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HUMAN CENTRIC LIGHTING DESIGN IN OFFICES: A RESEARCH ON USER LIGHTING PREFERENCES

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HUMAN CENTRIC LIGHTING DESIGN IN OFFICES: A RESEARCH ON USER LIGHTING PREFERENCES

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Ayşe Nur Acar

_____

Date (06/02/25)

To My Dearest Family...

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HUMAN CENTRIC LIGHTING DESIGN IN OFFICES:
A RESEARCH ON USER LIGHTING PREFERENCES

ABSTRACT

This thesis aims to identify user preferences and human-centered lighting in work environments. A questionnaire was created using 3D interior models prepared using Dialux Evo (DIAL GmbH, 2024) with reference to the TS EN 12461-1 (2021) standard. After a pilot study, the questionnaire was distributed to office workers from various professions and demographic data was collected. The results show that 5000K is the most preferred choice (42.16%), followed by 3000K (33.62%), 4000K (17.95%) and 6000K (6.27%). It was also observed that 300 lx was the least preferred level (23.9%), followed by 750 lx (36.8%) and 500 lx (39.3%). Gender was found to have a significant impact on office layout and color temperature preferences. While women preferred lower color temperatures and open plan offices, men preferred higher temperatures and cubic layouts. In addition, significant differences were found between the tendency of occupational groups to use lighting control systems. Workplace lighting conditions and preferences undoubtedly vary, but they can be categorized. An adaptive lighting system that utilizes modern technology would be a more appropriate choice for work environments.

Keywords: Human-centered lighting, lighting design, user preferences, working environment, office layout, workplace lighting

OFİSLERDE İNSAN ODAKLI AYDINLATMA TASARIMI:
KULLANICI AYDINLATMA TERCİHLERİ ÜZERİNE BİR ARAŞTIRMA

ÖZET

Bu tez, çalışma ortamlarında kullanıcı tercihlerini ve insan merkezli aydınlatmayı belirlemeyi amaçlamaktadır. TS EN 12461-1 (2021) standardı referans alınarak Dialux Evo kullanılarak hazırlanan 3D iç mekan modelleri kullanılarak bir anket oluşturulmuştur. Bir pilot çalışmanın ardından anket çeşitli mesleklerden ofis çalışanlarına dağıtılmış ve demografik veriler toplanmıştır. Sonuçlar 5000K'nın en çok tercih edilen seçenek olduğunu (%42,16), bunu 3000K (%33,62), 4000K (%17,95) ve 6000K'nın (%6,27) takip ettiğini göstermektedir. Ayrıca, 300 lx'in en az tercih edilen değer olduğu (%23,9), bunu 750 lx (%36,8) ve 500 lx'in (%39,3) izlediği görülmüştür. Cinsiyetin ofis düzeni ve renk sıcaklığı tercihlerinde önemli bir etkiye sahip olduğu görülmüştür. Kadınlar daha düşük renk sıcaklıklarını ve açık plan ofisleri tercih ederken, erkekler daha yüksek renk sıcaklıklarını ve kübik düzenleri tercih etmiştir. Ayrıca, meslek gruplarının aydınlatma kontrol sistemlerini kullanma eğilimleri arasında anlamlı farklar tespit edilmiştir. İşyeri aydınlatma koşulları ve tercihleri şüphesiz değişkenlik gösterir, ancak kategorize edilebilirler. Modern teknolojiden yararlanan uyarlanabilir bir aydınlatma sistemi, çalışma ortamları için daha uygun bir seçim olacaktır.

Anahtar Sözcükler: İnsan merkezli aydınlatma, aydınlatma tasarımı, kullanıcı tercihleri, çalışma ortamı, ofis düzeni, işyeri aydınlatması

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LIST OF SYMBOLS

A	Area
α	Shielding angle
Ap	Surface area
cd	Candela
χ^2	Chi-squared
df	Degrees of freedom
E_h	Horizontal illuminance
E_v	Vertical illuminance
$\bar{E}_{av}$	Average illuminance
$\bar{E}$	Average illuminance
$\bar{E}_m$	Maintained illuminance
$\bar{E}z$	Average cylindrical illuminance
$\bar{E}_{m,z}$	Maintained average cylindrical illuminance
Φ	Luminous flux
γ	Vertical photometric angle
I	Luminous intensity
L	Luminance
lm	Lumen
lx	Lux
p	Probability value
P	Power (W)
Q	Energy (J)
R	Reflectance
U_o	Illuminance uniformity
W	Watt (W)

LIST OF ACRONMYMS AND ABBREVIATIONS

ANSI: American National Standards Institute

BSI: British Standards Institution

BREEAM: Building Research Establishment Environmental Assessment Method

CFL: Compact Fluorescent Lamp

CIE: International Commission on Illumination

CRI: Colour Rendering Index

CT: Color Temperature

CTI: Color Tuning Index

DGP: Daylight Glare Probability

EML: Equivalent Melanopic Lux

EN: European Norm

HCL: Human-Centric Lighting

IESNA: Illuminating Engineering Society of North America

ISO: International Organization for Standardization

K: Kelvin

LED: Light Emitting Diode

LEED: Leadership in Energy and Environmental Design

SCN: Suprachiasmatic Nucleus

TS: Turkish Standards

UGR: Unified Glare Rating

UK: United Kingdom

US: United States

VDU: Visual Display Unit

WHO: World Health Organization

1. INTRODUCTION

It was believed that the only photoreceptor cells in the eye were rods and cones for over 150 years. However, in 2002, David Berson and his team from Brown University discovered a new, third type of photoreceptor cell in the retinas of mammals. This discovery showed that this new photoreceptor, identified as a subtype of certain retina ganglion cells, plays an important role in revealing the biological effects controlled by light and darkness. Along with extensive studies conducted over the past 25 years, this finding revealed that good lighting is not only limited to visual effects but also has biological effects such as health, well-being, alertness, and sleep quality (Manav, 2019a).

Therefore, in recent years, lighting experts and engineers have shown particular interest in the concept of Human-Centric Lighting (HCL). HCL proposes the use of light that benefits people by considering the full range of visual and non-visual effects. In particular, the changing nature of work environments in modern offices has led to significant changes in lighting dynamics. The transition from paper-based sources to digital platforms affects lighting requirements in offices.

With this transformation, companies are investing more in their workplace environments to ensure employee comfort and safety. These investments can be rewarded with increased employee productivity and satisfaction. Although this issue is still under debate, in modern office environments, human-centered lighting design is used both to provide visual comfort and to create a more efficient and happier working environment by reducing stress and fatigue of employees.

1.1 General Approach to the Problem

Today, in the working environment of contemporary offices, the significance of a thoughtfully designed lighting environment cannot be overstated. Lighting doesn't just influence vision; it deeply affects people physically and psychologically, shaping comfort and well-being at workspaces. This thesis centers on Human-Centric Lighting (HCL) and

its potential to enhance office environments by customizing lighting to align with the diverse needs of individuals. The goal is to understand the best lighting design criteria for working environments and office users' preferences.

1.2 Aim of the Study

The primary objective is to explore user perceptions regarding lighting standards, contemporary issues and human centric lighting design in office spaces. It is intended to understand how lighting influences visual comfort and space perceptions of people by an online survey. The aim is to suggest practical advice for interior architects, lighting designers, and decision-makers who contribute to the design of contemporary workplaces.

1.3 Structure of the Thesis

This thesis is structured into five chapters:

- Chapter one introduces the study by presenting the general approach to the problem and the aim of the study. It also emphasizes the importance of the research and outlines its scope.
- Chapter two presents the literature review on the relationship between light, health and visual comfort.
- Chapter three focuses on lighting in modern offices. These two chapters form the theoretical framework and contextual basis of the study.
- Chapter four describes the methodology used in the study. It details the research design, the online survey and the questionnaire design, participant selection process and data collection methods. It includes both qualitative and quantitative analyses supported by tables, figures and narratives addressing the research questions.
- Chapter five discusses the findings in the context of the existing literature. The results are given and discussed regarding the previous research in the field. The thesis concludes by summarizing the main findings and their contribution to the field.

2. LIGHT, HEALTH AND VISUAL COMFORT

The experience of the environment relies heavily on sight, and light is the source of that sight. While lighting physically guides us through space (Karlen et al., 2017), it also has a significant impact on how people feel, react and behave in many ways (Steffy, 2008). The photoreceptors in the human retina play important roles during this process, in our physiology and behavior (Spitschan & Joyce, 2023a).

2.1 Visual and Non-Visual Effects of Lighting

The relationship between light and health has been known since ancient times and has been used in the treatment of diseases. In recent years, because of scientific research, the relationship between light and health has come to the forefront again (van Bommel & van den Beld, 2004). The most important of these discoveries is the recently discovered third photoreceptor in the eye, which provides a new understanding of the regulatory role of the environmental effects of light in biological processes (Provencio et al., 1998).

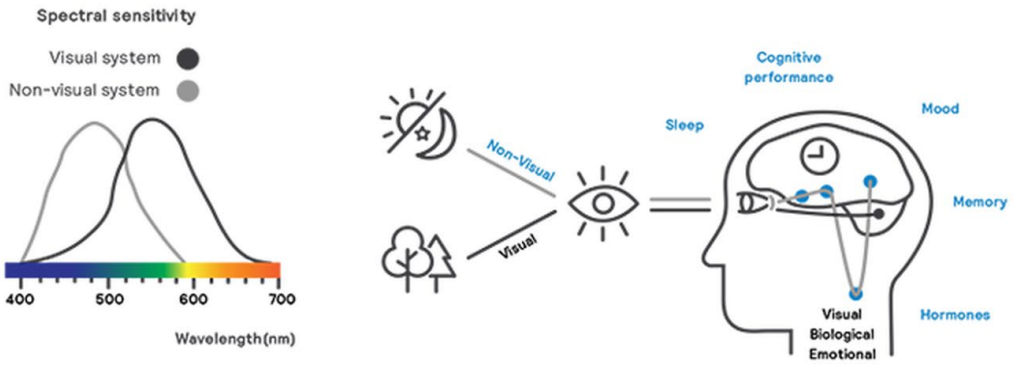


Figure 2.1: Non-visual aspects of light (Signify, 2023)

These photoreceptors are cones, rods, and retinal ganglion cells (ipRGCs) (van Bommel, 2019), which are in the human retina and send signals to the brain to drive visual and non-visual responses (Figure 2.1) (D. M. Berson et al., 2002a; Hattar et al., 2002a). Visual responses are eye-brain responses that contribute to visual function, supporting visual performance, visual experience (including emotional responses), and visual comfort (or

negative effects such as discomfort from glare). Visual performance indicates the ability to accurately perceive and process the visual environment to perform visual tasks (Rea, 1982).

Lighting conditions enable vision, i.e. visual performance, and affect visual comfort by providing sufficient light to perform visual tasks (Boyce, 2014a; M.S. (ed.) Rea, 2000). Visual experience is defined as how people experience and react to the visual environment. It is subjective and depends on photoreception, which creates images in the brain. Objects perceived through ambient light include the individual's evaluations and expectations of the perceived object (J. Veitch et al., 2008; J. A. Veitch et al., 2013).

Visual comfort refers to the perceptual response to the qualities and quantities of light in an environment and whether they result in comfortable or uncomfortable vision. Since visual discomfort is often easier to define than visual comfort, a visually comfortable environment is often defined as one that does not cause visual discomfort. Alertness refers to the potential of light to regulate a person's state of sensory awareness and active attention (Houser & Esposito, 2021).

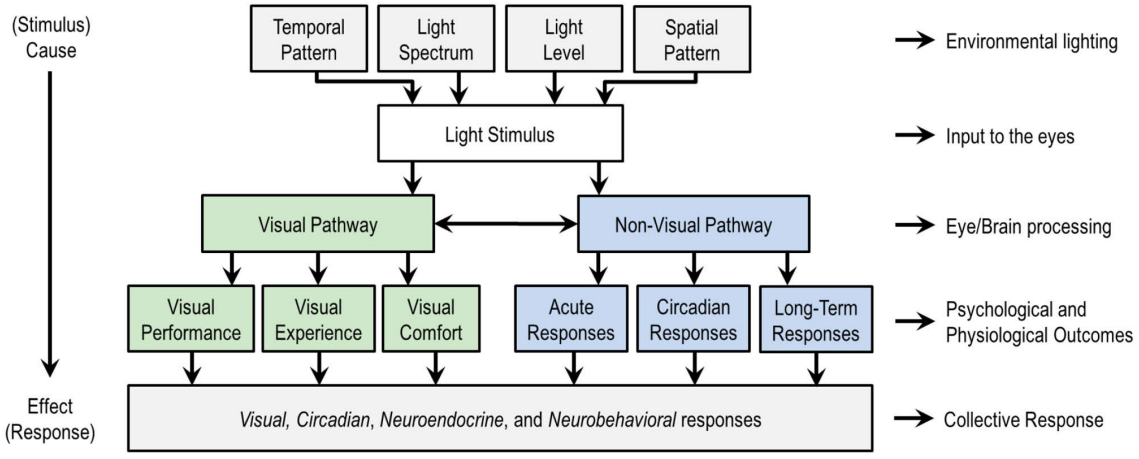


Figure 2.2: The stimulus-response relationship between light and human (Houser & Esposito, 2021)

Figure 2.2 schematizes the stimulus-response relationship between light and its effects on humans. These variables include temporal order, light level, light spectrum and spatial pattern. These first four categories refer to lighting variables that can be controlled in the design of a light stimulus, whether during lighting experiments or in the design of

structured environments. These four aspects of the light stimulus can be manipulated to influence people's visual and non-visual pathways (Houser & Esposito, 2021).

Non-visual responses are known as non-image-forming effects of light and can also be referred to as biological or physiological responses. Visual responses are mostly driven by rods and cones, whereas non-visual responses are driven by ipRGCs (D. M. Berson et al., 2002; Hattar et al., 2002). In short, while rod and cone cells in the eye provide visual perception, ipRGCs regulate light-related biological rhythms and enable human biology to adapt to environmental light conditions (Manav, 2019a; Spitschan & Joyce, 2023b). The photosensitivity of these cells can vary depending on the wavelength and color of light, which is particularly important for understanding the effects of environmental light on human biology (Manav, 2019a).

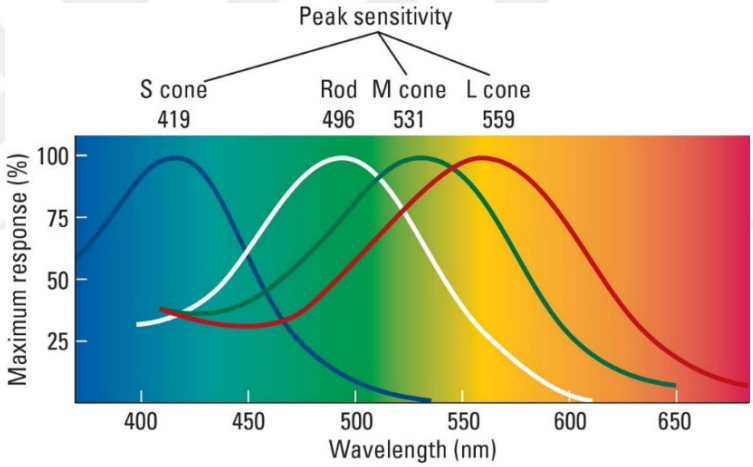


Figure 2.3: Wavelengths sensitivity of cones (Kolb et al., 2016)

Rods and cones contain different types of photopigments. As shown in Figure 2.3, cones are classified into three types: S-cones, M-cones, and L-cones, which are sensitive to blue, green, and red light, respectively. S-cones contain photopsin that is sensitive to short-wavelength light, while rods are particularly sensitive to green and blue light. The sensitivity curve of rods overlaps with that of S-cones and M-cones. The three types of cones form the basis of color vision, whereas rods alone contribute to achromatic (colorless) vision. The activity function of rods peaks at 505 nm (van Bommel, 2019).

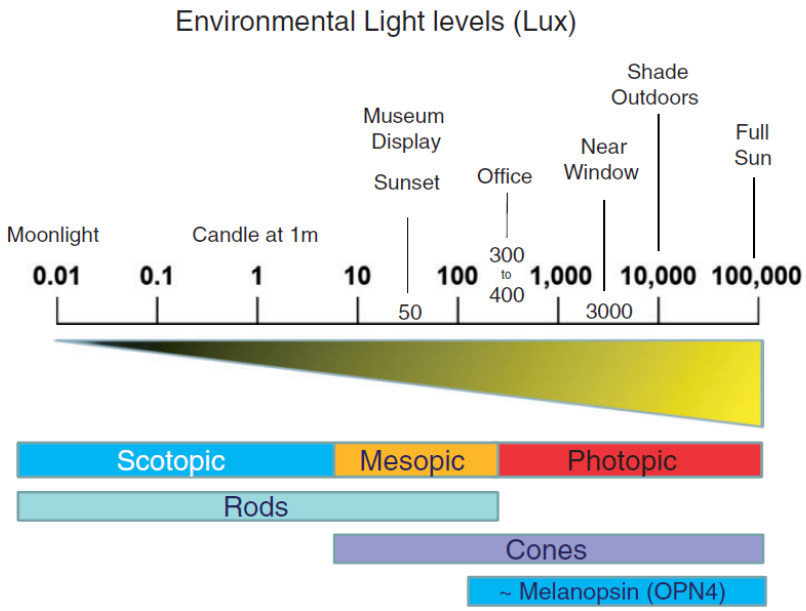


Figure 2.4: Light levels and vision conditions (R. G. Foster, 2021)

The transmission of light to the brain depends on the adaptation level of the eye. At luminance levels higher than about 5 cd/m², rods become inactive, and only cone photoreceptors are activated, resulting in photopic vision. Most indoor lighting systems are designed with photopic vision conditions in mind (Figure 2.4) (van Bommel, 2019). Cones are responsible for sharpness, detail, and color vision. Under luminance levels below 0.005 cd/m², cones lose sensitivity, and vision is provided solely by rods, leading to monochromatic scotopic vision, typically observed at night or in very low light. Rods function in extremely low light levels and do not enable color perception (van Bommel & van den Beld, 2004). At luminance levels between 0.005 and 5 cd/m², both rods and cones are active, resulting in mesopic vision, which combines characteristics of both scotopic and photopic vision (van Bommel, 2019; R. G. Foster, 2021). The sensitivity of rods and cones varies with light wavelength and color, making the spectrum of the light source important for both visual and non-visual effects of light (van Bommel & van den Beld, 2004).

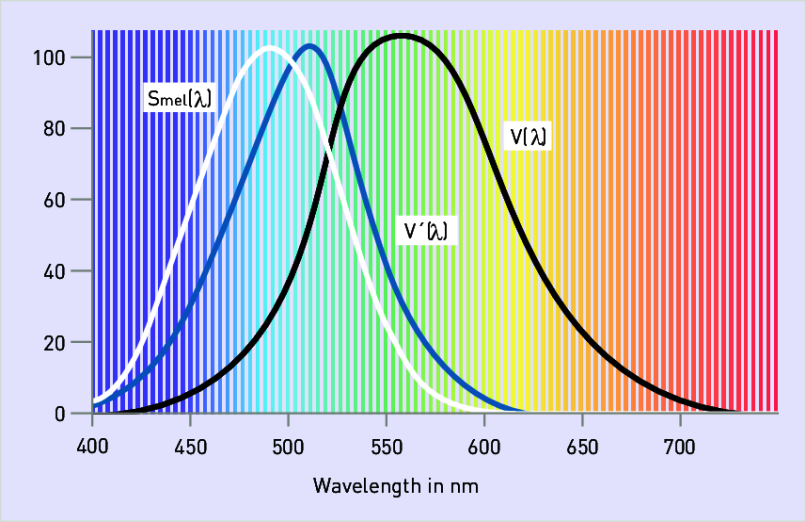


Figure 2.5: Luminous efficiency V(λ) for the eye adapted to light and darkness (TRILUX, 2024)

There is a photoreceptor containing the photopigment melanopsin. Melanopsin is more sensitive to short-wavelength light at 480 nm (blue wavelength), while the cone's peak sensitivity occurs at 555 nm (Figure 2.5). The sensitivity of ipRGCs varies with the intensity, duration/form and timing of light exposure compared to vision. Prolonged exposure to blue light is more effective in increasing alertness and enhancing concentration (Lockley et al., 2006). Cones, along with ipRGCs, also contribute to non-visual responses at the onset of light exposure and at low irradiance, although they are slower and sluggish than cones and rods (Chang et al., 2012). Melanopsin dominates the response to prolonged light exposures and high irradiances. During continuous light exposure, ipRGCs make sustained responses to light, but additive responses diminish over time (Gooley et al., 2012). Due to the difference in temporal properties between cone and ipRGCs, the magnitude of non-visual responses depends on both the spectral distribution and temporal properties of light stimuli (Ámundadottir et al., 2013; E. Chen, 2010). Furthermore, light exposure does not need to be continuous to have an effect on the non-visual system, as ipRGCs do not respond to intermittent light exposures of low irradiance but instead appear to integrate light over time until reaching a constant response (Gooley et al., 2012). A single brief exposure to light is highly effective for changing the phase of the circadian clock, suppressing melatonin and increasing alertness (Ámundadottir et al., 2013; Chang et al., 2012).

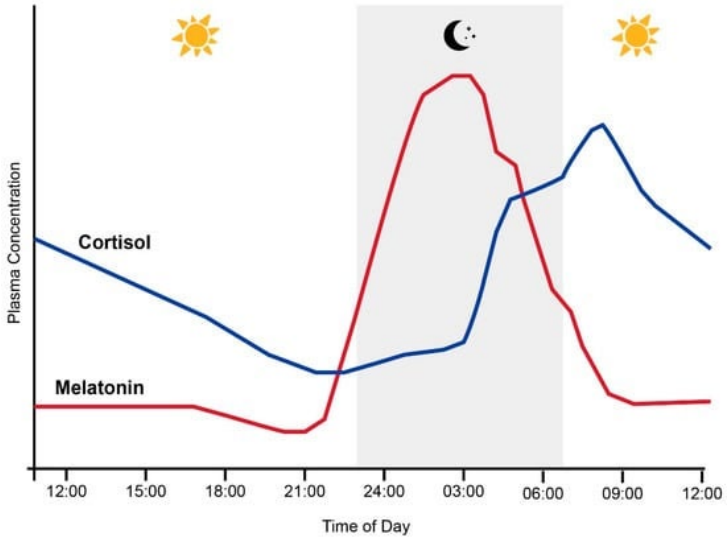


Figure 2.6: Cortisol and melatonin levels throughout the day (Robertson-Dixon et al., 2023)

The hormones cortisol ('stress hormone') and melatonin ('sleep hormone') play an important role in managing wakefulness and sleep. Cortisol raises blood sugar to energize the body and boosts the immune system. However, prolonged exposure to elevated cortisol levels can lead to system exhaustion and diminished efficiency. As can be seen in Figure 2.6, cortisol levels increase in the night, preparing the body for the next day's activity. It remains at a high enough level throughout the bright day and finally drops to a minimum at midnight. Levels of sleep hormone melatonin fall in the morning, reducing sleepiness. It normally rises again when it gets dark, allowing a healthy sleep. It is important for health that these rhythms are not disrupted. If the rhythm is disturbed, exposure to bright light in the morning will help to restore the normal rhythm (van Bommel & van den Beld, 2004). In other words, light plays an important role not only in visual perception but also in the regulation of biological and physiological processes (Gordon, 2015). These facts have important implications for the determination of healthy lighting (van Bommel & van den Beld, 2004).

