfort and perception. In conclusion, it becomes increasingly considerable for the spaces to provide good lighting conditions for user comfort. These spaces might be shaped according to the perception of people. Maybe the standards used for glazing can be reviewed, and better-illuminated spaces can be provided with the help of human-centered studies. In further studies, VR technology can be used for more realistic environments, or a real environment can be set up for a survey instead of renders.

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APPENDIX A

QUESTIONNAIRE

KATILIMCI ADI SOYADI	
YAŞI	
CİNSİYETİ	

Bu oda sizin için ne kadar ilginç?
(1 = ilginç değil) , (6 = oldukça ilginç)

1 ☐ 4 ☐

2 ☐ 5 ☐

3 ☐ 6 ☐

Bu oda sizin için ne kadar ilginç?
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3 ☐ 6 ☐

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(1 = hoş değil) , (6 = oldukça hoş)

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2 ☐ 5 ☐

3 ☐ 6 ☐

Bu odanın parlaklığı sizin için ne kadar yeterli?
(1 = yeterli değil) , (6 = oldukça yeterli)

1 ☐ 4 ☐
2 ☐ 5 ☐
3 ☐ 6 ☐

Bu odanın parlaklığı sizin için ne kadar yeterli?
(1 = yeterli değil) , (6 = oldukça yeterli)

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1 ☐ 4 ☐
2 ☐ 5 ☐
3 ☐ 6 ☐

Pencereden gördüğünüz manzara sizin için ne kadar hoş? (1 = hoş değil) , (6 = oldukça hoş)

1 ☐ 4 ☐

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3 ☐ 6 ☐

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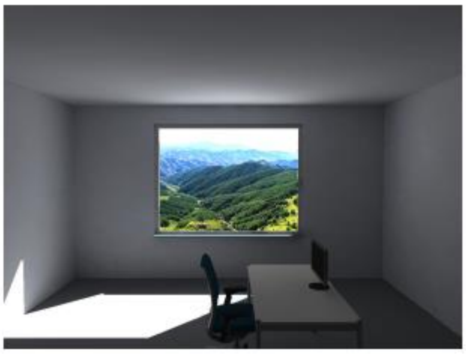
1 ☐ 4 ☐

2 ☐ 5 ☐

3 ☐ 6 ☐



Bu oda sizin için ne kadar ilginç?
(1 = ilginç değil) , (6 = oldukça ilginç)

1 ☐ 4 ☐
2 ☐ 5 ☐
3 ☐ 6 ☐

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(1 = ilginç değil) , (6 = oldukça ilginç)

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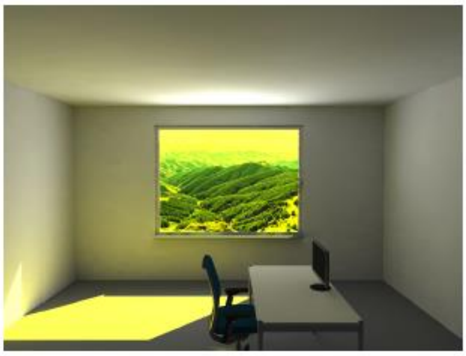
3 ☐ 6 ☐



Bu oda sizin için ne kadar ilginç?
(1 = ilginç değil) , (6 = oldukça ilginç)

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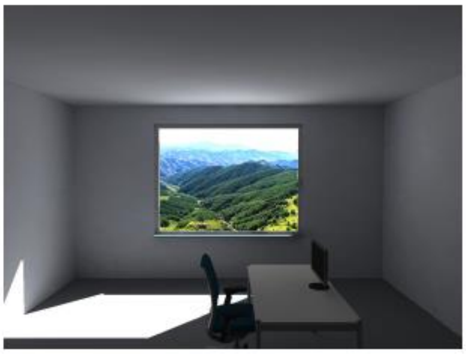
2 ☐ 5 ☐
3 ☐ 6 ☐



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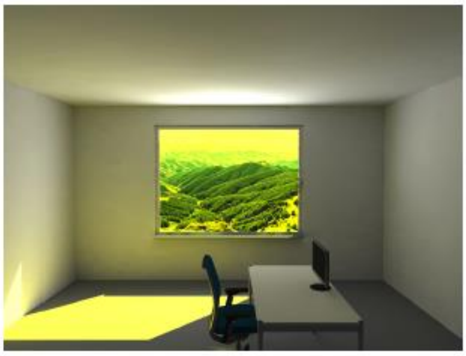

