EFFECTS OF ILLUMINANCE LEVELS OF SOLID STATE LIGHTING SOURCES ON VISUAL COMFORT

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EFFECTS OF ILLUMINANCE LEVELS OF SOLID STATE LIGHTING SOURCES ON VISUAL COMFORT

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

EFFECTS OF ILLUMINANCE LEVELS OF SOLID STATE LIGHTING SOURCES ON VISUAL COMFORT

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Lighting systems in interior architecture need to be designed according to the function of the space, user's comfort and needs. In order to see the environment, besides light and reflecting surfaces, desired lighting levels are required for visual comfort. Desired and comfortable lighting levels increase task efficiency. The aim of this study is to research the effects of illuminance levels on user's visual comfort and reading performance. Therefore, with the participation of eighty participants from the department of Interior Architecture of Çankaya University, six lighting scenarios were created with LED and OLED lighting sources that consisted of three different illuminance levels. A reading task was performed in each lighting scenario. The results indicated that the illuminance level of 500 lux was visually more comfortable than the other illuminance levels. Different illuminance levels were found to be more comfortable for different visual comfort criteria. OLED lighting was found visually more comfortable than LED lighting with respect to the visual comfort criteria. In addition, participants read slower under the illuminance level of 800 lux for each lighting source and it was concluded that illuminance levels effect user's visual comfort and reading performance.

Keywords: Illuminance Levels, LED, OLED, Reading Performance, Visual Comfort

ÖZET

ELEKTRİKLİ IŞILDAYAN AYDINLATMA KAYNAKLARININ AYDINLIK DÜZEYLERİNİN GÖRSEL KONFORA ETKİLERİ

AVCI, Ayşe Nihan
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İç mimaride mekanların aydınlatma sistemlerinin, mekanın işlevi, kullanıcının konforu ve ihtiyaçları göz önüne alınarak tasarlanması gerekmektedir. İçinde bulunduğumuz çevreyi görebilmek için, ışığın ve yansıdığı yüzeylerin yanı sıra, görsel konfor için yeterli düzeyde aydınlatmanın sağlanması gerekmektedir. Yeterli ve konforlu aydınlatma, verimli çalışmayı beraberinde getirmektedir. Bu çalışmanın amacı, farklı aydınlık düzeylerinin kullanıcının görsel konforu ve performansı üzerindeki etkisini araştırmaktır. Bu nedenle, Çankaya Üniversitesi İç Mimarlık Bölümü'nden 80 gönüllü öğrencinin katılımıyla LED ve OLED aydınlatmalardan ve her biri için 3 farklı aydınlık düzeyinden oluşan 6 aydınlatma senaryosu tasarlanmıştır. 6 farklı kitap özeti okuyup anket sorularını değerlendirmeleri istenmiştir. Sonuçlar göstermektedir ki, 500 lux aydınlık düzeyi diğerlerine göre daha konforlu çıkmıştır. Bazı görsel konfor kriterlerinde, farklı aydınlık düzeyi konforlu bulunmuştur. OLED aydınlatma, LED aydınlatmaya göre bütün aydınlık düzeylerinde daha konforlu bulunmuştur. Ek olarak, 800 lux aydınlık düzeyinde kişiler daha yavaş okumuş; aydınlık düzeylerinin görsel konfora ve okuma performansı üzerinde etkili olduğu sonucuna varılmıştır.

Anahtar Sözcükler: Aydınlık Düzeyleri, LED, OLED, Okuma Performansı, Görsel Konfor

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CHAPTER 1

INTRODUCTION

Lighting is the application and energy that supports user – environment interaction through natural and artificial lighting sources. It is designed to enable the user to perceive his/her environment and its elements in desired levels. Behind this technical information, there is a real meaning that lighting exists in every sphere of life and is a basic need for humans beings. Human beings usually need light to continue and complete their daily tasks. They need their senses, but seeing is more important and effective than the other senses. With the visual system, light provides us to understand and get information for visual tasks and it affects how we experience our environment (Smolders, de Kort & van den Berg, 2013).

Light is an essential requirement for human beings, since it enables us to experience the external world, but it also affects our physical, physiological and psychological behaviors. In interior architecture, one of the main purposes of lighting is creating comfortable and functional spaces for users to do their daily activities easily (Gümüş, Aykal & Murt, 2005). An optimal indoor environment can increase performance, comfort, motivation, interpersonal communication, health and well-being in human beings (Borisuit, Linhart, Scartezzini & Münch, 2015). Accordingly, studies have been conducted to analyze the effects of different lighting conditions on human beings to obtain good quality lighting. Since the 1990s, good quality lighting has been provided for users and its affects have been evaluated during tasks. In addition, the optimal level of lighting for visual performance has been investigated (Bellia, Bisegna & Spada, 2011). Visibility is very important for lighting design. Lighting affects user's motivation of work-related tasks, their health and well-being. Poor lighting can decrease motivation and increase the feeling of illness such as visual fatigue, headache and double vision. As a result, this decreases the performance of human vision system and motivation, speed and positive mood as well.

The quality of lighting is one of the essential elements of interior architecture. Light illuminates the space by three ways: naturally, artificially and in combination of natural and artificial. When natural lighting is not enough in a space, artificial lighting systems are preferred to obtain the desired levels of light. With the technological developments, the characteristics of light are being researched extensively and several studies have focused on its qualitative and quantitative properties (Shen, Shieh, Chao & Lee, 2009). These studies have increased the realization and the usage of artificial lighting systems. By changing the color, shape, intensity, luminous, temperature and illumination levels of light, various lighting fixtures have been manifactured that offer diversity to satisfy human needs (Avcı and Memikoğlu, 2016a). One of the most important lighting characteristics is the illuminance level. Illuminance level, which is indicated as lux, is the quantity of light measured on a working surface where the most important tasks in the space are performed (Recommended Light Levels, n.d.). Results of various studies show that illuminance levels have a substantial effect on user's performance, speed and comfort (Avcı and Memikoğlu, 2016b). Illuminance levels are usually adjusted according to user needs on a working surface. Several standards are used to obtain suitable illuminance levels for each space and each task, for instance, according to the Turkish standards, TS EN 12464-1, an optimal illuminance level for a reading task is 500 lux ("En Az Aydınlık Düzeyleri Tablosu", n.d.).

Together with the development of technology, in order to satisfy the needs, several lighting fixtures are produced such as spot halogen lamps, tungsten halogen lamps, fluorescent lamps, fiber optic cables, light stones, light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs). Fluorescent and other lighting fixtures are widely used, but newer technologies such as LED and OLED lightings have become more advantageous due to their low power consumption, flexibility in usage and long-life span than the other fixtures (Hawes, Brunye, Mahoney, Sullivan & Aal, 2012). Considerable amount of research has been done related to the technical aspects of lighting fixtures; however, little research has been considered on how LED and OLED lightings affect user performance and visual comfort.

1.1. Aim of the Study

The aim of this study is to analyze the effects of different illuminance levels of LED and OLED lightings on user visual comfort and reading performance. It also targets to research whether LED lighting or OLED lighting is comfortable, since there is not enough research about the relationship between illuminance levels, user visual comfort and reading performance. In addition, there is not sufficient research about the correlation of illuminance levels of LED and OLED lightings. The main aim of this study is to understand the interaction of lighting and user through LED and OLED lightings. OLED, as the next step of the SSL technology, has mainly been used in automobiles, mobile phones and television industry, but this thesis has considered OLED as an element on an interior environment affecting user visual comfort and task performance and compared it with LED. Results of the study will be useful for interior architects, producers, environmental psychologists, lighting designers who are studying these area.

1.2. Structure of the Thesis

This thesis consists of five chapters. The introduction, which is the first chapter, consists of two parts as aim of the study and structure of the thesis. This chapter generally aims to give general information about lighting and introduces the importance of lighting for human beings. It also aims to indicate the relations between illuminance levels of lighting and user from the point of their visual comfort and reading performance.

In order to analyze the history and meaning of light and lighting fixtures, the second chapter named as technical aspects of lighting involves three sub-titles: sources of lighting, properties of light and lighting systems. The first part explains how lighting was discovered and developed. In the second part, the technological developments of lighting fixtures are researched. The properties of lighting such as luminance and illuminance, color rendering index (CRI), correlated color temperature (CCT), glare, reflectance and transmittance, which affect visual comfort, are stated in the third part.

In the fourth part, lighting systems are described as general, task, accent and decorative lightings.

The third chapter explores how we see and how lighting effects the visual comfort of users. It involves four sub-titles such as light and vision, visual comfort criteria, lighting and illuminance levels and lighting in reading environments. They are elaborated with respect to other studies from the literature.

In the fourth chapter, the experiment is described with the aim, research questions and hypotheses. The participants are identified and the method of the study is defined with respect to the research questions. The results of the experiment are evaluated and discussed in relation to previous studies related to the subject. In the last chapter, major conclusions about the study are stated and suggestions for future research are generated.

CHAPTER 2

TECHNICAL ASPECTS OF LIGHTING

2.1. Sources of Lighting

With the forest fires and lightnings, prehistoric people experienced the power of fire. They understood that fire could be used to warm themselves and to protect themselves from dangers; however, the continuity of fire was a big problem. When prehistoric people discovered burning animal fat, they invented the first oil lamp that was shaped like a candle. In 2000 BC, glassworks developed with the process of sand, soda and rock-salt in hot conditions and this development blaze a trail on lamp design. In AD 900, Muhammad ibn Zakariya Razi who was a Persian scholar, discovered the first kerosene lamp (“A Brief History of Lighting”, n.d.). In late 18th century, while brightness of lighting sources and the materials used in the lighting fixtures were discussed in the developed countries, the usage of kerosene lamps became popular by the pressure of gas companies (Çalkın and Türkoğlu, 2011). Due to kerosene lamps, people were able to work at night.

Other developments can be stated as;

- Heinrich Göbel discovered the incandescent lamp in 1854,
- Peter Cooper Hewitt demonstrated the mercury-vapor lamp in 1901,
- Georges Claude improved the neon lamp in 1911,
- Edmund Germer patented the fluorescent lamp in 1926,
- Nick Holonyak improved the first light-emitting diode (LED) in 1962,
- Andre Bernanose and co-workers discovered OLED in the 1950s.

Lighting systems in living spaces should be designed according to user comfort, to the task being performed and function of the space. According to these, studies have been conducted to analyze how humans visually become comfortable and productive in their daily tasks (Benedetto, Carbone, Drai-Zerbib, Pedrotti & Baccino, 2014).

There are two main sources of lighting that are named as natural lighting and artificial lighting. The sun is a source for natural lighting. When natural lighting is not sufficient in a space, artificial lighting systems can be preferred additionally to obtain the desired illuminance levels. With the development of technology, various artificial lighting fixtures have been discovered and used such as incandescent, fluorescent and high intensity discharge lamps (HID), fiber optic cables and solid state lightings (LEDs and OLEDs).

2.1.1. Natural Lighting

Humanity has had several millennia to enhance its complicated interaction with the most suitable light source that is called natural light. Owing to the adaptability of the environment, humans adapt and develop themselves physically and psychologically in the natural world. This situation allows humans to create environments that make them feel good and comfortable. Designers sometimes create uncomfortable and unhealthy environments by using unnatural patterns. In order to change them, designers should analyze the qualities of natural light.

The natural world consists of various light sources that are not created by humans, for instance lightning, deep-sea creatures, fireflies and fires, but one of the important sources of natural light is sunlight. Sunlight is a vital and dominant natural light source for the earth radiating either directly or indirectly. There would be no life without it. Likewise, the human, physiological and psychological behaviors can be influenced by sunlight (Innes, 2012).

Sunlight reaches the earth, which is scattered in the atmosphere, enters from a window in various forms such as direct light from the sun, from the clear sky, as reflections from clouds, ground and nearby buildings (Çalkın and Türkoğlu, 2011; Innes, 2012). The various sources of natural light are shown in Figure 2.1. The light from all natural sources differs in quantity and quality with respect to illuminance levels, brightness, color and efficacy.

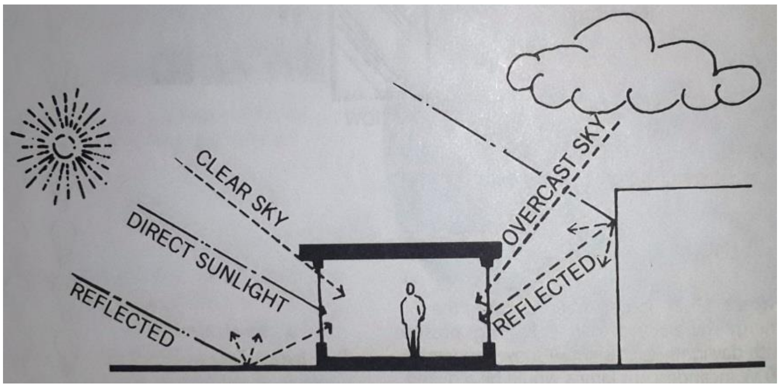


Figure 2.1. Various Sources of Natural Lighting (Lechner, 2009)

Illuminance is the amount of light falling on a surface and spreading over. The illuminance levels of natural light varies under different weather conditions. Compared to artificial lighting, natural lighting has a wide range of illuminance level. In overcast sky (100% cloud cover with sun not visible), the illuminance levels are three times greater at the zenith than at a horizontal direction. Although the illuminance levels are low in this condition (5.000 – 20.000 lux), it is one fifth more than indoors. On a clear day (< 30% cloud cover), the shiniest part of the sky is ten times shiny than the darkest part. The illumination level of a clear sky is between 60.000 – 100.000 lux and from 100 to 200 times greater than a good indoor illumination (Lechner, 2009).

The following techniques are useful to penetrate the natural light into the interior spaces:

Light Wells (Shafts): Light wells are top lighting devices that soften the brightness ratios at the boundary of the view of sky and ceiling (Egan, 1983). In order to transmit more light into the interior space, the surface of the well should be reflective and narrower. Light well is represented in Figure 2.2.

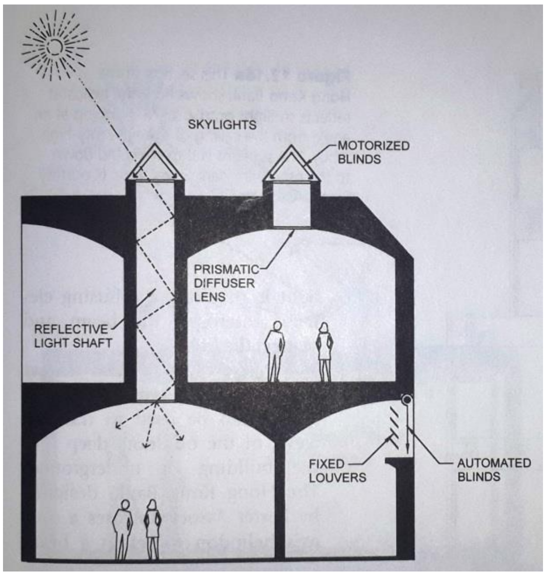


Figure 2.2. Light Well (Lechner, 2009)

Tubular Natural Lighting Devices: They are consisted of five main parts: dome, dome base, roof base, reflective channel and diffuser. Dome is placed on the roof and transmists the natural light to the reflective channel. Natural light comes into the channel and is reflected to the diffuser that distributes the light homogenously (Pirasaci, 2015). The quality and quantity of natural lighting are transmitted by splaying the ceiling around the light tube. Typical light tube is shown in Figure 2.3.

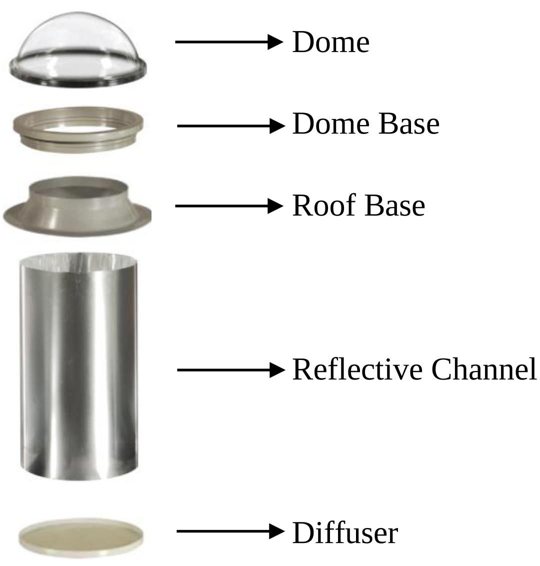


Figure 2.3. Typical Light Tube (Pirasaci, 2015)

Beamed Daylighting: A mirror mounted on a heliostat can track the sun and reflect a vertical beam of light through the roof. The technique is known as beamed daylighting. Various types of the Heliostat are produced to collect the sunlight by using a set of mirrors and/or lenses, which send itinto building core via vertical voids. A further set of internal mirrors may be used to distribute the daylight (Mayhoub, 2014). An example of beamed daylighting can be seen in Figure 2.4.

Figure 2.4. Beamed Daylighting (Mayhoub, 2014)

Natural lighting differs according to the location of the space with respect to latitude and longitude, time and atmosphere (Erlalelitepe, Aral & Kazanasmaz, 2011). During the design of a building, various components such as direction, transparency ratios, window types should be considered in order to provide sunlight to all of the space according to user needs.

2.1.2. Artificial Lighting

The usage of artificial lighting gained acceleration with the invention of incandescent lamp in the 19th century (Loe, 2016). There are a lot of special products in the artificial lighting industry; however, there are four principle lighting technologies. Generally, it is possible to classify the artificial lighting sources that are used in reading environments such as incandescent lamps, fluorescent lamps, high intensity discharge lamps and solid state lightings (LEDs and OLEDs).

2.1.2.1. Incandescent Lamps

Incandescent lamps are the common type of the lamp industry. Although they are generally outmoded due to their capability of sparkle, they are used in some lighting fixtures such as chandeliers and lamp-shades. In an incandescent lamp, light occurs by passing electricity through a tungsten filament that heats it and produces light. As the tungsten filament gets hotter the emitted light gets whiter (Lechner, 2009).

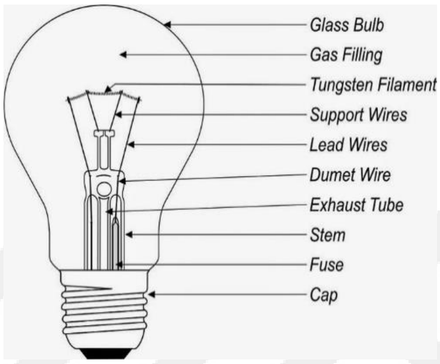


Figure 2.5. The Structure of a Typical Incandescent Lamp ("Uses of Light Bulbs and Their Structure", 2014)

The structure of a typical incandescent lamp is shown in Figure 2.5. Incandescent lamps involve glass bulbs made from a ribbon of hot glass that is first thickened and then blown into molds. These glass bulbs are cut from the ribbon and covered with a material named screw cap. The filament consists of drawing tungsten metal into a tightly coiled wire. The finished filament is then clamped or welded to leads that are embedded in a glass supporting structure. This structure is then inserted into the bulb and the parts are fused together. When most of the oxygen has been removed, the bulb opening is sealed and a base is attached ("Incandescent Lamps Information", n.d.).

Incandescent lamps are produced in several sizes, watts and voltages. The color temperature range, which is a measure of light source color appearance, varies from less than 2,650 kelvin to 3,350 kelvin and more. The color-rendering quality, which is a measure of how well a light source renders the colors of objects, surfaces and materials of them is accepted to be good. On the contrary, the life span of incandescent lamps are generally 1,000 – 3,000 hours, whereas other light sources are 100,000 hours. So, incandescent lamps are not preferred for reading environments in which high levels of illumination are required. Because of their low efficacy, they are energy wasteful and expensive. Therefore, incandescent lamps are preferred less than the other sources of light (Lechner, 2009).

2.1.2.2. Fluorescent Lamps

The fluorescent lamp was first discovered in 1926, but it is still very popular and the most common and modern artificial light source used all over the world. It is available in a wide range of sizes, shapes, different watts and colors; produces ultraviolet (UV) radiation and not visible light. On the inside of the glass tube, there is a layer of phosphorus and minerals, which is named as white coating, that react to UV radiation. The phosphorus absorbs high energy UV radiation and reradiates some of it as low energy visible light. This process is referred to as fluorescence ("Fluorescent Lamp", n.d.). The structure of a typical fluorescent lamp is presented in Figure 2.6.