While we can see our surroundings through the day, non-image-forming photoreception is responsible for the regulation of mood, physiology and behavior. This non-visual pathway affects individuals' biological clocks, levels of alertness and attention, and cognitive performance (Boyce, 2014a; Hanifin & Brainard, 2007; Provencio & Warthen, 2012). The visual and non-visual pathways in the brain can determine human physiology

and psychology (Kazanasmaz et al., 2023). In a draft international standard, CIE defines the term "complementary lighting" as lighting specifically designed to produce beneficial physiological and psychological effects through visual and non-visual effects (“CIE,” 2016; van Bommel, 2019).

2.2 Circadian Rhythms and Lighting

Light is the most important guidance in mammals (D. Berson, 2003; Roenneberg et al., 2003a; Yamazaki et al., 2000). Morning light in particular plays a crucial role in synchronizing the biological clock (Revell et al., 2012; Rosenthal et al., 1990; Terman et al., 1995). The rotation of the Earth not only creates a 24-hour light-dark rhythm, but also a 24-hour color rhythm. When the sun is below the horizon, the sky is filled with shorter wavelengths of light, such as blue light. This color transition can play an important role in synchronizing biological rhythms (van Bommel, 2019). This cycle-based biological rhythm is called the "circadian rhythm", derived from the Latin term "circa diem", meaning "about a day". Since the 1960s, researchers have agreed that circadian rhythm is a fundamental feature of all plants, animals and human life (Chovnick, 1960). In humans, this rhythm operates on a 24-hour cycle and plays a critical role in regulating the body's basic biological functions such as sleep and nutrition. In this process, regular changes are observed in many biological functions such as body temperature, hormone production, brain activity and cell renewal (Dijk & Archer, 2010). Additional signals sent to the brain by photoreceptor cells in the eye provide a better understanding of how light drives biological processes in the human body (van Bommel & van den Beld, 2004). In particular, the discovery of light-sensitive retinal ganglion cells (ipRGCs) has greatly contributed to human circadian rhythm research and led to a new understanding of how to design light systems to best support health and well-being (Spitschan & Joyce, 2023). Research by Walmsley et al. (2015) has shown that color transitions, especially during twilight, help synchronize biological rhythms. Other studies have also supported this, confirming that changes in light color can serve as cues to synchronize circadian activity (Pauers et al., 2012; van Diepen et al., 2015). However, further research is needed to understand the practical implications of these color transition signals in synchronizing human biological rhythms (van Bommel, 2019).

In human physiology, the circadian rhythm affects numerous functions such as sleep patterns, body temperature, blood pressure, testosterone production, immune system activities, muscle coordination and reaction times. This biological clock, which is in the suprachiasmatic nucleus (SCN) in the brain and has a cycle of approximately 24.5 hours, must be synchronized to the environmental day-night cycle (Schulkin, 1993). The synchronization of biological clocks with environmental cues occurs through a process called "entrainment", through factors such as the light-dark cycle, temperature changes, nutrition and physical activity (van Bommel, 2019). Every day, especially in the morning, the SCN is re-synchronized with light stimuli so that the sleep cycle is in harmony with the natural light-dark rhythm. However, it has been observed that this rhythm does not exactly coincide with the day-night cycle in people who are constantly in the dark or visually impaired (M. Rea et al., 2002). For example, individuals who are blind and lack functional retinas can adjust their biological clocks using these non-light cues (Klerman et al., 1998; Refinetti, 2015; Roenneberg et al., 2007). This highlights the important role of environmental factors in biological rhythms and suggests that synchronization can occur even in the absence of light (van Bommel, 2019). In addition, factors such as seasonal day-night changes, long-distance travel and night shifts can directly affect the timing of the biological clock (M. Rea et al., 2002). The SCN affects sleep and wake cycles by regulating hormones such as melatonin; increased melatonin levels facilitate the transition to sleep, while decreased melatonin levels increase mental and physical alertness (Czeisler et al., 1999; Morin, 1994).

The continuity of biological rhythms reflects the unique properties of the body clock that can vary between individuals. Aschoff's experiments showed that the free-running rhythm of humans does not exactly follow a 24-hour cycle but instead can vary by more than 1.5 hours between individuals (S. A. Brown et al., 2005; Czeisler et al., 1999). Humans can be classified as either morning types (matinal) or evening types (vexed). Morning types generally have a shorter free-running period for their biological clock, their melatonin levels rise earlier, making them prone to sleep earlier. In contrast, evening types experience a free-running rhythm of around 25 hours, which causes them to stay awake later and have difficulty transitioning to sleep (Roenneberg et al., 2003). Chronotype is also influenced by age, with the longest leisure time occurring during

adolescence and shortening after the age of 21 (Duffy et al., 2011; Roenneberg et al., 2004). Such differences may influence user preferences and human-centered lighting design parameters.

In some cases, however, biological rhythms can change in response to light exposure, a phenomenon known as phase shift. For example, long-haul flights or shift work in more than one time zone can disrupt the body's biological rhythm, causing a mismatch between the internal rhythm and the social clock. This is because the body adjusts itself to the light-dark cycle of the new time zone. The extent of this adjustment depends on the time zone difference, with larger changes requiring more light and dark periods to realign (Dunlap et al., 2007; van Bommel, 2019).

Circadian misalignment in night workers can lead to adverse health effects such as mental, gastrointestinal, cardiovascular and metabolic disorders (such as obesity and type 2 diabetes) and increased cancer risk (Archer & Oster, 2015; Costa, 2016; Frost et al., 2009; Vetter et al., 2018; Wang et al., 2011). Night lighting and circadian misalignment also have a negative impact on sleep and performance. This misalignment, often referred to as social jetlag, is commonly seen in individuals with an evening chronotype, who have difficulty waking up early on workdays but can compensate by sleeping in on weekends (van Bommel, 2019). The response of biological rhythms to light varies depending on factors such as body temperature, sleep-wake cycles and melatonin secretion. Early studies suggested that different biological rhythms respond differently to light during phase changes. However, more recent research suggests that these rhythms respond similarly and that phase changes observed in one rhythm also apply to others (Dunlap et al., 2007).

In terms of circadian phase shift, the body is in a state of ‘biological night’ when it should work and ‘biological day’ when it should sleep. Work environments with horizontal illumination of approximately 500 lux (roughly equivalent to 150-200 lux vertically at eye level) are not sufficient to produce effective phase shifts (van Bommel, 2019). Insufficient exposure to artificial light can also lead to circadian phase shifts, causing mild to severe disturbances. These disruptions affect sleep, digestion and gut activity and

have been associated with migraine (van Oosterhout et al., 2018), headaches (Pringsheim, 2002), irritability (J. A. Evans & Davidson, 2013), seasonal depression (Rosenthal, 2006), immune system deficiencies (Christoffersson et al., 2014), chronic fatigue (Bonsall & Harrington, 2013), obesity (Reiter et al., 2012) and diabetes mellitus (Cedernaes et al., 2015). Disruptions in the circadian system are also thought to increase the likelihood of tumor development as they affect hormone production and immune system activity (Stevens & Rea, 2001; Yadav et al., 2017). It has also been observed that in the absence of daily variations of natural light, most individuals have a circadian rhythm that lasts longer than 24 hours, disrupting the biological clock of the whole organism (Rossi, 2019).

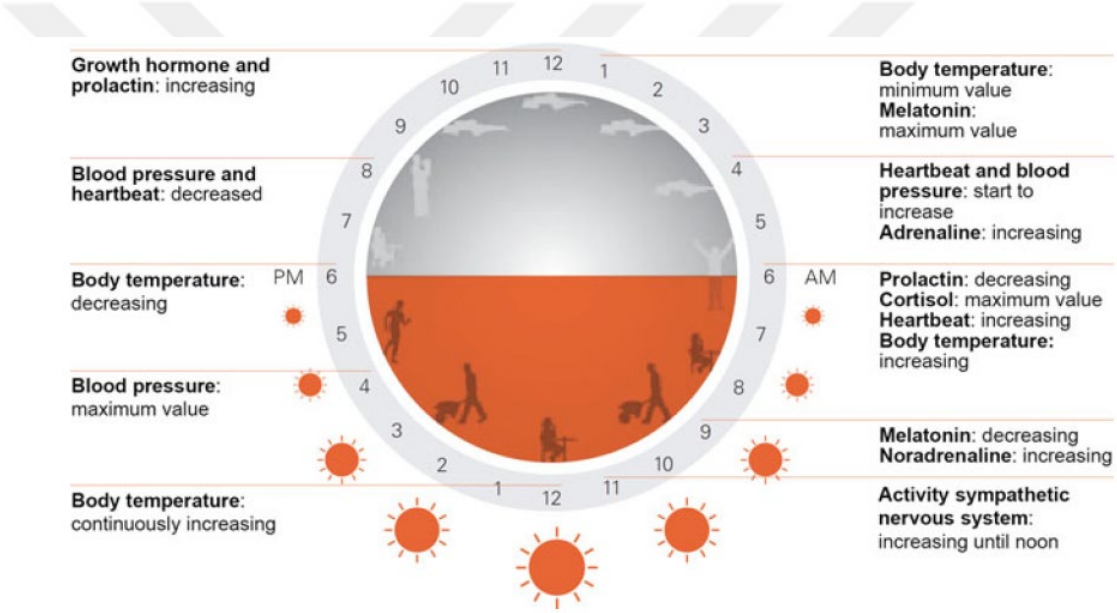


Figure 2.7: Effects of circadian rhythm (Rossi, 2019)

Since most of the working population spends most of their time indoors, electric lighting is critical for health (Beyer et al., 2018; Klepeis et al., 2001). Figure 2.7 above shows the effects of circadian rhythm on the biological functioning of our body. One of these is the hormones cortisol (stress hormone) and melatonin (sleep hormone), which regulate the circadian rhythm and affect wakefulness and sleep. Cortisol raises blood sugar to energize the body and boosts the immune system. But when cortisol levels are too high over a long period of time, the system becomes exhausting and inefficient. Cortisol levels increase in the morning and remain at a sufficiently high level throughout the bright day and fall to a minimum at midnight (Gomes & Preto, 2015).

Melatonin secretion, on the other hand, is not secreted during daylight hours, but rises in the evening about 1 to 3 hours before bedtime and continues throughout the night. Although this hormone is sometimes incorrectly called ‘sleep hormone’, it plays a role in the regulation of circadian rhythm and is widely used by individuals with sleep problems. It has been shown to improve the mental and physiological status of individuals when taken at the appropriate dose and time (Pévet et al., 2002). Melatonin suppression is an acute effect that occurs rapidly within 30 min of light exposure, and light has a wider impact on our physiology as a ‘zeitgeber’ that synchronizes the circadian clock (Khalsa et al., 2003; Minors et al., 1991; Rüger et al., 2013).

For people who are active during the day, visual and non-visual needs are often synchronized, whereas for people who are active at night, these needs are in conflict. To support the health of daytime active people, it may be sufficient to provide light with high biological power during the day and low biological power at night. For people who are active at night, factors such as visibility and alertness may be prioritized over circadian synchrony depending on the work they do, even though circadian disruption from asynchronous sleep-wake cycles is recognized to be associated with long-term adverse health outcomes (Stevens et al., 2007). Lighting design solutions for people who are active at night require full consideration of trade-offs (Houser & Esposito, 2021). Badia et al. (1991), Boyce et al. (1997), M. G. Figueiro et al. (2001) and others have shown that bright light at night can enhance performance on some tasks and improve subjective feelings of well-being and alertness. Since well-being is conceptual constructs based on complex neural interactions, the relationships between night light and human responses are not consistent. Because in a real scenario, these relationships are influenced by variables such as meal patterns, social relationships, and caffeine consumption (Wright et al., 1997). However, light in general has a significant effect on human behavior and well-being, day and night (M. Rea et al., 2002).

In the light of all this information, Human Centric Lighting Design is taken into consideration as a concept in lighting design today. The concept of "human-centric lighting" first emerged with the aim of transferring the dynamic atmosphere of sunlight to living spaces to prevent the disruption of biological clocks and circadian rhythms.

Human-centered lighting is a technical approach that aims to recreate the biological effects of daylight in artificial environments (Houser & Esposito, 2021). It emerged from the understanding of how the light spectrum affects circadian rhythms (F. R. Foster, 2010; M. S. Rea et al., 2010). Early studies focused on defining 'circadian light' and developing measurement methods (Bellia & Bisegna, 2013; M. Figueiro et al., 2011). Over time, this concept expanded to include not only biological rhythms but also visual perception, comfort, psychology, human performance, and well-being (Houser, 2018). The aim is to provide artificial light of natural daylight quality and enable individuals to metabolically respond to artificial light in the same way they do to natural light.

The central question revolves around the relationship between people's emotional states, performance, biological rhythms, and the light-dark cycle in their environment. To achieve this balance, human-centric lighting systems focus on harmonizing the visual, emotional, and biological benefits of light. Daylight remains the benchmark for high-quality light and serves as the foundation for human-centered lighting (M. Figueiro et al., 2019; Kompier et al., 2020; M. Rea & Figueiro, 2018).

Human-centric LED lighting systems represent a significant advancement in this field. These systems enable dynamic lighting designs that adapt to changes in light intensity, illuminance, and color temperature throughout the day (Lam, 2021). By considering the non-visual effects of light and its impact on circadian rhythms, they support attention, cognitive performance, and emotional well-being (Knoop, 2006). As the field evolves, the terminology surrounding human-centered lighting has become increasingly complex, reflecting the rapid growth of research and innovation.

We spend a large part of our lives indoors, some literature puts it between 70% and 90% (Hobday, 1999; Küller, 1986; Mahnke, 1996), in places such as our homes, workplaces, and even leisure environments. In many indoor environments, daylight penetrates the building for less than a few hours, especially in winter when days are shorter, and sunlight is weaker (Gomes & Preto, 2015). While natural light from the sky and sun is ideal for many light-related health outcomes, electric lighting has a critical role in supporting human health in the modern world (Houser & Esposito, 2021). Human-centered lighting

design (HCL) aims to develop integrated lighting solutions that align better with human biological rhythms. The non-visual effects of light should be used to recreate daylight indoors and go beyond static lighting solutions (Schulz, 2018). In design, natural daylight should be used as much as possible, and artificial lighting should be activated when necessary. During the day, human processes require more energy, but this should be avoided at night to balance circadian rhythms. Lighting should therefore allow a dynamic transition between different lighting scenarios from morning to evening (Spentza, 2022).

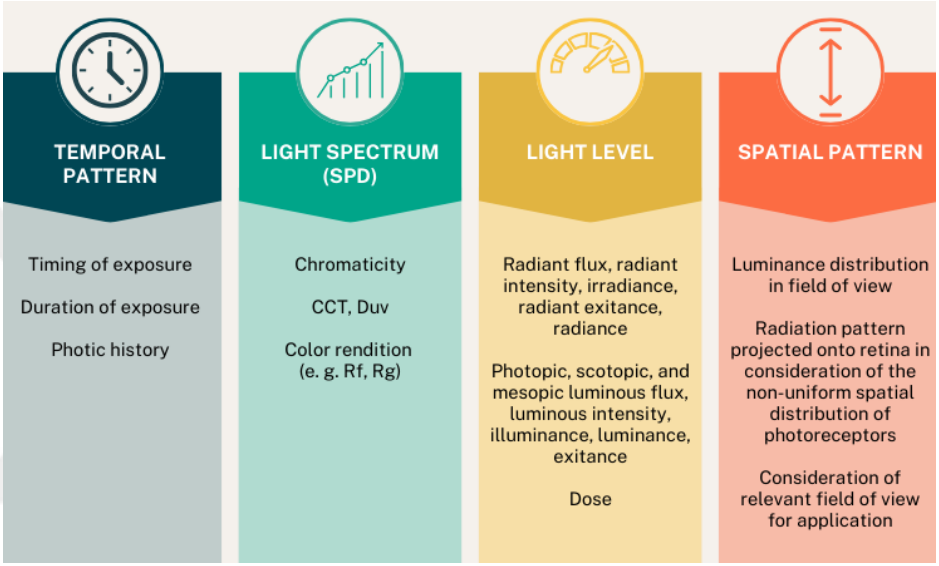


Figure 2.8: The main factors affecting the human circadian system in lighting design (Ulrichová, n.d.)

The main factors affecting the human circadian system in lighting design include light intensity, spectral power distribution of the light source, timing and duration of exposure, spatial distribution, and light history (Figure 2.8). These factors play a crucial role in circadian regulation, especially in indoor environments where daylight is often insufficient. To support circadian rhythms, the amount of indoor light should mimic outdoor levels as closely as possible. The spectral distribution of light is particularly important; shorter wavelengths (blue light) have the strongest effect on circadian regulation. Spatial distribution also matters, as it determines how light reaches different parts of the retina, with the most effective light typically coming from the sky (M. Rea et al., 2002).

Timing and duration of light exposure further influence the biological clock. Light exposure at specific times of the day can shift the circadian phase forward or backward. Short-term exposure, lasting between 15 minutes and a few hours, may cause minor adjustments like melatonin suppression or slight phase shifts. In contrast, long-term exposure, ranging from several hours to a full day, can lead to significant and lasting changes in the biological clock, strongly affecting circadian regulation (Cajochen et al., 2000; J. F. Duffy & Czeisler, 2009). Carefully controlling these factors is essential for optimizing biological rhythms and supporting overall well-being (Figure 2.9) (M. Rea et al., 2002).

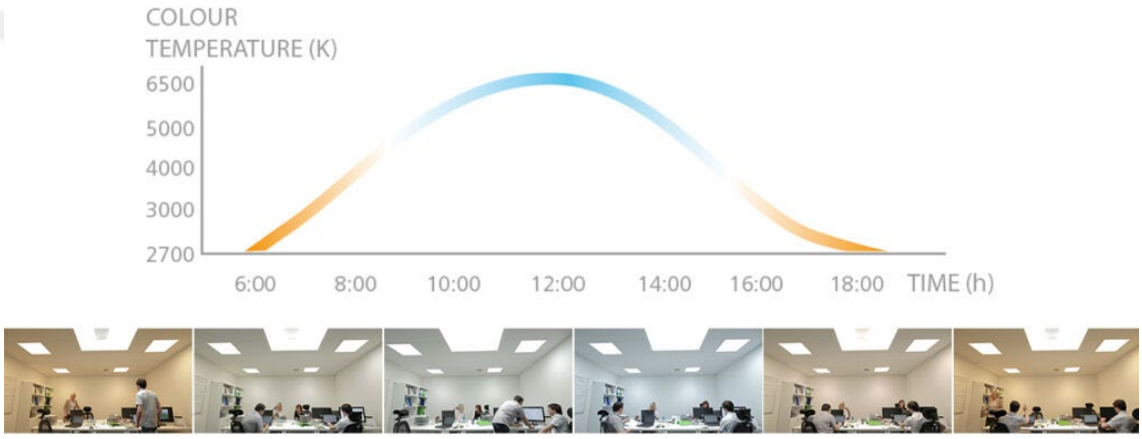


Figure 2.9: Different color temperatures throughout the day (Unknown, n.d.)

In recent years, there has been a consensus on the assessment of light incidence in the cornea. Two light sources may have similar color temperature values but provide different 'Circadian Stimulus' values. This difference is due to the spectral power distribution values. According to Figueiro et al. (2016) and colleagues, light sources with higher color temperature characteristics, such as 5000-6500 K, are generally considered to provide more circadian stimulus, but sometimes 3500 K sources provided less circadian stimulus than 3000 K sources. Another important consideration in lighting design in terms of circadian stimulus is the calculation of corneal illuminance in the eye. Vertical illuminance is as important as horizontal illuminance. Illuminance values are calculated according to the luminaires. This leads to the selection of the most appropriate luminaire type (Manav, 2019).

Today, the concept of "circadian lighting design" continues to maintain its importance in architectural lighting applications and has gained a place in the literature (Kazanasmaz et al., 2023). Light therapy has proven to be effective in treating problems such as seasonal affective disorder, Alzheimer's disease and the adaptation processes of premature infants. Challenging work schedules, such as night shifts, can also be improved with appropriate light exposure. However, the effects of light on mood and performance are based on complex neural interactions and differ between individuals (Badia et al., 1991; Boyce et al., 1997; M. G. Figueiro, 2013).

2.3 Interior Lighting Standards and Human Centric Lighting

International standards and recommendations for interior lighting installations suggest that lighting quality aspects, building energy features, lamp and luminaire specifications, wired and wireless connection features shall be considered for well-lit working environments (van Bommel, 2019).

In general, standards such as CIE, ISO and EN specify lighting in terms of both visual effects and non-visual biological effects (human-centered lighting). The CIE and ISO have a joint technical committee scientific studies and review experience from published practical studies on the non-visual effects of light on humans which provide guidance for safe and beneficial use in lighting applications beyond lighting for vision. Experts from different disciplines such as lighting, medical or (chrono)biological backgrounds work together in these committees (van Bommel, 2019).

TS-EN 12461-1:2021 Lighting Standards covers lighting design variables related to workplaces highlight the importance of visual quality under the headings of "lighting level", "glare control", "color quality" and "visual comfort". In the last revised/updated standard, "circadian lighting requirements" and "melanopic light measurements" that can be associated with HCL (Human-Centric Lighting) have been added. Hence, the WELL Standard is also used as a reference for studies on HCL subject. This section summarizes the lighting standards and recommendations of TS EN-12464-1:2021 and Well Building Standards, which define lighting in terms of visual performance and comfort.

2.3.1 TS-EN 12464-1 Light and lighting – Lighting of workplaces – Part 1: Indoor Workplaces

The standard includes requirements for lighting solutions for most enclosed workplaces and associated areas in terms of the quantity and quality of illumination. Recommendations are also for visual and non-visual (non-image forming) lighting needs. Illumination can be provided by daylight, electric lighting or a combination of both.

The 2011 and 2021 editions of the TS-EN-12464-1 standards include significant innovations aimed at improving visual comfort, effectiveness and energy efficiency in enclosed workspaces. The 2021 version introduced detailed and context-specific requirements on key issues such as light reflectance multipliers of surfaces, minimum illuminance levels, uniformity and glare control. These changes are also important for harmonizing international references in lighting design. CIE (Commission Internationale de l'Éclairage) standards, on which EN standards are based, are one of the most important sources that set international norms in lighting design. There is a close relationship between EN-12464-1 and CIE standards, especially on critical issues such as visual comfort, illuminance scale and glare control (Carter et al., 2018).