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1 ☐ 4 ☐

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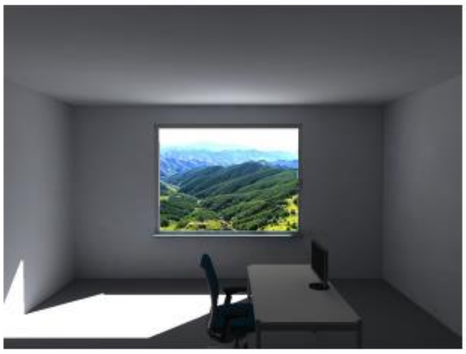
3 ☐ 6 ☐



Bu odanın parlaklığı sizin için ne kadar yeterli?
(1 = yeterli değil) , (6 = oldukça yeterli)

1 ☐ 4 ☐

2 ☐ 5 ☐

3 ☐ 6 ☐

Bu odanın parlaklığı sizin için ne kadar yeterli?
(1 = yeterli değil) , (6 = oldukça yeterli)

1 ☐ 4 ☐

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3 ☐ 6 ☐

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3 ☐ 6 ☐

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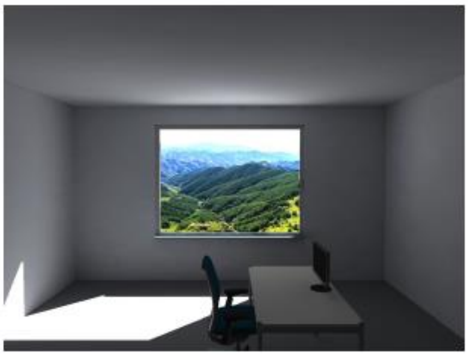
3 ☐ 6 ☐



Pencereden gördüğünüz manzara sizin için ne kadar hoş? (1 = hoş değil) , (6 = oldukça hoş)

1☐ 4☐

2☐ 5☐

3☐ 6☐

Pencereden gördüğünüz manzara sizin için ne kadar hoş? (1 = hoş değil) , (6 = oldukça hoş)

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2☐ 5☐

3☐ 6☐

Pencereden gördüğünüz manzara sizin için ne kadar hoş? (1 = hoş değil) , (6 = oldukça hoş)

1☐ 4☐

2☐ 5☐

3☐ 6☐

Pencereden gördüğünüz manzara sizin için ne kadar hoş? (1 = hoş değil) , (6 = oldukça hoş)

1☐ 4☐

2☐ 5☐

3☐ 6☐

Pencereden gördüğünüz manzara sizin için ne kadar hoş? (1 = hoş değil) , (6 = oldukça hoş)

1☐ 4☐

2☐ 5☐

3☐ 6☐

APPENDIX B

VOTES OF THE PARTICIPANTS

	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
0	11	8	10	5	5	7	5	2	5	3
1	13	11	9	5	6	3	3	11	5	4
2	7	6	5	5	8	9	7	8	2	8
3	8	9	10	4	8	11	11	12	5	8
4	0	4	4	12	9	4	10	3	16	11
5	1	2	2	9	4	6	4	4	7	6
0	8	3	12	24	11	0	0	2	12	0
1	5	5	9	8	10	1	0	6	10	7
2	7	12	11	3	8	4	2	12	7	12
3	9	12	7	1	3	13	10	11	5	5
4	5	4	1	4	6	15	17	5	4	10
5	6	4	0	0	2	7	11	4	2	6
0	6	0	2	7	1	2	0	2	7	1
1	11	3	0	9	8	8	0	2	8	3
2	11	2	3	13	8	14	6	4	12	13
3	6	16	4	8	12	7	13	5	9	13
4	4	13	14	3	9	7	14	11	3	6
5	2	6	17	0	2	2	7	16	1	4
0	6	5	19	25	12	0	0	1	12	1
1	4	8	12	4	8	1	1	5	7	5
2	9	7	7	6	7	1	2	9	9	7
3	8	12	1	0	6	5	9	10	4	10
4	8	6	1	4	3	7	15	6	2	4
5	5	2	0	1	4	26	13	9	6	13

APPENDIX C

MEAN VALUES OF THE VOTES

	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	Room 10
Q1	***1,4***	1,9	1,875	3	2,55	2,5	2,75	2,375	***3,025***	2,95
Q2	2,4	2,525	1,4	***0,825***	1,725	3,575	***3,925***	2,575	1,625	2,9
Q3	1,925	3,425	***3,975***	***1,775***	2,65	2,375	3,55	***3,975***	1,9	2,8
Q4	2,575	2,1	***0,825***	0,925	1,8	***4,4***	3,925	3,05	1,875	3,25