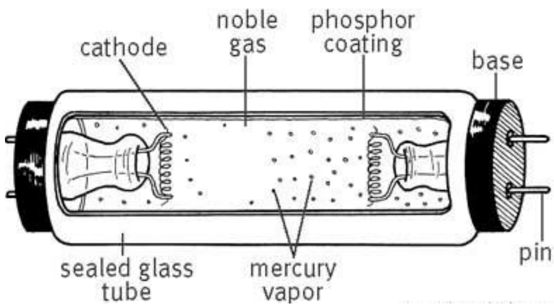


Figure 2.6. The Structure of a Typical Fluorescent Lamp ("Fluorescent Lamp", n.d.)

There are generally two types of fluorescent lamps that are linear and compact. Linear fluorescent lamps are named by T and it stands for the diameter as one-eights of an inch. T12, T8, T5 and T2 are samples of linear fluorescent lamps. Compact types are four pins, spiral, circular and bulbs. When producing light, fluorescent lamps are more efficient than incandescent and halogen lamps. They have life ratings from 7,500 hours to 24,000 hours that depend on such factors as ballast and lamp type and how they are switched on or off (“Electric Light Sources”, n.d.). Some of the fluorescent lamps can last for 30,000 hours. They are good at illuminating large spaces and offer the opportunity of dimming eventhough it is expensive. Household fluorescent are accepted to be around 4500 K. There is a variation between countries in terms of the fluorescent light color. Some countries use 4000 K neutral white. In the North countries, the CCT level of 3000 K fluorescent lamps are preferred to feel warmth (“Flourescent Lamp Colors”, 2011). The CCT level of 4000 – 4500 K fluorescent lamps are generally used in hospitals and offices. Fluorescent lamps achieve CRIs of anywhere from 50 to 98. They with low CRI have phosphors that emit too little red light. Skin appears less pink, and hence "unhealthy" compared with incandescent lighting. Colored objects appear muted (Wikipedia, 2016f) .

2.1.2.3. High Intensity Discharge (HID) Lamps

High-intensity discharge lamps have the highest efficacy and long-life span within all types of light sources. All discharge lamps need a ballast to work. Light is emitted from a small arc tube. They need ten minutes to produce light, since ballasts need time to establish the electric arc (“Light Bulb: High Intensity Discharge Lamps”, 2016). Due to their maximum light output, HID lamps are commonly used in large areas and outdoor lighting. The structure of a typical HID lamp is shown in Figure 2.7.

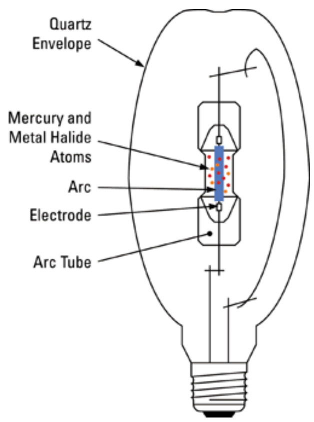


Figure 2.7. The Structure of a Typical HID Lamp (“HID Lighting Technology Fundamentals”, 2010)

HID lamps are divided into three categories: mercury, metal halide and high pressure sodium lamps. Mercury lamps are the oldest type of HID lamps and are not suitable for good color rendition. Due to their production of cool light, they are preferred in landscape lighting. Metal halide lamps produce bright-white light, have high efficacy, long life span (10,000 – 25,000 hours) and are used in stores, sports arenas etc. High pressure sodium lamps use sodium different from the other HID lamp types. Also, it has a very long life span (24,000 – 30,000 hours) (Lechner, 2009).

2.1.2.4. Solid-State Lighting (SSL)

The general concepts of artificial lighting sources are undergoing a change with the development of SSL technology (Kar and Kar, 2014). Due to task performances, human comfort and production of good quality lighting, researchers have focused on high-tech lighting sources by using solid-state and organic light-emitting devices that are more efficient than other lighting sources. SSL was developed in 1962 with semi-conductor materials such as gallium aluminium arsenide and it is believed to be capable of gaining a place besides traditional lighting sources including incandescent, fluorescent and high-intensity discharge sources (Peralta and Ruda, 1993; Tsao, Coltrin, Crawford & Simmons, 2010). Today's SSL sources create a research era to experiment and compete with other types of artificial lighting sources.

The term "solid-state lighting" is also referred to as "electroluminescent lighting" in which it produces electromagnetic radiation in response to power current, this process does not require heat and electric discharge via gas. As a result, they are cooler and smaller than other light sources (Innes, 2012). The most common types of SSL sources are light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs).

2.1.2.4.1. Light-Emitting Diode (LED)

LEDs are one of the newest improvements in the light world. They are intrinsically monochromatic and their alternation depends on the emitting wavelength. The first LED was developed in 1962 that consisted of a semi-conductor material (Steigerwald et al., 2002). The wavelength emitted by the semi-conductor joint is determined by the value of the energy gap between the conduction and valence bands (Cohen et al., 2011). Semi-conductors conduct electricity and isolate the flow of electricity. They are composed of different types of atoms and are grouped as III – V semiconductors. The characteristics of semi-conductors change when atoms switch their location in it (Sanderson and Simons, 2014). Two layers of semi-conductors called p-type and n-type generate a diode and they provide the flow of electricity in one direction. Electricity flow through the diode via right elements causes the diode to emit light. As a result, it is called a light-emitting diode. The following Figure 2.8 shows the structure of a typical LED lamp.

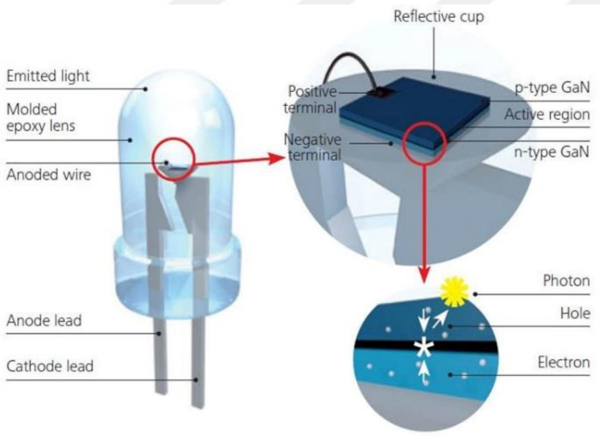


Figure 2.8. The Structure of a Typical LED Lamp (“LED’in Yapısı”, 2014)

Lamps include some electric components in which electric currents flow. Electric currents generate magnetic and electric fields of low and high frequencies that change with the type of lamp (European Union, 2008). As analyzed in the development of lighting technologies, electromagnetic fields are decreased. LEDs are significantly below the limits that are recommended by International Commission for Nonionizing Radiation Protection (ICNIRP) (Ticleanu and Littlefair, 2015).

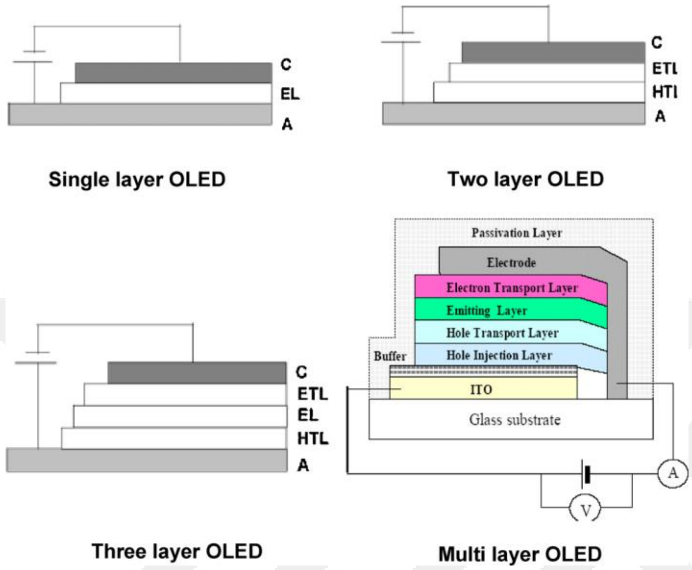
LED lamps are very durable; have long life span and no mercury (Jaadane et al, 2015). They are useful where coloured light or small white light are needed and preferred for decorative, task and accent lighting, during wayfinding, exit signs, traffic lights and path lighting. Rather than incandescent and fluorescent lamps, LEDs do not produce excessive heat. In addition, LEDs offer high color rendering, dimming and compactness (Kar and Kar, 2014).

Incandescent lamps are no longer used in European countries since September 2016. They are being replaced with inorganic or organic light-emitting diodes. LEDs do not contain mercury like fluorescent lights, have low toxicity and do not generate magnetic fields that are dangerous to human health (Li et al., 2015). New LEDs are made from materials such as gallium, aluminium and indium. Various studies have researched that toxicity of different metals involved in some lamps are dangerous waste (Osram, 2014; Osram 2009; Scholand and Dillon, 2012; Lim et al., 2011). One of the studies found that incandescent lamps are more dangerous than LEDs (Osram, 2009). Additionally, most materials that are used in LEDs can be recycled and removed. If white LEDs are replaced with other artificial lighting sources, approximately 270 million tons of CO_2 will not be emitted each year (Cohen et al., 2011). As a result, this will help to protect the balance of nature.

2.1.2.4.2. Organic Light-Emitting Diode (OLED)

OLEDs, which are one of the most important developments in the lighting industry, are different and innovative SSL sources. After, Bernanose and co-workers discovered electroluminescence in organic materials (Kunic and Sego, 2012). Eastman Kodak Company produced some materials to improve this technology in 1985. The first OLED device was released in 1987. Later on, some companies such as Samsung, LG, Panasonic and Sony, developed them further. OLEDs are currently used in several electronical devices such as TV, mobile phone and cars all around the world.

OLEDs consist of several organic layers sandwiched between the cathode and the anode. They are semi-conductive; they emit light and are producted on a subtrate. The material of a subtrate can be a conductive organic film, plastic or glass. There is an oxidized area containing dopant molecules that emit light and transport charge. Voltage occurs between two electrodes; at the same time, charge carriers are sent to the organic layers and rebond in it for producing light (Kar and Kar, 2014). The color of the light emitted is related to the composition of organic layer. In order to produce any color including white, multiple layers (for instance blue, green and red) are combined to together. The following Figure 2.9 shows the structure of different organic light-emitting diodes.



C: Cathode

EL: Emitting Layer

ETL: Electron Transport Layer

HTL: Hole Transport Layer

HIL: Hole Injection Layer

A: Anode Small Molecules

Figure 2.9. The Structure of Different OLEDs (Kalyani and Dhoble, 2012)

OLEDs vary their structure, material and emission type. Passive matrix OLED (PMOLED), active matrix OLED (AMOLED), transparent OLED, top-emitting OLED, bottom-emitting OLED, foldable or flexible OLED and white OLED (WOLED) are seven types of OLEDs. PMOLEDs and flexible or foldable OLEDs are used for small screen and cell phone applications; AMOLEDs are used for computer monitor and TV screens, transparent OLEDs are used for head up displays; WOLEDs are used to use in homes and buildings (Kunic and Sego, 2012).

Although LEDs and OLEDs are the new developments of the lighting industry, they are different from each other. OLEDs have several advantages such as being flexible and bendable, brighter, thinner, providing wide viewing angle, having different shapes, some are transparent, easier to produce, even providing an ambient glow. In addition, they consume less energy than other SSL sources. OLED lamps are glare-free and produce no harsh shadows (Eley, 2015). Due to these characteristics, they provide visual comfort, low light pollution for humans and diffuse in appearance

(Kar and Kar, 2014). Most types of OLEDs are used as accents lights, wall sconces, and in commercial, residential, and automotive lighting industries. Compared to other display technology products, it is likely that OLED lighting sources will become popular and be the mainstream in interior lighting design for the future (Öztank and Halıcıoğlu, n.d.).

2.2. Properties of Light

Light is a form of energy and is a part of the electromagnetic spectrum that consists of X-rays, microwaves, radio waves, infrared and ultraviolet to which our eyes are sensitive (Lechner, 2009). Visible light is defined simply as the visible energy that our system is sensitive to and gives us the sensation of sight (Innes, 2012). Humans have a visual system that can identify and interpret information from visual light to construct a representation of the environment (Wikipedia, 2016a). Since light can be produced by heat, by the transformation of chemical energy and other kinds of electromagnetic energy such as microwave energy, humans are incapable of measuring the quantity of light. Likewise, they can feel infrared energy as heat on their body. The wavelengths of light are presented in Figure 2.10.

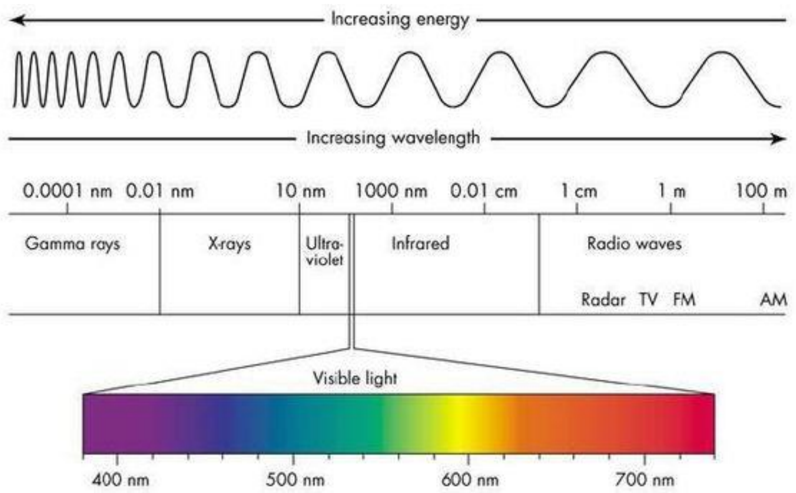


Figure 2.10. The Wavelengths of Light (“Easiest Way To Make A Laser Burn”, 2016)

The characteristics of light named as brightness, luminance and illuminance, color rendering index (CRI), correlated color temperature (CCT), spatial light distribution, brightness and glare, reflectance and transmittance are explained in detail.

2.2.1 Brightness, Luminance and Illuminance

Brightness is a visual perception in which an object appears to radiate or reflect light. In other words, it refers to the subjective perception of how bright an object is. Whereas, illuminance is an objectively measurable attribute that is measured by a light meter. The portion of light can be defined as illuminance and luminance. While these characteristics of light are interchangeable, there is an important difference between what we see (brightness) and what a light meter reads (luminance) (Lechner, 2009).

Luminance is the amount of light that reflects from on object's surface and reaches the eye. The SI unit (International System of Units) for luminance is candela per square meter (cd/m^2) (Innes, 2012). Luminance is what the humans perceive when looking at a scene or when using a camera. The quality and intensity of the light differ according to the properties of the objects' surfaces, such as material color, reflectance, texture and geometry. In addition, luminance can mean the amount of light emitted from glowing and transluscent surfaces. The luminance value for the sun is 1.600.000.000 cd/m^2 and for the moon it is 2.500 cd/m^2. So, humans can not look directly at the sun for a long time ("What Is Luminance", 2016).

Illuminance is the amount of light falling on a surface and spreading over. Humans can not see illuminance, but the light that reflects from the surface is what humans see as luminance. The SI unit is footcandle (lux). The illuminance levels of spaces are determined according to the requirements and functions of the spaces. In reading environments, the desired illuminance levels are specified according to a reading plane and human's visual comfort. According to the Turkish standards (TS EN 12464-1), the minimum illuminance level of a reading environment is 500 lux ("En Az Aydınlık Düzeyleri Tablosu", n.d.). However, in different situations, the illuminance levels can be below or above the standards. Due to the varieties of real conditions and current situations, illuminance levels can be below or above of the standards (Avcı and Memikoğlu, 2016a).

2.2.2 Color Rendering Index (CRI)

Color is the characteristic of human visual perception described through color categories, with names such as red, yellow, purple or bronze. This perception of color derives from the stimulation of cone cells in the human eye (Wikipedia, 2016b). Color consists of three main properties: hue, value and saturation. Hue specifies the color of light such as red, green, blue and yellow based on the wavelength of light. Value is the lightness or darkness of a color. Saturation is used to influence purity and vividness of a color that graded from pure color (100%) to gray (0%) (Innes, 2012).

Color rendering index (CRI) is a measure of light source's ability to show objects colors realistically or naturally (Lighting Research Center, 2004). CRI is calculated from the differences in the chromaticities of eight CIE standard color samples that is scaled from 0 to 100. A CRI of 100 shows the maximum value. A CRI value (Ra) of 90 is accepted quite good, 70 is sometimes satisfactory (Fitoz, n.d.). Table 2.1 represents the color rendering groups retrieved from the Turkish National Committee on Illumination.

Table 2.1. Turkish National Committee on Illumination Color Rendering Groups (Fitoz, n.d.)

Turkish National Committee On Illumination Color Rendering Groups	
Color Rendering Property	Color Rendering Index (Ra)
Very Good	$90 \leq Ra$
Very Good	$80 \leq Ra < 90$
Good	$60 \leq Ra < 80$
Mean	$40 \leq Ra < 60$
Bad	$20 \leq Ra < 40$

Because of the characteristics of spaces and their intended usage purposes, CRI levels can change. Boyce (2003) showed that a light source of a CRI level above 80 was visually accepted comfortable for reading environments. According to the Turkish Standards (TS EN 12464-1), the CRI level (Ra) of reading environments is 80 (“En Az Aydınlık Düzeyleri Tablosu”, n.d.). Light sources that have a high CRI level are visually preferred comfortable (Jou et al., 2012).

2.2.3 Correlated Color Temperature (CCT)

Correlated color temperature is a specification of the color appearance of light source measured in Kelvin (K). The CCT values give a general indication of the “warmth” or “coolness” of the light emitted the sources (Lechner, 2009). CCT values can be classified into four groups:

- 3000 > K color temperatures are warm colors (reddish-white),
- 3000 – 5000 K color temperatures are mid-warm (white),
- 5000 – 6500 K color temperatures are cool colors (bluish-white),
- 6500 < K color temperatures are used for daylight (Innes, 2012).

CCT values of different light sources varies. Blue sky is between 10,000 – 25,000 K, overcast sky is 7,000 K, incandescent lamps are generally 4,000 K, fluorescent lamps are between 3,500 – 4,500 K, LEDs are 2700 K and OLEDs are 2900K.

In the recent years, there have been several researches about the relations between CCT of lighting and visual comfort and task performance (Lee, Moon & Kim, 2014). Color temperature affects visual comfort during task performances. According to Manav (2008), a color temperature value of 4,000 K was suitable for visual comfort and 2,700 K was preferred for relaxation. In Knez and Kers (2000) study, 3,000 K was experienced negatively; whereas 4,000 K was experienced positively. In another study, fluorescent lamps with low color temperatures such as 3,000 K resulted in visual discomfort during paper-based and computer-based reading tasks (Lee, Moon & Kim, 2014). As a result, values can differ according to the test environment, task type, number of participants and their physical and psychological conditions.

2.2.4 Glare

Glare is a distressed vision condition in which it is hard to distinguish objects and their details as a result of inappropriate distribution of luminance (Sirel, 1997). It is described by the Unified Glare Rating (UGR) as having different indices from 13 to 28 in interior spaces. Glare is caused by a luminance difference between the task and the glare source (Wikipedia, 2016c). It can be disabling and uncomfortable. Glare can be divided into two types that are named as disability glare and discomfort glare (Lechner, 2009).

Disability glare is caused by the reflection of light on the retina that reduces the human's working abilities. In other words, disability glare is the "reduction in visibility caused by intense light sources in the field of view" (Lighting Research Center, 2007). Glare can be measured with luminance meters. Disability glare can change proportionally with the glow of a light source and inversely with the angle between source and a visual object. Disability glare can be prevented by;

- Expanding the angular deviation of light source,
- Masking the light source with light-emitting or chopper material,
- Rising the illuminance level on a visual object,
- Preventing high reflective surfaces around a visual object (Lechner, 2009).

Discomfort glare is an instant occurrence that comes from the light source and it occurs when its luminance is greater than what the human eye can see. According to Boyce (2014), visual discomfort happens from a composition of photometric conditions in the environment or from the visual task itself. Ostberg, Stone and Benson (1975) found that the same luminous source was accepted as more discomfortable if the concurrent task was comparatively difficult. Likewise, Altomonte, Kent, Tregenza and Wilson (2016) indicated that "the effect of time of day on glare sensation may be affected by the level of visual discomfort experienced and may be masked by other factors such as the difficulty of the task". Sivak, Flannagan, Ensing and Simmons (1989) indicated that disability and discomfort glares are accepted as the same phenomenon, they do not have completely different mechanisms. They were noticed by the luminance ranges in the visual field.

2.2.5 Reflectance / Transmittance

An object or a surface transmits, absorbs or reflects light. The reflectance factor (RF) indicates how much light is reflected from a surface. When the reflected light is less than incident light (it is the light that falls on a subject, either directly or indirectly), the RF is always less than 1. When little light is reflected, RF is never 0. The RF of a white surface is approximately 0.85 and the RF of a black surface is 0.05 (Lechner, 2009).