The UGR (Unified Glare Rating) method defined by the CIE is the basis for controlling glare from electric light in TS-EN-12464-1 standards (Turkish Standards Institution (TSE), 2021). This method encourages optimizing the arrangement and optical properties of luminaires to reduce glare. The daylight glare probability (DGP) assessment is based on CIE's approaches to optimize visual comfort and the use of natural light. TS-EN-12464-1:2021 relates these principles to EN 17037 and EN 14501 standards, providing a more comprehensive methodology for glare control (British Standards Institution (BSI), 2018; Yaguchi et al., 2017).

In terms of light reflectance multipliers and minimum illuminance levels of surfaces, the 2021 version is based on the visual performance standards recommended by CIE. For example, while standards such as CIE 17.4 and CIE 101 address the effects of the optical properties of surfaces on lighting design, TS-EN-12464-1:2021 supplemented this information with context-specific criteria (BSI, 2021; CIE , 1995). The recommended

light reflectance value for flooring was 0.2-0.4 in 2011, while in 2021 this range has been expanded to 0.2-0.6 (Table 2.1).

Table 2.1: Light Reflectance Factors of Surfaces Turkish Standards Institution (TSE), 2021

Surface Type	2011	2021
Ceiling	0,7 - 0,9	0,7 - 0,9
Wall	0,5 - 0,8	0,5 - 0,8
Flooring	0,2 - 0,4	0,2 - 0,6
Accessories	0,2 - 0,7	0,2 - 0,7

In terms of the luminance scale, TS-EN-12464-1:2021 adopts the wide range of luminance steps recommended in the CIE standards, whereas in 2011 the luminance steps started at 20 lx, the 2021 version adds low values (e.g. 5 lx, 7.5 lx) and high values (e.g. 7500 lx, 10000 lx) to this scale (Table 2.2). This improvement allows more flexible planning for both sensitive areas with low illuminance requirements and large spaces with high illuminance levels (TSE), 2021).

Table 2.2: Luminance Level Steps for Perceptual Difference (Turkish Standards Institution (TSE), 2021)

Version	Scale of Illuminance (lx)
2011	20, 30, 50, 75, 100, 150, 200, 300, 500, 750, 1000, 1500, 2000
2021	5, 7.5, 10, 15, 20, 30, 50, 75, 100, 150, 200, 300, 500, 750, 1000, 1500, 2000, 3000, 5000, 7500, 10000

As a result, TS-EN-12464-1:2021 offers significant improvements compared to the 2011 version by adopting a visual comfort, energy efficiency and user-oriented design approach. TS-EN-12464-1 to offer more inclusive and context-specific solutions, and it stands out as an innovative and functional guide in lighting design.

2.3.2 WELL building standards

The WELL Building Standard is designed as a certification system that aims to improve the impact of buildings on human health and well-being. Lighting design is an important component of this system and is addressed in a holistic approach, considering both visual and non-visual impacts. The WELL standard sets certain prerequisites and optimizations

for lighting. These prerequisites include many elements from natural light access to visual balance, while optimizations include detailed design criteria such as melanopic light and glare control (WELL V2), 2020).

The WELL standard sets two basic prerequisites for lighting design: L01 - Light Exposure and User Training and L02 - Visual Lighting Design. L02 requires a design compliant with TS-EN 12464-1 standards and aims to increase visual comfort in work environments (Table 2.3) (WELL V2), 2020). These prerequisites aim to optimize occupants' access to both natural and artificial lighting.

Table 2.3: WELL Standard Requirement (WELL V2), 2020)

Criteria	Description	WELL Standard Requirement
Melanopic Lux (EML)	Amount of light affecting circadian rhythms by stimulating ipRGC receptors in the eye.	150-240 lx
Targeted Height	Melanopic illuminance should be measured at working level or eye level.	1.4 m (eye level) or 45 cm (desk level)
Implementation Duration	The minimum time during the day for the EML level to be effective.	≥4 hours
Calculation Method	Calculated by multiplying the photopic lux value by the melanopic ratio.	EML = Photopic Lux × M/P Ratio
Minimum Melanopic Proportion (M/P)	The minimum ratio required for melanopic lighting depends on the light source used.	≥0.8
Working Areas	These requirements apply to offices, training areas and other public spaces.	All workspaces

The WELL standard presents the concept of melanopic lighting as an important criterion for supporting circadian rhythms. Melanopic lighting influences circadian rhythms through ipRGC receptors in the eye and provides positive effects on sleep-wake cycle, attention and mood (WELL V2), 2020). Recommended melanopic illuminance levels are between 150-240 melanopic lux in public areas and are recommended to be applied for at least four hours during working hours (Table 2.4). Melanopic illuminance levels are calculated by multiplying photopic illuminance levels by certain coefficients (Carter et al., 2018).

Table 2.4: Recommended illuminance levels (WELL V2), 2020)

Illuminance Type	Objective	WELL Advice
Photopic Lux	Supporting visual tasks	300-500 lx (EN 12464-1)
Melanopic Lux	Supporting circadian rhythms	150-240 lx

The WELL standard places special emphasis on glare control to improve visual comfort. L04 - Glare Control requires UGR in workspaces to be below 19 and light sources to be directed at the correct angle. It also recommends controlling 100% of the light emitted above the horizontal plane (WELL V2), 2020).

Table 2.5: WELL Requirement (WELL V2), 2020)

Criteria	Necessity/WELL Requirement
CRI (Color Rendering Index)	>80
R9 (Red Tone Representation)	>50
Vibration Frequency	>90 Hz
UGR (Unified Glare Rating)	<19
Light Source Shield Angle	Limitations based on cd/m² value

The WELL standard also aims to optimize the natural light intake of buildings. L05 - Improved Natural Light Access aims to increase the daylight exposure of interior spaces and optimize the distribution of natural light within space. These goals are important to support the biological clocks of building occupants and reduce energy consumption (WELL V2), 2020).

To assess whether the requirements in the WELL Standard for the specified time intervals in the day are met, lighting simulations are performed incorporating electric lighting and daylight for the morning (09:00) and the noon (13:00) hours by a term called Equivalent Melanopic Lux (EML).

$$EML = L \times R$$

where L is the simulated illuminance on the working plane and R is the melanopic ratio of the light source. This efficacy (R) is also referred to as “Melanopic to Photopic ratio”

(M/P Ratio) in the WELL Building Standard. In EML calculations, the simulated average illuminance (E_{av}) is multiplied by the M/P ratios for the 2700 K and 4000 K LED sources and daylight at 6500 K (D65) which are assumed to be 0.45, 0.76, and 1.1, respectively in line with IWBI (2019) (IWBI International Well Building Institute, 2019).

The WELL standard requires a color quality (Color Rendering Index) of at least 80 and an R9 value of at least 50 points to support the representation of red hues (Table 2.6). It also aims to improve visual comfort by setting a criterion for light pulsations to operate at a minimum frequency of 90 Hz (IEEE 1798, 2015).

Table 2.6: Melanopic Lux Necessity (WELL V2), 2020)

Standard	Melanopic Lux Necessity	Description
WELL Building Standard	150-240 lx	Minimum requirement for circadian rhythm support and sleep patterns.
CIE S 026/E	200 lx	Minimal requirement for melatonin suppression and circadian effects.
DIN SPEC 67600	250 lx	Providing circadian effects equivalent to daylight.

The WELL Building Standard considers lighting design as a tool not only for the fulfillment of visual tasks, but also for human health and biological needs. With criteria such as melanopic lighting, glare control and optimization of natural light, the WELL standard offers a human-centered design approach. These approaches both enhance individual well-being and support sustainability goals such as energy efficiency. WELL provides integrated guidance on lighting design in line with TS-EN 12464-1 and CIE standards.

2.4 Visual Comfort Parameters

Visual comfort refers to the perceptual response to the quality and quantity of light in an environment and whether it causes a comfortable or uncomfortable view. The parameters that provide 'comfort' conditions are defined as 'physiological comfort' and 'psychological comfort'. The three visual comfort parameters are illuminance, brightness and color characteristics of light sources. These are measurable elements related to physical

comfort; however, visual comfort also includes psychological comfort. Psychological comfort is related to subjective perceptions and emotional responses to the lighting environment such as relaxation, spaciousness, comfort and visual clarity. The technical characteristics of light sources and lighting elements and their location in the space should be appropriate to the building typology and user requirements (Manav, 2015).

2.4.1 Physical comfort parameters

Physical comfort is affected by parameters such as illuminance, the characteristics of the light source, visual acuity, the speed of vision, light and dark adaptation, luminance contrast and glare, surface reflectance's and so on (Manav, 2015; Ozenen, 2024). It covers measurable quantities such as light intensity, color temperature, and luminance distribution, which directly impact visual performance and comfort.

2.4.1.1 Illuminance

Illuminance *(E)* describes the amount of light incident on the surface. It is the ratio of the incident luminous flux *(Φ)* to the size of the surface *(A)* (Figure 10). The unit of measurement of illuminance is lux (lx). This is defined as lumens per square meter (1lx=1lm/m2). Illuminance decreases with the square of the distance from the light source (Ganslandt & Hofmann, 1992). It is one of the most important factors affecting visual perception. In lighting design, the light falling on the surface plays a critical role in achieving goals such as visual comfort, safety and performance. Illuminance can vary across different surfaces, including the task area, its perimeter, ceiling, walls and objects within space (ISO & CIE, 2023).

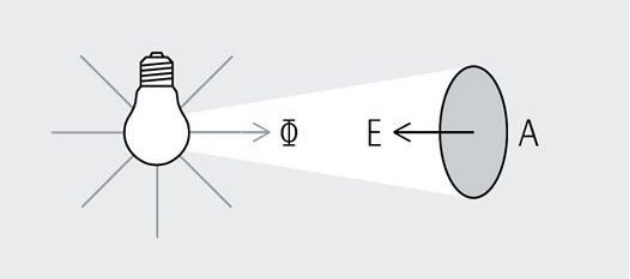


Figure 2.10: Illuminance E as a measure of luminous flux incident per surface unit A (Ganslandt & Hofmann, 1992)

Illuminance and luminance are two important photometric parameters in lighting design (Figure 2.10). Both consider the brightness sensitivity curve of the human eye. Illuminance is a measure of light incident on the surface, while luminance describes the light reflected from the surface (Figure 2.11). If a white and a black sheet of paper are illuminated with the same intensity, the same luminance is measured on both sheets. However, as the reflectivity of the white paper is higher than the black one, it seems brighter (it is perceived brighter) (Ganslandt & Hofmann, 1992).

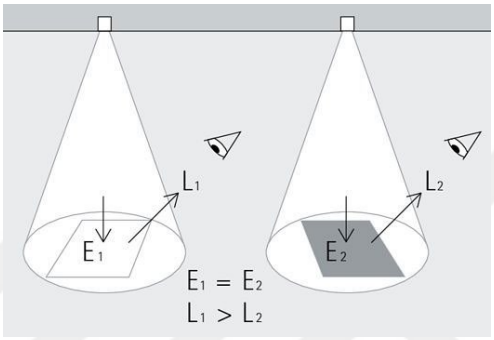


Figure 2.11: The Relationship Between Illuminance and Luminance (Ganslandt & Hofmann, 1992)

The criteria reflecting the scientific level of knowledge on occupational safety and health in the establishment and operation of workplaces are detailed in the EN 12464-1 standard (Table 2.7) (BSI, 2021; Ganslandt & Hofmann, 1992):

- The average illuminance around a workstation with 300lx illuminance should be at least 200lx.
- For workstations illuminated at 500lx or more, the average surrounding illuminance should be at least 300lx.
- Illuminances above 500lx in workstation areas may require a higher average illuminance in surrounding areas.
- The minimum illuminance in the surrounding area should not fall below 0.5 times the average illuminance of the surrounding area

Table 2.7: Necessity illuminance of workspaces (Committee for Workplaces et al., n.d.)

Workspaces and Activities	Illuminance (lx)
Tea points, canteens, and break rooms	200
Office: filing and copying	300
Office: writing, reading, and data processing	500
Office: technical drawing by hand	750
Archives	200
Sales area	300
Checkout areas	500
Control, fine work	1000

Adequate visual performance for simple visual tasks requires low illuminance, whereas complex visual tasks require high illuminance. For example, 20 lux is a lower limit for distinguishing human facial features (Ganslandt & Hofmann, 1992).

The distribution of lighting levels directly affects how comfortably, safely and efficiently activities in the task area can be performed. Higher illuminance levels should be used especially for tasks that require visual performance. Factors such as light direction, color and distribution should be considered in the design to achieve optimal visual perception. In addition, not only the task and activity areas should be properly illuminated in lighting design, but also the surrounding areas, backgrounds, walls and ceilings should be adequately illuminated. The values specified in lighting standards are set to meet visual comfort and performance requirements. Higher illuminance levels are recommended to provide flexibility, especially at certain times of the day or under certain conditions. The minimum level of illuminance maintained should meet the required standards while considering factors such as visual comfort, task requirements, ergonomics, safety and cost (ISO & CIE, 2023).

As defined before, illuminance *(E)* is the light incident on the surface *(m2)*, while Luminance *(L)* describes the light emitted from that surface. Light can be emitted from the surface itself, for example from a lamp, but it can also be reflected or transmitted from a surface. For diffusely reflective and diffusely transmissive materials, gloss can be calculated based on the amount of light falling on the surface (illuminance) and the

material's reflection or transmission factor. These parameters affect the surface's gloss level, playing a crucial role in the overall lighting design of the space (Ganslandt & Hofmann, 1992).

2.4.1.2 Luminance

Luminance *(L)* describes the brightness perceived by the human eye of a surface that emits light as a light source or by transmission or reflection. Brightness is defined as the ratio of light intensity *(I)* to the area (A_p) projected perpendicular to the direction of observation. The photometric unit is candela per square meter (cd/m2) (Ganslandt & Hofmann, 1992).

Luminance thus forms the basis of perceived brightness, but the actual impression of brightness is still influenced by the eye's state of adaptation, environmental contrast ratios and the information content of the viewed surface (Figure 2.12) (Ganslandt & Hofmann, 1992).

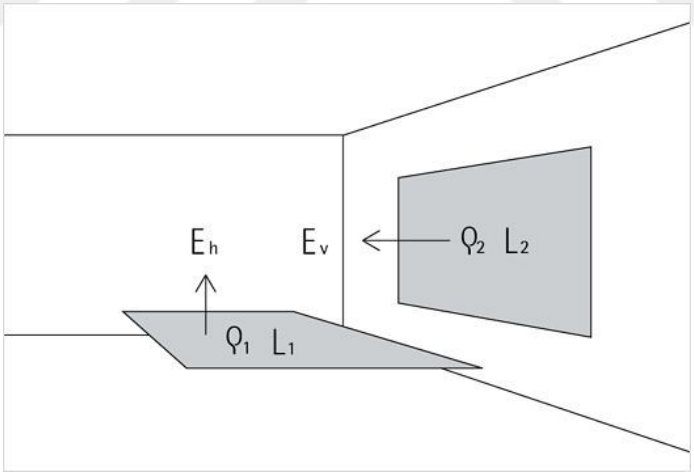


Figure 2.12: Luminance of a diffusely reflecting illuminated surface. Horizontal illuminance E_h and vertical illuminance E_v in indoor spaces (Ganslandt & Hofmann, 1992)

The distribution of luminance across the visual field governs how effectively the eyes adapt to lighting conditions and directly affects task visibility. A well-balanced adaptation luminance improves visual acuity by enabling precise identification of fine details, increases contrast sensitivity to distinguish subtle differences in luminance, and

optimizes the efficiency of ocular functions by allowing the eyes to perform critical tasks smoothly (ISO & CIE, 2023).

Brightness distribution also plays an important role in maintaining visual comfort. Excessively high luminance and sharp luminance contrasts can cause glare, leading to discomfort and impairing task performance. Conversely, environments with excessive brightness variation can cause the eyes to readjust frequently, leading to visual fatigue. On the other hand, excessively low luminance and minimal luminance contrasts can create dull, unstimulating environments, reducing engagement and productivity. A balanced luminance distribution minimizes these issues and ensures a comfortable visual experience (ISO & CIE, 2023).

To achieve a balanced distribution of brightness, it is important to consider the reflective properties of all surfaces and the illuminance levels that affect them. For example, bright interior surfaces increase adaptation levels and prevent dark environments. This can be achieved by setting appropriate illuminance levels for walls and ceilings and using surfaces with high reflectance values. These measures ensure that interiors are visually comfortable and conducive to effective visual performance (ISO & CIE, 2023).

2.4.1.3 Luminance Contrast

Luminance contrast is important to visualize and differentiate an object from its surroundings. This contrast results from the difference in luminance between the object and the background and plays a critical role, especially for perception, recognition and visual clarity. Shadows, because of light obstruction, can significantly alter luminance contrast and impact visual clarity in both positive and negative ways.

Shadows are formed when light from a certain direction is blocked by an opaque object. If the object is large enough, this effect reduces the illuminance over a large area, creating a shadow. The effect of these shadows can be reduced by increasing the amount of reflected light by using highly reflective surfaces or by providing localized illumination in shadowed areas. If the object is smaller, the shadow can fall over a significant area, which can lead to perceptual confusion, especially if the shadow moves. This problem

can be reduced by increasing the amount of reflected light in space or by providing adjustable local lighting (Boyce, 2014).

Although shadows can cause visual discomfort, it is important to remember that they are a crucial element in revealing the form of 3D objects (Lam, 1977; Tregenza & Loe, 2013). The number and quality of shadows produced by a lighting system depends on the size and number of light sources and the extent to which light is reflected and forth across the space. The strongest shadow is cast by a single point source in a completely dark room. Weak shadows occur when light sources are large and the level of interreflection is high (Boyce, 2014).

2.4.1.4 Color characteristics of light sources (CRI and CCT)

The color of anything is determined by the light reflected or transmitted. Color is not a physical property but a physical and psychological response to light waves entering the eye. What is perceived as color is the result of the size, geometry, brightness and background of materials that reflect or transmit energy in certain regions of the visible spectrum (Gordon, 2015). Physical comfort parameters are affected mainly by two important color properties of light sources: Correlated Color Temperature and Color Rendering Index.

Correlated Color temperature

Correlated color temperature describes the visual "warmth" or "coolness" of a light source and is expressed in Kelvin (K). It represents the color emitted by a blackbody radiator at a given temperature. Low color temperatures (2000-3000 K) produce a yellowish-red hue usually associated with "warm" light, while higher temperatures (5000-6500 K) emit bluish-white hues described as "cool" light (Figure 2.8). Neutral white light is in the 4000 K range (Ozenen, 2024).

Table 2.8: Light color and closest color temperature of lamps (Turkish Standards Institution (TSE), 2021)

Light Color	Correlated Color Temperature
Warm White	Below 3,300 K
Cool White	From 3,300 K to 5,300 K
Daylight White	Above 5,300 K

The standard reference for color temperature is CIE 15:2004, which provides guidelines for measuring and determining color temperature using precision methods and instruments. These guidelines are widely applied in lighting design to meet specific visual and functional requirements of spaces (Ozenen, 2024). For example, warm light (e.g. 2700 K) is often used for comfort and relaxation in residences, while cool light (e.g. 6500 K) is preferred in offices to enhance alertness and productivity (Gordon, 2015).

The TS-EN 12464-1 standard does not recommend any specific light color for the illuminators to be used, as their choice depends largely on psychology, aesthetics and culture. The choice of the appropriate light color for the illuminant also depends on the illuminance levels, the colors of the room and furniture, the surrounding climate and the application scenario. In warmer climates, a higher color temperature, such as daylight white, is generally preferred, while in colder climates people prefer a lower color temperature, as in warm white light colors. For most visual tasks, warm white and neutral white light colors are recommended, which are preferred around Central Europe (TRILUX GmbH & Co. KG, 2024).

It is important to note that color temperature alone does not fully determine the perceived quality of a light source. While it affects the mood and visual comfort of a space, other factors such as color rendering significantly influence how objects appear under light (Ozenen, 2024).

Color rendering index

The Color Rendering Index (CRI) measures the ability of a light source to accurately reproduce the colors of illuminated objects compared to a reference light source with the same color temperature. This value is expressed on a scale from 0 to 100, with higher

values indicating better color rendering. A CRI of 100 represents excellent color accuracy as seen under natural sunlight (Ozenen, 2024).

Despite the same color temperatures, illuminants can have different color rendering properties due to the different spectral compositions of their radiation. The general color rendering index Ra was introduced to enable objective labeling of color rendering properties. The color rendering index (Ra) represents a measure of correspondence between the body color seen and its appearance under a reference light source of interest (Table 2.9). A light source with Ra = 100 will ideally render all colors as in reference light source. The lower the Ra value, the lower the quality of the color rendition. The reference light source is a radiator with a black body for color temperatures up to 5,000. For higher color temperatures, the reference light source is a daylight spectrum standardized at 6,500 K (TRILUX GmbH & Co. KG, 2024). A high CRI makes colors appear natural and vibrant, increasing visual comfort and improving the aesthetics of the environment (Gordon, 2015). This is especially important in workplaces, retail environments and healthcare facilities where color accuracy affects productivity, decision-making and well-being.

Table 2.9: Areas for the general color rendering index Ra of lamps (TRILUX GmbH & Co. KG, 2024)

Ra Range	**Typical Types of Lamps**
90 and above	Improved color "de Luxe" fluorescent lamps, improved color metal halide lamps, incandescent lamps, LEDs
80 to 90	Tri-phosphor fluorescent lamps, metal halide lamps, LED
70 to 80	Standard fluorescent lamps universal white*, LED
60 to 70	Standard fluorescent lamps bright white*, metal halide lamps, LED
40 to 60	Standard fluorescent lamps warm tone*, high-pressure mercury vapor lamps*
20 to 40	Sodium vapor high-pressure discharge lamps
Below 20	Low-pressure sodium vapor lamps not permitted in workspaces

Illuminants with a color rendering index below 80 should not be used indoors where people work or linger for long periods of time (more than 2 hours) according to TS-EN-12464-1. The norm allows exceptions for certain lighting tasks, for example when economic reasons require lamps with high luminous efficiency, such as high-pressure sodium vapor lamps with limited color rendering. This applies, for example, to the lighting of high halls. However, in such cases, appropriate measures must be taken to ensure higher color rendering at fixed and continuously used workstations and in areas where safety colors must be recognized without fail (TRILUX GmbH & Co. KG, 2024).

Color temperature and CRI work together to shape the perceived color and mood of a space. For example, warm light with a high CRI is often chosen for hospitality and residential environments to create a welcoming ambience, while cool light with a similar CRI is ideal for workspaces to support focus and performance. Standards such as the IES Lighting Handbook provide detailed recommendations for appropriate color temperature and CRI values for specific use cases (Ozenen, 2024).

2.4.1.5 Glare

A healthy eye may temporarily lose sight of surrounding objects due to environmental factors; this condition is called ‘glare’. When the luminance *(L)* in the visual field reaches values of 10^4 cd/m² or more, ‘disability glare’ occurs. “Discomfort Glare” is caused by high luminance differences in the visual field. Factors causing discomfort glare typically include large window areas, incorrectly positioned luminaires and lamps with high luminance values entering the visual field. ‘Direct glare’ occurs when the glare-causing object is very close to or overlaps the observed object, while “reflected glare” occurs when the distance between objects increases. For office workplaces, a distinction is made between glare and the following (Figure 2.13) (Ganslandt & Hofmann, 1992):

- Firstly, direct glare caused by luminaires (1),
- Reflected glare in horizontal visual tasks (2) and
- Reflected glare in vertical visual tasks such as displays (3).