Transmittance is a measure of how much light passes through a surface. It is described as the proportion of the intensity of incident light. If the surface is opaque, the vibrations of electrons can not pass through it (Lechner, 2009).

2.3. Lighting Systems

It should not be forgotten that lighting is one of the most fundamental elements of spaces. Lighting not only presents light; but also it is used to show typical aspects and focus on certain things of spaces. In order to provide an effective, comfortable and qualified lighting in spaces, techniques, types and rules of lighting should be analyzed.

According to the American Lighting Association, there are three basic types of artificial lighting that can work together in spaces: general (ambient) lighting, task lighting and accent lighting ("Basic Types of Lighting", 2016). In addition, decorative lighting can be considered. A space can be composed of layering different types of artificial light sources, which are related to the tasks to be performed, in order to achieve the desired lighting. These light sources can also be used separately.

2.3.1 General (Ambient) Lighting

General lighting is used in an area with overall horizontal illumination. It is also known as ambient lighting that provides a desired level of brightness, ensures humans to find their way around the space safely and allow them to perform their daily tasks (Lechner, 2009). Various types of general lighting fixtures such as chandeliers, ceiling or wall-mounted fixtures, floor and table lamps, recessed or track lights (Figure 2.11). All these general lighting fixtures are popular due to the flexibility in arranging and rearranging spaces.

Figure 2.11. General Lighting (Halper, 2016)

2.3.2 Task Lighting

Task lighting enables us to perform specific task and activities such as reading, writing, computer work, cooking, sewing, working on hobbies in which a brighter light is needed at a focal point within the space. Because of this, task lighting differs from general lighting. Task lighting should be bright enough and should be free of glare to prevent eye strain (“Basic Types of Lighting”, n.d.). Task lighting is created by using directional recessed fixture or downlight, track lighting, pendant lighting, portable or desk lamps, as well as undercabinet lighting (see Figure 2.12).

Figure 2.12. Task Lighting (Sauer, 2015)

2.3.3 Accent Lighting

Accent lighting is also referred to as highlighting that it is used to highlight an object, a texture or a part of the building. It is a way of lighting to make something remarkable in a space. Additionally, accent lighting gives a space extra dimension and helps to make it larger. Accent lighting requires ten times more light on the focal point than general lighting (Lechner, 2009). Accent lighting is usually achieved with wall-mounted picture lights, recessed and track lighting, spot lights or canned downlights (Figure 2.13).

Figure 2.13. Accent Lighting ("Basic Types of Lighting", n.d.)

2.3.4 Decorative Lighting

Unlike the other basic types of artificial lighting systems, the lamps and the fixtures themselves are the objects that add character to the space (“Basic Types of Lighting”, 2015). The term decorative lighting covers all traditional lighting fixtures such as floor lights, pendants, chandeliers, table lamps, wall lamps (Figure 2.14).

Figure 2.14. Decorative Lighting (“Basic Types of Lighting”, 2015)

As understood from the technical aspects of lighting, natural and artificial lighting are around us everyday. By considering the technical aspects of lighting, the next chapter discusses the effects of lighting on visual comfort within reading environments.

CHAPTER 3

EFFECTS OF LIGHTING ON VISUAL COMFORT

3.1. Light and Vision

Light, which has an extensive electro-magnetic spectrum, is visible to the human eye between the wavelength of 400 – 760 nanometers (nm) and is responsible for the sense of sight (Innes, 2012). It is invisible unless aimed directly into the eye creating a bright and sometimes uncomfortable image, or by reflection through the illumination of objects enabling human vision of the world around us and the performance of tasks from the simple to the complex (Loe, 2016). All of these are significant according to lit environment both for daily tasks and other needs.

The human eye is a spectacular concourse organ that collects the light to sense the external world. The human eye consists of approximately 120 million receptors (Innes, 2012). As early as 1722, Dutchman Antony van Leeuwenhoek discovered the existence of rod and cone cells in the retina. Gottfried Treviranus accepted their existence in 1834 and it opened new doors to analyze the effects of visual lighting on human and creating comfortable lighting installations in interior spaces. In 2002, David Berson and friends of Brown University discovered a third type of photoreceptor called novel (Bommel and Beld, 2004).

The rod and cone cells in the retina arrange the visual effects. In other words, they allow light perception and vision (Wikipedia, 2016d). The rod cells are charged with low-level light circumstances; the cone cells are responsible for color, detailed and sharpness vision. When light reaches them, there is a chemical reaction in the retina.

This chemical reaction is converted into electrical signals that are transmitted to the brain. The electrical signals are interpreted as “vision”. The wavelength sensitivity of the rod and cone cells are different from each other (Loe, 2016). Figure 3.1 indicates the spectral eye sensitivity curves.

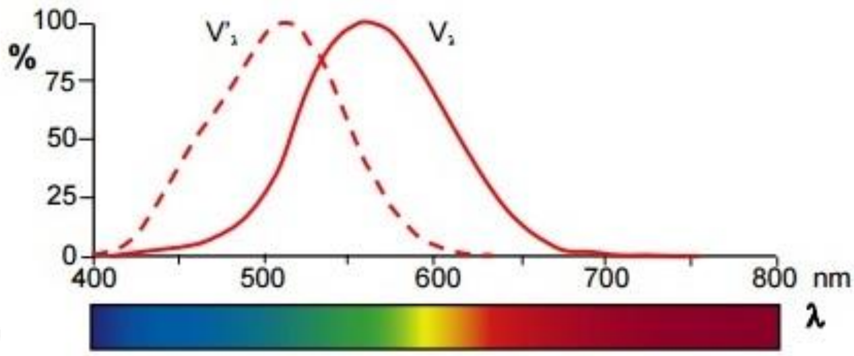


Figure 3.1. Spectral Eye Sensitivity Curves, Vλ for the Rod Cells and Vλ for the Cone Cells (Bommel and Beld, 2004, p.257)

The novel photoreceptors organize the biological effects. When light reaches these cells, chemical reaction occurs that it includes photo pigment melanopsin. The novel cells have their own nerve connection (Bommel and Beld, 2004).

The iris, which is a circular structure in the eye consisting of melamin, is responsible for the size of pupil. By absorbing the light wavelengths, it enables the pupil to adapt to a large range of brightness levels in the environment (Cohen et al., 2011). When the eye is exposed to the UV radiations, the diameter of pupil reaches 7mm. This is very important and influential to insulate the retina towards poor and excessive light. Fovea, which is another area of the eye, is a small area in the retina that is responsible for central vision. It consists of cone cells and deals with the information of details and colors from the environment.

UV radiation and blue light, which are short wavelengths, are irritating for visual comfort. The lens, cornea and conjunctiva are most sensitive to them. Blue light also affects the retina, because UV radiation is absorbed by the rest of the eye before it reaches the retina and approximately 1 – 2 % of the longer wavelength UV radiation reaches the retina (Ticleanu and Littlefair, 2015). LEDs emit little or no UV radiation; however, they can be accepted as a bright light source.

Despite the fast and big variances in light that may cause discomfort, the human eye is a good complex organ to minimize them. Owing to the eye's behavior towards light, humans perceive small changes in the levels of light (Lechner, 2009). No matter how smart the eyes, the good quality lighting should be provided to assist visual comfort in tasks. As shown in Figure 4.2, light, illumination, vision and health are closely interrelated with each other. In addition, the lighting design is in relation with other psychological and physical sciences such as neurology, psychology, ophthalmology (Loe, 2016).

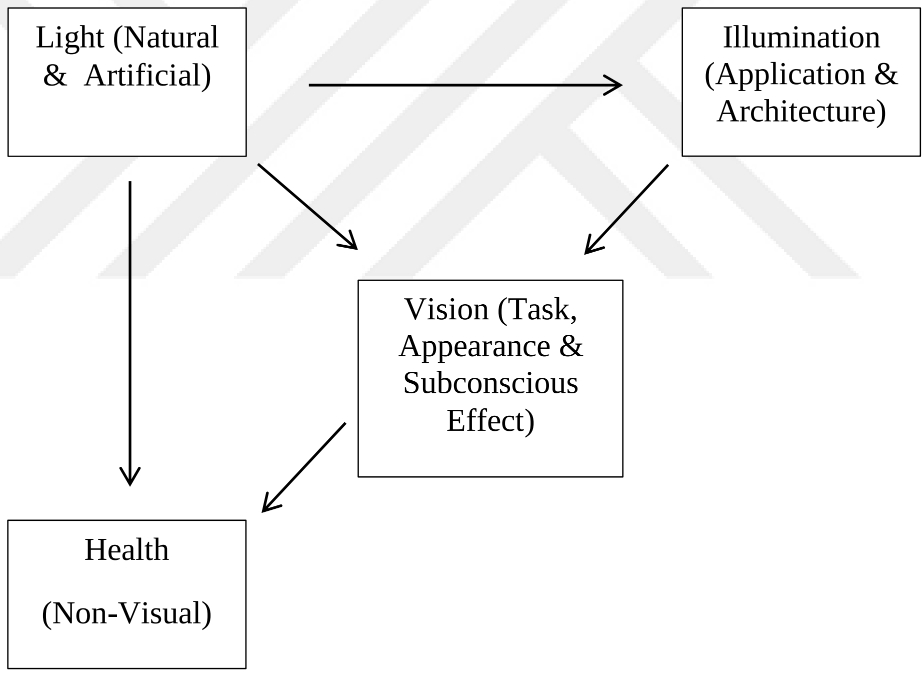


Figure 3.2. The Interaction Between Light, Vision and Illumination (Loe, 2016)

3.2. Visual Comfort Criteria

Visual comfort criteria are used to provide humans comfortable spaces to perform their daily tasks with regards to perception of their environments ("Visual Comfort", n.d.). They are related with many factors such as light intensity, direction of light source, contrast and reflection of surfaces, control of glare and reflections, positive and negative factors affecting the human eye. Poor lighting can also cause headaches, aches and pains due to body posture, skin conditions, double vision and loss of sight. Most national and international standards indicate lighting quality criteria for different spaces and tasks within them. According to the Turkish Standards (TS EN 12464-1), the required comfortable illuminance levels, unified glare ratings (UGR) and color rendering indices of working environments that are very important are shown in Table 3.1 ("En Az Aydınlık Düzeyleri Tablosu", n.d.). These values meet the desired levels of visual comfort and task performance for working environments according to different tasks.

Table 3.1. Lighting Requirements for Working Environments ("En Az Aydınlık Düzeyleri Tablosu", n.d.).

Type of Interior, Task or Activity	**Ix**	**UGRL**	**U0**	**Ra**
Filing, copying etc.	300	19	0,4	80
Writing, typing, reading, data processing	500	19	0,6	80
Technical drawing	750	16	0,7	80
CAD workstations	500	19	0,6	80
Conference and meeting rooms	500	19	0,6	80
Reception desk	300	22	0,6	80
Archives	200	25	0,4	80

In order to obtain a good qualified lighting in terms of visual comfort, some criteria are provided by lighting institutions. The International Commission on Illumination (CIE) specified the following parameters for visual comfort in lighting of spaces: glare (from luminaires, daylight, bright surfaces like windows etc.) veiling reflections, illuminance levels (work plane, surrounding etc.), luminous ratios and uniformities, color rendering index (CRI), correlated color temperature (CCT) and flicker ("Review of Lighting Quality", 2013). Likewise, a study considered space and room appearance, surfaces brightness and color, light distribution and appearance of light and luminaires as parameters for visual comfort (Iacomussi, Radis, Rossi & Rossi, 2015).

The evaluation of visual comfort in England, USA and Europe are determined according to various institutions. According to the British Standards Institution (BSI) and Chartered Institution of Building Services Engineers (CIBSE), several visual comfort criteria are specified that are brightness distribution, illuminance level, glare, interior lighting design, color, flicker and its stroboscopic effects, lighting for display screen areas, variability of lighting etc. (Yılmaz and Yener, 2013). Taking into account these criteria, natural and artificial lighting sources are examined from the point of view of providing visual comfort in reading environments.

3.3. Lighting and Illuminance Levels

Lighting is an application, which is supported by technology, that connects humans and space to perceive their space. Humans always need light in order to continue their lives. Without the existence of light, they can not perceive their environment. Lighting is one of the most important architectural elements that should be designed to obtain good and qualified spaces. Lighting not only affect humans physiologically; but also affects them psychologically.

In order to discuss the effects of illuminance levels of artificial lighting sources on visual comfort and human performance, analyzing what they are and their relations to other characteristics of lighting are very important. According to Smolders, de Kort and Cluitmans (2012), one of the most important quantitative features of lighting is the illuminance level that effects visual comfort and performance of humans. Since illuminance is the amount of light falling on a surface and spreading over, usually the illumination level of big surfaces are discussed. The term "average of illuminance level" has been developed, since the obtained illuminance levels from all points of a surface may not be the same as a result an average is taken.

Various charts appear in regulations and specifications in which they are used to calculate illuminance levels of spaces ("Aydınlatma Semineri Notları, 2007). Charts differ between countries; in Turkey, the minimum illuminance levels of different areas and tasks are set by the TS EN 12464-1 (“En Az Aydınlık Düzeyleri Tablosu”, n.d.).

One of the most important point in understanding the term illuminance level is examining the relationship between correlated color temperature and illuminance levels that is portrayed by the Kruithof Curve. Kruithof, a pioneer in this field of research, indicated the psychological effects of light and that there is a curve for a comfort zone of the combination of illuminance level and color temperature referred to as the “pleasing area” (Shin et al., 2015).

The Kruithof Curve is presented in Figure 3.3. In this figure, the area above the “pleasing area” appears reddish and the area below the “pleasing area” appears bluish. Daylight, which has a CCT of 6,500 K and an illuminance level of between 10,000 – 100,000 lux, appears in the “pleasing area”.

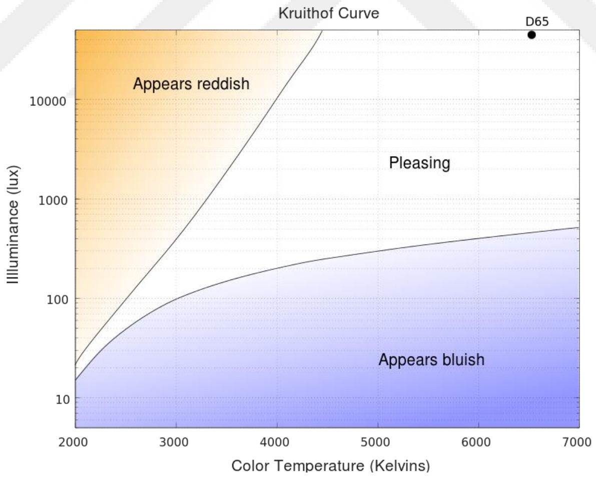


Figure 3.3. Kruithof Curve (Wikipedia, 2016e)

In the work of Avcı and Memikoğlu (2016a), effects of different illuminance levels of lighting on visual comfort were analyzed. LED and halogen lamps; and illuminance levels of 150, 300 and 450 lux were used in the experiment. It was found that 150 lux was generally uncomfortable for both LED and halogen lamps; 300 and 450 lux were visually comfortable for both types of artificial lighting sources. As it is understood artificial lighting sources and the effects of illuminance levels on visual comfort humans are very important to provide adequate lighting.

3.4. Lighting in Reading Environments

Natural lighting is undoubtedly the main source of lighting and provides comfortable, aesthetic and functional value to interior spaces till sunset. It also infuses into interior spaces with light, color, texture and shadow (Rockcastle and Andersen, 2014). When natural lighting is not enough in the space, artificial lighting is preferred additionally to obtain the desired levels. By using suitable artificial lighting sources, optimal levels of lighting can be supported in the interiors.

Several researches have been conducted to analyze the productivity and performance of humans in working environments. Evaluation of the working environment is directly related with job satisfaction. As a result, visual comfort, task performance and getting efficiency from daily tasks are fundamental criteria in working environments. There are several tasks such as reading, listening, writing in these working environments and one of the most important tasks is reading. Lighting circumstances in reading environments promotes to a diversity of effects connected with visual comfort, work satisfaction, reading comprehension and productivity (Borisut, Linhart, Scartezzini & Münch, 2015). The lighting quality in the reading environments is not only determined by the lighting on the visual task, but also the amount of light entering the eye. It also makes humans feel healthy and wellbeing, and causes sufficient work performance, fewer absenteeism and fewer accidents (Bommel and Beld, 2004).

In reading environments, satisfaction of lighting is related to qualified illuminance, ratio of horizontal and vertical illumination, lighting uniformity and directionality, great brightness, absence of glare etc. (Borisuit et al., 2015). For several years, International standards for these types of criteria were in existence. However, interpersonal preferences of illuminance levels have been researched and it has been reported that no more that 50% of humans feel comfortable within 100 lux of illuminance on a reading plane (Newsham and Veitch, 2001). In the work of Fotios and Cheal (2010), preferred illuminance levels are close to the mean of available illuminance ranges and this affects the overall illuminance levels preferred by humans. Küller and Wetterberg (1993) studied the brain wave pattern of people in a laboratory and focused on the effects of high (1700 lux) and low (450 lux) lighting levels on human. They found that bright light causes an alerting effect on the central nervous system.

On the other hand, CCT of light has an important role on physiological and psychological needs of humans. Warm white (WW), cool white (CW) and artificial daylight (DL) were used to investigate the effects on human performance, visual comfort and preferences. In the work of Sivaji, Shopian, Nor, Chuand and Bahri, (2013), CCT values of WW 2,700 K, CW 4,000 K and DL 6,200 K were used and 4,000 K was found the most comfortable CCT of light.

Both illuminance levels and correlated color temperature are quantitative characteristics of lighting used to assess in reading environments. The color temperature and illuminance levels of artificial lighting sources influence human's visual perception that is related with visual comfort and task performance (Lee, Moon & Kim, 2014). A study conducted by Lee and his colleagues (2014) researched the relationship between illuminance levels and correlated color temperature of artificial lighting sources and its effects on reading performance. Illuminance levels of 500 lux and 750 lux and CCT levels of 3,000 K, 4,000 K and 6,500 K were considered. When performing reading tasks it was found that 500 lux under 6,500 K, and 500 lux and 750 lux under 4,000 K were comfortable.

In the work of Chang, Chou and Shieh (2013), visual comfort and reading performance were researched by reading different electronic paper displays under different illuminance levels. It was found that 1,000 lux and 1,500 lux promoted good visual comfort; 500 lux and 1,000 lux were average and 200 lux was bad on electronic paper displays.

As it can be seen, notably illuminance levels and other characteristics of lighting are very important on visual comfort and performance in reading environments. For reading environments, visual comfort parameters are identified by standards; but they may change in line with the requirements of humans and their environments. In the next chapter, the participants, setting of the experiment and procedure are described. The results of the experiment are evaluated and discussed in relation to previous studies related to the subject.

CHAPTER 4

THE EXPERIMENT

4.1. Aim of the Study

The aim of this study is to analyze the effects of different illuminance levels of LED and OLED lightings on human visual comfort and reading performance. It also targets to research whether LED lighting or OLED lighting is comfortable. Examining previous studies, it is seen that there has been considerable research into the technical aspects of lighting systems; but there is not enough research about the relationship between illuminance levels and user visual comfort with respect to LEDs and OLEDs. In addition, there is insufficient research about the correlation of illuminance levels LED and OLED lightings. The research issues consist of six lighting scenarios and their relation with visual comfort and reading performance.

4.1.1. Research Questions

1. Is there a statistically significant difference between illuminance levels on users' visual comfort?
2. Is there a statistically significant difference between the illuminance levels of LED and OLED lightings on users' visual comfort?
3. Is there a statistically significant correlation between illuminance levels on reading speed?

4.1.2. Hypotheses

1. There is a statistically significant difference between the illuminance levels. The illuminance level of 200 lux is more comfortable than the illuminance levels of 500 and 800 lux for both two types of lighting sources.
2. There is a statistically significant difference between LED and OLED lightings. OLED lighting is more comfortable than LED lighting for all illuminance levels.
3. There is a statistically significant correlation between the effects of different illuminance levels on reading speed. The participants read under the illuminance level of 200 lux faster than other illuminance levels for both two types of lighting.

4.2. Participants

The sample group consisted of 2015-2016 academic year undergraduate students from the Department of Interior Architecture at Çankaya University. Eighty undergraduate students were chosen randomly from the 2nd, 3rd and 4th years. As 2nd, 3rd and 4th year students, they were familiar with natural and artificial lighting due to the course named as "INAR 209 Natural and Artificial Lighting" that they took during the 2nd year of their education. After contacting the volunteering participants, they were invited to and informed about the test cabin. There were 41 (51.3%) females and 39 (48.7%) males and their ages were in the range from 19 to 30 years old in order to avoid the influences of age-related effects in vision. The mean age was 22.74, the median age was 22, and the standard deviation was 2.49. Twenty-three participants out of 80 either used eye glass or contact lens.

4.3. Description of the Setting

The test cabin, which was created in the office of two research assistants, is in Çankaya University / Balgat Campus in Ankara and the campus is located in the Çankaya District. The office is on the first floor of B block and on the north facade of the building. The test cabin was designed in the left corner of the office. The dimensions of the cabin were 1.60 m x 2.60 m x 2.80 m. In order to eliminate the affect of color and prevent the absorption of light, white curtain was used around the cabin. Except the flooring, all the surfaces and furnishings in the cabin were white. A white table (1.20 m x 0.80 m x 0.80 m) and a stool were used in the cabin during the reading of the texts. The test cabin is represented in Figure 4.1.

Figure 4.1. The Test Cabin (LED Lamps and White OLED Panels)

In order to understand the effects of different illuminance levels of LED and OLED lightings on user visual comfort, the illuminance levels were determined for each light source. Three illuminance levels were identified as 200 lux (below standards), 500 lux (as standards), 800 lux (above standards). After contacting with the suppliers about the properties of the products and analyzing their IES files, DIALux Evo 6.1, which is the lighting design software that was used in order to decide the number of LED lamps and OLED panels. Five LED lamps and ten white OLED (WOLED) panels were purchased to obtain these three illuminance levels (200 – 500 – 800 lux). After that, the lighting setting was designed. The lighting setting consisted of a white frame that was installed to carry the suspended lamps, five LED lamps, ten WOLED panels and their drivers. The lighting setting was suspended from four points by chains and the height from the floor was 2.20 m. All artificial light sources were placed at the ceiling level, roughly over the center of the desk to avoid glare or reflections on the paper (Ferlazzo et al., 2014). Three electrical systems that were connected in series were designed to light all the lamps. LED lamps and WOLED panels were controlled by a dimmable switch separately. Two adaptors were used for the WOLED panels and their drivers. The properties of LED lamp, WOLED panel and WOLED panel driver are shown in Table 4.1. The WOLED has plenty of different types of materials that can adjust the emitting peak wavelength so as to be a good and green lighting product for human use (Zhang, Xia & Yan, 2016). Illuminance levels inside the cabin were measured with the TES 1332A Illuminance Meter (range of 0.01 to 200.000 lux).

Table 4.1. The Properties of LED Lamp, WOLED Panel and WOLED Panel Driver

Type of Light Source	Name / Brand	Dimension	Lumen	CCT	CRI	Product
LED lamp	Osram LED Star Classic A 60	11 cm x 6 cm	806 lm	2700 K	≥ 80	
WOLED panel	Philips Lumiblade OLED Panel Brite FL300 L WW	24.8 cm x 7 cm	300 lm	2900 K	80	
WOLED panel driver	Philips Driver D024V 10W/0.1-0.4A/28V D/A	5.8 cm x 5 cm				

4.4. Procedure

The experiment was conducted between 3rd of October and 21st of October, 2016. Before each experiment, participants were informed about the setting and the procedure.

The experiment was conducted in the morning due to the cortisol hormone (stress hormone) and melatonin hormone (sleep hormone) that play an important role on alertness and sleepiness. The level of cortisol increases in the morning to prepare the body for daily tasks (Bommel and Beld, 2004). It remains in a high level over in the morning hours. However, there was no daylight penetration during the experiments; daylight penetration was blocked with jalousies. Several studies indicated that time awake, hours of sleep, time spent outside, travelling across time zones, drinking coffee and smoking cigarettes are very important factors that affect performance (Smolders et al., 2012; Ferlazzo et al., 2014). Before the experiment, all participants declared that they had had adequate sleep, did not travel across time zones and had not spent time outside, did not drink coffee and did not smoke cigarette.

The questionnaire had seventeen questions that consisted of “Office Lighting Survey” questions, which were generated by Eklund and Boyce in 1996 (Sivaji et al., 2013). The reliability of these questions was determined statistically (Cronbach Alpha = 0.928). The questionnaire was divided into three parts. The first part consisted of four questions that aimed to get general information about the participants. The second part was divided into six sub-parts. All the sub-parts had the same questions, but the reading texts were different. In the sub-parts, familiarity with the books from which the reading texts were selected from were indicated. The seven-point Likert scale was used to evaluate the visual comfort criteria while reading texts. These criteria were indicated as visual distraction, visual clarity, visual fatigue, eye burning, focusing problem and glare.

Studies with more alternative options are very important in reliability and validity (Schielke and Leudesdorff, 2015). The last part of the questionnaire aimed to get general information about all the illuminance levels. A seven-point Likert scale was also used to quantify the visual comfort of the LED and OLED lightings with six different illuminance levels (see Appendix A). All the participants answered the questionnarie in the same order.

Reading / writing on paper are more transportable and comfortable than reading / writing on screen-keyboard for users. Moreover, this method is useful for speed reading (Fortunati and Vincent, 2014). Thus, participants read six reading texts on white A4 pages that were the abstracts of some book. Their names were "Little Prince", "My Left Foot", "Pomegranate Tree", "Of Mice and Men", "My Sweet Orange Tree" and "Madonna In a Fur Coat" (see Appendix B). The word count of the reading texts were between 375 to 383. There were six lighting scenarios in the experiment that consisted of different illuminance levels (LED 200 – 500 – 800 lux and OLED 200 – 500 – 800 lux) and reading texts. Lighting scenarios were carried out in random order to avoid the adaption of the eye. When the participants started to read the first reading text, their reading speeds were timed. After the reading, the participants answered the questions related to each scenario and got out of the test cabin. In between each lighting scenario, participants had a rest time of about five minutes and they continued with the next scenario in the same way. The duration time for a person was about forty minutes.

The six lighting scenarios can be seen in Table 4.2. Some studies have been concluded that font character effects the visual performance and 12-point Times New Roman font style is comfortable (Shen et al., 2009; Wang et al., 2015). Thus, the questionnaire and reading texts were printed in black ink on white A4 pages with the 12-point Times New Roman font style.

Table 4.2. Details of Lighting Scenarios

Lighting Scenario	Illuminance Level	Light Source	Reading Text	Word Count
1	200 lux	LED	Little Prince	383
2	800 lux	LED	Pomegranate Tree	375
3	500 lux	LED	My Left Foot	378
4	200 lux	OLED	Of Mice and Men	378
5	800 lux	OLED	Madonna In a Fur Coat	380
6	500 lux	OLED	My Sweet Orange Tree	377

4.5. Results

Statistical Package for the Social Sciences (IBM Corp. SPSS) 20.0 program was used to analyze the data. In the analysis of the data, frequency tables, descriptive tables, factor analysis, bivariate correlation analysis, univariate analysis, paired samples t-test and one-way analysis of variance (ANOVA) were conducted. Results from the statistical analysis were given in respect to the stated research questions.

The participants rated their current physical condition on a seven-point Likert scale as being “little tired” (33.8%) and “normal” (28.8%) (M = 4.21, SD = 1.61); see Appendix C, Table C1).

The results of the second part of the questionnaire is presented in Table 4.3. The second part of the questionnaire was divided into six sub-parts. Their reading texts were different; but the questionnaire was the same. The participants were familiar with the first reading part more than others, but they read the third and sixth reading texts more quickly than the others.

Table 4.3. Details of the Second Part of the Questionnare

Reading Text	Familiarity	Light Source	Illuminance Level	Mean Reading Speed
Little Prince	71 (88.8%)	LED	200 lux	1.90 (SD = 0.56)
Pomegranate Tree	9 (11.3%)	LED	800 lux	1.83 (SD = 0.50)
My Left Foot	38 (47.5%)	LED	500 lux	1.61 (SD = 0.42)
Of Mice and Men	48 (60.0%)	OLED	200 lux	1.50 (SD = 0.45)
Madonna In a Fur Coat	69 (86.3%)	OLED	800 lux	1.69 (SD = 0.49)
My Sweet Orange Tree	62 (77.5%)	OLED	500 lux	1.50 (SD = 0.43)

According to the first research question, six visual comfort criteria were evaluated with respect to the iIlluminance levels of LEDs and OLEDs (200 – 500 – 800 lux). In order to find out the effects of illuminance levels on users’ visual comfort, ANOVA was conducted.

4.5.1. Related to the Illuminance Levels of LED Lighting

According to ANOVA, the mean of the visual distraction levels of participants for LED 500 lux ($M = 5.75$, $SD = 1.71$) was higher than that of the LED 200 lux ($M = 4.91$, $SD = 1.87$) and 800 lux ($M = 4.70$, $SD = 1.97$; see Appendix C, Table C2). There was statistically no significant difference between 200 lux and 800 lux on users' visual comfort in this criteria (Wilks' $\Lambda = 0.77$, $F(3,80) = 11.44$, $p = 0.395 > 0.05$). However, there was a statistically significant difference between 200 lux and 500 lux in this criteria ($p = 0.000 < 0.05$; see Appendix C, Tables C3 and C4).

The mean of the visual clarity levels of participants for LED 500 lux ($M = 5.80$, $SD = 1.66$) was higher than that of the LED 200 lux ($M = 5.40$, $SD = 1.80$) and 800 lux ($M = 5.09$, $SD = 1.96$; see Appendix C, Table C5). There was statistically no significant difference between 200 lux and 800 lux on users' visual comfort in this criteria (Wilks' $\Lambda = 0.89$, $F(3,80) = 4.91$, $p = 0.248 > 0.05$). However, there was a statistically significant difference between 500 lux and 800 lux in this criteria ($p = 0.003 < 0.05$; see Appendix C, Tables C6 and C7).

The mean of the visual fatigue levels of participants for LED 500 lux ($M = 5.16$, $SD = 1.82$) was higher than that of the LED 200 lux ($M = 5.04$, $SD = 1.86$) and 800 lux ($M = 4.23$, $SD = 1.89$; see Appendix C, Table C8). There was statistically no significant difference between 200 lux and 500 lux on users' visual comfort in this criteria (Wilks' $\Lambda = 0.80$, $F(3,80) = 10.05$, $p = 0.633 > 0.05$; see Appendix C, Tables C9 and C10). However, there was a statistically significant difference between 200 lux and 800 lux point of visual fatigue ($p = 0.001 < 0.05$).

The mean of the burning eye levels of participants for LED 200 lux ($M = 5.81$, $SD = 1.44$) was higher than that of the LED 500 lux ($M = 5.75$, $SD = 1.72$) and 800 lux ($M = 4.81$, $SD = 1.90$; see Appendix C, Table C11). There was statistically no significant difference between 200 lux and 500 lux on users' visual comfort in this criteria (Wilks' $\Lambda = 0.75$, $F(3,80) = 13.03$, $p = 0.754 > 0.05$). However, there was a statistically significant difference between 200 lux and 800 lux on users' visual comfort in this criteria ($p = 0.000 < 0.05$; see Appendix C, Tables C12 and C13).

The mean of the focusing problem levels of participants for LED 500 lux ($M = 5.59$, $SD = 1.83$) was higher than that of the LED 200 lux ($M = 5.05$, $SD = 2.04$) and 800 lux ($M = 4.74$, $SD = 2.01$; see Appendix C, Table C14). There was a statistically significant difference between 500 lux and 800 lux on users' visual comfort in this criteria (Wilks' $\Lambda = 0.88$, $F(3,80) = 5.18$, $p = 0.002 < 0.05$; see Appendix C, Tables C15 and C16).

The mean of the glare levels of participants for LED 500 lux ($M = 5.68$, $SD = 1.70$) was almost the same with LED 200 lux ($M = 5.63$, $SD = 1.75$) and higher than 800 lux ($M = 4.65$, $SD = 2.15$; see Appendix C, Table C17). There was statistically no significant difference between 200 lux and 500 lux on users' visual comfort in this criteria (Wilks' $\Lambda = 0.82$, $F(3,80) = 8.60$, $p = 0.817 > 0.05$). However, there was a statistically significant difference between 200 lux and 800 lux in this criteria ($p = 0.000 < 0.05$; see Appendix C, Tables C18 and C19).

The mean of the levels of all criteria of participants for LED 500 lux ($M = 33.73$, $SD = 8.32$) was higher than LED 200 lux ($M = 31.84$, $SD = 8.50$) and 800 lux ($M = 28.21$, $SD = 9.52$; see Appendix C, Table C20). There was statistically no significant difference between 200 lux and 500 lux on users' visual comfort in all criteria (Wilks' $\Lambda = 0.76$, $F(3,80) = 12.25$, $p = 0.076 > 0.05$). However, there was a statistically significant difference between 500 lux and and 800 lux in all criteria ($p = 0.000 > 0.05$; see Appendix C, Tables C21 and C22). Results of difference between the illuminance levels of LED lighting are shown in Table 4.4.

Table 4.4. Differences Between the Illuminance Levels of LED Lighting

	Visual Distraction		Visual Clarity		Visual Fatigue		Burning Eye		Focusing Problem	Glare		All Criteria	
	200lux-800lux	200lux-500lux	200lux-800lux	500lux-800lux	200lux-500lux	200lux-800lux	200lux-500lux	200lux-800lux	500lux-800lux	200lux-800lux	200lux-800lux	200lux-500lux	500lux-800lux
No Sig. Dif.	p=0.4		p=0.25		p=0.63		p=0.75		p=0.02	p=0.00	p=0.82	p=0.08	
Sig Dif.		p=0.00		p=0.00		p=0.00		p=0.00					p=0.00

4.5.2. Related to the Illuminance Levels of OLED Lighting

According to ANOVA, the mean of the visual distraction levels of participants for OLED 500 lux ($M = 6.03$, $SD = 1.28$) was higher than that of the OLED 200 lux ($M = 5.66$, $SD = 1.68$) and 800 lux ($M = 5.16$, $SD = 1.90$; see Appendix C, Table C23). There was a statistically low significant difference between 200 lux and 500 lux on users' visual comfort in this criteria (Wilks' $\Lambda = 0.78$, $F(3,80) = 10.76$, $p = 0.040 < 0.05$). In addition, there was a statistically significant differences between 500 lux and 800 lux on users' visual comfort in this criteria ($p = 0.000 < 0.05$; see Appendix C, Tables C24 and C25).

The mean of the visual clarity levels of participants for OLED 500 lux ($M = 5.98$, $SD = 1.38$) was higher than that of the OLED 200 lux ($M = 5.80$, $SD = 1.53$) and 800 lux ($M = 5.14$, $SD = 1.78$; see Appendix C, Table C26). There was statistically no significant difference between 200 lux and 500 lux on users' visual comfort in this criteria (Wilks' $\Lambda = 0.83$, $F(3,80) = 8.06$, $p = 0.335 > 0.05$). However, there were statistically significant difference between 200 lux – 800 lux and 500 lux – 800 lux on users' visual comfort in this criteria ($p = 0.005 < 0.05$, $p = 0.000 < 0.05$; see Appendix C, Tables C27 and C28).

The mean of the visual fatigue levels of participants for OLED 500 lux ($M = 5.50$, $SD = 1.59$) was higher than that of the OLED 200 lux ($M = 5.38$, $SD = 1.71$) and 800 lux ($M = 4.51$, $SD = 1.89$; see Appendix C, Table C29). There was statistically no significant difference between 200 lux and 500 lux on users' visual comfort in this criteria (Wilks' $\Lambda = 0.78$, $F(3,80) = 10.76$, $p = 0.517 > 0.05$). However, there was a statistically significant difference between 200 lux – 800 lux and 500 lux – 800 lux on users' visual comfort in this criteria ($p = 0.001 < 0.05$, $p = 0.000 < 0.05$; see Appendix C, Tables C30 and C31).

The mean of the burning eye levels of participants for OLED 500 lux ($M = 5.98$, $SD = 1.47$) was higher than that of the 200 lux ($M = 5.95$, $SD = 1.52$) and 800 lux ($M = 5.14$, $SD = 1.91$; see Appendix C, Table C32). There was statistically no significant difference between 200 lux and 500 lux on users' visual comfort in this criteria (Wilks' Λ = 0.80, F(3,80) = 10.00, p = 0.893 > 0.05). However, there were statistically significant difference between 200 lux – 800 lux and 500 – 800 lux on users' visual comfort in this criteria (p = 0.000 < 0.05; see Appendix C, Tables C33 and C34).

The mean of the focusing problem levels of participants for OLED 500 lux (M = 5.90, SD = 1.37) was higher than that of the 200 lux (M = 5.46, SD = 1.79) and 800 lux (M = 4.76, SD = 1.92; see Appendix C, Table C35). There was a statistically significant differences between 200 lux and 500 lux in this criteria (Wilks' Λ = 0.77, F(3,80) = 12.00, p = 0.026 < 0.05). There was a statistically significant differences between 200 lux and 800 lux in this criteria (p = 0.005 < 0.05). There was also a statistically significant differences between 500 lux and 800 lux in this criteria (p = 0.000 < 0.05; see Appendix C, Tables C36 and C37).

The mean of the glare levels of participants for OLED 200 lux (M = 6.35, SD = 1.19) was higher than 500 lux (M = 6.07, SD = 1.41) and 800 lux (M = 4.72, SD = 2.03; see Appendix C, Table C38). OLED 200 lux was more comfortable than others. There was statistically no significant difference between 200 lux and 500 lux on users' visual comfort in this criteria (Wilks' Λ = 0.61, F(3,80) = 25.17, p = 0.074 > 0.05). However, there was a statistically significant difference between 200 lux and 800 lux on users' visual comfort in this criteria (p = 0.000 < 0.05; see Appendix C, Tables C39 and C40).

The mean of the levels of all criteria of participants for OLED 500 lux (M = 35.46, SD = 6.40) was higher than 200 lux (M = 34.60, SD = 7.24) and 800 lux (M = 29.44, SD = 9.02; see Appendix C, Table C41). There was statistically no significant difference between 200 lux and 500 lux on users' visual comfort in all criteria (Wilks' Λ = 0.65, F(3,80) = 20.62, p = 0.234 < 0.05). However, there was a statistically significant difference between 200 lux – 800 lux and 500 lux – 800 lux on users' visual comfort in this criteria (p = 0.000 < 0.05; see Appendix C, Tables C42 and C43). Results of difference between the illuminance levels of OLED lighting are shown in Table 4.5.

Table 4.5. Differences Between the Illuminance Levels of OLED Lighting

	Visual Distraction		**Visual Clarity**		**Visual Fatigue**		**Burning Eye**		**Focusing Problem**		**Glare**		**All Criteria**	
	200lux-500lux	**500lux-800lux**	**200lux-500lux**	**200lux-800lux**	**200lux-500lux**	**200lux-800lux**	**200lux-500lux**	**200lux-800lux**	**200lux-500lux**	**200lux-800lux**	**200lux-500lux**	**200lux-800lux**	**200lux-500lux**	**500lux-800lux**
No Sig. Dif.			p=0.34		p=0.52		p=0.89				p=0.07		p=0.23	
Sig Dif.	p=0.04	p=0.00		p=0.01		p=0.00		p=0.00	p=0.00	p=0.01		p=0.00		p=0.00

4.5.3. Correlations of the Three Illuminance Levels of LED and OLED Lightings

Three different illuminance levels are analyzed within itself. The mean (M) and standard deviation (SD) values of the visual comfort criteria for 200 lux of LED and OLED lightings are shown in Table 4.6. The number of the participants who found OLED lighting comfortable were slightly more than LED lighting for all of the visual comfort criteria. To determine if there was a significant relationship between all visual comfort criteria in LED and OLED lightings, paired-samples t-test was conducted.

Table 4.6. Group Statistics for LED and OLED Lightings (200 Lux)

Visual Comfort Criteria	Light Source	Mean	Std. Deviation
Visual Distraction	LED	4.91	1.87
	OLED	5.66	1.68
Visual Clarity	LED	5.40	1.80
	OLED	5.80	1.53
Visual Fatigue	LED	5.04	1.86
	OLED	5.38	1.71
Burning eye	LED	5.81	1.44
	OLED	5.95	1.52
Focusing Problem	LED	5.05	2.03
	OLED	5.46	1.79
Glare	LED	5.63	1.75
	OLED	6.35	1.19
All Criteria	LED	31.84	8.49
	OLED	34.60	7.24

There was a significant correlation between LED and OLED lightings with respect to the criteria of visual distraction ($t = -2.89$, $df = 79$, two-tailed $p = 0.005$). There were no significant correlation between LED and OLED lightings with respect to the criteria of visual clarity, visual fatigue, burning eye and focusing problem (see Appendix C, Table C44). There was a significant correlation between LED and OLED lightings with respect to the criteria of glare ($t = -3.78$, $df = 79$, two-tailed $p = 0.000$). There was a significant correlation between LED and OLED lightings with respect to all of the visual comfort criteria ($t = -3.07$, $df = 79$, two-tailed $p = 0.003$).