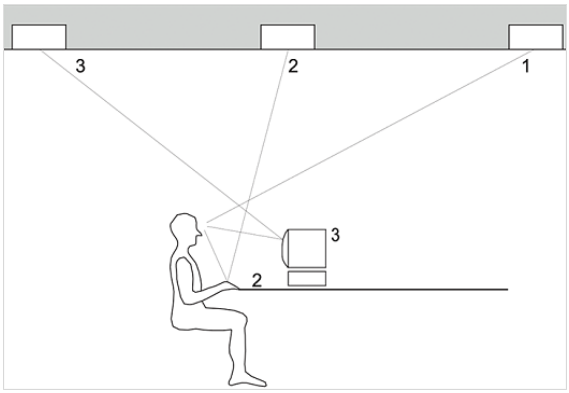


Figure 2.13: Direct and Reflected Glare in Visual Tasks (Ganslandt & Hofmann, 1992)

Direct glare considers the ceiling area in front of the viewer when viewed at angles shallower than 45°. Reflected glare is glare caused mainly by luminaires in the ceiling area, which cause an unpleasant visual disturbance directly in front of the viewer. Reflected glare on screens is a special case. The visual discomfort is mainly caused by glare light sources in the ceiling area behind the viewer. In office workplaces, the UGR method (Unified Glare Rating) can be applied to determine glare for a specific viewer location (Ganslandt & Hofmann, 1992).

Glare causes eye fatigue, reduced vision and decreases work performance. To avoid glare, general illumination should be provided in working environments and the use of a single light source on the ceiling should be avoided. In addition to general lighting, task lighting' close to the working plane can be used, but attention should be paid to the position of the light source (Ganslandt & Hofmann, 1992).

Glare effects can be reduced primarily by reducing the brightness contrast between the surroundings and the glare-causing light source. Therefore, either the brightness of the surroundings should be increased, or the brightness of the glare-causing light source should be reduced. However, it is a more preventive method to avoid glare by selecting luminaires with good protection and arranging the luminaires correctly (Ganslandt & Hofmann, 1992).

2.4.1.6 Light Reflectance in Design

Reflection is the process by which a portion of the light falling on a surface is reflected from that surface. This property can influence both visual comfort and energy efficiency. High surface reflectance values can contribute to energy savings while enhancing visual comfort in interior spaces (BSI, 2021).

Surfaces with high reflectance allow more light to be reflected into space, helping to create a brighter environment and promote energy savings. At the same time, they can improve visual comfort by ensuring a more even distribution of light. Therefore, the reflectance properties of surfaces used in interior lighting are crucial for both energy efficiency and user comfort. Reflectance values vary depending on the material and finish of the surface. Matte surfaces tend to have lower reflectance values, while glossy or polished surfaces have higher reflectance values. For material selection, the following reflectance values are recommended:

- ceiling between 0.7 to 0.9,
- walls between 0.5 to 0.8,
- floor between 0.2 to 0.6.

The reflectance of major objects (such as furniture, machinery, etc.) should range from 0.2 to 0.7. The reflectance of light sources affects the distribution of light within a room and the perceived brightness levels. High-reflectance surfaces allow light to spread over a larger area, providing more uniform lighting. In contrast, low-reflectance surfaces create more intense, localized light reflections, which can result in higher light intensity in specific areas (BSI, 2021).

2.4.1.7 Adaptation

The ability of the eye to adapt to changing light levels is known as ‘adaptation’. There are two types of adaptation, dark adaptation’ and ’light adaptation.’ Dark adaptation occurs when moving from a high-light to a low-light environment. Due to the sudden reduction in light entering the eye, cones accustomed to higher levels of brightness take

time to adapt. This process can take up to an hour to complete. In the first moments, the pupil dilates about ten times and the cones gradually increase their sensitivity by up to 100 times compared to the initial level. On the other hand, light adaptation takes place when moving from the dark to a well-lit environment. Adaptation to the brighter environment is relatively fast. Since the cones resume their function almost immediately, there may be a short-term feeling of discomfort, such as a burning or stinging sensation (Ganslandt & Hofmann, 1992).

2.4.2 Psychological comfort parameters

The psychological environment refers to how individuals perceive their physical surroundings. This perception process occurs with the help of sensory organs, and aesthetic judgments play a critical role in this process. The interaction of the sensory organs enables the environment to be perceived as a whole. Stimuli such as objects, smells, images, or sounds in the physical environment can combine to evoke memories of past experiences. The impact of the environment on individuals can either be motivating (positive) or demotivating (negative). This highlights the importance of the designer's role, as the designer is responsible for the aesthetic elements of space and their psychological effects on individuals. Environmental psychology investigates the physical and psychological conditions necessary to enhance individual comfort levels and examines the relationship between architecture and psychology. Lighting plays a significant role in achieving these conditions. William Lam's perspective on the intersection of lighting, psychology, and architecture emphasizes several key considerations that are still relevant in current design thinking (Manav, 2015). First, the user's physical closeness to both natural and artificial light sources plays a significant role. The presence and positioning of windows, the arrangement of artificial lighting, and the user's proximity to these elements influence the degree of control one has over the lighting environment. In addition, designers must take into account users' cognitive expectations, shaped by prior experiences. It is essential to recognize how different qualities of light—such as the contrast between warm and cool tones—are perceived in a space and how these perceptions influence user expectations, which should be addressed during the design process. Biological rhythms are another crucial factor that should not be underestimated. Variables such as geographical location, season, time of day, and

prevailing weather conditions, along with users' light level expectations, should inform design decisions. For instance, overcast weather during midday in summer can evoke a sense of discomfort, just as unexpectedly bright light in the evening may disrupt psychological balance. While natural light is not entirely within our control, artificial lighting can be adjusted to support user comfort and well-being (Manav, 2015).

The relationship between lighting and architecture is a key consideration for successful design. Elements of the structure, such as the load-bearing system, partition walls, ceiling, and floor, should be designed according to users' needs and expectations. Additionally, lighting solutions suitable for the building's typology should be developed. Lighting should be in harmony with architectural elements and designed in parallel with the activities being carried out. Proper lighting design positively impacts the perception of space, provides psychological comfort, contributes to energy efficiency, and enhances individuals' attention, concentration, and performance (Manav, 2015).

The characteristics of lighting systems can vary depending on the position of the light source within the space and the distribution of light levels, which leads to different perceptions of the space. According to the ANSI IESNA report titled "Lighting in Office Environments," based on research conducted by Flynn and his team, these perceptions can be grouped into four main categories: spaciousness, comfort, visual clarity, and satisfaction (Illuminating Engineering Society of North America & Office Lighting Committee, 1993).

2.4.2.1 Spaciousness

The feeling of "spaciousness" in space is an impression influenced by the geometric properties of the environment, and this perception is directly related to lighting conditions. To create a spacious atmosphere, it is important to ensure that the lighting levels are evenly distributed throughout the space. In particular, in narrow and long spaces, a uniform distribution of light on the wall surfaces is recommended. This arrangement allows the space to be perceived as larger and more open. Additionally, higher lighting levels can be used to enhance the feeling of "satisfaction." The use of

regional lighting on side walls and creating contrasts in brightness can also contribute to creating a spacious atmosphere in the environment (Manav, 2015).

Flynn's research has shown that variations in the horizontal illuminance significantly affect impressions of spaciousness and perceptual clarity. Higher illumination values make space appear "clear," "bright," "distinct," and "larger" (Gordon, 2015).

2.4.2.2 Comfort

The feeling of "comfort" is directly related to the lighting arrangement in space. To create a comfortable atmosphere, a uniform light distribution should be ensured, and warm light sources should be preferred. In addition, maintaining lower lighting levels in space can have a positive impact on enhancing comfort (Manav, 2015).

2.4.2.3 Visual clarity

Clarity is the property of a transparent or semi-transparent material that allows distinct, high-contrast images to be seen clearly through it from a distance (CIE, 2020a). "Visual clarity" is related to how objects are perceived, and this perception changes depending on the distance of the objects from the viewer and the lighting conditions in the environment. To create a feeling of clarity, even light distribution and high lighting levels are required in space. Additionally, illuminating the object in conjunction with its surrounding area enhances visual clarity (Manav, 2015). Visual clarity and visual acuity are closely related, as both depend heavily on the quality of lighting and the contrast between objects and their surroundings.

Visual clarity refers to the eye’s ability to perceive fine details and distinguish objects with small angular separation, reflecting overall sharpness of vision (CIE, 2020b). Visual acuity is also dependent on the contrast between the object and its background. Therefore, proper lighting is essential for achieving visual clarity. In this context, the effects of lighting parameters play an important role in the visual threshold. However, a lighting arrangement that exceeds the visual perception threshold ensures a safer and more efficient working environment (van Bommel, 2019).

Facial perception is one of the most essential components of visual clarity. Flynn demonstrated that lighting arrangements with high facial clarity have a more public effect, while those with low facial clarity create a more private atmosphere. In public spaces, increasing lighting intensity to make faces more visible allows people to recognize each other more easily. On the other hand, in private spaces, shadows and silhouettes reinforce a sense of privacy by inhibiting the visibility of facial details (Gordon, 2015).

2.4.2.4 Relaxation

To enhance the feeling of "relaxation," another important factor to consider in lighting systems is the variation in brightness within space. By using regional lighting on side walls, varying brightness levels and reflections on surfaces can strengthen the feeling of relaxation. In addition to evenly distributed light, creating focal points within the space also enhances the impression of relaxation (Manav, 2015).

Lighting solutions suitable for office types are essential for enhancing psychological comfort. Especially in open-plan offices, lighting systems that can be controlled by users, considering the space's size and functions, can be integrated into the design. This type of design helps define the boundaries of the space and ensures proper perception of circulation areas (Manav, 2015).

Flynn found that lighting systems with non-uniform brightness, such as downward-focused lighting, are perceived as more pleasant than uniform brightness from diffuse systems. Non-uniform brightness is considered "friendly," "pleasant," "sociable," and "interesting," creating an effect that enhances social interaction (Gordon, 2015).

3. LIGHTING DESIGN IN CONTEMPORARY OFFICES

People spend most of their time indoors and most of the world's population works in offices (De Dear & Brager, 2002). Therefore, healthy office environments have a significant impact on the safety, health and well-being of employees (WHO), 2010). In addition, workspaces are one of the important factors affecting productivity and employee satisfaction in the workplace (Fischer et al., 2004). As will be elaborated further, design changes in closed office environments have been shown to have significant effects on employee productivity (Haynes, 2008; World Green Building Council, 2014). Therefore, these spaces should be considered in terms of their design and environmental attributes that affect well-being, motivation and job satisfaction as well as productivity and performance.

3.1 Office Types and Working Styles

Lighting design is one of the environmental factors that influence employee well-being and workplace performance. These spaces affect employees not only physically but also psychologically and socially (Fischer et al., 2004). Therefore, these environments play a decisive role in determining not only individual but also societal health (Bodin Danielsson & Theorell, 2019). Therefore, the concept of workspace includes the analysis of environmental factors, psychological effects and functional use. In this context, office design can be considered from different perspectives; for example, physical space that is appropriately designed for a work activity is considered as an environment in which work activities take place. Furthermore, workspace as a concept emphasizing the relationship between work and space is essential for the execution of work in a functional context. The workspace allows for interactions at the individual and group level, which in turn affects how employees experience their work (Fischer et al., 2004). It has been observed that employee productivity is directly proportional to satisfaction with environmental factors. However, since comfort is a concept based on personal experiences, different office environments may have different comfort experiences, which in turn affects employee performance (Oseland, 2004).

In the 21st century, technological developments, especially computer-based innovations, have reshaped the impact of office layout and workspaces on business processes. With this change, the number of studies examining the relationship between office design and employee health (Clements-Croome, 2017; Jensen & van der Voordt, 2020; World Green Building Council, 2014). In one of these studies, the relationship between performance and productivity was found to be directly linked to office organization and work styles.

Performance is assessed in terms of the work performed by employees, while productivity focuses on the outputs of that work (El-Zeiny, 2012). Office designs that provide comfort for employees can significantly increase labor productivity. Gensler (2005) emphasized that poorly designed workplaces cost more than £135 billion a year, whereas well-designed offices can increase productivity by 19%. Furthermore, good office designs can increase workplace satisfaction by 79% and positively affect the success of organizations. Dozie Ilozor et al. (2002) stated that different office layouts can increase productivity by encouraging employee interaction and innovation (Nanayakkara et al., 2021).

Consequently, employee satisfaction and productivity are a result of the quality of the interior space, and office layouts that enhance this quality increase overall productivity in the workplace (Singh et al., 2010; Vischer, 2007). Therefore, the design of workspaces is an important factor not only for employee satisfaction and health, but also for the success and profitability of companies.

3.1.1 Office types

Office designs offer a wide variety, ranging from long-established enclosed spaces to open plan layouts. Most buildings are designed according to widely accepted working hours (9 am to 5 pm) based on scientific management theory (Szarejko & Trocka-Leszczynska, 2007). However, over time, the increasing popularity of flexible and agile working models has led to changes in office arrangements. The biggest transformation in office space began in the 1960s and 1970s with the shift from traditional, isolated offices to open-plan and shared spaces (Brennan et al., 2002a; De Croon et al., 2005; Kaarlela-Tuomaala et al., 2009; Lee, 2010). This shift is driven by key motivations such as

reducing costs, optimizing space utilization and providing flexibility (Baldry & Barnes, 2012; Parkin et al., 2011). The main motivation was to make workspaces more flexible, enabling reorganization without the need for large costs, and to increase creativity by encouraging collaboration among employees (Brennan et al., 2002; Parkin et al., 2011). Increased communication with fewer or no physical barriers was also thought to increase employee morale and productivity (Brennan et al., 2002). In economic terms, Hedge (1984) argued that the design and maintenance of open offices can save 20% of costs.

Today, there are many different layout models, ranging from the traditional closed offices to open offices. In open offices, people working together are physically co-located with layout geometry that reflects the organization of work groups. Plants, low movable screens, cabinets, shelves or other furniture are used to separate spaces (Sanders & McCormick, 1993). The openness of the space, the number of employees and architectural accessibility can cause some differences between open offices (Oldham, 1988; Oldham & Rotchford, 1983). For example, (Marans & Yan, 1989) categorized a national sample of offices into six different design categories: private enclosed, private shared, individual open, shared open, or bullpen, based on the number of walls and partitions surrounding employees' workspace (Brennan et al., 2002). Liang (2011) focused on the effects of office layouts on productivity and proposed four metaphors to meet different work needs: The ‘hive’ offers a combination layout suitable for low-interaction individual work, while the ‘cell’ focuses on individual intensive work. The ‘center’ layout supports group work, while the ‘club’ layout encourages independent and interactive work for knowledge-intensive tasks. This is because many studies emphasize that the mismatch between the office environment and the work process of companies leads to loss of production (Laing et al., 1998; Mawson, 2002).

These different layouts offer solutions for both the efficient execution of business processes and the improvement of business performance by adapting to the task complexity and needs of employees. All of this highlights the importance of a workplace strategy designed to meet customer needs (Barber et al., 2005; Bradley & Woodling, 2000; Duffy, 2000).

In conclusion, although the debate on which office layout is more appropriate is multidimensional, Duffy (1997) stated that modern offices should be designed in accordance with the characteristics of the job and the way of working (Davis et al., 2011). In this thesis, based on the literature and our own observations, six categories of office types will be introduced: open plan, traditional closed plan, cubicle office plan, team-based office plan, mixed plan and home office. These categories represent different approaches designed to meet various business requirements.

3.1.1.1 Open plan office

Open-plan office layouts (Figure 3.1), also known as hives (Candido et al., 2016) are, as the name suggests, collaborative workspaces shared by employees (Laughton, 2018). Characteristically, it has no internal walls but is divided into individual workspaces or partitions and contains a larger number of employees within the room (Davis et al., 2011). In this layout, the space between employees is either completely open or divided with the help of low partitions, cupboards or flowers to reinforce the feeling of space within the openness (Kim & de Dear, 2013a). Designed in the 1950s and gaining popularity in the early 1970s, open offices emerged with the idea of easily adapting to organizational changes by creating a flexible space (Hedge, 1984) and removing physical barriers to communication (Pile, 1979). This organization allows for the exchange of information and ideas among employees (Pile, 1979).

Figure 3.1: Open plan office (OpenAI, 2023)

Open-plan offices have been categorized based on criteria such as space density, number of partitions, height of partitions and openness. For example, in CBE's (Center for the Built Environment) Occupancy Survey, there are three layouts ranging from high-panel partitioned offices where the individual workspace is surrounded by partitions that are above eye level when seated, to a team-oriented bullpen with small groups of desks in a completely open space (Altomonte & Schiavon, 2013). In Kim and de Dear (2013) study, open-plan offices were categorized as "partitions with high partitions approximately five or more feet high, partitions with partitions lower than five feet, and open office with no partitions or limited partitions". However, it remains unclear how an open-plan office is defined (J. A. Veitch et al., 2007).

Many companies continue to adopt the open office layout because of its low construction and maintenance costs. There is also a widespread belief that this layout allows for more communication and increases productivity (Boje & Walley, 1971; Pile, 1979). Although open offices offer economic advantages such as more usable space and easy reorganization (Duffy & Hannay, 1992; Hedge, 1982), there is limited empirical evidence that this layout increases communication between employees (Kaarlela-Tuomaala et al., 2009). On the contrary, open plan offices negatively affect employees' environmental satisfaction, leading to problems such as distraction, loss of privacy and perceived poor performance (Brennan et al., 2002). Moreover, noise and lack of privacy in open offices cause productivity losses and negative reactions among employees (Banbury & Berry, 2005; C. Danielsson et al., 2008.). Noise reduces individual performance on cognitive tasks, while loss of personal privacy leads employees to develop negative attitudes towards the overall office environment (Haapakangas et al., 2008). For this reason, some employees preferred to return to the traditional closed office setting, which provides more privacy (Pile, 1979). All these findings question the claimed benefits of open offices (Laughton, 2018).

A versatile approach to lighting is required in open-plan offices, where different tasks, circulation areas and face-to-face meetings often coexist. As there are no interior walls, lighting is usually provided by ceiling-mounted luminaires. According to the TS-EN-

12464-1 standard, it is important to ensure appropriate lighting for all tasks performed in the office.

3.1.1.2 Traditional-close plan office

Traditional closed office layouts (Figure 3.2) consist of cubicles where one or two employees work in private spaces surrounded by walls, often housing the equipment needed for work (C. B. Danielsson & Bodin, 2008; Davis et al., 2011; Vischer, 2007). This arrangement, also known as the “corridor office” in research, provides a suitable environment for intensive and independent work (Baldry & Barnes, 2012; Candido et al., 2016). Kim and de Dear (2013) noted that these offices are usually designed to meet the needs of employees but may require the use of shared spaces when all the necessary equipment is not available. This makes the perception that private offices are only suitable for independent work misleading, as other layouts can also meet similar concentration requirements. In this context, a better approach to assessing office layouts would be to focus on their intended use rather than the facilities offered (Laughton, 2018).

Figure 3.2: Traditional-close plan office (OpenAI, 2023)

The level (i.e. size and scale) of physical barriers (e.g. walls or panels) between workers shapes the physical layout of offices. Traditional (closed cellular) and open-plan offices differ significantly in the level of physical barriers. Employees' reactions after moving from traditional to landscaped offices showed a loss of privacy in addition to visual distraction (Hatch, 1987). Although open-plan offices encouraged staff participation,

they were sometimes rejected due to employee complaints about increased levels of discomfort and disruption. Since then, some employees prefer to return to the traditional closed office layout where they can maintain the level of privacy they desire (Pile, 1979).

In addition, differences in privacy and space at workstations can symbolically represent status differences between employees, which in turn can affect workplace behaviors and interactions (Cameron & Quinn, 2013; Elsbach & Pratt, 2007; Welch, 1980). In contrast to these differences, workstation equity refers to perceived similarities between employees. A study by Zhang and Spicer (2014) found that the types of office layout (e.g., partitioned or enclosed private offices) and the space provided to employees reflect status differences in the organization. Larger and more private spaces are often allocated to senior employees, reinforcing the hierarchy within the organization. This finding suggests that the size and level of privacy of workstations may symbolize power and status differences in the organization (Zerella et al., 2017).

3.1.1.3 Cubicle plan office

The cubicle office layout (Figure 3.3) is an office design created by subdividing open office spaces without walls, providing employees with a certain level of privacy and workspace. This system, which became widespread in the late 1960s, quickly became a preferred layout for white-collar workers. Today, about 70% of office work takes place in partitioned offices. The main reason for the rapid adoption of partitions is that they offer economic advantages. Partitions are a highly efficient way of organizing office space. With standard and inexpensive construction costs, they can be manufactured in large quantities and installed with minimal specialized labor. Furthermore, the building envelope, lighting and ventilation systems can be easily installed without considering internal walls, allowing contractors to build economical office spaces in the form of large white boxes, which can then be filled with “office furniture systems” (Franz, 2008).

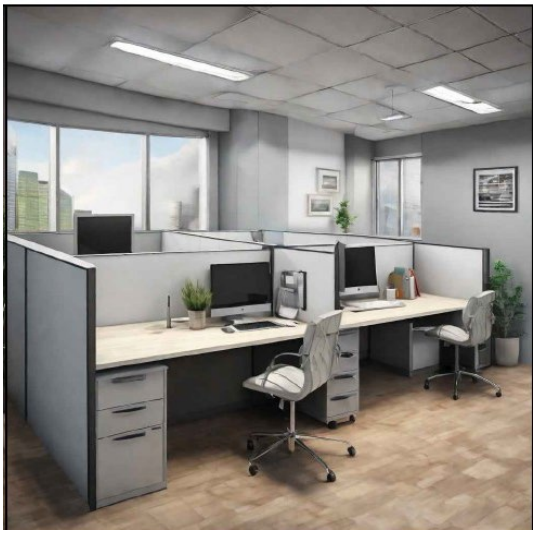


Figure 3.3: Cubicle plan office (OpenAI, 2023)

One of the most important advantages of partitions is the ability to use floor space with maximum efficiency. Employees are allocated only the required square meters, and this ratio is gradually decreasing. According to real estate surveys cited by National Real Estate Investor, the average office space per employee in the US fell from approximately 23.2 square meters in 2000 to 17.7 square meters in 2005. Given the increasing trend towards flexible working arrangements, remote work, and shared office spaces, this figure is expected to be significantly lower in the present day. This shrinkage not only saves space, but also time. For example, there is less time spent going to the restroom, the coffee machine or the marketing department. Furthermore, partitioned offices facilitate supervision; the absence of walls means that employees must be working, or at least appear to be working (Franz, 2008).