The mean (M) and standard deviation (SD) values of the visual comfort criteria for 500 lux of LED and OLED lightings are shown in Table 4.7. The participants who found OLED lighting comfortable were slightly more than LED lighting for all of the visual comfort crtierias. To determine if there was a significant relationship between all visual comfort criteria on LED and OLED lightings, paired-samples t-test was conducted. There was no significant difference between LED and OLED lightings with respect to all of the visual comfort criteria (see Appendix C, Table C47).

Table 4.7. Group Statistics for LED and OLED Lightings (500 Lux)

Visual Comfort Criteria	Light Source	Mean	Std. Deviation
Visual Distraction	LED	5.75	1.71
	OLED	6.04	1.28
Visual Clarity	LED	5.80	1.66
	OLED	5.98	1.38
Visual Fatigue	LED	5.16	1.82
	OLED	5.50	1.59
Burning eye	LED	5.75	1.72
	OLED	5.98	1.47
Focusing Problem	LED	5.59	1.83
	OLED	5.90	1.37
Glare	LED	5.68	1.70
	OLED	6.08	1.41
All Criteria	LED	33.73	8.33
	OLED	35.46	6.40

The mean (M) and standard deviation (SD) values of the visual comfort criteria for 800 lux of LED and OLED lightings are shown in Table 4.8. The number of the participants who found OLED lighting comfortable were slightly more than LED lighting for all of the visual comfort criteria. To determine if there was a significant relationship between all visual comfort criteria on LED and OLED lightings, paired-samples t-test was conducted.

Table 4.8. Group Statistics for LED and OLED Lightings (800 Lux)

Visual Comfort Criteria	Light Source	Mean	Std. Deviation
Visual Distraction	LED	4.70	1.97
	OLED	5.16	1.90
Visual Clarity	LED	5.09	1.96
	OLED	5.14	1.78
Visual Fatigue	LED	4.23	1.89
	OLED	4.51	1.89
Burning eye	LED	4.81	1.90
	OLED	5.14	1.91
Focusing Problem	LED	4.74	2.01
	OLED	4.76	1.92
Glare	LED	4.65	2.15
	OLED	4.73	2.03
All Criteria	LED	28.21	9.52
	OLED	29.44	9.02

There was a significant difference between LED and OLED lightings with respect to visual distraction ($t = -2.25$, $df = 79$, two-tailed $p = 0.027$). There was no significant difference between LED and OLED lightings with respect to visual clarity, visual fatigue, burning eye, focusing problem and glare. According to all criteria, there was a significant difference between LED and OLED lightings ($t = -1.32$, $df = 79$, two-tailed = 0.192; see Appendix C, Table C50).

4.5.4. Correlations of LED and OLED Lightings with respect to Reading Speed

Seven physical condition types were evaluated together in all of the lighting scenarios from the point of reading speed. Correlation analysis was conducted to research the relationship between different illuminance levels and reading speeds.

In the first lighting scenario, there was statistically no significant correlation between LED 200 lux and reading speed ($R = 0.053$, $p = 0.641 > 0.05$; see Appendix C, Table C53). In the second lighting scenario, there was also statistically no significant correlation between LED 500 lux and reading speed ($R = 0.093$, $p = 0.411 > 0.05$;

see Appendix C, Table C54). However, in the third lighting scenario, there was a statistically negative correlation between LED 800 lux and reading speed (R = -0.240, p = 0.032; see Appendix C, Table C55). In the fourth lighting scenario, there was statistically no significant correlation between OLED 200 lux and reading speed (R = -0.127, p = 0.260 > 0.05; see Appendix C, Table C56). In the fifth lighting scenario, there was statistically no significant correlation between OLED 500 lux and reading speed (R = -0.064, p = 0.571 > 0.05; see Appendix C, Table C57). In the sixth lighting scenario, there was also statistically no significant correlation between OLED 800 lux and reading speed (R = -0.156, p = 0.168 > 0.05; see Appendix C, Table C58).

4.5.5. Other Findings Related to LED and OLED Lightings with respect to Physical Condition

Seven physical condition types that were used in the questionnaire was divided into three groups as “felt tired” (very tired, tired and little tired), “felt normal” and “felt good” (very good, good and little good). ANOVA was conducted to compare the three groups from the point of illuminance levels of LED and OLED lightings.

In the LED 200 lux scenario, the mean of the “felt good” group (M = 34.17, SD = 7.15) was higher than the “felt normal” group (M = 32.91, SD = 8.64) and the “felt tired” group (M = 29.40, SD = 8.89; see Appendix C, Table C59). There was statistically no significant difference between the physical conditions and this lighting scenario (p = 0.191 > 0.05). However, there was a statistically significant difference between the “felt tired” and the “felt good” groups (p = 0.036 < 0.05; see Appendix C, Table C61).

In the LED 500 lux scenario, the mean of the “felt normal” group (M = 34.87, SD = 8.13) was higher than the “felt good” group (M = 34.25, SD = 8.62) and the “felt tired group (M = 32.55, SD = 8.36; see Appendix C, Table C62). There was statistically no significant difference between physical conditions and this lighting scenario (p = 0.951 > 0.05). In addition, there was statistically no significant difference between groups (see Appendix C, Table C64).

In the LED 800 lux scenario, the mean of the “felt normal” group (M = 30.83, SD = 8.58) was higher than the “felt good” group (M = 29.17, SD = 9.43) and the “felt tired” group (M = 25.70, SD = 9.84; see Appendix C, Table C65). There was statistically no significant difference between physical conditions and this lighting scenario ($p = 0.432 > 0.05$). However, there was a statistically significant difference between felt tired and normal groups (see Appendix C, Table C67).

In the OLED 200 lux scenario, the mean of the “felt good” group (M = 36.67, SD = 6.34) was higher than the felt normal group (M = 36.26, SD = 6.14) and felt tired group (M = 31.94, SD = 7.89; see Appendix C, Table C68). There was statistically no significant difference between physical conditions and this lighting scenario ($p = 0.241 > 0.05$). However, there was a statistically significant difference between the “felt tired” and the “felt normal” groups ($p = 0.025 < 0.05$) and the “felt tired” and the “felt good” groups ($p = 0.014 < 0.05$) (see Appendix C, Table C70).

In the OLED 500 lux scenario, the mean of the “felt normal” group (M = 36.65, SD = 6.09) was higher than the “felt good” group (M = 35.88, SD = 6.82) and the “felt tired” group (M = 34.33, SD = 6.30; see Appendix C, Table C71). There was statistically no significant difference between physical conditions and this lighting scenario ($p = 0.851 > 0.05$). In addition, there was statistically no significant difference between groups (see Appendix C, Table C73).

In the OLED 800 lux scenario, the mean of the “felt good” group (M = 30.71, SD = 8.59) was higher than the “felt normal” group (M = 29.87, SD = 9.00) and the “felt tired” group (M = 28.21, SD = 9.45; see Appendix C, Table C74). There was statistically no significant difference between physical conditions and this lighting scenario ($p = 0.655 > 0.05$). In addition, there was statistically no significant difference between groups (see Appendix C, Table C76).

4.6. Discussion

The aim of this study was to analyze the effects of different illuminance levels of LED and OLED lightings on user visual comfort during a reading task. It also aimed to research whether LED lighting or OLED lighting was visually more comfortable and identify which illuminance levels of LED and OLED lightings were visually more comfortable than the others. Therefore, the effects of illuminance levels of LED and OLED lightings on visual comfort were compared according to lighting scenarios that consisted of six reading texts and three different illuminance levels (200 – 500 – 800 lux).

It was hypothesized that there would be a statistically significant difference between the illuminance levels that illuminance of 200 lux will be visually more comfortable than 500 lux and 800 lux. For LED lighting, the results indicated that the illuminance level of 500 lux was found visually slightly more comfortable than the other illuminance levels according to visual distraction, visual clarity, visual fatigue, focusing problem and glare. On the contrary, the illuminance level of 200 lux was found slightly more comfortable than other illuminance levels according to burning eye. The results were not in line with Shen et al. (2009) and it was proposed that light sources did not have any significant effect on visual comfort and visual fatigue. According to TS EN 12464-1 of the Turkish Standards, the optimal illuminance level for a reading task was determined as 500 lux (“En Az Aydınlık Düzeyleri Tablosu”, n.d.). For OLED lighting, the results indicated that the illuminance level of 500 lux was found visually slightly more comfortable than the other illuminance levels with respect to visual distraction, visual clarity, visual fatigue, burning eye and focusing problem. On the contrary, the illuminance level of OLED 200 lux was found visually slightly more comfortable than others with respect to glare. According to Kim et al. (2007), as the illuminance level increases above 500 lux, brightness and glare negatively effect visual comfort. The preferred illuminance levels of work plane were either above or below 500 lux, but the reasons were variable (Borisuit et al., 2015).

The results revealed that there was a statistically significant correlation between the illuminance levels of LED and OLED 200 lux according to visual distraction and glare. There was also a statistically significant correlation between them in total. Although there was statistically no significant difference between these two lighting sources according to other visual comfort criteria, due to the mean scores, it can be said that the illuminance level of OLED 200 lux was slightly more comfortable than LED 200 lux. There was statistically no significant correlation between the illuminance levels of LED and OLED 500 lux according to all the visual comfort criteria. Due to the mean scores, it can be concluded that the illuminance level of OLED 500 lux was visually slightly more comfortable than LED 500 lux. For the illuminance levels of 800 lux, there was a statistically significant correlation in the visual distraction. Through the mean scores, it can be said that the illuminance level of OLED 800 lux was visually slightly more comfortable than LED 800 lux. In the work of Smolders et al. (2013), it was stated that type of light source affected users' task performance. As stated in the second hypothesis, the illuminance levels of OLED lighting is accepted more comfortable than LED lighting. There is not any research about the differences between LED and OLED lightings with respect to the illuminance levels in the literature. The reason of the finding the OLED lighting slightly more comfortable than LED lighting can be the features of OLED lighting that they are glare-free and produce no harsh shadows (Eley, 2015). Due to these characteristics, they provide visual comfort, low light pollution for humans and diffuse in appearance (Kar and Kar, 2014).

There were statistically no significant differences between the illuminance levels of LED 200 lux and 800 lux from the point of visual distraction and visual clarity. However, there was a statistically significant difference between them from the point of other visual comfort criteria. Due to the mean scores, LED 200 lux was visually more comfortable than 800 lux. For OLED lighting, there was a statistically significant difference between the illuminance levels of 200 and 800 lux from the point of all visual comfort criteria. According to all mean scores and p values, LED 200 and OLED 200 lux were found visually more comfortable than 800 lux. Shen et al. (2009) stated a different result that an illumination of 300 lux was uncomfortable than 700 lux.

For LED lighting, there were statistically no correlations between the illuminance levels and reading speeds except in the illuminance level of 800 lux. There was a statistically negative correlation that as the illuminance level increases, reading speed decreases. The mean scores of the reading speeds of 800 lux were more slower than the other illuminance levels. For OLED lighting, there were statistically no correlations between all illuminance levels and reading speeds. The mean score of the reading speed of OLED 200 lux and 500 lux was faster than other the illuminance levels. In addition, participants found 500 lux visually more comfortable than others. It can be stated that illuminance levels of the light source have an effect on visual comfort and reading performance. The results are not in line with many studies (Lee et al., 2008; Smolders et al., 2012; Chang et al., 2013; Wang et al., 2015). Lee and his colleagues (2008) indicated that reading speeds increased as the illuminance levels increased from 300, 700 to 1500 lux. According to Smolders et al. (2012), higher illuminance levels could result in better performance for fluorescent tubes. Chang et al. (2013) proposed that illuminance levels of 1000 and 1500 lux supported faster reading than did those of 200 and 500 lux. Moreover, in the work of Wang et al. (2015), in the lighting scenario of the illuminance level of LED 1000 lux, participants read faster than the illuminance levels of LED 300 and 500 lux. However, except the technical information, there is not any sufficient information about OLED lighting in the literature.

The results revealed that the participants read the text of first lighting scenario slower than other texts (M = 1.90). The illuminance level of this lighting scenario was LED 200 lux. LED lighting was found visually slightly uncomfortable than OLED lighting and 200 lux was also found slightly uncomfortable than 500 lux. On the other hand, the familiarity ratio of this text was the highest ratio (88.8%). Therefore, it can be stated that illuminance levels of light source has an effect on reading speed, but familiarity has not an effect on it.

There were statistically no significant difference between the physical conditions and all of the lighting scenarios. There were also statistically no significant difference between physical conditions and the lighting scenarios of LED 500 lux, OLED 500 lux and OLED 800 lux. However, in the LED 200 lux and OLED 200 lux scenarios, there was a statistically significant difference between the “felt tired” and the “felt good" groups. According to the mean scores and p values, the "felt tired" group found visually uncomfortable than the "felt good" group for these lighting scenarios.It can be stated that when the user feel tired, they are affected from the illuminance levels which are below the standards more than feel good users and the physical condition and the illuminance level are in a relationship between each other. In the LED 800 lux and OLED 200 lux lighting scenarios, there were a statistically significant difference between the "felt tired" group and the "felt normal" group. Due to the mean scores and p values, the "felt tired" group found visually uncomfortable than the "felt normal" group for these lighting scenarios.

CHAPTER 5

CONCLUSION

Lighting, as an application and energy that supports user – environment interaction, is essential for human beings since it enables us to experience the surrounding environment by natural and artificial lighting sources. In interior architecture, one of the main purposes of lighting is creating comfortable and functional spaces for users to do their daily activities easily. Lighting was used mainly as a tool to see; but now, it is one of the most important design criteria for human beings in interior architecture, enables us to experience our environment and it also affects our physical, physiological and psychological behaviors. Therefore, desired and comfortable lighting systems increase task efficiency.

Previous studies have focused on the technical aspects of lighting; however, very little research has considered the effects of illuminance levels of lighting sources on visual comfort and user performance. Moreover, there is not sufficient research exploring the relationship between LED and OLED lighting as the recently developed technologies. This thesis focused on solid-state lighting (SSL) sources especially LED and OLED as the new research area of artificial lighting sources.

The study aimed to analyze the effects of different illuminance levels of LED and OLED lighting on users' visual comfort and reading performance, and compare LED and OLED with respect to the different illuminance levels. Three illuminance levels were identified, 200 lux, 500 lux and 800 lux. According to the TS EN 12464-1 of the Turkish Standards, 500 lux is considered optimal for a reading task. The result of this study revealed that illuminance levels have a significant effect on users' visual comfort. The illuminance level of LED 500 lux was generally found visually more comfortable; on the other hand, the illuminance level of LED 200 lux was found visually more comfortable than the other illuminance levels with respect to the criteria of burning eye. Likewise, the illuminance level of OLED 500 lux was generally found visually more comfortable; on the other hand, the illuminance level of OLED 200 lux was visually more comfortable than the other illuminance levels with respect to the criteria of glare. In general, the illuminance levels of OLED lighting was accepted visually more comfortable than LED lighting.

Since there has been no research on the effects of OLED with respect to the users' visual comfort and task performance. OLED, as the next step of the SSL technology, has mainly been used in automobiles, mobile phones and television industry, but this thesis has considered OLED as an element on an interior environment affecting user visual comfort and task performance and compared it with LED. The results of this study might shed light to interior architects, psychologists, lighting designers and manifacturers. They might use the results of this thesis in order to create visually comfortable and innovative interiors and decide how the good quality lighting should be manufactured. As used in this thesis, white OLEDs emit white light that is brighter, more uniform and energy efficient than fluorescent lights. They have also flexibility, transparency, durability, long life span, low driving voltage, wide viewing angle, minimizing glare, less heat production and reduce the space required for lighting installations. It is possible that OLED will begin to be used more than other artificial lighting sources in the interior environment due to these advantages.

For further studies, the effects of illuminance levels of LED and OLED lighting on gender and age can be compared. The effects of illuminance levels of LED and OLED lighting on different task performances other than reading performance can be researched and be compared within each task. The relationship of color and texture with LED and OLED lighting can be researched. Moreover, future research might be conducted on the effects of LED and OLED lightings in different interior environments such as public, commercial, private, residential and industrial spaces.

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APPENDIX A

Anket No: Saat:

Bu anket, Çankaya Üniversitesi Fen Bilimleri Enstitüsü İç Mimarlık Anabilim Dalı'nda hazırlanan bir yüksek lisans tez çalışmasında kullanılacaktır. Bu ankette kimliğiniz ve vereceğiniz cevaplar kesinlikle gizli tutulacaktır. Vermiş olduğunuz cevaplar sadece akademik amaçla kullanılacaktır. Bu çalışmaya katılım tamamen isteğe bağlıdır.

Araştırmayla ilgili bilgi almak için: nihanavci@cankaya.edu.tr.

1. Yaş:

2. Cinsiyet: Kadın ☐ Erkek ☐

3. Gözlük ya da Lens Kullanımı: Evet ☐ Hayır ☐

4. Kendinizi fiziksel olarak nasıl hissediyorsunuz? Lütfen birini seçiniz.

Çok Yorgun Yorgun Biraz Yorgun Normal Biraz İyi İyi Oldukca İyi

KÜÇÜK PRENS

Okuma süresi: Lamba Türü: LED Lux Değeri: 200

5. Okuduğunuz metinde anlatılan kitabı daha önce duydunuz mu? Evet ☐ Hayır ☐

6. Okurken olumsuz yönde etkilendiğiniz bir şey oldu mu? Evet ☐ Hayır ☐

7. Lütfen aşağıdaki kriterlerle ilgili yaşadığınız sıkıntı derecesini belirtiniz.

	Evet			Kararsızım			Hayır
Dikkatin dağılması	-3	-2	-1	0	1	2	3
Yazıların düzgün görülememesi	-3	-2	-1	0	1	2	3
Göz yorgunluğu	-3	-2	-1	0	1	2	3
Göz yanması	-3	-2	-1	0	1	2	3
Odaklanma problem	-3	-2	-1	0	1	2	3
Parlama oluşması	-3	-2	-1	0	1	2	3
Diğer, lütfen belirtin.	-3	-2	-1	0	1	2	3

SOL AYAĞIM

Okuma süresi: Lamba Türü: LED Lux Değeri: 500

8. Okuduğunuz metinde anlatılan kitabı daha önce duydunuz mu? Evet ☐ Hayır ☐

9. Okurken olumsuz yönde etkilendiğiniz bir şey oldu mu? Evet ☐ Hayır ☐

10. Lütfen aşağıdaki öğelerle ilgili yaşadığınız sıkıntı derecesini belirtiniz.

	Evet			Kararsızım			Hayır
Dikkatin dağılması	-3	-2	-1	0	1	2	3
Yazıların düzgün görülememesi	-3	-2	-1	0	1	2	3
Göz yorgunluğu	-3	-2	-1	0	1	2	3
Göz yanması	-3	-2	-1	0	1	2	3
Odaklanma problem	-3	-2	-1	0	1	2	3
Parlama oluşması	-3	-2	-1	0	1	2	3
Diğer, lütfen belirtin	-3	-2	-1	0	1	2	3

NAR AĞACI

Okuma süresi: Lamba Türü: LED Lux Değeri: 800

11. Okuduğunuz metinde anlatılan kitabı daha önce duydunuz mu? Evet☐ Hayır ☐

12. Okurken olumsuz yönde etkilendiğiniz bir şey oldu mu? Evet☐ Hayır ☐

13. Lütfen aşağıdaki öğelerle ilgili yaşadığınız sıkıntı derecesini belirtiniz.

	Evet			Kararsızım			Hayır
Dikkatin dağılması	-3	-2	-1	0	1	2	3
Yazıların düzgün görülememesi	-3	-2	-1	0	1	2	3
Göz yorgunluğu	-3	-2	-1	0	1	2	3
Göz yanması	-3	-2	-1	0	1	2	3
Odaklanma problem	-3	-2	-1	0	1	2	3
Parlama oluşması	-3	-2	-1	0	1	2	3
Diğer, lütfen belirtin	-3	-2	-1	0	1	2	3

FARELER VE İNSANLAR

Okuma süresi: Lamba Türü: OLED LuxDeğeri:200

14. Okuduğunuz metinde anlatılan kitabı daha önce duydunuz mu? Evet☐ Hayır ☐

15. Okurken olumsuz yönde etkilendiğiniz bir şey oldu mu? Evet☐ Hayır ☐

16. Lütfen aşağıdaki öğelerle ilgili yaşadığınız sıkıntı derecesini belirtiniz.

	Evet			Kararsızım			Hayır
Dikkatin dağılması	-3	-2	-1	0	1	2	3
Yazıların düzgün görülememesi	-3	-2	-1	0	1	2	3
Göz yorgunluğu	-3	-2	-1	0	1	2	3
Göz yanması	-3	-2	-1	0	1	2	3
Odaklanma problem	-3	-2	-1	0	1	2	3
Parlama oluşması	-3	-2	-1	0	1	2	3
Diğer, lütfen belirtin	-3	-2	-1	0	1	2	3

ŞEKER PORTAKALI

Okuma süresi: Lamba Türü: OLED Lux Değeri: 500

17. Okuduğunuz metinde anlatılan kitabı daha önce duydunuz mu? Evet ☐ Hayır ☐

18. Okurken olumsuz yönde etkilendiğiniz bir şey oldu mu? Evet ☐ Hayır ☐

19. Lütfen aşağıdaki öğelerle ilgili yaşadığınız sıkıntı derecesini belirtiniz

	Evet			Kararsızım			Hayır
Dikkatin dağılması	-3	-2	-1	0	1	2	3
Yazıların düzgün görülememesi	-3	-2	-1	0	1	2	3
Göz yorgunluğu	-3	-2	-1	0	1	2	3
Göz yanması	-3	-2	-1	0	1	2	3
Odaklanma problem	-3	-2	-1	0	1	2	3
Parlama oluşması	-3	-2	-1	0	1	2	3
Diğer, lütfen belirtin	-3	-2	-1	0	1	2	3

KÜRK MANTOLU MADONNA

Okuma süresi: Lamba Türü: OLED Lux Değeri: 800

20. Okuduğunuz metinde anlatılan kitabı daha önce duydunuz mu? Evet ☐ Hayır ☐

21. Okurken olumsuz yönde etkilendiğiniz bir şey oldu mu? Evet ☐ Hayır ☐

22. Lütfen aşağıdaki öğelerle ilgili yaşadığınız sıkıntı derecesini belirtiniz

	Evet			Kararsızım			Hayır
Dikkatin dağılması	-3	-2	-1	0	1	2	3
Yazıların düzgün görülememesi	-3	-2	-1	0	1	2	3
Göz yorgunluğu	-3	-2	-1	0	1	2	3
Göz yanması	-3	-2	-1	0	1	2	3
Odaklanma problem	-3	-2	-1	0	1	2	3
Parlama oluşması	-3	-2	-1	0	1	2	3
Diğer, lütfen belirtin	-3	-2	-1	0	1	2	3

23. LED ve OLED lambaların aydınlık düzeylerini karşılaştırdığınızda, görsel konfor açısından değerlendiriniz

	Çok Konforsuz			Kararsızım			Çok Konforlu
LED Lamba (200 LUX)	-3	-2	-1	0	1	2	3
LED Lamba (500 LUX)	-3	-2	-1	0	1	2	3
LED Lamba (800 LUX)	-3	-2	-1	0	1	2	3
OLED Lamba (200 LUX)	-3	-2	-1	0	1	2	3
OLED Lamba (500 LUX)	-3	-2	-1	0	1	2	3
OLED Lamba (800 LUX)	-3	-2	-1	0	1	2	3

Katılımınız için teşekkür ederim.