With these features, cubicles have become the epitome of efficiency. But in addition to economic reasons, there are also moral reasons for the rise of cubicles. The offices of the 1970s and 1980s were seen by critics as cumbersome relics of a bygone era and inhuman and ineffective symbols of bureaucracy. In contrast, partitioned offices have removed the fixity and bureaucratic constraints of the old office layouts. The fact that each cubicle had an open door supported the perception that everyone was an equal employee. In this respect, partitioned offices were perceived as a system that empowered employees and seemed to create a humane workplace (Franz, 2008).

3.1.1.4 Team-based plan office

A team-based office layout (Figure 3.4) is a flexible, open-plan workspace where employees do not have a fixed desk and can work in the space that best supports their work. This layout is often designed to support the Activity Based Working (ABW) approach and is organized to suit the different work tasks and activities in modern offices (Candido et al., 2016). Activity-based EU environments, also called agile or flexible working, provide more diverse spaces for working individually (solo, dyads or small teams) (Divett, 2020).

Figure 3.4: Team-based plan office (OpenAI, 2023)

Activity-based settings provide a greater number of spaces to meet formally in closed meeting spaces or informally in improvised collaboration spaces. Compared to open plan, a greater proportion of the activity-based environment is shared. Users are encouraged to choose the workspace that best suits the tasks they need to perform or the environment they prefer at that moment, either in the whole building or in group-based neighborhoods (Divett, 2020). By combining spaces with different functions, such as team desks, brainstorming areas, and multimedia spaces, this layout allows employees to have a wide range of workspaces, from individual stations to the entire office (Candido et al., 2016; Keeling et al., 2015).

However, research on these deskless layouts shows that they are often not welcomed by employees (Babapour et al., 2018; Gao et al., 2022; Rolfö, 2018). The lack of a fixed

desk can be an uncomfortable experience for employees and is seen as the end of traditional private workspaces. However, it has been emphasized that changes in management processes and the way employees interact with space should be considered to make flexible workspaces more efficient and user-friendly (Laughton, 2018).

3.1.1.4 Mixed plan office

The mixed-plan office layout (Figure 3.5) is a design approach that aims to respond to the increasing need for flexible work by adjusting suit the nature of the work. It is an innovative concept (Candido et al., 2016) that entails the creation of a variety of spaces for users to choose from depending on the requirements of the task at hand and supports the idea of a workspace that is suitable for the type of work being done and for employees to collaborate in teams. In this way, it expands the boundaries of the employees' workspace from an individual station to the entire office space. Therefore, it often includes combinations of space types, from individual desks to brainstorming areas. In this way, employees are mobile and can work in whichever part of the office space best supports their tasks (Candido et al., 2016; Keeling et al., 2015). This flexible office layout provides significant advantages for mobile workers (Keeling et al., 2015) and can increase satisfaction levels by giving employees more control over choosing their own workplace.

Figure 3.5: Mixed plan office (OpenAI, 2025)

Keeling (2015) and Candido et al. (2016) argue that the driving force behind the shift towards such environments is their ability to support growth-oriented business objectives, reduce costs and increase flexibility, all in combination to provide more sustainable systems. However, it has also been found that flexibility is not always a positive experience for employees. Employees may need more control and retreat space when interacting with colleagues, which can create difficulties in adapting to the work environment. This suggests that the advantages of flexibility can be uncomfortable in some cases, depending on individual needs and work patterns (Keeling et al., 2015).

3.1.1.5 Home office

The pandemic marked the beginning of a new era that radically changed the way of working and offered employees more freedom in time and space. In this process, the flow of information, work efficiency and productivity of distributed teams increased with the spread of digital infrastructure. Working outside the office has become less limited for employees in terms of time and space. Setting up their own workplace at home (or elsewhere) meant that part of the workforce could create bespoke solutions to suit their needs in terms of control over the overall physical layout of the office and, most importantly, interruptions, interactions and the ability to concentrate. However, while managers expressed concerns about loss of productivity, weakening workplace culture and safety, employees faced challenges such as lack of social connectivity, internet access issues and increased workload (Marzban et al., 2021). Many employees expressed a desire to return to the office due to the need for face-to-face interaction with colleagues (Durakovic et al., 2022). However, the ergonomic inadequacies of home offices have led to increased screen time and health problems such as burnout (Hayes et al., 2021; Niebuhr et al., 2022).

While the pandemic experience gave employees the opportunity to create their own workspace at home, it also showed that face-to-face interactions in the office are critical for collaboration and productivity. This has led to fundamental changes to create a more efficient and flexible office experience through the integration of digital and physical spaces. Office spaces need to evolve to support employees to work in a healthy, environmentally friendly and motivating environment (Candido et al., 2024).

3.1.2 Working styles and design approaches

While office environments concern a large proportion of the working population, the number of people working in offices is expected to increase further as technology becomes more widespread and continues to evolve (Margaritis & Marmaras, 2007). Workplace design and office layout come to the fore when we consider that they reflect the culture, values and working styles of an organization. Organizational theorists such as Fredrick Taylor and Henri Fayol had a great influence on office design, especially Taylor's theory of "scientific management" shaped office layouts with strict hierarchies and control mechanisms over employees (Duffy, 1997). In addition, ergonomic requirements have also become an important factor directly affecting workplace design. Employees' psychological responses to office design are also a critical element to be considered in the design process. While personalization of office spaces can improve employee well-being and job satisfaction, lack of control over environmental stressors can negatively affect employee motivation (G. Brown et al., 2005; G. W. Evans & Johnson, 2000; Pierce et al., 2001). For example, studies have shown that personalization of the workspace can positively affect both employee mood and the relationship between employees (G. Brown et al., 2005; O'driscoll et al., 2006; Pierce et al., 2001). Lack of control over environmental stressors can negatively affect job satisfaction and reduce motivation (Banbury & Berry, 2005; G. W. Evans & Johnson, 2000; Kim & de Dear, 2013).

Brill (2001) identified the characteristics of a good workplace from a designer's perspective. These include the ability to do distraction-free solo work; support for impromptu interactions; support for meetings and undistracted group work; workspace comfort, ergonomics and enough space for work tools; workspace side-by-side work and "dropping into chat"; located near or can easily find co-workers; workplace has good places for breaks; access to needed technology; quality lighting and access to daylight; and temperature control and air quality. Vischer (2007) claims that workspace configuration and layout are the biggest environmental factors affecting satisfaction and performance, followed by sound and visual openness, ventilation and thermal comfort. According to Frontczak et al. (2012) the highest satisfaction comes from ease of interaction with coworkers and lighting, while the lowest satisfaction comes from noise,

air quality, visual privacy and temperature. Lighting research includes distinguishing the effects of artificial light and daylight and demonstrating that controlling glare improves comfort and productivity (Vischer, 2007).

Work practices are shaped by innovative technologies, globalization and advanced communication technologies as well as employee expectations such as communication, collaboration and information sharing (French & Salisbury Jones, 2010; Joroff et al., 2003; Saurin et al., 2008). With the introduction of the computer into our lives, ergonomic requirements for office design have also changed. The workspace should be free from unwanted reflections and glare, lighting should be appropriate to the needs of the task, and lighting should be uniform across the visual field of the worker. The layout of workstations should be appropriate to the organizational structure (Margaritis & Marmaras, 2007). There is evidence that ergonomic design of office workspaces improves work performance (Dainoff, 1990; Francis & Dressel, 1990; Kroemer, 2002; Ong, 1990).

Klitzman and Stellman, (1989) reported that there are relationships between the physical indoor features of office workspaces such as temperature, ventilation, lighting, workstation design, and comfort, satisfaction, turnover, employee attitudes and behaviors (Laughton, 2018). Two different studies by Singh et al. (2010) and El-Zeiny (2012) have shown that improving the quality of the indoor environment can increase employee productivity. Bergs (2002) believes that 90% of health complaints related to the work environment have a technical cause and that improved Indoor Environmental Quality can improve health (Allen et al., 2016). De Croon et al. (2005) found inconsistent evidence in their review of relevant studies, but most of the literature suggests that the indoor environment affects occupants' working comfort and health (Ghodrati et al., 2012; Hedge & Dorsey, 2013). This transformation in office layouts has been influenced by factors such as market changes, competition, new technologies, workforce structure and organizational structures, and has evolved into designs that meet the needs of the modern business world (Harris, 2015).

3.2 Lighting Approach and Techniques

No other workspace has been subject to as much change in recent years as the office (TRILUX GmbH & Co. KG, 2024). Thanks to technology, office work is no longer tied to specific places and times (Ganslandt & Hofmann, 1992). Responding to these changing needs requires flexible adaptations to requirements, new job hierarchies, responsibilities and flexibility in design layout (TRILUX GmbH & Co. KG, 2024). With the use of displays, office lighting is no longer just workstation lighting, but becomes architectural lighting with visual comfort. Activity-appropriate brightness distribution and high visual comfort ensure visual quality and good spatial orientation, resulting in concentrated and productive work (Ganslandt & Hofmann, 1992).

Good visual comfort can be created with the correct use of glare-reducing luminairesIn offices, an illuminance level of 500 lx is sufficient for detailed and attention-demanding work such as computer-based work and project drawing, while a horizontal illuminance level of 300 lx may only be suitable for simple activities such as note-taking (Ganslandt & Hofmann, 1992).

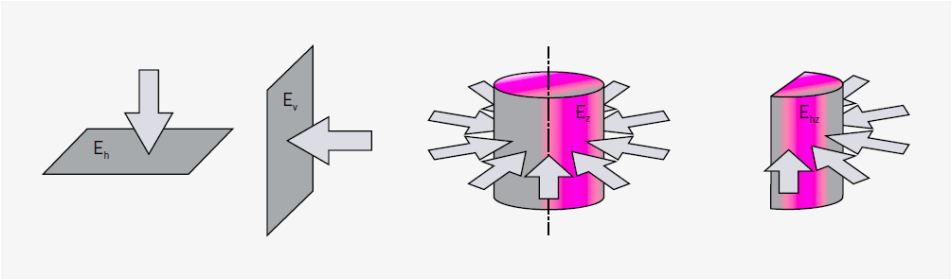


Figure 3.6: Explanation of the horizontal illuminance E_h, the vertical illuminance E_v, the cylindrical illuminance E_z and the semi-cylindrical illuminance E_{sz} (TRILUX GmbH & Co. KG, 2024)

When designing workstations, elements such as space openings, walls and furniture should be designed to avoid direct glare and as far as possible, reflections on the screen (TRILUX GmbH & Co. KG, 2024). While vertical lighting is important for the best distribution of brightness when working on the screen, horizontal lighting complements the ambient lighting for viewing documents on the desk (Ganslandt & Hofmann, 1992). Cylindrical lighting is the lighting quality criterion that ensures the recognizability of facial features required for good visual communication (Figure 3.6) (TRILUX GmbH & Co. KG, 2024).

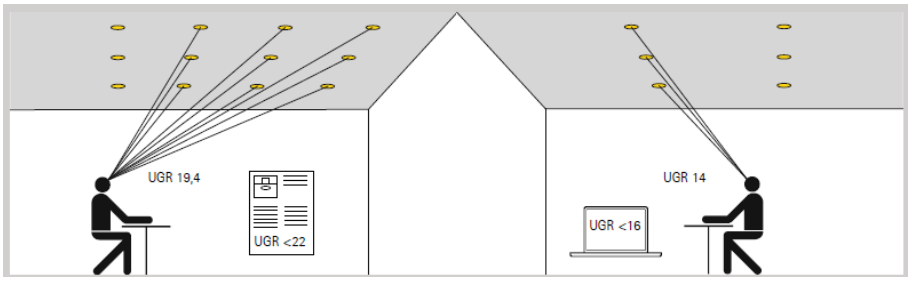


Figure 3.7: UGR Levels: Evaluating Glare in Office Lighting (Ganslandt & Hofmann, 1992)

Lighting used for good visual communication in offices should provide a compromise between high vertical illuminances in space and good glare control in the line of sight of the workstation. A combination of directional light and an indirect light component is ideal. Reflected light reduces visual acuity and can cause physical problems such as fatigue and headaches (Ganslandt & Hofmann, 1992). Therefore, luminaires need to be selected, placed and arranged to avoid reflections of higher luminance values. The designer should identify the area of luminaire installation that may cause discomfort and choose the type and arrangement of luminaires to prevent uncomfortable reflections (TRILUX GmbH & Co. KG, 2024). Direct and reflected glare reduces visual comfort at office workstations. To avoid such situations, luminaires must have good glare control and be correctly arranged. Whether an arrangement complies with the UGR < 19 specification can only be verified by a simulation; the values in the data sheets refer only to matrix arrangements in rectangular reference rooms (Ganslandt & Hofmann, 1992) (Figure 3.7). Actual glare must be calculated separately by observation location (TRILUX GmbH & Co. KG, 2024).

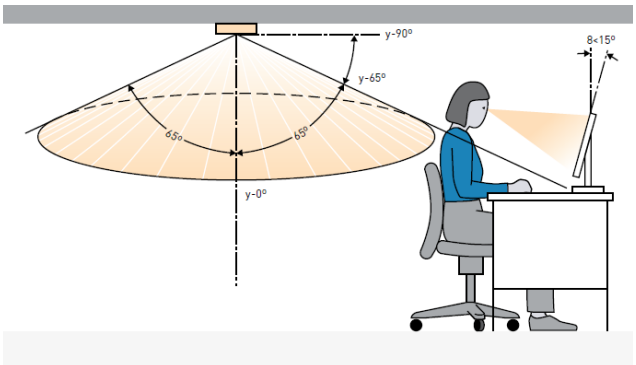


Figure 3.8: Geometry at a VDU workstation in relation to avoiding disturbing reflections by luminaires (TRILUX GmbH & Co. KG, 2024)

Due to the visual strain associated with screen operation, VDU (Visual Display Unit) workstations are subject to high ergonomic and lighting requirements. A slight tilt of the head forward and a viewing direction of about 15° below horizontal has proven to be beneficial. The screen should be tilted about 15° from vertical. This geometry is the basis for the shielding conditions (shielding angle) for high luminance surfaces specified in EN 12464-1 to avoid annoying reflections as defined in the EU directive. According to EN 12464-1, the luminaires' luminance should be limited to certain values starting from a limiting distribution angle of 65° (Figure 3.8). This means that with a screen tilt of up to 15°, no disturbing reflections can occur on the screen (TRILUX GmbH & Co. KG, 2024).

In addition, artificial lighting can be used to define spaces, create atmosphere and affect the psychology of users. Lighting design in offices can be addressed in three main layers: General lighting, task lighting and accent lighting (Ozenen, 2024).

- General (Ambient) Lighting: Provides general lighting of the space and forms the basis for other lighting layers. It is usually provided with ceiling fixtures, recessed lighting or natural light.
- Task Lighting: A type of lighting focused on performing specific tasks. It allows users to comfortably perform activities such as reading, writing or working. It can be provided with table lamps, floor lamps or under-cabinet lighting.
- Accent Lighting: Used to emphasize the aesthetic features of space. It creates visual interest and a dramatic effect. It can be provided with track lighting, wall fixtures or directed spotlights (Ozenen, 2024).

The effective combination of these three lighting layers creates a balanced lighting environment in terms of both functionality and aesthetics. An effective lighting design should be selected in accordance with the purpose of use of the space and the activities performed (Ozenen, 2024).

3.2.1 General (ambient) lighting

Ambient lighting is the basic type of lighting used to provide the overall level of illumination in a space and create a cozy, inviting atmosphere. By adequately illuminating the entire space, this type of lighting affects the visual perception of the surrounding areas and contributes to the aesthetic appeal of the space. In addition, ambient lighting balances the perimeter of visual task areas and makes it possible to provide less lighting in these areas (Gordon, 2015). To ensure the required level of illumination and homogeneous distribution, luminaires are regularly placed throughout the office room. In this way, the entire office space is considered as a task area, allowing flexibility in the positioning of work (van Bommel, 2019).

Factors such as the size and shape of the space, the color of the walls, the height of the ceiling and natural light should be considered when designing ambient lighting. Ambient lighting can also affect the mood of space. The characteristics of the light sources used to provide the right ambient lighting, such as color temperature and color rendering, should also be considered. These factors directly affect the overall aesthetics of space and the user's perceptual experience. For example, warm-toned ambient lighting can create a cozy and inviting atmosphere in spaces such as living rooms, while cooler-toned light can create a more energetic atmosphere in spaces such as bathrooms or kitchens (Ozenen, 2024). According to another study, ambient lighting has a psychological effect on individuals' motivation to approach a certain area. It has been observed that people's willingness to approach an area decreases in a dark environment, suggesting that ambient lighting plays an important role in social interactions (Gordon, 2015).

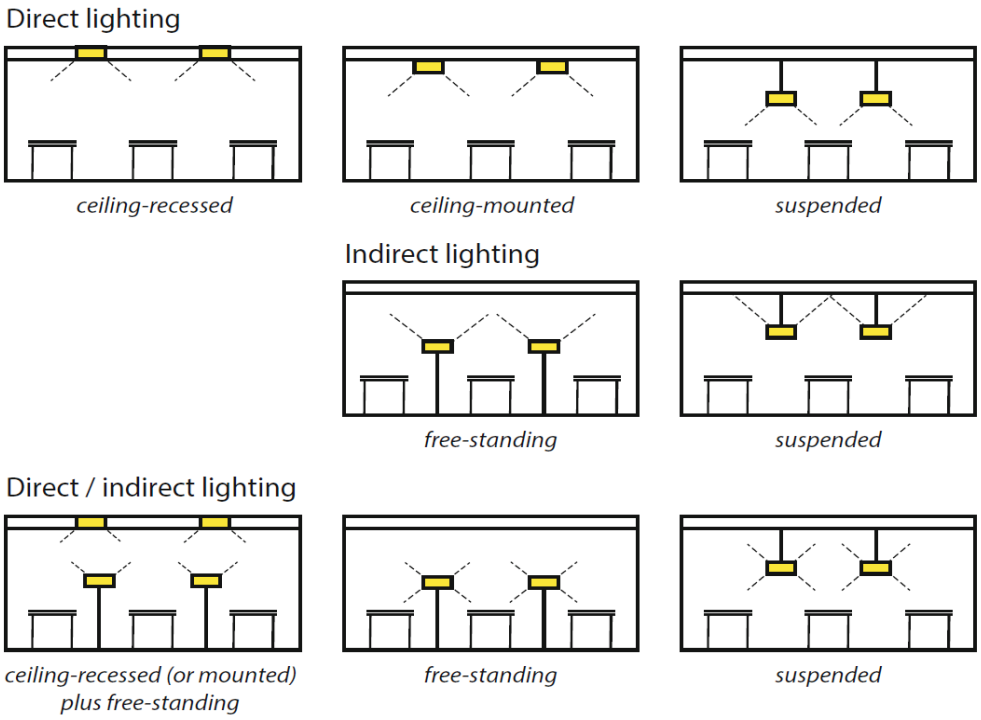


Figure 3.9: General Lighting Systems (van Bommel, 2019)

Ambient lighting can be provided by two basic methods (Figure 3.9): direct and indirect lighting. Direct lighting allows light to be cast directly into space by placing ceiling luminaires and generally provides an even distribution of light in space (Gordon, 2015). It can be ceiling-surface mounted or recessed and pendant luminaires. It can be efficient as the lighting reaches directly to the working plane (van Bommel, 2019). Indirect lighting, on the other hand, allows light to be directed to the ceiling and then reflected from the ceiling and spread throughout space. This method provides a more uniform distribution of light and illuminates the space with a softer light. A well-designed ambient lighting system provides visual comfort by creating a balanced brightness throughout the space (Gordon, 2015).

Ambient lighting can work in conjunction with other types of lighting in space, such as task lighting and accent lighting, to enhance the functionality and aesthetics of the space. Well-designed ambient lighting is not only functional, it is also an element that enhances the atmosphere of space. Therefore, ambient lighting is an essential component of interior design and, when designed correctly, provides users with both visual comfort and an aesthetically pleasing experience (Ozenen, 2024).

3.2.2 Task lighting

Task lighting (Figure 3.10-3.11) is designed to provide the light required for a specific task or activity and offers important benefits such as improving visual performance, reducing eye strain and promoting productivity (Sholanke et al., 2021). It can appear in different forms and for different purposes. It is common where the tasks to be performed are more difficult or detailed, or where general lighting is not sufficient (Boyce, 2014b). However, when designing task lighting, it is important to avoid large variations in illumination levels, as such variations not only negatively affect visual performance, but can also disrupt the psychological state of users (Veenstra & Koole, 2018).

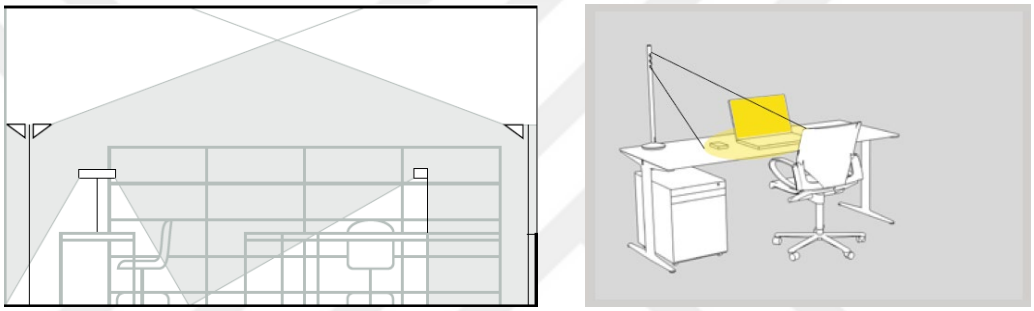


Figure 3.10: Workplace Lighting Distribution and 3.11: Focused Task Lighting on Work Desk (Ganslandt & Hofmann, 1992)

Task lighting is also the basis for most lighting standards, defining the direction and amount of light required for specific tasks. However, these designs should not only comply with the standards but should also be organized in such a way that they do not interfere with users' work. For example, high light levels on a book in a dark environment can negatively impact the reading experience. Good task lighting not only provides light intensity and direction appropriate to the task but also offers better experience by giving users personal control. This can be implemented with locally controlled luminaires and can increase user satisfaction (Veenstra & Koole, 2018).

Task lighting in workplaces is designed with one of two basic approaches to ensure correct visual perception: General Ambient Approach or Task-Environment Approach. The general ambient approach is suitable for situations where the space is frequently reorganized and provides uniform light throughout the entire space. In contrast, the task-

perimeter approach is more energy efficient, providing higher light levels for task areas and lower light levels for perimeter areas. In these systems, task areas are illuminated first and then the peripheral areas are supplemented with low levels of general ambient lighting. This method is more suitable for spaces with permanent task areas such as private offices, factories, laboratories and shops (Behera et al., 2018).

This type of lighting not only improves visual acuity and reduces eye fatigue but also contributes to energy efficiency. It saves energy by allowing the use of lower levels of ambient light and creates a relaxing effect on users (Behera et al., 2018).

3.2.3 Accent lighting

Accent lighting is a type of lighting used to draw attention to specific objects or areas within a space. Our visual system is generally more attracted to brightly lit objects because brightness makes it easier to identify shapes. This gives lighting designers the power to create a visual hierarchy. Highlights can be created not only by increasing light levels, but also by changing the direction or color of light. In this way, certain areas or objects can be emphasized (Ozenen, 2024).

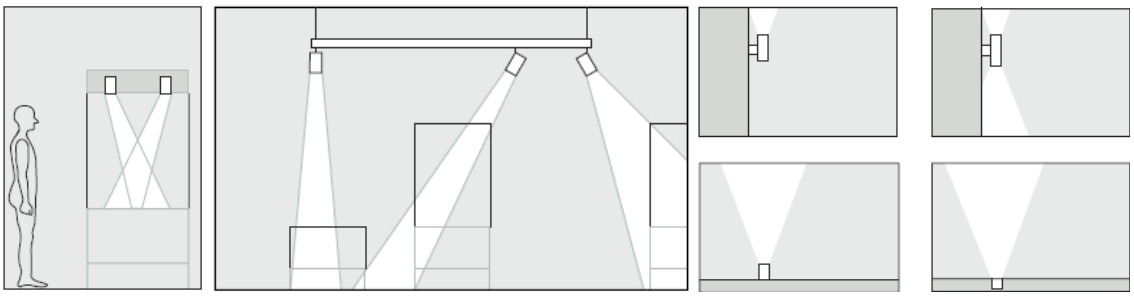


Figure 3.12, 3.13 and 3.14: Accent Lighting Techniques and Beam Distribution (Ganslandt & Hofmann, 1992)

Accent lighting can be used for a wide variety of purposes, from defining architectural form to emphasizing artistic details, and is often found in areas such as museums and galleries (Veenstra & Koole, 2018). With the direction and intensity of the light, the illuminated area or object is emphasized by making it more prominent. However, factors such as the color temperature and color rendering of the light source should also be taken into account when designing accent lighting. To create the desired effect, the appropriate light intensity should be used to illuminate the area correctly without drowning it

(Veenstra & Koole, 2018). There are various types of accent lighting. For example, spotlights, which allow the size and direction of the light beam to be adjusted, are used to emphasize the targeted area more effectively, while wall washers are used to evenly illuminate the wall or area. They are particularly useful for highlighting works of art or architectural details (Figure 3.12-3.13-3.14). Accent lighting has both aesthetic and practical benefits and can increase visual interest in desired areas or objects (Wu, 2012).

3.3 Lighting System Design and Technology

Lighting control systems have experienced significant transformations, especially in the last decade. This transformation has not only provided energy efficiency but also created new opportunities to improve the user experience and increase aesthetic values in spaces. The right lighting strategies optimize energy consumption while accommodating the visual needs and physical comfort of users. Task/ambient lighting systems and properly commissioned lighting controls have great potential to achieve these goals. These systems are effective in adapting to the individual needs of building occupants while reducing electricity consumption by targeting only the necessary parts of space (Boyce, 2014).

This transformation in the lighting industry has been brought about by the development of LED technology, enabling the use of energy efficient light sources. LEDs offer great advantages over traditional lighting systems with their low energy consumption and long lifetime. In addition, the wide color spectrum offered by LEDs enables a more aesthetic experience of light and opens new dimensions in lighting design. The development of LED technology has also enabled a new generation of lighting controls. These developments enable energy savings and application diversity not possible with traditional light sources (Pandharipande & Newsham, 2018).

This development is even more important when the role of lighting in energy consumption is considered. For example, 33% of total electricity consumption in office buildings in the UK and 25-40% in commercial buildings in the USA is spent on lighting (Boyce, 2014). In this context, innovations in lighting systems play an important role in reducing environmental impacts.

In addition, the widespread use of networked smart lighting systems has enabled the development of more flexible and efficient lighting solutions. By offering previously impossible sensing and control possibilities, more optimized lighting experiences can be provided for users and spaces (Pandharipande & Newsham, 2018).

3.3.1 Contemporary Light Sources and Systems at Workspaces

LEDs, now in widespread use, and fluorescent lights, still in use, can affect the human circadian system. This shows that we need to combine both visual acuity and non-visual effects in lighting design (Burnett, 2012). The extent of blue light in the spectrum of light sources increases proportionally with color temperature. High color temperatures have a significant effect on human beings when they stimulate the level of mental activity (Deguchi & Sato, 1992) and strengthen the parasympathetic and sympathetic nervous systems; (Mukae & Sato, 1992) also, sleepiness is higher under low color temperature lighting (Mills et al., 2007; Noguchi & Sakaguchi, 1999).

3.3.1.1 LED lighting

LEDs offer significant advantages over other electric light sources in terms of energy efficiency. They consume less energy than filament light sources and last longer than most conventional sources. LEDs can operate at lower temperatures using cold beam technology, which keeps the output light cooler. However, this can have some reliability issues. Energy efficiency, low temperature performance and the ability to offer wide optical distributions make LED technology an attractive option (Gordon, 2015).

LEDs produce light with a narrow spectral spread, and although this can limit their use in general lighting, they can produce white light in two basic ways. In the first method, three or more different LEDs are combined in a luminaire to produce the desired colors. In the second method, an LED emitting short-wavelength visible radiation illuminates one or more phosphor surfaces to produce white light. This method reduces color variations and provides more consistent light quality in applications (Boyce, 2014).

Despite their advantages, LEDs also have some disadvantages. Their initial cost is higher than conventional light technologies, due to lower lumen output, driver circuits and power supply requirements. In addition, ambient temperature greatly affects LED performance; high temperatures can negatively affect the lifetime, luminous efficiency and color accuracy of LEDs. Over time, the light output of LEDs decreases, which can cause them to fall below the light levels targeted by designers or specified by regulations (Gordon, 2015). In recent years, research on LED technology has led to innovations such as intelligent lighting systems, tunable white light and human-centered lighting solutions. In addition to increasing energy savings, these innovations offer functionalities such as remote control, automation and integration into IoT (Internet of Things) platforms. Furthermore, sustainability initiatives such as recyclable materials and energy efficient manufacturing processes aim to reduce the environmental impact of LED technology (Ahmad et al., 2019; Nair & Dhoble, 2020; Zissis et al., 2021; Houser et al., 2021).

As a result, LEDs have many advantages such as energy efficiency, long lifetime, durability and wide application areas, but also disadvantages that need to be carefully considered depending on the application context. Continuous developments in LED technology have made this technology one of the cornerstones of the lighting industry, offering more flexible and environmentally friendly solutions in lighting design.

3.3.1.2 Fluorescent lamp

Fluorescent lamps are a frequently preferred lighting solution in commercial and industrial areas with their important features such as efficiency and long life. More efficient than traditional incandescent lamps, fluorescent lamps produce more light with the same energy consumption. In addition, their longer life reduces the need for frequent replacement (Ozenen, 2024). The efficiency of fluorescent tubes generally ranges from 20-96 lm/W, while their lifespan can be up to 19,000 hours. These characteristics make them an efficient and durable option (Boyce, 2014).

Fluorescent lamps are widely used in commercial and industrial areas such as offices, warehouses, and schools. They are also preferred in private applications such as kitchens, garages, aquariums and plant growing areas in homes. Fluorescent lamps adapt to various

lighting needs by offering different color temperatures and color rendering indices (CRI). These lamps can offer a wide range of colors, from warm white to cool white, and CRI values affect the quality of the light, determining the overall aesthetics of the environment (Ozenen, 2024).

However, the environmental impact of fluorescent tubes should also be considered. Fluorescent lamps contain small amounts of mercury and can therefore harm the environment if not disposed of properly. They are also not environmentally friendly as they consume more energy in the long run compared to LED and compact fluorescent lamps. This is an important consideration in terms of environmental sustainability (Ozenen, 2024).

In conclusion, fluorescent tubes have many advantages in terms of efficiency and durability, but their environmental impact and mercury content require a careful approach to their use and disposal. Considering these characteristics, fluorescent lamps still remain a widely preferred option in commercial and industrial applications.

3.3.2 Energy efficient lighting design

Energy-efficient lighting design aims to both enhance visual comfort and minimize environmental impact by reducing energy consumption. This approach goes beyond simply providing light levels that meet visual needs; it also uses advanced technologies and control mechanisms to save energy. Energy efficient lighting technologies such as LED and fluorescent lighting offer much higher efficiency compared to traditional incandescent lamps. LED technology in particular has become a prominent solution in the lighting industry thanks to its long lifespan, low energy consumption and flexible color temperatures. LEDs are three to four times more efficient than incandescent lamps, can last up to 50,000 hours and significantly reduce energy costs (Boyce, 2014; Ozenen, 2024).

High-efficiency lighting systems include solutions that reduce energy consumption or improve system performance while maintaining the same lighting performance. These solutions save energy by regulating light levels and optimizing the electrical power of the

system, both through the use of high-efficiency components and by increasing the efficiency of control systems. In this context, the light emission spectra and orientation characteristics of LEDs also make a significant contribution to energy efficiency (Martirano et al., 2021). Furthermore, proper commissioning of lighting systems and implementation of appropriate control algorithms are critical to maximize potential energy savings (Pandharipande & Newsham, 2018).

LED panels allow to control the intensity and direction of light, with high energy efficiency. In this way, the combination of dimmable LED panels and electronic controls offers an efficient solution for designing new lighting systems or retrofitting existing ones (Martirano et al., 2021). These technologies, especially when combined with lighting control mechanisms such as occupancy sensors, daylight sensors and dimming systems, can prevent unnecessary energy consumption by using light only in areas where it is needed (Ozenen, 2024).

Lighting control systems are among the most effective approaches to save energy. These systems ensure that light is used only when and where it is needed, thus reducing energy consumption while at the same time increasing user comfort. The effectiveness of these systems is further enhanced by the use of technologies such as occupancy sensors, daylight sensors and automatic dimming (Boyce, 2014).

Energy efficiency regulations are important tools to control energy consumption. These regulations restrict the use of energy-inefficient products by limiting the intensity of lighting power or introducing minimum luminous efficiency standards. Furthermore, certification systems such as BREEAM and LEED encourage energy efficiency in design by assessing the energy performance of buildings (Boyce, 2014).

As a result, energy-efficient lighting design requires an integrated approach that combines sustainability and user satisfaction. Advanced solutions such as LED technology and lighting control systems provide visual and psychological benefits in addition to reducing energy consumption. Making effective use of daylight not only saves energy, but also improves employee well-being. Long-term field studies show that

electricity consumption can be significantly reduced in environments where task/ambient lighting and the right control systems are implemented. These methods will continue to play a fundamental role in reducing both energy costs and environmental impacts in future lighting designs (Boyce, 2014).

3.3.3 Dynamic lighting approach

Dynamic lighting is a human-centered lighting strategy that adapts to the needs of individuals and creates positive impacts on health, well-being and productivity. These systems offer different light levels and color temperatures to mimic natural changes in light throughout the day, providing a lighting experience that is in tune with circadian rhythms. For example, using high-intensity cool white light in the morning and lower-intensity warm white light later in the day can increase individuals' alertness and help them relax in the evening (Gomes & Preto, 2015).

Through the use of intelligent control systems and sensor technologies, luminaires that emit direct and indirect light simultaneously can be equipped with individually controllable light sources with different light colors. Managed by a lighting management system, these luminaires can provide light with varying color temperatures to support natural biological rhythms. A good lighting installation adjusts light levels to the visual task, limits direct and reflected glare by distributing brightness evenly in the room, and should have good color rendering characteristics. These requirements include the minimum values defined in the TS-EN 12464-1 standard and the necessary conditions for good lighting quality. A biologically effective lighting system should also ensure that the color and direction of light are appropriate to the conditions. This is because light color plays an important role in the circadian effect. Different color temperatures of fluorescent lamps produce different spectral distributions depending on the phosphor mixture in the tube, and these have different effects on the human circadian system (Patania et al., 2012).

Dynamic lighting is especially applied in spaces such as schools, hospitals and offices. These systems have been proven to improve sleep quality, reduce depression and anxiety, and increase productivity. It also supports individuals' circadian cycles, improving their

long-term indoor experience (Ozenen, 2024). Dynamic lighting also regulates individuals' sleep-wake cycles and positively affects mood in home environments. As people have different chronotypes, dynamic lighting can be adapted to individual needs by providing a flexible solution (Spentza, 2022). Therefore, compared to static lighting designs, dynamic lighting offers more long-term and targeted benefits. Studies show that brighter and cooler white light in the morning increases alertness, while warmer white light in the evening aids relaxation. This type of arrangement is particularly beneficial for individuals coping with challenges such as jet lag or shift work (Kazanasmaz et al., 2023).

In addition to light color, a biologically effective lighting design should also be important so that the eyes can effectively perceive bright areas in the room. This can be achieved through the use of large-area luminaires or luminaires with indirect rays that illuminate the upper third of the ceiling and walls. The activating effect of light is especially necessary during the day, and warmer light colors should be chosen in the evening. In this case, the visible brightness in the upper part of the room can also be reduced. For dynamic lighting, it is important that the spectrum of light emitted by the lamp is not adversely affected by the ambient colors in the room. In particular, optical control elements such as louvers, enclosures or prisms can change the spectral components of light, which can lead to the light reaching the eye not having the same spectral composition as the light emitted by the lamp. This is a factor that determines the quality of dynamic lighting (Patania et al., 2012).

Positive aspects of dynamic lighting include easy installation, easy access to electrical equipment, ease of use, easy connectivity, and the ability to achieve research goals. Furthermore, these systems enhance circadian biorhythm balance and have positive effects on psychological well-being. However, dynamic lighting also has some challenges. Disadvantages such as adaptation difficulties, complexity of electrical equipment settings and time-consuming adjustment of lighting scenarios can make these systems difficult to implement (Spentza, 2022).

As a result, dynamic lighting improves energy efficiency and user well-being by providing a lighting experience optimized to the needs of individuals. With the help of

technological innovations, it provides both psychological and physiological benefits by mimicking the effect of natural light in interiors, and thanks to advanced control mechanisms, dynamic lighting solutions will have an important place in the sustainable and human-centered lighting designs of the future (Spentza, 2022).

4. SURVEY ON HUMAN-CENTRIC LIGHTING DESIGN IN OFFICES

This section presents the findings of a user-centered survey conducted to explore the lighting preferences of Turkish office workers across various professional backgrounds. The primary objective of the study is to investigate how office users perceive and evaluate lighting conditions in their work environments, with a particular emphasis on the principles of human-centric lighting (HCL) design. This study seeks to understand user expectations related to comfort, well-being, productivity, and circadian alignment within office lighting schemes. By examining both natural and artificial lighting conditions, as well as factors such as color temperature, brightness, and control mechanisms, the research aims to provide insights into how lighting design can better support human health and performance in office settings.

4.1 Material / Method

A web-based quantitative method was used, featuring a structured survey and lighting simulations to assess user preferences regarding illuminance, light distribution, luminance, and color temperature. This approach adheres to the TS-EN 12464-1:202115 standard, ensuring compliance with suggested illuminance levels, surface reflection factors, and conditions for visual comfort.

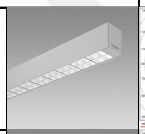
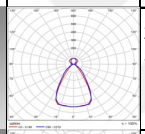
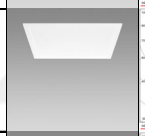
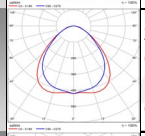
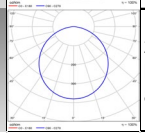
4.1.1 Determination of the HCL parameters in the survey

The study involves a web-based quantitative data collection focusing on key variables for HCL such as illuminance, light distribution, luminance, and color temperature of the light source, based on insights from the literature review. The three-dimensional interior visuals used in the survey were created in the Dialux Evo (DIAL GmbH, 2024) Program with reference to the TS-EN 12464-1:2021. The modeled office space was designed based on a real-life office environment to enhance the realism and contextual relevance of the visual scenarios presented to participants. Particular attention was paid to ensure

that the illuminance levels in the workspace adhered to the Standard. The reflection factors of surfaces, as well as the Color Temperature Index (CTI), should be considered to satisfy visual comfort conditions.

The selected luminaires with their technical data (specifications) are given in Table 4.1. The questionnaire was prepared and distributed to a group of office workers from various professions. Based on their feedback it was revised and redistributed to the targeted group. A total of 117 participants took part in the survey. Two statistical programs were used: Qualtrics (Qualtrics International Inc., 2024) was utilized for data collection, and Jamovi (Jamovi 2.3.28, 2024) was employed for the statistical analysis.

Table 4.1: Light Distribution, Technical Data (Specifications) of Selected LED Luminaires

Mounting Mode and Product Image		Light Distribution	Product Name	Technical Data			
PENDANT			2002.9399 - CHAN-SUP-BO PEN1250-1500 LED3840-830 DID DALI	P: 43.4 W Φ: 3840 lm CCT: 3000 K CRI: 90	P: 43.4 W Φ: 3840 lm CCT: 4000 K CRI: 90	P: 43.4 W Φ: 3840 lm CCT: 5000 K CRI: 90	P: 43.4 W Φ: 3840 lm CCT: 6000 K CRI: 90
SURFACE MOUNTED			2005.9924 - GEO4 CR596x596 CLD LED3600-830 WH ONF	P: 33.0 W Φ: 3600 lm CCT: 3000 K CRI: 90	P: 33.0 W Φ: 3600 lm CCT: 4000 K CRI: 90	P: 33.0 W Φ: 3600 lm CCT: 5000 K CRI: 90	P: 33.0 W Φ: 3600 lm CCT: 6000 K CRI: 90
SPOT			2009.2340 - VIVA DL CR155 LED1520-830105 WH DALI	P: 15.0 W Φ: 1520 lm CCT: 3000 K CRI: 90	P: 15.0 W Φ: 1520 lm CCT: 4000 K CRI: 90	P: 15.0 W Φ: 1520 lm CCT: 5000 K CRI: 90	P: 15.0 W Φ: 1520 lm CCT: 6000 K CRI: 90

4.2 The Participant Group

A total of 117 individuals participated in the survey, including 75 women and 42 men. Among the 75 women, 9 were aged 18-24, 35 were aged 25-34, 20 were aged 35-44, 10 were aged 45-54, and 1 was aged 55-64. Of the 42 men, 2 were aged 18-24, 13 were aged 25-34, 21 were aged 35-44, 6 were aged 45-54, and no participants were aged 55-64 (Figure 4.1).

The participants included 16 academics (12 women and 4 men), 29 administrative personnel and office managers (19 women and 10 men), 41 architects and designers (32

women and 9 men), 18 engineers (4 women and 14 men), and 13 individuals from other professions (8 women and 5 men).

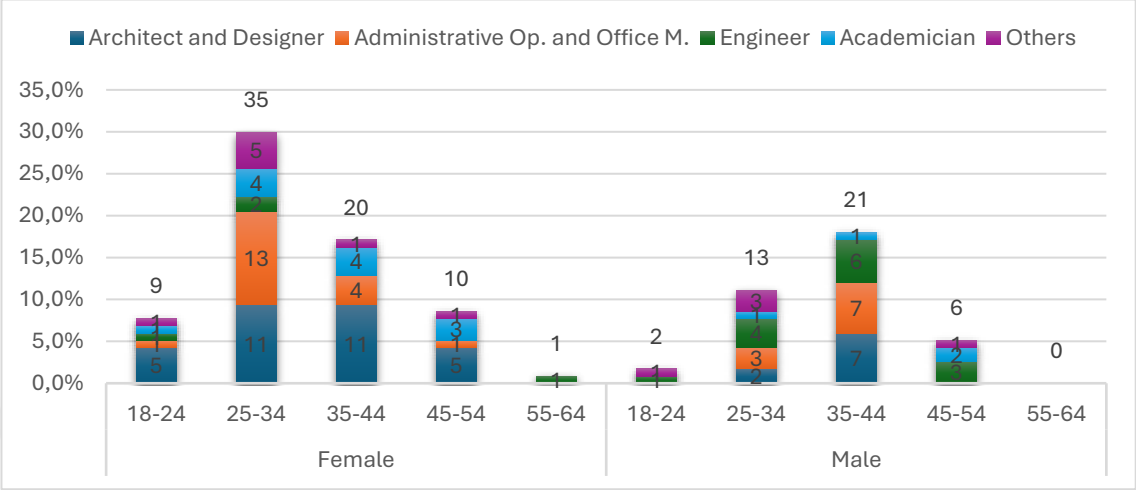


Figure 4.1: Demographic Data Distribution

4.3 The Simulation Programs

Different softwares were used in the process of creating the survey questions and visuals, collecting and analyzing the data collected.

4.3.1 Dialux Evo 12.0

Dialux Evo 12.0 (DIAL GmbH, 2024) is a professional lighting design software. In the research, indoor lighting scenarios were modelled to create visuals to be used in the survey questions based on an existing space. The program was used to create 18 different lighting scenarios. In each scenario:

- The CRI value is kept constant,
- The surface reflectance values are left unchanged,
- Furniture layout was kept constant .

The following values were assumed for the degree of reflection:

- Ceiling: 90.0% (r_c=0.90),
- Walls: 80.0% (r_w=0.80),
- Floor: 40.0% (r_f=0.40).

The following parameters have been changed:

- Kelvin (colour temperature)
- Illuminance (E),
- Luminance (L),
- Distribution of illuminance.

These scenarios were developed to analyse the visual impact of specific lighting conditions. In addition, the maintenance multiplier was set to 0.80 (maintenance factor) and the Unified Glare Rating (UGR) value for glare assessment was calculated as a maximum of 19, which is in line with the specified limit (UGR, max 19 ≤ 19).

The figures 4.2, 4.3 and 4.4 numerically show illuminance distribution on the working plane for different luminaires (surface mounted, spotlight and pendant light) in the office area designed in the program. In Appendix A1, luminaires selected in Dialux Files are given.