Respondent Number: Time:

1. Age:

2. Gender: Female ☐ Male ☐

3. Usage of Eye Glass or Contact Lens: Yes ☐ No ☐

4. How do you feel at the moment? Please choose one of them.

Very Tired	Tired	Little Tired	Normal	Little Good	Good	Very Good
☐	☐	☐	☐	☐	☐	☐

LITTLE PRINCE

Reading Time: Lighting Type: LED Illuminance Level: 200

5. Have you ever heard of this book which was mentioned before? Yes ☐ No ☐

6. Please specify the amount of distress you experience regarding each visual comfort criteria while reading the text.

	Comp. Agree			Neutral			Comp. Disagree
Visual Distraction	-3	-2	-1	0	1	2	3
Visual Clarity	-3	-2	-1	0	1	2	3
Visual Fatigue	-3	-2	-1	0	1	2	3
Eye Burning	-3	-2	-1	0	1	2	3
Focusing problem	-3	-2	-1	0	1	2	3
Glare	-3	-2	-1	0	1	2	3
Others, (please specify)	-3	-2	-1	0	1	2	3

MY LEFT FOOT

Reading Time: Lighting Type: LED Illuminance Level: 500

7. Have you ever heard of this book which was mentioned before? Yes ☐ No ☐

8. Please specify the amount of distress you experience regarding each visual comfort criteria while reading the text.

	Comp. Agree			Neutral			Comp. Disagree
Visual Distraction	-3	-2	-1	0	1	2	3
Visual Clarity	-3	-2	-1	0	1	2	3
Visual Fatigue	-3	-2	-1	0	1	2	3
Eye Burning	-3	-2	-1	0	1	2	3
Focusing problem	-3	-2	-1	0	1	2	3
Glare	-3	-2	-1	0	1	2	3
Others, (please specify)	-3	-2	-1	0	1	2	3

POMEGRANATE TREE

Reading Time: Lighting Type: LED Illuminance Level: 800

9. Have you ever heard of this book which was mentioned before? Yes ☐ No ☐

10. Please specify the amount of distress you experience regarding each visual comfort criteria while reading the text.

	Comp. Agree			Neutral			Comp. Disagree
Visual Distraction	-3	-2	-1	0	1	2	3
Visual Clarity	-3	-2	-1	0	1	2	3
Visual Fatigue	-3	-2	-1	0	1	2	3
Eye Burning	-3	-2	-1	0	1	2	3
Focusing problem	-3	-2	-1	0	1	2	3
Glare	-3	-2	-1	0	1	2	3
Others, (please specify)	-3	-2	-1	0	1	2	3

OF MICE AND MEN

Reading Time: Lighting Type: OLED Illuminance Level: 200

11. Have you ever heard of this book which was mentioned before? Yes☐ No☐

12. Please specify the amount of distress you experience regarding each visual comfort criteria while reading the text.

	Comp. Agree			Neutral			Comp. Disagree
Visual Distraction	-3	-2	-1	0	1	2	3
Visual Clarity	-3	-2	-1	0	1	2	3
Visual Fatigue	-3	-2	-1	0	1	2	3
Eye Burning	-3	-2	-1	0	1	2	3
Focusing problem	-3	-2	-1	0	1	2	3
Glare	-3	-2	-1	0	1	2	3
Others, (please specify)	-3	-2	-1	0	1	2	3

MY SWEET ORANGE TREE

Reading Time: Lighting Type: OLED Illuminance Level: 500

13. Have you ever heard of this book which was mentioned before? Yes ☐ No ☐

14. Please specify the amount of distress you experience regarding each visual comfort criteria while reading the text.

	Comp. Agree			Neutral			Comp. Disagree
Visual Distraction	-3	-2	-1	0	1	2	3
Visual Clarity	-3	-2	-1	0	1	2	3
Visual Fatigue	-3	-2	-1	0	1	2	3
Eye Burning	-3	-2	-1	0	1	2	3
Focusing problem	-3	-2	-1	0	1	2	3
Glare	-3	-2	-1	0	1	2	3
Others, (please specify)	-3	-2	-1	0	1	2	3

MADONNA IN A FUR COAT

Reading Time: Lighting Type: OLED Illuminance Level: 800

15. Have you ever heard this book which was mentioned before? Yes ☐ No ☐

16. Please specify the rates of visual comfort criteria what you feel while reading a part.

	Comp. Agree			Neutral			Comp. Disagree
Visual Distraction	-3	-2	-1	0	1	2	3
Visual Clarity	-3	-2	-1	0	1	2	3
Visual Fatigue	-3	-2	-1	0	1	2	3
Eye Burning	-3	-2	-1	0	1	2	3
Focusing problem	-3	-2	-1	0	1	2	3
Glare	-3	-2	-1	0	1	2	3
Others, (please specify)	-3	-2	-1	0	1	2	3

17. Please evaluate the illuminance levels of LED lamps and OLED panels from the point of visual comfort.

	Comp. Uncomfortable			Neutral			Comp. Comfortable
LED Lamp (200 LUX)	-3	-2	-1	0	1	2	3
LED Lamp (500 LUX)	-3	-2	-1	0	1	2	3
LED Lamp (800 LUX)	-3	-2	-1	0	1	2	3
OLED Panel (200 LUX)	-3	-2	-1	0	1	2	3
OLED Panel (500 LUX)	-3	-2	-1	0	1	2	3
OLED Panel (800 LUX)	-3	-2	-1	0	1	2	3

Thank you for your participation.

APPENDIX B

Küçük Prens **(LED Lamp 200 lux)**
(http://kitap.yazarokur.com/kucuk-prens)

Antonie De Saint Exupery tarafından 1943 yılında NewYork'ta bir otel odasında yazılmıştır. Kendisi de bir pilot olan Fransız yazarımız, Küçük Prens adlı başka bir gezegenden gelen bir çocuğun gözünden büyüklerin yanlışlarını anlatır. Küçük Prens kitabı yazarın 6 yaşında iken "Yaşanmış Öyküler" adlı bir kitapta, avını yutan bir boğa yılanının resmini anlatarak başlar. Bundan esinlenerek fil yutmuş bir boğa yılanı çizer. Büyüklere "Korktunuz mu" diye sorar. Herkes bir şapkadan korkmayacaklarını söyler. Hiç kimse onun fil yutan bir boğa yılanı olduğunu anlamaz. Bunun üzerine büyükler tarih, aritmetik, coğrafya, dil bilgisine yoğunlaşmasını söyler ve yazarımızın resim yeteneği kaybolur. Yıllar sonra büyür ve pilot olur. Sahra Çölü üzerinde giderken bir uçak kazası yapar, motorunun bir parçası bozulur. Yardım isteyecek kimse yoktur. Ölüm kalım meselesi olur, çünkü yanında sadece 8 günlük suyu kalmıştır. Uyurken "Bana bir koyun resmi çizer misin?" diyen birinin sesiyle uyanır. Kimseye benzemeyen sarı saçlı küçük bir çocuktur bu. Farklı bir gezegenden gelen Küçük Prens'tir. Önce fil yutan boğa yılanını çizer. Prens, "Ben fil yutan bir boğa yılanı istemiyorum" der. Pilot şaşırır, çünkü kimse o güne dek bu resmi anlamamıştır. Sonra bir kaç denemeden sonra kapalı bir kutu çizer, içinde koyun var der. Prens bu resme bayılır. Sonra Küçük Prens kendi öyküsünü anlatmaya başlar. Biri sönmüş üç volkanı ve harika, kainatta eşi benzeri olmayan bir çiçeği ve baobap ağaçları kaplı küçük bir gezegende tek başına yaşadığını söyler. Kendine bir uğraş bulup bilgisini ve görgüsünü artırmak amacıyla bölgesinde bulunan diğer asteroidleri gezmeye karar verir. Hepsinde çok farklı ve ilginç karakterler vardır. Her gezisinin sonunda "Şu büyükler, kesinlikle çok ama çok tuhaf insanlar der". Gezenin birinde her şeyini yönettiğini söyleyen bir kral, diğerinde kendini beğenmiş bir adam, sayılarla uğraşan bir işadamı, devamlı fenerini yakıp söndüren bir fenerci ve devamlı içen bir ayyaşla karşılaşır. En sonuncu gezegende buluşlarını kaybeden bir kaşife rastlar. Kaşif ona dünyaya gitmesini salık verir. Böylece prensimizin gittiği yedinci gezegen dünya olur. Dünyada bir tilkiyi evcilleştirir. Tilki ona bir sır verir: "İşte sırrım, çok basit: En iyi yüreğiyle görebilir insan. Gözler asıl görülmesi gerekeni göremez" der. Diğer gezegenlerde gördüğü karakterlerin aynısının dünyada binlerce olduğunu görür. Böylece bir yıl kaldığı dünyadan kendi gezegenine dönmek ister. Çünkü orada bakmak zorunda olduğu bir çiçeği vardır. Aslında o çiçekten dünyada binlercesi vardır ama büyükler çiçeklerinin kıymetlerini bilemezler. Ayrılık pilotumuz için zor olur çünkü aradığı konuşma arkadaşını çok geç bulmuştur.

Sol Ayağım **(LED Lamp 500 lux)**
(http://kitap.yazarokur.com/sol-ayagim)

İrlandalı yazar Christy Brown'un dünyanın en iyi otobiyografi kitaplarından bir tanesi olan Sol Ayağım otobiyografiden öteye daha çok motive edici mükemmel bir kişisel gelişim kitabı da diyebiliriz. Christy Brown'un gerçek hayat hikayesini ve mücadelesini okudukça hayata olan bakışınız değişiyor ve başarmak istediğiniz hedefler gözünüzde daha erişilebilir hale geliyor. Sol Ayağım romanı 16 kısa bölümden oluşuyor ve her bölüm Christy Brown'un hayatından bir macera sunuyor. Beyin felci ile doğan ve bu yüzden doktorların zihinsel özürlü olduğu ve fazla yaşamayacağını düşündüğü Christy Brown'un farklı bir çocuk olduğu annesi keşfediyor. Doktorların ne dediğini umursamadan ve umudunu kaybetmeden oğlu için her şeyi yapıyor. Bunun farkında olan Christy Brown bir süre vücudunu hareket ettiremeden çevresini gözlemleyerek hayatına devam ediyor. Bir gün kız kardeşinin tebeşir ile ödevini yapmasını izlerken içinden bir dürtü ile tebeşiri sol ayağı ile alıp bir şeyler çizmeye başlıyor. Bu annesi dahil herkeste bir şok etkisi yaratır ve annesi ondaki umudu bir kez daha durur. Bunun üzerine annesi ona harfleri öğretmeye karar verir ve Christy Brown ilk olarak sol ayağı ile A harfini yazar. Bir sonraki bölümde Christy Brown sol ayağını kullanarak ve annesinin yardımı ile alfabeyi baştan sona öğrenmesi anlatılıyor. Sol ayağı ile bir şeyler çizmek ve öğrenmek onun hayatında yeni bir sayfanın başlangıcıdır. Christy Brown daha fazlasını ister ve alfabenin ötesinde kelimeleri de öğrenmeye başlar. İlk olarak da annesini yanına çağırır ve ona ilk kelimesini gösterir. Kelime ANNE'dir. Christy Brown hayatını tamamen sol ayağına dayanak yaşamaya devam eder. Fakat onun bağımlı olduğu bir de oyuncağı vardır. O da oyuncak bebek arabasıdır. Onun vasıtası ile birlikte kardeşleri ile her yere gidebilir ve hayatının tadını çıkartabilmektedir. Onu dış dünyaya bağlayan tek şey Hanry adını verdiği oyuncak bebek arabasıdır. Fakat araba eskidir ve bir gün kırılır ve kullanılamayacak hale gelir. Christy'nin hayatı başına yıkılmıştır. Kardeşleri artık onu almadan oynamaya giderler ve o elinden bir şey gelmeden onları öylece izler. Bir süre sonrası annesi Christy'ye yeni bir araba alır fakat hayat artık eskisi gibi değildir. Christy büyümektedir ve çevresinde olanları artık daha iyi algılayabilmektedir. Bir keresinde kendisini aynada görür ve gördüğü pek hoşuna gitmez. Yeni arabasına rağmen Christy artık dışarı çıkmak istemez ve eve daha da kapanır. Yeni yıl gelir ve herkes yeni yıl hediyelerini açar. Christy oyuncak askerler almıştır fakat onun gözü kardeşine hediye edilen boyalara takılır.

Nar Ağacı **(LED Lamp 800 lux)**
(http://kitap.yazarokur.com/nar-agaci)

Nazan Bekiroğlu yine mükemmel bir iş çıkartıyor ve Balkan savaşı ile Birinci Dünya Savaşı arasında birbirinden farklı noktalarda tarihin sayfalarında güzel aşk hikayelerini bize sunuyor. Trabzon, Tebriz, Tiflis, Batum ve İstanbul'da geçen Nar Ağacı romanı ile tarihte bir yolculuğa çıkıyorsunuz ve o zamanın şartlarında iki savaş ile dağılıp bir araya gelen hayatları adeta yaşıyorsunuz. Aşk romanlarını sevenler için kaçırılmaması gereken romanlardan biri adeta. Bir de tarihin gizemli sayfalarında dolaşmak da hoşunuza gidiyorsa bir oturuşta okuyup bitirebileceğiniz kadar kısa olan uzun bir roman sizi bekliyor demektir. Nazan Bekiroğlu'nun Nar Ağacı romanı Trabzon, Tebriz, Tiflis, Batum, Bakü ve İstanbul hakkında geçen mükemmel bir hikaye sunuyor. Otuz yıl önce postaya verilen mektup dedesinin ölümünün ikinci gününde gelir. Mektupda sadece selam ve adres vardır. Frasça'dan Türkçe'ye çevrilir. Taht-ı Sülayman'dan gelir. Dedesini ve büyük annesini araştırmaya karar verir torunu. Tebriz'e gider ve adresi bulur. Doksana merdiven dayamış bu ihtiyar kalkıp torunu ile Meşhed yollarına düştüğü gibi hem geçmişi hem de bugünü gayet iyi hatırlıyordur. Beyzat amcaya fotoğraflar ve dedesinin hikayesini sorar. Ne olmuştu da Tebriz'li tacir yerini yurdunu terk etmişti, evinden ocağından anasından atasından kopmuştu. Dedesi Setterhan halı ticareti yapan bir aileden gelir. Taht-ı Suleyman'dan her nasılsa gökten düşen elma gibi Trabzon'a düşüvermişti dedesinin hikayesi. O Tebriz – Batum – Tiflis hattında halı ticareti yapan bir tacirdir. Settarhan, Azam adında bir halı dokuyucu kıza aşık olur. Babası bunu anlar ama önce Yezde gitmesi ve halıları kendi elleri ile teslim etmesi gerektiğini söyler ve dönüşte nişan yapacaklarına söz verir. Azam'ın bunlardan haberi yoktur. Halıları teslim eder fakat Zerdüst ağasının halısı kalır. Zerdüst ağasının evine vardığında onu oğlu Piruz karşılar. Zerdüst ağasının cenazesi vardır ama Piruz Serttahanı misafir eder ve ikisi çok iyi arkadaş olurlar. Serttahan Piruzu Taht-ı Suleyman'a davet eder. Piruz daveti kabul eder ve gelir. Serttahan arkadaşına dokuma tezgahlarını gösterir. O anda Piruz Azam'a, Azam da Piruz'a aşık olur ve ikisi birlikte Tah-ı Suleyman'dan kaçarlar. Serttahan ikisini de öldürmesi gerekir yoksa orasını tamamen terk etmesi gerekir. O ikinciyi seçer ve Batum'a gider. Batum'da iken Bolşevik ihtilali patlar ve bir daha Tebriz'e dönemez. Burada arkadaşları olan Safia ve Vasili bulur. En iyi yaptığı iş olan halıcıkta iş bulamayınca Sofia'nın yanında kitapçıda çalışmaya başlar. Sofia ile çok iyi arkadaş olurlar ve birbirlerine her konuda yardımcı olurlar. Bu sırada Vasili askere gider ve ihtilal olur.

Fareler ve İnsanlar **(White OLED Panel 200 lux)**
(http://kitap.yazarokur.com/john-steinbeck-kitaplari)

Pulitzer ve Nobel Edebiyat Ödüllü Amerikalı ünlü yazar John Steinbeck'in Gazap Üzümleri ile birlikte en tanınan romanı olan Fareler ve İnsanlar okurlarına tam bir arkadaşlık dramı sunuyor. İlk olarak 1937 yılında yayınlanan ve çok tartışılan roman zamanla hak ettiği değeri gördü ve okunması gereken romanlar listesinde yer almayı başardı. Halen tartışmalara neden olan, bazı ülkelerde yasaklanan ya da sansüre uğrayan kitap adını fareler ile ilgili bir şiirden alır. Kitabın ana iki karakteri olan Lennie ve George birbirine kardeş gibi yakın çok iyi dosttur. Lennie zihinsel engelli, uzun boylu ve çok güçlü bir kişidir. George ise aklı başında Lennie'ye göz kulak olan biridir. Lennie'nin yaptıklarından dolayı başları sürekli belaya girer ve o yüzden sürekli seyahat etmek zorunda kalırlar. En büyük hayalleri yeterince para biriktirip kendilerine ufak bir çiftlik almak ve hayatlarını orada devam ettirmektir. Çiftliklerinde her türlü sebzenin yanında hayvanlara da bakmak isterler ve Lennie özellikle tavşan sahibi olmak ister. Lennie'nin en büyük zayıflığı ise güzel ve yumuşak şeyleri çok sevmesidir. Tavşanları da bu ister ve hatta sırf yumuşak olduğu için cebinde ölü fare taşır. Son yaşanan olaydan sonra Lennie ve George yeni bir çiftlikte işe başlarlar. Fakat çiftlik sahibinin oğlunun kısa boy takıntısı vardır ve bu yüzden uzun boylu kişileri hiç sevmez. Bu yüzden daha ilk günden kafayı uzun boylu olan Lennie'ye takar. Fakat onların huzurunu kaçıran başka bir şey daha vardır. O da çiftlik sahibinin güzel karısıdır. Güzelliği ile Lennie'yi daha ilk görüşte etkiler ve George Lennie'den ondan uzak durmasını ister. Fakat çiftlikte yalnızlıktan bunalan ve sohbet edecek birilerini arayan kadın George ve Lennie'yi pek rahat bırakmaz. George kişiliği ile Lennie de gücü ve çalışkanlığı ile çiftlikte çalışan herkesin beğenisini kazanır. Çiftlikte bir elini kaybetmiş Candy adında yaşlı bir adam vardır. Kendi gibi köpeği de çok yaşlıdır ve bu yüzden köpek çiftlikte istenmez. Bir gün köpeği alırlar ve silah ile başının arkasından vurarak öldürürler. Candy bir anlamda çok sevdiği köpeğinde kendi geleceğini görür. Bir gün onu da işe yaramadığı için bir kenara atacaklarını düşünür ve Lennie ile George'nun küçük çiftlik hayallerine kulak misafiri olur. Birikmiş parasını da ortaya koyarak onlara katılmaya karar verir ve üçlü artık hayallerine birkaç ay uzaktadırlar. İşler yolunda giderken George'un korktuğu başına gelir. George ortalıklarda yokken Lennie'nin samanlıkta ziyaretine güzel kadın gelir. Lennie kaçmak istese de sadece sohbet etmek isteyen kadın onu etkiler.