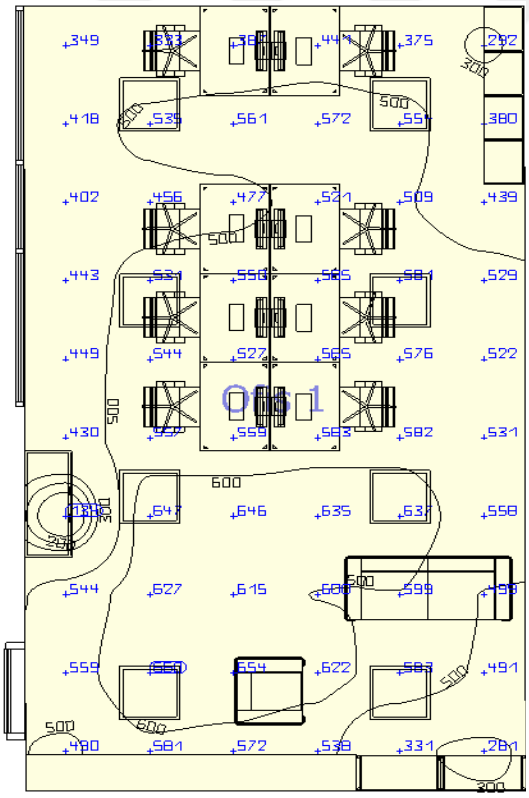


Figure 4.2: Illuminance distribution of surface mounted lighting

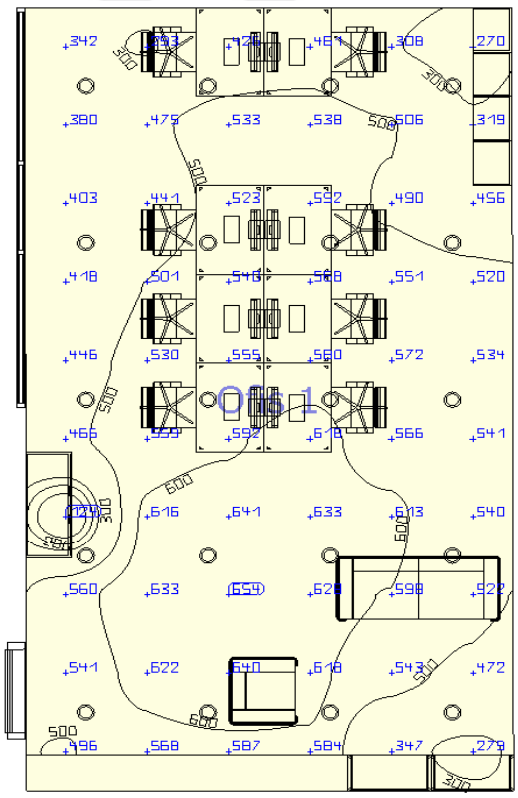


Figure 4.3: Illuminance distribution of spotlight

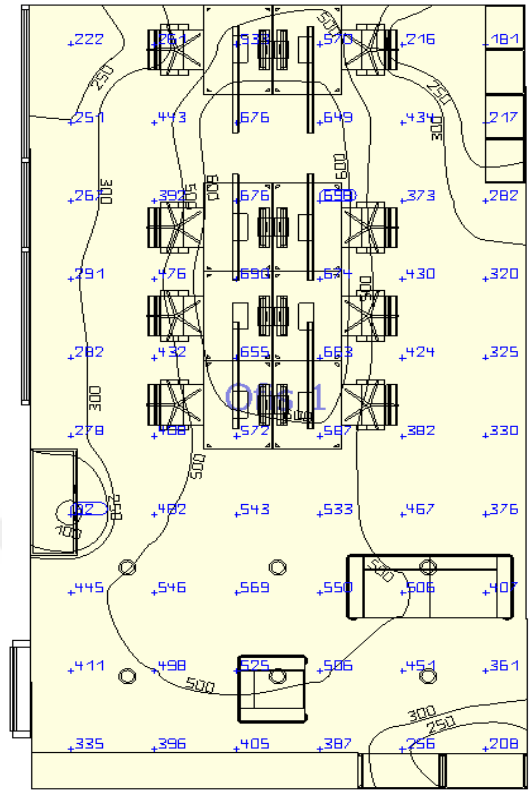


Figure 4.4: Illuminance distribution of pendant light

4.3.2 Qualtrics

Qualtrics (Qualtrics International Inc., 2024) is an online platform used for survey preparation, distribution and data collection. The questionnaire used in the research was designed on Qualtrics and presented to the participants online. Participants' access to the survey was provided through the links created, and all data was collected on this platform.

4.3.3 Jamovi 2.3.28

Jamovi 2.3.28 (Jamovi 2.3.28, 2024) is an open-source statistical analysis software widely used for data analysis in various research fields. It has gained increasing recognition in scientific research for its transparency, reproducibility, and user-friendly interface, and is frequently used in psychology, health sciences, education, and social sciences.

In this study, Jamovi was used to perform comprehensive analyses of the collected data. Its user-friendly interface and extensive statistical toolset enabled effective processing and interpretation of the data.

The analysis included various statistical methods such as chi-square tests to examine relationships between categorical variables and regression analyses to identify potential correlations between variables. In addition, contingency tables and frequency analysis were used to summarize and explore the distribution of the data.

Jamovi's visualization features played an important role in creating clear and illustrative representations of the results, including graphs and charts. In addition, the software was instrumental in generating well-structured tables, such as frequency tables and cross tabulations, which helped to present the analyzed data in an organized and comprehensible manner.

The combination of statistical analysis, data visualization and table creation made Jamovi an essential tool in this study, ensuring a thorough and reliable analysis of the research findings.

4.4 The Questionnaire

There are 15 questions which were designed to explore various aspects of office lighting, such as luminaire differences, lighting distribution variations, color temperature, and illuminance preferences. Additionally, factors such as office layout, work habits, daylight preferences, and the controllability of lighting systems were examined, as all of these are considered to influence participants' lighting choices. The survey investigates lighting preferences across different professional groups.

Furthermore, the survey also considers user-based factors like age, gender, and profession to understand how these demographics relate to lighting preferences in office spaces. Ultimately, the goal of the survey is to explore the relationship between various design parameters for Human-Centered Lighting (HCL) and how they align with user needs in modern office environments. The questionnaire can be found in Appendix A2.

5. RESULTS

Within the scope of this study, 8 hypotheses were determined, chi-square test was primarily used in the evaluation of the hypotheses, and regression and post-hoc analyses were performed when deemed necessary.

H1: Age, gender and profession significantly influence office layout preferences.
Following the initial questions about age, gender and profession, participants were asked about the type of office layouts in which they worked. The responses revealed a variety of office arrangements (Figure 5.1). Traditional closed offices are the most common, with 44 respondents (37.6%) working in them. This is followed by open-plan offices where 35 respondents (29.9%) work. Twelve respondents (10.3%) work in cubicle offices and eleven respondents (9.4%) work in team-based offices. Nine respondents (7.7%) reported working in mixed office layouts, while five respondents (4.3%) work from home offices. Finally, one respondent (0.9%) reported using the 'other' option. These results highlight the prevalence of traditional and open-plan offices among participants but also reflect a range of alternative office arrangements.

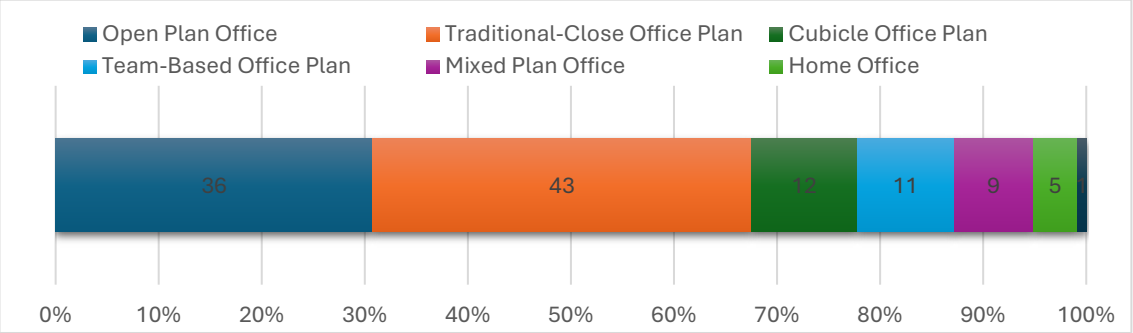


Figure 5.1: The Type of Offices

To assess this relationship, a Chi-Square test was carried out, yielding the following results: $x^2 = 24.7$, df = 24, and p-value = 0.425. As the p-value exceeds the 0.05 threshold, the analysis indicates that there is no statistically significant relationship between age groups and office layout preferences. This suggests that office layout preferences are not strongly influenced by the age groups represented in the study.

The results in Table 5.1 also show this:

- Traditional closed office plans (38.3%) are the most common overall, with a notable preference among participants aged 35-44 and 45-54.
- Open plan offices (29.9%) are the second most popular, particularly among the 25-34 age group.
- Cubicle offices (10.3%) and team-based office plans (9.4%) are moderately popular, while mixed-plan offices (8.5%) and home offices (4.3%) are less common.
- The 'other' category (0.9%) represents a very small proportion of respondents, indicating minimal use of alternative office layouts.

Table 5.1: Age and office layout preferences

Office Layout	**18-24**	**25-34**	**35-44**	**45-54**	**55-64**	**Total**
Cubicle Office Plan	1	5	2	4	0	10.3%
Home Office	0	3	1	1	0	4.3%
Mixed Plan Office	0	2	5	2	0	8.5%
Open Plan Office	6	18	10	1	0	29.9%
Team-Based Office Plan	0	6	5	0	0	9.4%
Traditional-Close Office Plan	4	13	18	8	1	38.3%
Other	0	1	0	0	0	0.9%

The relationship between office layout and gender was further explored following the analysis of age and office layout. The results of both the chi-square test and the likelihood ratio test show a significant relationship between office layout preferences and gender, with a p-value < 0.05 (Table 5.2). This suggests that preferences for different office layouts vary significantly by gender.

Further analysis using Fisher's Exact Test confirmed this relationship with a p-value of 0.027, supporting the significance of gender differences in office layout preferences. In addition, the Cramer's V value of 0.346 indicates a moderate relationship between gender and office layout preferences, suggesting that gender has a moderate impact on the type of office layout selected by participants.

Table 5.2: Chi-Squared Test Results for office layout and gender

Analyses	Value	Test	p-Value
χ^2 Test	14.0	Chi-Square	0.030
Likelihood Ratio	14.1	Likelihood Ratio Test	0.028
Fisher's Exact Test	-	Fisher's Exact Test	0.027
Cramer's V	0.346	Cramer's V	-

Given the significant result, a multinomial logistic regression test was conducted as a secondary analysis to further examine the impact of gender on office organization preferences. According to the values given in Table 5.3:

- Men are significantly more likely to work in a Cubicle Office layout compared to a Traditional-Closed Office layout ($p = 0.005$). This indicates that women are less likely to work in the Cubicle Office layout and that this layout is more preferred by men.
- In terms of Home Office, Mixed Plan Office, Open Plan Office, Team Based Office and other layouts, no significant difference was found between genders when compared to Traditional-Closed Office. However, women tend to work in Home Office, Mixed Plan and Open Plan organizations. Although these preferences are observed, they are not statistically significant.
- In general, women exhibit a balanced preference for Traditional-Closed Office and Open Plan Office layouts, while men have a strong preference for working in the Cubicle Office layout.

Table 5.3: Multinomial Logistic Regression for office layout and gender

Comparison	Gender Odds Ratio	p-value
Cubicle Office Plan -Traditional-Close Office Plan	106.973	0.005
Home Office - Traditional-Close Office Plan	0.5360	0.592
Mixed Plan Office - Traditional-Close Office Plan	10.718	0.929
Open Plan Office - Traditional-Close Office Plan	0.8572	0.755
Other - Traditional-Close Office Plan	1.13e−4	0.947
Team-Based Office Plan -Traditional-Close Office Plan	12.249	0.774

Lastly, the relationship between occupation and office layout was examined. The chi-squared test applied to understand the relationship between office layout and profession. Since the p-value (0.006) is less than 0.05, there is a statistically significant relationship between occupational groups and office layout preferences, and Cramer's V (0.310) value shows that this relationship is at a moderate level (Table 5.4).

Table 5.4: Chi-Squared Test Results for office layout and profession

Tests	Value	df	p
χ^2	44.9	24	0.006
Likelihood ratio	41.9	24	0.013
Cramer's V	0.310		

To better understand this relationship, a multinomial logistic regression test was applied as a secondary analysis. Table 5.5 shows the significant values that emerged as a result of the analysis:

- Engineers are more likely to prefer a Cubicle Office layout compared to a Traditional-Close Office layout ($p = 0.058$), but this result is not statistically significant. This suggests that engineers may lean towards working in Cubicle Offices more than academics, though this preference is not strongly supported by the data.
- In terms of Home Office layout, no significant difference was found between Others and Academicians ($p = 0.173$). While the data suggests that Others may slightly prefer Home Offices over Traditional-Close Offices, this difference is not statistically meaningful.
- Architects and Designers are significantly more likely to prefer a Mixed Plan Office layout compared to a Traditional-Close Office layout ($p < 0.001$). This indicates a strong preference for Mixed Plan Offices among Architects and Designers relative to Academicians.
- Others are significantly more likely to prefer an Open Plan Office layout compared to a Traditional-Close Office layout ($p = 0.038$). This shows that Open Plan Offices are a more popular choice among Others when compared to Academicians.

- Architects and Designers are significantly less likely to prefer an "Other" layout compared to a Traditional-Close Office layout ($p < 0.001$). This indicates that this layout is strongly disfavored by Architects and Designers relative to Academicians.
- Administrative Operations and Office Managers are significantly more likely to prefer a Team-Based Office layout compared to a Traditional-Close Office layout ($p < 0.001$). This highlights a strong preference for Team-Based Offices among this group relative to Academicians.
- Overall, Academicians tend to exhibit a balanced preference for Traditional-Close Offices, while specific professional groups such as Architects, Designers, and Administrative Managers show distinct and significant preferences for alternative layouts like Mixed Plan and Team-Based Offices.

Table 5.5: Multinomial Logistic Regression for office layout and profession

Comparison	Odds Ratio	P-Value
Cubicle Office Plan - Traditional-Close Office Plan	9.42574 (Engineer - Academician)	0.058
Home Office - Traditional-Close Office Plan	11.00210 (Others - Academician)	0.173
Mixed Plan Office - Traditional-Close Office Plan	2.61e+12 (Architect and Designer - Academician)	<0.001
Open Plan Office - Traditional-Close Office Plan	14.66781 (Others - Academician)	0.038
Other - Traditional-Close Office Plan	0.01923 (Architect and Designer - Academician)	<0.001
Team-Based Office Plan - Traditional-Close Office Plan	8.00e+12 (Administrative Op. and Office M. - Academician)	<0.001

H2: Age, gender and profession significantly influence the perception of daylight adequacy in the workspace.

Participants were asked whether they had access to daylight in their offices and, if so, whether it was sufficient or not. Accordingly, 62 out of 117 participants stated that they utilized daylight in their workspaces and that it was sufficient (Table 5.6). Among them, 33 were women and 29 were men. 42 people stated that they benefit from daylight in their offices, but it is not sufficient. Among them, 33 are female and 9 are male. Finally, 13 people, 9 women and 4 men, stated that there is no daylight in their workspaces.

Table 5.6: Perception of daylight sufficiency in workspaces by gender

Daylight in Work Spaces		Female	Male	Total
No.	Observed	9	4	13
	Expected	8.33	4.67	13.0
Yes, it is not sufficient.	Observed	33	9	42
	Expected	26.92	15.08	42.0
Yes, it is sufficient.	Observed	33	29	62
	Expected	39.74	22.26	62.0

The chi-squared test was conducted separately to assess the relationships between age and daylight sufficiency, and profession and daylight sufficiency. The results show no statistically significant relationship between age and daylight availability or sufficiency ($p = 0.598$). Similarly, the p-value ($p = 0.598$) indicates no significant relationship between profession and adequacy of daylight in the workplace.

However, when the Chi-square test was used to analyze the relationship between daylight adequacy and gender, it was found that there was a relationship between gender and daylight adequacy, albeit a weak and moderate one (Table 5.7).

Table 5.7: Chi-Squared Test Results for daylight sufficiency and demographic data

Tests	Value	df	p
χ^2	7.16	2	0.028
Likelihood ratio	7.38	2	0.025
Fisher's exact test			0.027
Cramer's V	0.247		

Based on the observed and expected values (Table 5.6), there is a notable difference between men and women regarding the adequacy of daylight in the workplace:

- The observed value for men in the "Yes, it is sufficient" category is higher than the expected value, indicating that men are more likely to report having sufficient daylight in their work environment.
- In contrast, the observed value for women in the "Yes, it is not sufficient" category is much higher than the expected value, while the observed value for men in this

category is lower than expected. This suggests that women are more likely to report insufficient daylight.

From this analysis, the following conclusions can be drawn:

- Women may place greater importance on the availability and adequacy of daylight in their workspaces compared to men. This could reflect a heightened sensitivity or preference for natural light, influencing their perceptions and expectations of workplace lighting conditions.
- Women are more likely to work in environments with insufficient daylight, while men are more likely to be in environments with sufficient daylight. This indicates that workplace light conditions may vary by gender.
- Women are more inclined to perceive daylight as insufficient in the workplace, whereas men are more inclined to perceive it as sufficient. This highlights a potential gender-based difference in the perception of natural light adequacy in workspaces.

H3: Age, gender and profession significantly preferences for lighting control systems.

It was intended to understand if the participants have the opportunity to control the lighting system or not. As seen in Table 5.8, most responses regarding the control of lighting in work areas fall under the 'Yes' option, meaning that they have control over the lighting system. Among women, the most notable group is those aged 25-34 in the profession of administrative operations and office management, with a rate of 8.5%. This is followed by women in the same age group in the profession of architects and designers, with a rate of 6%. For male respondents, the highest concentration is in the 35-44 age group, with a notable presence in both the Administrative Operations & Office Management and Architect & Designer occupations, each contributing 6%.

Table 5.8: Demographics distribution in lighting system control preferences

Controlling Lighting System	Age	Gender	Proffesion	Total
No	18-24	Female	Architect and Designer	1.7 %
	25-34	Female	Administrative Op. and Office M.	2.6 %
			Architect and Designer	3.4 %
	35-44	Female	Architect and Designer	4.3 %
		Male	Engineer	1.7 %
		Male	Engineer	1.7 %
Yes	18-24	Female	Architect and Designer	2.6 %
	25-34	Female	Academician	3.4 %
			Administrative Op. and Office M.	8.5 %
			Architect and Designer	6.0 %
			Others	4.3 %
		Male	Administrative Op. and Office M.	1.7 %
			Engineer	2.6 %
			Others	1.7 %
	35-44	Female	Academician	3.4 %
			Administrative Op. and Office M.	2.6 %
			Architect and Designer	5.1 %
		Male	Administrative Op. and Office M.	6.0 %
			Architect and Designer	6.0 %
			Engineer	3.4 %

Chi-squared tests were performed separately for age, gender and profession variables to examine relationships with the lighting control system. The analyses showed marginal significance between age and lighting control systems ($p = 0.050$). However, this result indicates that age does not have a strong effect on lighting control and therefore further analysis is not considered necessary.

No statistically significant relationship was found between gender and lighting control ($p = 0.734$), indicating that gender has no significant effect on lighting control. On the other hand, a statistically significant relationship was found between occupation and lighting

control (p = 0.013, Cramer's V = 0.329). This result indicates that occupation has a moderate effect on lighting control. Post-hoc analysis was applied as a second test to examine this relationship (Table 5.9).

Table 5.9: Results of post-hoc analysis of lighting control by profession

Comparison	χ^2	p-value	Adjusted p-value
Academician vs Administrative Op. and Office M.	1.603	0.205	1.000
Academician vs Architect and Designer	4.301	0.038	0.381
Academician vs Engineer	8.463	0.004	0.036
Academician vs Others	3.416	0.065	0.646
Administrative Op. and Office M. vs Architect	0.762	0.383	1.000
Administrative Op. and Office M. vs Engineer	4.240	0.039	0.395
Administrative Op. and Office M. vs Others	0.338	0.561	1.000
Architect and Designer vs Engineer	1.528	0.216	1.000
Architect and Designer vs Others	0.000	1.000	1.000
Engineer vs Others	0.493	0.483	1.000

The observed value for engineers in the "No" category is significantly higher than the expected value, suggesting that engineers are less likely to control the lighting system in their work environment. In contrast, the observed value for academicians in the "Yes" category is higher than the expected value, indicating that academicians are more likely to have control over the lighting system in their workspace.

H4: The types of lighting used in the office environment of the employees do not significantly overlap with the preferences in their personal workspaces.

Participants were asked to define the lighting types currently used in their offices and their preferred lighting types in their personal workspaces. The aim was to understand the extent to which the current lighting system is in line with personal preferences and needs, and what types of lighting fixtures are preferred. Figure 5.2 shows that, surface-mounted light is the most preferred one with a range of 45.71% in both workspaces and 27.58% in personal workspaces. This is followed by pendant and spot lighting. Among the binary combinations, the pendant-table lamp combination is preferred by 19.35% and

28.57% in both cases. Among the triple combinations, the pendant light - wall lamp - spot light and pendant light - floor lamp - desk lamp are the most frequently used combinations in offices, while the pendant light - spot light - surface light and other combinations are less preferred. In the personal work area, the pendant-floor lamp-table lamp combination has increased significantly, while the pendant-spot lamp-surface lamp and other combinations have changed. The quartile combinations are significantly the lowest.

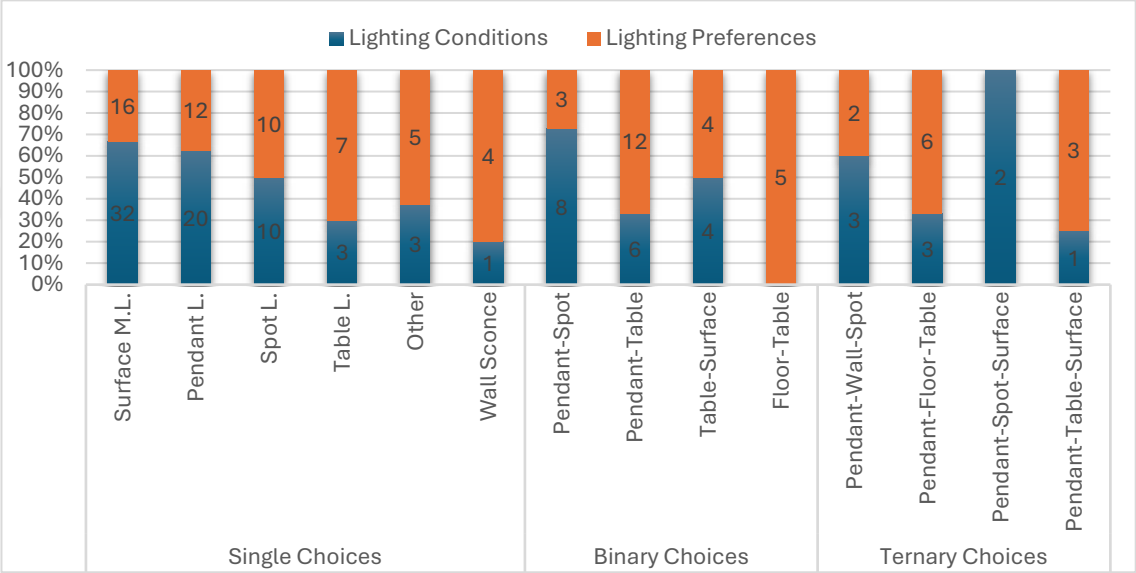


Figure 5.2: Lighting Conditions and Lighting Preferences at Workplaces

H5: Workers most often encounter lighting-related problems such as dark spots, glare and shiny surfaces in their work areas.

In the tenth question, the participants were asked whether they experienced any lighting-related problems in their workspaces. As can be seen in Figure 5.3, Dark Spot, Glare and Shiny Surface are among the most frequently encountered problems with 15 times each (12.8%). These problems are followed by Shadow (9 times, 7.7%) and Daylight (7 times, 6%). Looking at the binary choices, the combination of Shiny Surface and Glare (7 times, 6%) stands out. This combination is followed by the category formed by adding Shadow (6 times, 5.1%) to the Dark Spot problem.