Şeker Portakalı **(White OLED Panel 500 lux)**
(http://kitap.yazarokur.com/seker-portakali)

Jose Mauro De Vasconcelos edebiyat dünyasının en ilginç yazarlarından biri. Nedeni ise yazarlık yeteneğini uzun yıllar keşfedememesi ve hayatın onu bir çok birbirinden alakasız işlere sürüklemesi ve yaşadıkları ile içinde barındırdığı hikayesini yazmaya karar vererek edebiyat dünyasında yeri alması. Hayatında bir çok farklı işte çalışan ve içinde kendine göre bir hikaye geliştiren yazar en sonunda bunu kağıda dökmeye karar verir ve 12 gün gibi kısa bir sürede kitabını tamamlar. Bu kitabı sayesinde de en çok satanlar listesine giren yazar bir anda kendini farklı bir dünyada bulur. İşte bu kitabın adı Şeker Portakalı. Aydın Emeç tarafından Türkçeye çevrilen bu değerli romanda yoksul bir ailenin oğlu olan bir çocuğun yüzmeye daha yeni başladığında ilerde yüzme şampiyonu olma hayalini kurmasını ve bu hayali için ilerlerken hayatın ona nasıl oyunlar oynadığını ve onu nasıl farklı yerlere sürüklediğini anlatıyor. Şeker Portakalı okuyucularına tam bir hayat dersi sunuyor ve hayata dair gerçekleri su yüzeyine çıkartıyor. Bunu yaparken de okuyucunun kendi geçmişinden parçaları bulmasını ve hayatı daha iyi anlamasını sağlıyor. Şeker Portakalı 5 yaşındaki Zeze isimli bir çocuğun acı hikayesini anlatıyor. Çok fakir bir ailenin çocuklarından biri olan ve 5 yaşında olmasına rağmen hayal gücü ve zekası çok gelişmiş olan Zeze çok yaramaz bir çocuktur ve o yüzden mahalle için şeytan olarak anılmaktadır. Çok meraklı olan ve çevresindeki her şeyi keşfetmeye çalışan bu çocuğun diğer ilginç noktası ise okumayı çok erken çözmesidir. Bu yüzden öğretmeni tarafından sevilen ve Zeze'nin şeytan olmadığı bir tek öğretmeni kendisi gibi sarışın olan ablası inanmaktadır. Zeze'nin babası işsizdir ve aile bu yüzden büyük bir fakirlik çeker. Taşınmak zorundadırlar ve bu Zeze'ye acı verir. Bu acısını azaltmak içinde Zeze'ben bir şeker portakalı fidanı seçmesi istenir. Zeze' de bir tane seçer ve kendi ağacı olduğu için ona ilgi gösterir. Fakat bu şeker portakalı fidanının başka bir özelliği daha vardır. O da Zeze ile konuşmasıdır. İkili bu sayede çok iyi arkadaş olur ve Zeze tüm gün yaptıklarını şeker portakalı fidanına anlatmaya başlar. Yeni yıl yaklaştığında Zeze de her çocuk gibi hediye bekler. Fakat ailesi çok fakir olduğu için pek umudu yoktur. Buna rağmen pabuçlarını kapının önüne koyar ve odasında beklemeye başlar. Gelenek olarak babası kapının önüne hediye koyması gerekir ve Zeze merakına yenilerek hediye var mı diye kapıyı açar. Tahmin ettiği gibi hediye yoktur fakat karşısında babası ıslak gözler ile ona bakar.

Kürk Mantolu Madonna **(White OLED Panel 800 lux)**
(http://kitap.yazarokur.com/kurk-mantolu-madonna)

Kürk Mantolu Madonna, Türk Edebiyatı'nın öncü yazarlarından biri olan Sabahattin Ali'nin başyapıtlarından biridir. Yazar kitapta Raif Efendi'nin içsel yolculuğunu aşk ile sarıp sarmalayarak okuyucuya sunmuştur. Okunduğunda uzun süreli izler bırakan, mutlaka okunması gereken bir kitap ve aynı zamanda psikolojik tahliller, betimlemeler açısından çok tatmin edici. Kitap, Rasim'in işini kaybetmesi ve iş arayışına koyulmasıyla başlar. İş aradığı bir gün, eski arkadaşlarından Hamdi ile karşılaşır ve ondan yardım ister. Nitekim Hamdi, müdürü olduğu işyerinde bir iş teklif eder. Rasim, utana sıkıla da olsa bu teklifi kabul eder. Raif Efendi denen yaşlı, sessiz, sakin bir adamla aynı odada çalışacaktır. Raif Efendi çok az konuşuyor, kendisine verilen çevirileri titizlikle yapıyor ve boş zamanlarında masasının çekmecesinde duran bir kitabı okuyordur. Raif Efendi'nin hastalanıp işe gelmediği günlerden birinde, yapılacak bir çevirinin ona ulaştırılması gerektiğinden Rasim, Raif

Efendi'nin evinin yolunu tutar. İçeri adımını atar atmaz, Raif Efendi'nin içine kapanıklığının sebebini anlamıştır. Bu zavallı, yaşlı adam oldukça kalabalık bir evde sürekli ezilmektedir ve üstelik bu kalabalık ailenin tek geçim kaynağı Raif Efendi'nin üç kuruşluk maaşıdır. Lakin bu defa Raif Efendi çok hastadır. Rasim'den iş yerindeki çekmecesinden eşyalarını getirmesini rica eder. Asıl hikaye, Rasim'in çekmecedeki kara kaplı defteri bulup okumasıyla başlar. Okuduktan sonra defteri yakacağına dair Raif Efendi'ye söz verir. Defter, Raif Efendi'nin hayat öyküsünü anlatmaktadır: Raif, genç bir delikanlı olmasına rağmen içine kapanık ve oldukça yalnızdır. Tek dostu kitaplarıdır. Babası bir sabun fabrikası işletmektedir ve Raif'in sabunculuğu öğrenebilmesi için onu Almanya'ya göndermeye karar verir. Raif Efendi, Almanya'ya vardığında bir pansiyona yerleşir ve bir sabun fabrikasında işe başlar. Lakin zamanla fabrikaya daha az uğramaktadır. Her gün parkları, sergileri ve Almanya'nın çeşitli yerlerini sabahtan akşama kadar gezmektedir. Bir gün, gazetede reklamını gördüğü bir sergiye gider ve bir tabloyla karşılaşır: Kürk Mantolu Madonna ile. O gün ve devamında serginin açılışından kapanışına kadar o tabloyu seyreder. Kürk Mantolu Madonna onu çok etkilemiştir. Yine Kürk Mantolu Madonna'yı seyre daldığı günlerden birinde, yanına bir kadın gelir ve tabloyu birine benzetip benzetmediğini sorar. Raif Efendi utancından kafasını kaldırıp kadının yüzüne bakamadan onu annesine benzettiğini söyler. Ama utancından yalan söylemiştir. Raif Efendi, pansiyonda kalan bir arkadaşıyla gezerken, sergide konuştuğu kürk mantolu kadına rastlar. Ertesi gün, kadını tekrar görebilme umuduyla aynı yerde onu beklemeye başlar ve geldiğinde onu bir gece kulübü olan Atlantis'e kadar takip eder. İçeri girdiğinde, Kürk Mantolu Madonna ile karşılaşır, keman çalıp şarkı söylemektedir.

APPENDIX C

Table C1. Frequency of Physical Condition

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very tired	2	2,5	2,5	2,5
	Tired	4	5,0	5,0	7,5
	Little tired	27	33,8	33,8	41,3
	Normal	23	28,8	28,8	70,0
	Little Good	1	1,3	1,3	71,3
	Good	12	15,0	15,0	86,3
	Very Good	11	13,8	13,8	100,0
	Total	80	100,0	100,0	

Table C2. Group Statistics of the Three LED Lighting Scenarios For Visual Distraction

	N	Mean	Std. Deviation
LED200	80	4,9125	1,87045
LED500	80	5,7500	1,70999
LED800	80	4,7000	1,97067

Table C3. Comparisons of the Three LED Lighting Scenarios For Visual Distraction

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,227	11,445[a]	2,000	78,000	,000	,227
Wilks' lambda	,773	11,445[a]	2,000	78,000	,000	,227
Hotelling's trace	,293	11,445[a]	2,000	78,000	,000	,227
Roy's largest root	,293	11,445[a]	2,000	78,000	,000	,227

Table C4. Comparisons of the Three LED Lighting Scenarios For Visual Distraction

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,838*	,209	,000	-1,254	-,421
	3	,212	,248	,395	-,282	,707
2	1	,838*	,209	,000	,421	1,254
	3	1,050*	,253	,000	,547	1,553
3	1	-,212	,248	,395	-,707	,282
	2	-1,050*	,253	,000	-1,553	-,547

1: LED 200 lux **2:** LED 500 lux **3:** LED 800 lux

Table C5. Group Statistics of the Three LED Lighting Scenarios For Visual Clarity

	N	Mean	Std. Deviation
LED200	80	5,4000	1,79733
LED500	80	5,8000	1,65659
LED800	80	5,0875	1,95645

Table C6. Comparisons of the Three LED Lighting Scenarios For Visual Clarity

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,112	4,907[b]	2,000	78,000	,010	,112
Wilks' lambda	,888	4,907[b]	2,000	78,000	,010	,112
Hotelling's trace	,126	4,907[b]	2,000	78,000	,010	,112
Roy's largest root	,126	4,907[b]	2,000	78,000	,010	,112

Table C7. Comparisons of the Three LED Lighting Scenarios For Visual Clarity

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,400	,249	,113	-,896	,096
	3	,313	,268	,248	-,222	,847
2	1	,400	,249	,113	-,096	,896
	3	,712*	,229	,003	,257	1,168
3	1	-,313	,268	,248	-,847	,222
	2	-,712*	,229	,003	-1,168	-,257

1: LED 200 lux **2:** LED 500 lux **3:** LED 800 lux

Table C8. Group Statistics of the Three LED Lighting Scenarios For Visual Fatigue

	N	Mean	Std. Deviation
LED200	80	5,0375	1,85857
LED500	80	5,1625	1,81724
LED800	80	4,2250	1,88918

Table C9. Comparisons of the Three LED Lighting Scenarios For Visual Fatigue

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,205	10,045[b]	2,000	78,000	,000	,205
Wilks' lambda	,795	10,045[b]	2,000	78,000	,000	,205
Hotelling's trace	,258	10,045[b]	2,000	78,000	,000	,205
Roy's largest root	,258	10,045[b]	2,000	78,000	,000	,205

Table C10. Comparisons of the Three LED Lighting Scenarios For Visual Fatigue

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,125	,261	,633	-,645	,395
	3	,813*	,233	,001	,349	1,276
2	1	,125	,261	,633	-,395	,645
	3	,938*	,236	,000	,467	1,408
3	1	-,813*	,233	,001	-1,276	-,349
	2	-,938*	,236	,000	-1,408	-,467

1: LED 200 lux **2:** LED 500 lux **3:** LED 800 lux

Table C11. Group Statistics of the Three LED Lighting Scenarios For Burning Eye

	N	Mean	Std. Deviation
LED200	80	5,8125	1,44164
LED500	80	5,7500	1,71737
LED800	80	4,8125	1,89666

Table C12. Comparison of the Three LED Lighting Scenarios For Burning Eye

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,250	13,026[b]	2,000	78,000	,000	,250
Wilks' lambda	,750	13,026[b]	2,000	78,000	,000	,250
Hotelling's trace	,334	13,026[b]	2,000	78,000	,000	,250
Roy's largest root	,334	13,026[b]	2,000	78,000	,000	,250

Table C13. Comparisons of the Three LED Lighting Scenarios For Burning Eye

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	,063	,199	,754	-,334	,459
	3	1,000*	,213	,000	,575	1,425
2	1	-,063	,199	,754	-,459	,334
	3	,938*	,214	,000	,512	1,363
3	1	-1,000*	,213	,000	-1,425	-,575
	2	-,938*	,214	,000	-1,363	-,512

1: LED 200 lux **2:** LED 500 lux **3:** LED 800 lux

Table C14. Group Statistics of the Three LED Lighting Scenarios For Focusing Problem

	N	Mean	Std. Deviation
LED200	80	5,0500	2,03700
LED500	80	5,5875	1,82593
LED800	80	4,7375	2,01101

Table C15. Comparisons of the Three LED Lighting Scenarios For Focusing Problem

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,117	5,184[b]	2,000	78,000	,008	,117
Wilks' lambda	,883	5,184[b]	2,000	78,000	,008	,117
Hotelling's trace	,133	5,184[b]	2,000	78,000	,008	,117
Roy's largest root	,133	5,184[b]	2,000	78,000	,008	,117

Table C16. Comparisons of the Three LED Lighting Scenarios For Focusing Problem

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,538	,292	,070	-1,119	,044
	3	,313	,295	,293	-,275	,900
2	1	,538	,292	,070	-,044	1,119
	3	,850*	,265	,002	,322	1,378
3	1	-,313	,295	,293	-,900	,275
	2	-,850*	,265	,002	-1,378	-,322

1: LED 200 lux **2:** LED 500 lux **3:** LED 800 lux

Table C17. Group Statistics of the Three LED Lighting Scenarios For Glare

	N	Mean	Std. Deviation
LED200	80	5,6250	1,74570
LED500	80	5,6750	1,69717
LED800	80	4,6500	2,14712

Table C18. Comparisons of the Three LED Lighting Scenarios For Glare

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,181	8,597[b]	2,000	78,000	,000	,181
Wilks' lambda	,819	8,597[b]	2,000	78,000	,000	,181
Hotelling's trace	,220	8,597[b]	2,000	78,000	,000	,181
Roy's largest root	,220	8,597[b]	2,000	78,000	,000	,181

Table C19. Comparisons of the Three LED Lighting Scenarios For Glare

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,050	,216	,817	-,479	,379
	3	,975*	,261	,000	,455	1,495
2	1	,050	,216	,817	-,379	,479
	3	1,025*	,264	,000	,499	1,551
3	1	-,975*	,261	,000	-1,495	-,455
	2	-1,025*	,264	,000	-1,551	-,499

1: LED 200 lux **2:** LED 500 lux **3:** LED 800 lux

Table C20. Group Statistics of the Three LED Lighting Scenarios For All Criteria

	N	Mean	Std. Deviation
LED200	80	31,8375	8,49489
LED500	80	33,7250	8,32865
LED800	80	28,2125	9,51573

Table C21. Comparisons of the Three LED Lighting Scenarios For All Criteria

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,239	12,245[b]	2,000	78,000	,000	,239
Wilks' lambda	,761	12,245[b]	2,000	78,000	,000	,239
Hotelling's trace	,314	12,245[b]	2,000	78,000	,000	,239
Roy's largest root	,314	12,245[b]	2,000	78,000	,000	,239

Table C22. Comparisons of the Three LED Lighting Scenarios For All Criteria

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-1,888	1,050	,076	-3,978	,203
	3	3,625*	1,197	,003	1,243	6,007
2	1	1,888	1,050	,076	-,203	3,978
	3	5,513*	1,107	,000	3,309	7,716
3	1	-3,625*	1,197	,003	-6,007	-1,243
	2	-5,513*	1,107	,000	-7,716	-3,309

1: LED 200 lux **2:** LED 500 lux **3:** LED 800 lux

Table C23. Group Statistics of the Three OLED Lighting Scenarios For Visual Distraction

	N	Mean	Std. Deviation
OLED200	80	5,6625	1,67592
OLED500	80	6,0375	1,27730
OLED800	80	5,1625	1,89899

Table C24. Comparisons of the Three OLED Lighting Scenarios For Visual Distraction

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,216	10,759[b]	2,000	78,000	,000	,216
Wilks' lambda	,784	10,759[b]	2,000	78,000	,000	,216
Hotelling's trace	,276	10,759[b]	2,000	78,000	,000	,216
Roy's largest root	,276	10,759[b]	2,000	78,000	,000	,216

Table C25. Comparisons of the Three OLED Lighting Scenarios For Visual Distraction

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,375*	,180	,040	-,733	-,017
	3	,500*	,241	,041	,021	,979
2	1	,375*	,180	,040	,017	,733
	3	,875*	,195	,000	,487	1,263
3	1	-,500*	,241	,041	-,979	-,021
	2	-,875*	,195	,000	-1,263	-,487

1: OLED 200 lux **2:** OLED 500 lux **3:** OLED 800 lux

Table C26. Group Statistics of the Three OLED Lighting Scenarios For Visual Clarity

	N	Mean	Std. Deviation
OLED200	80	5,8000	1,52946
OLED500	80	5,9750	1,37772
OLED800	80	5,1375	1,78420

Table C27. Comparisons of the Three OLED Lighting Scenarios For Visual Clarity

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,171	8,056[b]	2,000	78,000	,001	,171
Wilks' lambda	,829	8,056[b]	2,000	78,000	,001	,171
Hotelling's trace	,207	8,056[b]	2,000	78,000	,001	,171
Roy's largest root	,207	8,056[b]	2,000	78,000	,001	,171

Table C28. Comparisons of the Three OLED Lighting Scenarios For Visual Clarity

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,175	,180	,335	-,534	,184
	3	,662*	,230	,005	,205	1,120
2	1	,175	,180	,335	-,184	,534
	3	,837*	,208	,000	,424	1,251
3	1	-,662*	,230	,005	-1,120	-,205
	2	-,837*	,208	,000	-1,251	-,424

1: OLED 200 lux **2:** OLED 500 lux **3:** OLED 800 lux

Table C29. Group Statistics of the Three OLED Lighting Scenarios For Visual Fatigue

	N	Mean	Std. Deviation
OLED200	80	5,3750	1,70906
OLED500	80	5,5000	1,59111
OLED800	80	4,5125	1,88930

Table C30. Comparisons of the Three OLED Lighting Scenarios For Visual Fatigue

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,216	10,755[b]	2,000	78,000	,000	,216
Wilks' lambda	,784	10,755[b]	2,000	78,000	,000	,216
Hotelling's trace	,276	10,755[b]	2,000	78,000	,000	,216
Roy's largest root	,276	10,755[b]	2,000	78,000	,000	,216

Table C31. Comparisons of the Three OLED Lighting Scenarios For Visual Fatigue

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,125	,192	,517	-,507	,257
	3	,862*	,244	,001	,377	1,348
2	1	,125	,192	,517	-,257	,507
	3	,987*	,214	,000	,562	1,413
3	1	-,862*	,244	,001	-1,348	-,377
	2	-,987*	,214	,000	-1,413	-,562

1: OLED 200 lux **2:** OLED 500 lux **3:** OLED 800 lux

Table C32. Group Statistics of the Three OLED Lighting Scenarios For Burning Eye

	N	Mean	Std. Deviation
OLED200	80	5,9500	1,51699
OLED500	80	5,9750	1,46672
OLED800	80	5,1375	1,91426

Table C33. Comparisons of the Three OLED Lighting Scenarios For Burning Eye

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,204	9,994[b]	2,000	78,000	,000	,204
Wilks' lambda	,796	9,994[b]	2,000	78,000	,000	,204
Hotelling's trace	,256	9,994[b]	2,000	78,000	,000	,204
Roy's largest root	,256	9,994[b]	2,000	78,000	,000	,204

Table C34. Comparisons of the Three OLED Lighting Scenarios For Burning Eye

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,025	,186	,893	-,395	,345
	3	,813*	,208	,000	,399	1,226
2	1	,025	,186	,893	-,345	,395
	3	,837*	,204	,000	,432	1,243
3	1	-,813*	,208	,000	-1,226	-,399
	2	-,837*	,204	,000	-1,243	-,432

1: OLED 200 lux **2:** OLED 500 lux **3:** OLED 800 lux

Table C35. Group Statistics of the Three OLED Lighting Scenarios For Focusing Problem

	N	Mean	Std. Deviation
OLED200	80	5,4625	1,79270
OLED500	80	5,9000	1,37427
OLED800	80	4,7625	1,92416

Table C36. Comparisons of the Three OLED Lighting Scenarios For Focusing Problem

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,235	11,996[b]	2,000	78,000	,000	,235
Wilks' lambda	,765	11,996[b]	2,000	78,000	,000	,235
Hotelling's trace	,308	11,996[b]	2,000	78,000	,000	,235
Roy's largest root	,308	11,996[b]	2,000	78,000	,000	,235

Table C37. Comparisons of the Three OLED Lighting Scenarios For Focusing Problem

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,438*	,192	,026	-,820	-,055
	3	,700*	,244	,005	,214	1,186
2	1	,438*	,192	,026	,055	,820
	3	1,138*	,232	,000	,675	1,600
3	1	-,700*	,244	,005	-1,186	-,214
	2	-1,138*	,232	,000	-1,600	-,675

1: OLED 200 lux **2:** OLED 500 lux **3:** OLED 800 lux

Table C38. Group Statistics of the Three OLED Lighting Scenarios For Glare

	N	Mean	Std. Deviation
OLED200	80	6,3500	1,19174
OLED500	80	6,0750	1,41220
OLED800	80	4,7250	2,03124

Table C39. Comparison of the Three OLED Lighting Scenarios For Glare

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,392	25,169[b]	2,000	78,000	,000	,392
Wilks' lambda	,608	25,169[b]	2,000	78,000	,000	,392
Hotelling's trace	,645	25,169[b]	2,000	78,000	,000	,392
Roy's largest root	,645	25,169[b]	2,000	78,000	,000	,392

Table C40. Comparisons of the Three OLED Lighting Scenarios For Glare

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	,275	,152	,074	-,027	,577
	3	1,625*	,231	,000	1,166	2,084
2	1	-,275	,152	,074	-,577	,027
	3	1,350*	,218	,000	,916	1,784
3	1	-1,625*	,231	,000	-2,084	-1,166
	2	-1,350*	,218	,000	-1,784	-,916

1: OLED 200 lux **2:** OLED 500 lux **3:** OLED 800 lux

Table C41. Group Statistics of the Three OLED Lighting Scenarios For All Criteria

	N	Mean	Std. Deviation
OLED200	80	34,6000	7,24368
OLED500	80	35,4625	6,40005
OLED800	80	29,4375	9,02155

Table C42. Comparisons of the Three OLED Lighting Scenarios For All Criteria

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	,346	20,615[b]	2,000	78,000	,000	,346
Wilks' lambda	,654	20,615[b]	2,000	78,000	,000	,346
Hotelling's trace	,529	20,615[b]	2,000	78,000	,000	,346
Roy's largest root	,529	20,615[b]	2,000	78,000	,000	,346

Table C43. Comparisons of the Three OLED Lighting Scenarios For All Criteria

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-,862	,720	,234	-2,295	,570
	3	5,163*	1,024	,000	3,124	7,201
2	1	,862	,720	,234	-,570	2,295
	3	6,025*	,935	,000	4,164	7,886
3	1	-5,163*	1,024	,000	-7,201	-3,124
	2	-6,025*	,935	,000	-7,886	-4,164

1: OLED 200 lux **2:** OLED 500 lux **3:** OLED 800 lux

Table C44. Paired Sample Test for LED and OLED Lightings on Visual Comfort Criteria

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 LED200 OLED200	-,75000	2,31943	,25932	-1,26616	-,23384	-2,892	79	,005
Pair 2 LED200 OLED200	-,40000	2,04134	,22823	-,85428	,05428	-1,753	79	,084
Pair 3 LED200 OLED200	-,33750	1,94184	,21710	-,76963	,09463	-1,555	79	,124
Pair 4 LED200 OLED200	-,13750	1,62062	,18119	-,49815	,22315	-,759	79	,450
Pair 5 LED200 OLED200	-,41250	2,24845	,25138	-,91287	,08787	-1,641	79	,105
Pair 6 LED200 OLED200	-,72500	1,71350	,19157	-1,10632	-,34368	-3,784	79	,000
Pair 7 LED200Total OLED200Total	-2,7625	8,05086	,90011	-4,55413	-,97087	-3,069	79	,003

Table C45. Paired Samples Correlation for LED and OLED Lightings (200 lux) on Visual Comfort Criteria

		N	Correlation	Sig.
Pair 1	LED200 OLED200	80	,148	,190
Pair 2	LED200 OLED200	80	,255	,022
Pair 3	LED200 OLED200	80	,410	,000
Pair 4	LED200 OLED200	80	,401	,000
Pair 5	LED200 OLED200	80	,316	,004
Pair 6	LED200 OLED200	80	,368	,001
Pair 7	LED200Total OLED200Total	80	,486	,000

Table C46. Paired Samples Statistics for LED and OLED Lightings (200 lux) on Visual Comfort Criteria

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	LED200	4,9125	80	1,87045	,20912
	OLED200	5,6625	80	1,67592	,18737
Pair 2	LED200	5,4000	80	1,79733	,20095
	OLED200	5,8000	80	1,52946	,17100
Pair 3	LED200	5,0375	80	1,85857	,20779
	OLED200	5,3750	80	1,70906	,19108
Pair 4	LED200	5,8125	80	1,44164	,16118
	OLED200	5,9500	80	1,51699	,16960
Pair 5	LED200	5,0500	80	2,03700	,22774
	OLED200	5,4625	80	1,79270	,20043
Pair 6	LED200	5,6250	80	1,74570	,19518
	OLED200	6,3500	80	1,19174	,13324
Pair 7	LED200Total	31,8375	80	8,49489	,94976
	OLED200Total	34,6000	80	7,24368	,80987

Table C47. Paired Sample Test for LED and OLED Lightings (500 lux) on Visual Comfort Criteria

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	LED500 OLED500	-,28750	1,76602	,19745	-,68051	,10551	-1,456	79	,149
Pair 2	LED500 OLED500	-,17500	1,99223	,22274	-,61835	,26835	-,786	79	,434
Pair 3	LED500 OLED500	-,33750	1,73529	,19401	-,72367	,04867	-1,740	79	,086
Pair 4	LED500 OLED500	-,22500	1,93551	,21640	-,65573	,20573	-1,040	79	,302
Pair 5	LED500 OLED500	-,31250	1,98471	,22190	-,75418	,12918	-1,408	79	,163
Pair 6	LED500 OLED500	-,40000	1,96553	,21975	-,83741	,03741	-1,820	79	,073
Pair 7	LED500Total OLED500Total	-1,73750	8,64891	,96698	-3,66222	,18722	-1,797	79	,076

Table C48. Paired Samples Correlation for LED and OLED Lightings (500 lux) on Visual Comfort Criteria

		N	Correlation	Sig.
Pair 1	LED500 OLED500	80	,329	,003
Pair 2	LED500 OLED500	80	,148	,192
Pair 3	LED500 OLED500	80	,488	,000
Pair 4	LED500 OLED500	80	,269	,016
Pair 5	LED500 OLED500	80	,256	,022
Pair 6	LED500 OLED500	80	,211	,060
Pair 7	LED500Total OLED500Total	80	,333	,003

Table C49. Paired Sample Test for LED and OLED Lightings (500 lux) on Visual Comfort Criteria

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	LED500	5,7500	80	1,70999	,19118
	OLED500	6,0375	80	1,27730	,14281
Pair 2	LED500	5,8000	80	1,65659	,18521
	OLED500	5,9750	80	1,37772	,15403
Pair 3	LED500	5,1625	80	1,81724	,20317
	OLED500	5,5000	80	1,59111	,17789
Pair 4	LED500	5,7500	80	1,71737	,19201
	OLED500	5,9750	80	1,46672	,16398
Pair 5	LED500	5,5875	80	1,82593	,20415
	OLED500	5,9000	80	1,37427	,15365
Pair 6	LED500	5,6750	80	1,69717	,18975
	OLED500	6,0750	80	1,41220	,15789
Pair 7	LED500Total	33,7250	80	8,32865	,93117
	OLED500Total	35,4625	80	6,40005	,71555

Table C50. Paired Sample Test for LED and OLED Lightings (800 lux) on Visual Comfort Criteria

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	LED800 OLED800	-,46250	1,84146	,20588	-,87230	-,05270	-2,246	79	,027
Pair 2	LED800 OLED800	-,05000	1,78531	,19960	-,44730	,34730	-,250	79	,803
Pair 3	LED800 OLED800	-,28750	1,91724	,21435	-,71416	,13916	-1,341	79	,184
Pair 4	LED800 OLED800	-,32500	2,10950	,23585	-,79445	,14445	-1,378	79	,172
Pair 5	LED800 OLED800	-,02500	1,94855	,21785	-,45863	,40863	-,115	79	,909
Pair 6	LED800 OLED800	-,07500	2,27131	,25394	-,58046	,43046	-,295	79	,769
Pair 7	LED800Total OLED800Total	-1,22500	8,32561	,93083	-3,07777	,62777	-1,316	79	,192

Table C51. Paired Samples Correlation for LED and OLED Lightings (800 lux) on Visual Comfort Criteria

		N	Correlation	Sig.
Pair 1	LED800 OLED800	80	,548	,000
Pair 2	LED800 OLED800	80	,548	,000
Pair 3	LED800 OLED800	80	,485	,000
Pair 4	LED800 OLED800	80	,387	,000
Pair 5	LED800 OLED800	80	,510	,000
Pair 6	LED800 OLED800	80	,410	,000
Pair 7	LED800Total OLED800Total	80	,598	,000

Table C52. Paired Sample Test for LED and OLED Lightings (800 lux) on Visual Comfort Criteria

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	LED800	4,7000	80	1,97067	,22033
	OLED800	5,1625	80	1,89899	,21231
Pair 2	LED800	5,0875	80	1,95645	,21874
	OLED800	5,1375	80	1,78420	,19948
Pair 3	LED800	4,2250	80	1,88918	,21122
	OLED800	4,5125	80	1,88930	,21123
Pair 4	LED800	4,8125	80	1,89666	,21205
	OLED800	5,1375	80	1,91426	,21402
Pair 5	LED800	4,7375	80	2,01101	,22484
	OLED800	4,7625	80	1,92416	,21513
Pair 6	LED800	4,6500	80	2,14712	,24006
	OLED800	4,7250	80	2,03124	,22710
Pair 7	LED800Total	28,2125	80	9,51573	1,06389
	OLED800Total	29,4375	80	9,02155	1,00864

Table C53. Correlation Test For Physical Conditions and Reading Time For LED 200 Lux

		LED 200	LED 200 Reading Time
LED 200	Pearson Correlation	1	,053
	Sig. (2-tailed)		,641
	N	80	80
LED 200 Reading Time	Pearson Correlation	,053	1
	Sig. (2-tailed)	,641	
	N	80	80

Table C54. Correlation Test For Physical Conditions and Reading Time For LED 500 Lux

		LED 500	LED 500 Reading Time
LED 500	Pearson Correlation	1	-,093
	Sig. (2-tailed)		,411
	N	80	80
LED 500 Reading Time	Pearson Correlation	-,093	1
	Sig. (2-tailed)	,411	
	N	80	80

Table C55. Correlation Test For Physical Conditions and Reading Time For LED 800 Lux

		LED 800	LED 800 Reading Time
LED 800	Pearson Correlation	1	-,240*
	Sig. (2-tailed)		,032
	N	80	80
LED 800 ReadingTime	Pearson Correlation	-,240*	1
	Sig. (2-tailed)	,032	
	N	80	80

Table C56. Correlation Test For Physical Conditions and Reading Time For OLED 200 Lux

		OLED 200	OLED 200 Reading Time
OLED 200	Pearson Correlation	1	-,127
	Sig. (2-tailed)		,260
	N	80	80
OLED 200 ReadingTime	Pearson Correlation	-,127	1
	Sig. (2-tailed)	,260	
	N	80	80

Table C57. Correlation Test For Physical Conditions and Reading Time For OLED 500 Lux

		OLED 500	OLED 500 Reading Time
OLED 500	Pearson Correlation	1	-,064
	Sig. (2-tailed)		,571
	N	80	80
OLED 500 ReadingTime	Pearson Correlation	-,064	1
	Sig. (2-tailed)	,571	
	N	80	80

Table C58. Correlation Test For Physical Conditions and Reading Time For OLED 800 Lux

		OLED 800	OLED 800 Reading Time
OLED 800	Pearson Correlation	1	-,156
	Sig. (2-tailed)		,168
	N	80	80
OLED 800 ReadingTime	Pearson Correlation	-,156	1
	Sig. (2-tailed)	,168	
	N	80	80

Table C59. Group Statistics of the Three Physical Condition Groups For LED 200 Lux

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
1,00		33	29,3939	8,89150	1,54781	26,2412	32,5467
2,00		23	32,9130	8,63878	1,80131	29,1774	36,6487
3,00		24	34,1667	7,14853	1,45919	31,1481	37,1852
Total		80	31,8375	8,49489	,94976	29,9471	33,7279
Model	Fixed Effects			8,33319	,93168	29,9823	33,6927
	Random Effects				1,50655	25,3553	38,3197

1: Tired **2:** Normal **3:** Good

Table C60. Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
1,689	2	77	,191

Table C61. Comparisons of the Three Physical Condition Groups For LED 200 Lux

(I) MOOD ANOVA	(J) MOOD ANOVA	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1,00	2,00	-3,51910	2,26352	,124	-8,0263	,9881
	3,00	-4,77273*	2,23556	,036	-9,2243	-,3212
2,00	1,00	3,51910	2,26352	,124	-,9881	8,0263
	3,00	-1,25362	2,43159	,608	-6,0955	3,5883
3,00	1,00	4,77273*	2,23556	,036	,3212	9,2243
	2,00	1,25362	2,43159	,608	-3,5883	6,0955

1: Tired **2:** Normal **3:** Good

Table C62. Group Statistics of the Three Physical Condition Groups For LED 500 Lux

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
1,00		33	32,5455	8,35947	1,45520	29,5813	35,5096
2,00		23	34,8696	8,12574	1,69433	31,3557	38,3834
3,00		24	34,2500	8,61874	1,75929	30,6106	37,8894
Total		80	33,7250	8,32865	,93117	31,8715	35,5785
Model	Fixed Effects			8,37226	,93605	31,8611	35,5889
	Random Effects				,93605[a]	29,6975[a]	37,7525[a]

1: Tired **2:** Normal **3:** Good

Table C63. Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
,050	2	77	,951

Table C64. Comparisons of the Three Physical Condition Groups For LED 500 Lux

(I) MOOD ANOVA	(J) MOOD ANOVA	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1,00	2,00	-2,32411	2,27413	,310	-6,8525	2,2043
	3,00	-1,70455	2,24604	,450	-6,1770	2,7679
2,00	1,00	2,32411	2,27413	,310	-2,2043	6,8525
	3,00	,61957	2,44299	,800	-4,2451	5,4842
3,00	1,00	1,70455	2,24604	,450	-2,7679	6,1770
	2,00	-,61957	2,44299	,800	-5,4842	4,2451

1: Tired **2:** Normal **3:** Good

Table C65. Group Statistics of the Three Physical Condition Groups For LED 800 Lux

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
1,00		33	25,6970	9,84405	1,71363	22,2064	29,1875
2,00		23	30,8261	8,57932	1,78891	27,1161	34,5361
3,00		24	29,1667	9,43014	1,92492	25,1847	33,1487
Total		80	28,2125	9,51573	1,06389	26,0949	30,3301
Model	Fixed Effects			9,37363	1,04800	26,1257	30,2993
	Random Effects				1,57511	21,4353	34,9897

1: Tired **2:** Normal **3:** Good

Table C66. Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
,849	2	77	,432

Table C67. Comparisons of the Three Physical Condition Groups For LED 800 Lux

(I) MOOD ANOVA	(J) MOOD ANOVA	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1,00	2,00	-5,12912*	2,54613	,047	-10,1991	-,0591
	3,00	-3,46970	2,51468	,172	-8,4771	1,5377
2,00	1,00	5,12912*	2,54613	,047	,0591	10,1991
	3,00	1,65942	2,73519	,546	-3,7870	7,1059
3,00	1,00	3,46970	2,51468	,172	-1,5377	8,4771
	2,00	-1,65942	2,73519	,546	-7,1059	3,7870

1: Tired **2:** Normal **3:** Good

Table C68. Group Statistics of the Three Physical Condition Groups For OLED 200 Lux

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
						Lower Bound	Upper Bound
1,00		33	31,9394	7,88963	1,37341	29,1419	34,7369
2,00		23	36,2609	6,14386	1,28108	33,6041	38,9177
3,00		24	36,6667	6,33600	1,29333	33,9912	39,3421
Total		80	34,6000	7,24368	,80987	32,9880	36,2120
Model	Fixed Effects		6,97458	,77978	33,0473	36,1527	30,2993
	Random Effects			1,60591	27,6903	41,5097	34,9897

1: Tired **2:** Normal **3:** Good

Table C69. Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
1,451	2	77	,241

Table C70. Comparisons of the Three Physical Condition Groups For OLED 200 Lux

(I) MOOD ANOVA	(J) MOOD ANOVA	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1,00	2,00	-4,32148*	1,89449	,025	-8,0939	-,5491
	3,00	-4,72727*	1,87108	,014	-8,4531	-1,0015
2,00	1,00	4,32148*	1,89449	,025	,5491	8,0939
	3,00	-,40580	2,03515	,842	-4,4583	3,6467
3,00	1,00	4,72727*	1,87108	,014	1,0015	8,4531
	2,00	,40580	2,03515	,842	-3,6467	4,4583

1: Tired **2:** Normal **3:** Good

Table C71. Group Statistics of the Three Physical Condition Groups For OLED 500 Lux

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
1,00	33	34,3333	6,29815	1,09637	32,1001	36,5666
2,00	23	36,6522	6,09477	1,27085	34,0166	39,2878
3,00	24	35,8750	6,82268	1,39267	32,9940	38,7560
Total	80	35,4625	6,40005	,71555	34,0382	36,8868
Model		6,40330	,71591	34,0369	36,8881	30,2993
			,71591[a]	32,3822[a]	38,5428[a]	34,9897

1: Tired **2:** Normal **3:** Good

Table C72. Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
,161	2	77	,851

Table C73. Comparisons of the Three Physical Condition Groups For OLED 500 Lux

(I) MOOD ANOVA	(J) MOOD ANOVA	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1,00	2,00	-2,31884	1,73931	,186	-5,7823	1,1446
	3,00	-1,54167	1,71782	,372	-4,9623	1,8790
2,00	1,00	2,31884	1,73931	,186	-1,1446	5,7823
	3,00	,77717	1,86846	,679	-2,9434	4,4977
3,00	1,00	1,54167	1,71782	,372	-1,8790	4,9623
	2,00	-,77717	1,86846	,679	-4,4977	2,9434

1: Tired **2:** Normal **3:** Good

Table C74. Group Statistics of the Three Physical Condition Groups For OLED 800 Lux

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
1,00	33	28,2121	9,44973	1,64499	24,8614	31,5628
2,00	23	29,8696	9,00154	1,87695	25,9770	33,7621
3,00	24	30,7083	8,58957	1,75334	27,0813	34,3354
Total	80	29,4375	9,02155	1,00864	27,4299	31,4451
Model		9,07192	1,01427	27,4178	31,4572	30,2993
			1,01427[a]	25,0734[a]	33,8016[a]	34,9897

1: Tired **2:** Normal **3:** Good

Table C75. Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
,425	2	77	,655

Table C76. Comparisons of the Three Physical Condition Groups For OLED 800 Lux

(I) MOOD ANOVA	(J) MOOD ANOVA	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1,00	2,00	-1,65744	2,46418	,503	-6,5643	3,2494
	3,00	-2,49621	2,43374	,308	-7,3424	2,3500
2,00	1,00	1,65744	2,46418	,503	-3,2494	6,5643
	3,00	-,83877	2,64715	,752	-6,1099	4,4324
3,00	1,00	2,49621	2,43374	,308	-2,3500	7,3424
	2,00	,83877	2,64715	,752	-4,4324	6,1099

1: Tired **2:** Normal **3:** Good