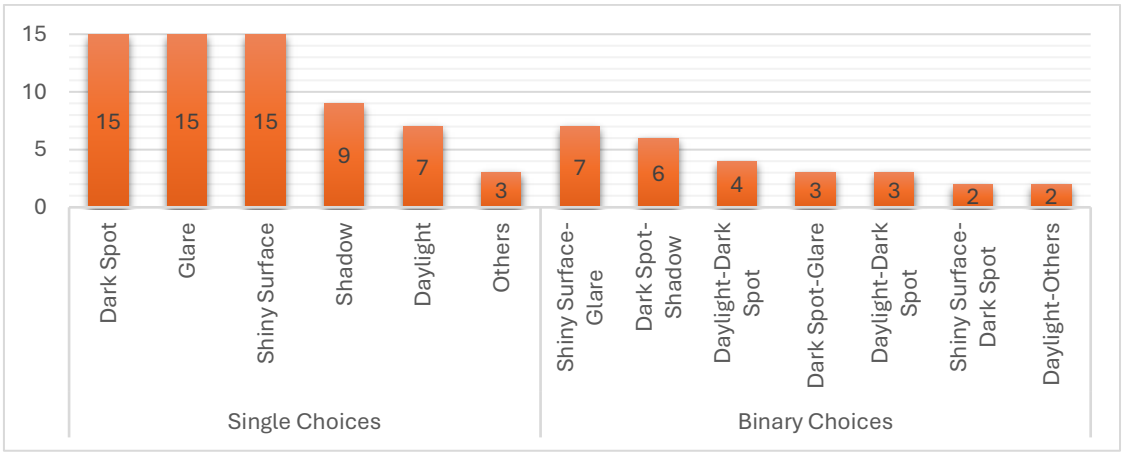


Figure 5.3: Distribution of lighting-related issues in workspace

H6: Gender significantly influences preferences of color temperature.

The participants were also asked to evaluate their color temperature preferences for 3000K, 4000K, 5000K and 6000K regarding different luminaire types (surface mounted lighting, spotlight and pendant light) on rendered office images. Figure 5.4 shows distribution of the results including gender, color temperature and luminaire types. According to responses, 5000K was the most preferred color temperature value in all three questions with 43.6%, 43.6% and 39.3% respectively. Additionally, 3000K was the second most preferred option with 34.2%, 31.6%, and 35.0% in each category. 4000K was chosen by 15.4%, 18.8%, and 19.7% of respondents, making it a moderately popular choice. 6000K was the least preferred color temperature across all three categories, with 6.8%, 6.0%, and 6.0% respectively.

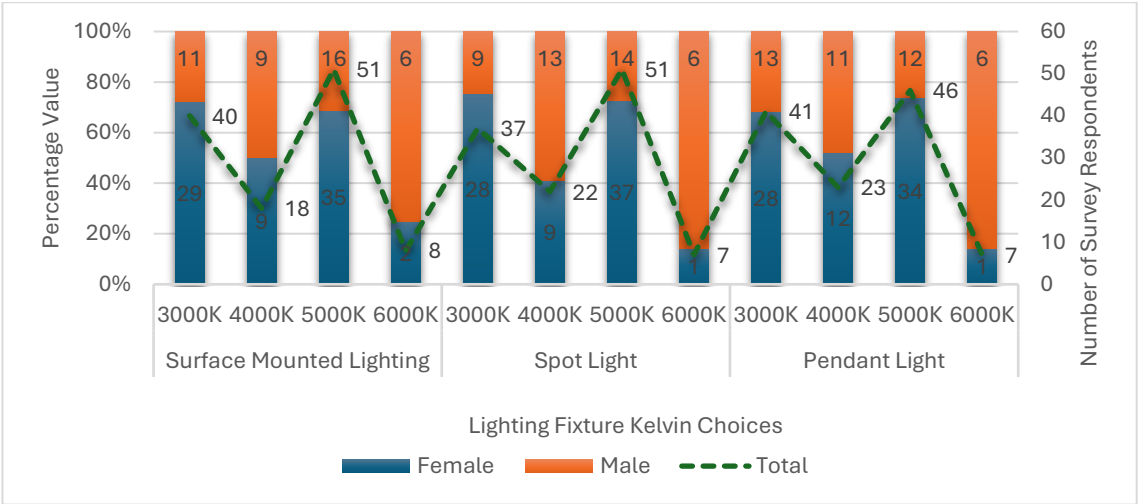


Figure 5.4: Color temperature, lighting types and gender relationship

Table 5.10 summarizes the results of the Likelihood Ratio test, Fisher's Exact test and three different Chi-square (χ^2) tests that were run for examining the relationship between gender and preferred color temperature values (3000K, 4000K, 5000K, 6000K) across different lighting types (surface mounted, spot and pendant). The results show that there is a statistically significant relationship between gender and lighting type preference ($\chi2=16.4$, df=3, $p<0.01$) and ($\chi2=11.2$, df=3, $p<0.01$). Women generally prefer lower and medium color temperature values (3000K, 5000K), while men tend to prefer higher color temperature values (6000K). This trend is observed across all three lighting types; however, the differences are particularly pronounced in preferences for spotlight.

Table 5.10: Statistical analysis of lighting fixture types

	Surface Mounted	**Spotlight**	**Pendant Light**
χ^2	$p = 0.036$ (value $= 8.55$, df $= 3$)	$p < 0.001$ (value $= 16.4$, df $= 3$)	$p = 0.011$ (value $= 11.2$, df $= 3$)
Likelihood Ratio Testi	$p = 0.040$ (value $= 8.31$)	$p = 0.001$ (value $= 16.3$)	$p = 0.011$ (value $= 11.2$)
Fisher's Exact Test	$p = 0.039$	$p = 0.001$	$p = 0.012$

After the chi-square test data, post-hoc test was applied (Table 5.11). According to the results of this analysis, women significantly prefer 3000K more than men in all lighting types, particularly in surface-mounted and pendant lighting. Men, on the other hand, have a significantly higher preference for 6000K, especially in spotlight and pendant light types. For 4000K and 5000K preferences, no significant gender differences were observed across lighting types. However, across all lighting types, 5000K emerges as the most preferred option overall.

Table 5.11: Multinomial logistic regression analysis of color temperature preferences by lighting types

Lighting Type	Comparison	Adjusted p-value
Surface-Mounted	6000K (Male vs. Female)	< 0.001
	4000K (Male vs. Female)	0.254
Spotlight	6000K (Male vs. Female)	< 0.001
	4000K (Male vs. Female)	0.020
Pendant Light	6000K (Male vs. Female)	< 0.001
	4000K (Male vs. Female)	0.251

H7: Age, gender and profession data significantly influences preferences of luminaire.

The participants were asked about their luminaire preferences based on fixed kelvin degrees. Chi-square test was applied to evaluate whether there is a statistical relationship between these preferences and demographic variables such as age, gender and occupation (Table 5.12). According to the results of the analyses, age and occupation variables were found to have a statistically significant relationship with luminaire preference. However, gender has no statistically significant effect on luminaire preference.

Table 5.12: Chi-Squared test results for lighting fixture choices by age, gender and profession

Variable	χ^2 Value	Degrees of Freedom (df)	p-value
Age	16.5	8	0.035
Gender	1.10	2	0.576
Profession	17.6	8	0.025

To better understand the relationship between age and occupation with this choice, a post-hoc analysis was used as a secondary test (Table 5.13). According to the results:

- The 25-34 age group prefers spotlights significantly more than the 18-24 age group.
- The 45-54 age group prefers surface-mounted lighting significantly more than the 25-34 age group.
- There is no statistically significant difference in preference for pendant lighting between the 35-44 and 55-64 age groups, although the difference is marginal ($p = 0.062$).

- There is a statistically significant difference between 'Academicians' and 'Administrative Operations and Office Management' in terms of choice of luminaire (adjusted p = 0.026). This indicates that these two groups have different preferences for luminaires.

Table 5.13: Multinomial logistic regression analysis of lighting fixture choices by demographic predictors

Comparison	p-value	Adjusted p-value
Academician vs. Administrative Op. and Office M.	0.009	0.026
Academician vs. Architect and Designer	0.072	0.216
Academician vs. Engineer	0.121	0.363
Academician vs. Others	0.142	0.426
Administrative Op. and Office M. vs. Architect and Designer	0.054	0.162
Administrative Op. and Office M. vs. Engineer	0.083	0.249
Administrative Op. and Office M. vs. Others	0.069	0.207
Architect and Designer vs. Engineer	0.098	0.294
Architect and Designer vs. Others	0.111	0.333
Engineer vs. Others	0.077	0.231
25-34 (Spotlight)	0.043	0.043
45-54 (Surface Mounted Lighting)	0.038	0.038
55-64 (Pendant Light)	0.062	0.062

H8: Age, gender and profession significantly influence preferences of illuminance.

In the last question, participants were asked to rate the preferred illuminance based on the 3D model renderings where the lighting fixture is constant. It was recorded that the most preferred illuminance was 500 lx with a range of 39.31%, followed by 750 lx with a range of 36.75%. While women's preference was concentrated at 500 lx with a range of 44%, men preferred 750 lx with a range of 47.61% (Figure 5.5).

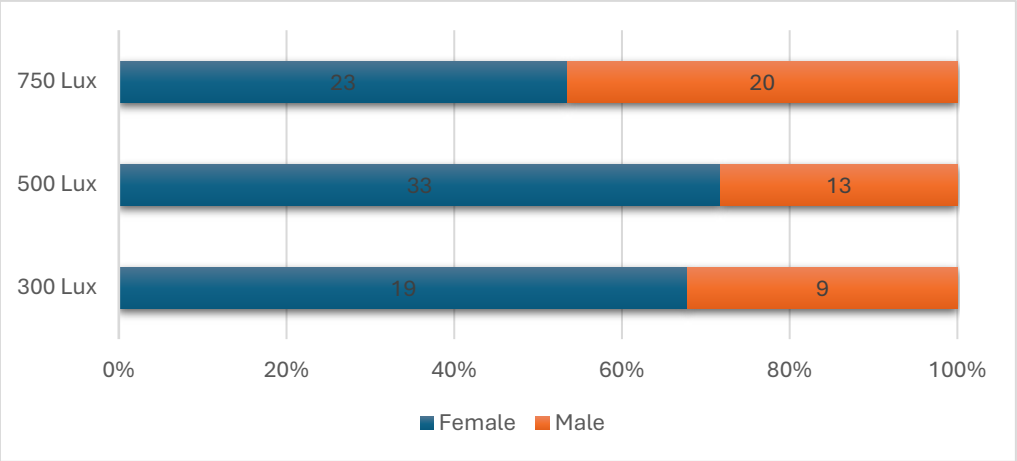


Figure 5.5: The Illuminance Preferences

Table 5.14 presents a frequency table for age, gender, and profession. Based on the data:

- The 300 lx is primarily favored by younger respondents aged 18-44, particularly those aged 25-34, with women showing a stronger preference for Administrative and Office Management and Architect and Designer roles.
- 500 lx emerges as the most popular choice overall, particularly among 25-34 year olds. While both genders prefer this lighting level equally, preferences are higher in Administrative and Office Management and Architect and Designer occupations.
- 750 lx is preferred by older respondents (45-64), who are predominantly men working in technical fields such as engineering. This preference increases with age and reflects the need for brighter lighting for detailed or precision work.
- Younger individuals (18-34) favor 300 lx and 500 lx, while older respondents (45-64) favor 750 lx, possibly due to different visual needs. Despite these trends, no statistically significant relationship was detected.

Table 5.14: Frequency table of illuminance preferences and age, gender and profession

Choices of Lighting Levels	Age	Gender	Profession	Counts	% of Total
300 Lux	18-24	Female	Architect and Designer	1	0.9%
	25-34	Female	Administrative Op. and Office M.	6	5.1%
	25-34	Female	Architect and Designer	2	1.7%
	25-34	Male	Administrative Op. and Office M.	1	0.9%
	35-44	Female	Academician	1	0.9%
	35-44	Male	Architect and Designer	2	1.7%
500 Lux	18-24	Female	Architect and Designer	2	1.7%
	25-34	Female	Administrative Op. and Office M.	6	5.1%
	25-34	Female	Architect and Designer	5	4.3%
	25-34	Male	Architect and Designer	1	0.9%
	35-44	Female	Architect and Designer	7	6.0%
750 Lux	25-34	Female	Architect and Designer	4	3.4%
	25-34	Male	Architect and Designer	1	0.9%
	35-44	Female	Architect and Designer	3	2.6%
	45-54	Male	Engineer	2	1.7%
	55-64	Male	Engineer	1	0.9%

6. DISCUSSION

Hypothesis 1

After the analysis, it was seen that there is a relationship between gender and office layout. It was observed that women's workspaces are mostly open and traditionally planned offices, while men mostly work in cubicle-planned offices. Christina Bodin Danielsson and Töres Theorell's (2018) study showed that women prefer collaborative, and men prefer individual workspaces. This is in line with our findings.

In another analysis, no significant relationship was found between age and office layout preferences. On the other hand, Haynes et al. (2017) found that older employees evaluated office environments more positively in terms of productivity, while younger employees' positive perceptions of the advantages of open-plan offices decreased over time. This contrast suggests that age-related preferences may be more context-dependent and shaped by organizational culture and spatial demands, as also discussed in recent studies emphasizing the need for further investigation into age-layout relationships (Haynes et al., 2017).

Hypothesis 2

There is a relationship between gender and daylight adequacy. Women were more likely to rate daylight in their workspace as inadequate, while men tended to rate daylight as adequate. Research shows that women are more sensitive to lighting conditions and this affects their satisfaction (Dosumu & Aigbavboa, 2019; Kim et al., 2013). Men are more likely to turn on artificial lights when they feel hot or cold, while women use less artificial light in these situations (Andersen et al., 2009). Also, women are more inclined to open windows in response to the perception of brightness, while men are less affected by these conditions (Psomas et al., 2024).

These findings are also supported by recent studies showing that women more often perceive daylight as insufficient and associate natural light with comfort and emotional

well-being, whereas men focus more on task-related visual sufficiency (Chellappa et al., 2017; Haselsteiner, 2021).

Hypothesis 3

There is a significant relationship between occupation and the presence/preference of lighting control systems. According to the results of the analysis, the Academics group almost never uses lighting control systems. On the other hand, the Architect and Designer group stands out as the occupational group that uses these systems the most, and the observed and expected values are in line. In the Engineers group, the number of those who do not use these systems is higher than expected. These findings show that occupational groups are a determining factor in the use of lighting control systems. Customizing lighting designs according to occupational needs can increase the effective use of these systems and improve user satisfaction.

In addition, the literature emphasizes the importance of dynamic lighting systems in windowless environments, showing that adjusting illuminance and color temperature throughout the day enhances circadian alignment, well-being, and productivity (Huang et al., 2020). Incorporating tunable lighting systems that replicate the rhythm of natural daylight is suggested as a viable strategy to support psychological and physiological needs in office environments (Sithravel & Ibrahim, 2021; van Duijnhoven et al., 2019).

Hypothesis 4

The analysis reveals a partial overlap in lighting preferences. Surface-mounted lighting is the most preferred type in offices (45.71%) but less common in personal spaces (27.58%). Personal workspaces favor more layered combinations such as pendant-floor lamp-table lamp, while offices tend towards simpler installations. Complex quadrant combinations remain the least used combinations in both environments, emphasizing the different needs and preferences between the two environments. Although there are several studies on lighting control in this area, there is no study directly addressing luminaire preferences.

Recent research also highlights that layered lighting systems are more appreciated in personal settings for their flexibility and ability to create ambiance. Meanwhile, younger individuals (25–34) were more likely to prefer surface-mounted luminaires, while older adults (55–64) favored spotlighting due to its task-specific advantages (Haselsteiner, 2021). Interestingly, gender was not found to be a significant factor in luminaire preference, indicating that design preferences are driven more by functional and occupational requirements than by demographic identity (Boyce et al., 2006).

Hypothesis 5

The findings reveal that dark spots, glare, and shiny surfaces are the most common lighting issues (12.8% each), followed by shadows (7.7%) and daylight problems (6%). Binary combinations, such as shiny surface and glare, further highlight the impact of these conditions. Literature supports these findings, with studies emphasizing the adverse effects of glare and shiny surfaces on comfort and productivity. The Canadian Centre for Occupational Health and Safety (CCOHS) highlights that glare can be mitigated through proper light placement and matte finishes. Similarly, poor lighting conditions, including glare and uneven illumination, have been associated with visual fatigue, headaches, and decreased satisfaction (Sithravel & Ibrahim, 2021; van Duijnhoven et al., 2019). Incorporating ergonomic lighting solutions and user-adjustable systems is essential for optimizing both health and performance in the workplace.

Hypothesis 6

According to the literature (Huang et al., 2020), the color temperature preference can vary according to the physical characteristics of the space/object (illuminance, color characteristics of illuminated objects etc.) and the user's background (regional or cultural differences). Gender emerges as an important factor in color temperature preference. Men prefer higher color temperatures (6000K) in all lighting types, while women prefer medium and low temperatures (3000K and 5000K). These findings are consistent with studies showing that women prefer warmer tones for comfort, while men associate cooler tones with productivity (Chellappa et al., 2017; Haselsteiner, 2021). Furthermore, younger and middle-aged groups (25-44) prefer higher temperatures, while older individuals (55-64) prefer warmer tones. This is in line with the literature where aging is

associated with decreased sensitivity to blue-enriched light (Wright et al., 2004). Additionally, according to responses, 5000K was the most preferred color temperature value in all three questions with 43.6%, 43.6% and 39.3% respectively. Contrary to our data, Shamsul et al. and Kang et al. (Kang et al., 2013; Shamsul et al., 2013) suggested that 4000K was preferred as the most comfortable value among 3000K, 4000K and 6500K.

Hypothesis 7

The results reveal age-specific lighting element preferences. While the 55-64 age group prefers spot lighting more, the 25-34 age group prefers surface mounted lighting more. While there is a significant tendency towards pendant lighting among individuals in managerial positions and architects, this difference is not statistically significant. The lack of a significant effect of gender on lighting preferences reveals that individual needs and professional requirements are more determinant in these preferences.

These findings are consistent with literature that suggests lighting selection is strongly influenced by task specificity and control needs rather than gender (Boyce et al., 2006; Haselsteiner, 2021). Preferences for layered lighting systems also reflect the demand for flexibility and adaptability in modern work environments.

Hypothesis 8

Previous studies have measured sensitivity to light and brightness (Knez and Kers, 2000; Chellappa et al., 2017; Cirrincione et al., 2018), revealing a relationship with gender, which is further supported by Haselsteiner's results (2021). According to these results, men had higher brightness perception and faster reaction times in tasks requiring attention under blue-enhanced light. And this difference between men and women was observed even under very low illuminance, such as 40 lx. The authors found that women preferred light at 2500 K (87.5%) compared to 6500 K (12.5%), while the opposite was observed in men (6500 K - 62.5%, 2500 K -37.5%) (Chellappa et al., 2017).

The results showed that there are gender differences in brightness perception and light preference (Haselsteiner, 2021). These results are aligned with the findings of our

research. Women's preference for 500 lx and men's preference for 750 lx is consistent with gender sensitivity to brightness. Women prefer lower illuminance for comfort and men prefer higher levels for focus (Boyce et al., 2006). Moreover, higher illuminance levels (750–1000 lx) were also found to support non-visual responses such as alertness and well-being in windowless environments (Huang et al., 2020), reinforcing the relevance of tailoring lighting to both visual and biological needs.

7. CONCLUSION

This study highlights the essential role of demographic characteristics in shaping workplace lighting preferences, emphasizing the need for adaptable and user-centered lighting solutions. The findings underscore that age, gender, and professional background influence not only illuminance and color temperature preferences but also engagement with lighting control systems and luminaire choices. These insights offer valuable guidance for optimizing office lighting design to enhance employee comfort, satisfaction, and productivity.

To create more inclusive and efficient work environments, future lighting strategies should prioritize flexibility and personalization, allowing users to adjust lighting conditions according to their needs. Implementing dynamic and responsive lighting systems can bridge the gap between standardized office lighting and individual preferences, particularly in diverse professional settings. Furthermore, fostering a balance between task-specific functionality and personal comfort will contribute to a more adaptable and user-friendly workplace.

Limitations of the study include the dependence on rendered images to assess lighting preferences, and potential inconsistencies caused by screen variations due to the digital distribution of the survey. It was not possible to have a complete control of the lighting conditions of the room in which participants completed the survey, as well as the color calibration of their reproduction devices, personal laptops.

Beyond immediate design implications, this study also opens avenues for further research. Future studies should explore the long-term effects of tailored lighting on employee well-being, cognitive performance, and job satisfaction. Additionally, investigating the psychological and physiological impacts of lighting variations could provide deeper insights into optimizing work environments. By integrating these

considerations, office lighting designs can evolve into more sustainable, responsive, and productivity-enhancing systems, ultimately benefiting both employees and organization.

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APPENDIX A

A.1 Luminaires used in Dialux Evo

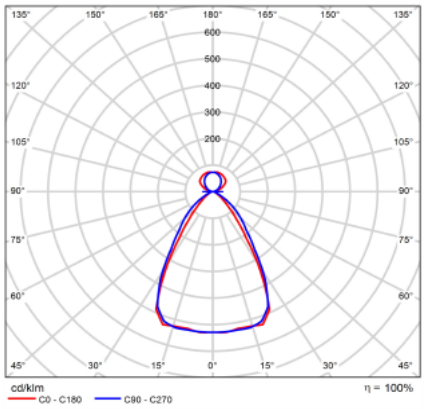
Ürün bilgi föyü

Regent - Pendant luminaire Channel S Up Boost Office 37W 3840lm CRI

REGENT LIGHTING

Ürün No.	2002.9399 - CHAN-S-UP-BO PEN1250-1500 LED3840-830 DID DALI
P	43.4 W
Φ_{Lamba}	3840 lm
$\Phi_{Işıklık}$	3844 lm
η	100.10 %
Işık verimi	88.6 lm/W
CCT	3000 K
CRI	90

Pendant luminaire Channel S Up Boost Office with LED, system power: 37 W, standby power 0.5 W, luminous flux of luminaire 3840 lm, colour rendering index CRI >80, 3000 K, warm white, colour tolerances SDCM 2, lifetime LED L80 50'000 h, office-compatible and glare-free according to EN 12464-1 (UGR < 19; Lmax ≥ 65° ≤ 3000 cd/m²), 230 V, direct-indirect light emission housing in aluminium natural-colour anodised, Boost optics, for an LED-optimised office-suitable and highly aesthetic grid optics made of high-grade plastic, 1 integral control gear, DALI, with halogen-free wiring, Boost optics with LED-specific optics and design.
Office-compatible and glare-free according to EN 12464-1 (UGR < 19 and Lmax> 65°< 3000 cd/m2) without direct view of the LED thanks to satined primary optics and louvre optics in low gloss, with unrestricted light quality.
Regent certified MINERGIE®-Modul luminaires S.A.F.E. 2019 (Re-0300), luminaire complies with the strict requirements for Minergie-certified luminaires protection class I, ingress protection IP20, glow wire test 650 °C, impact strength: IK 08, service temperature range -5 to +30 °C, this product contains a light source of energy



Polar LDC

UGR'ye göre kamaşma değerlendirmesi

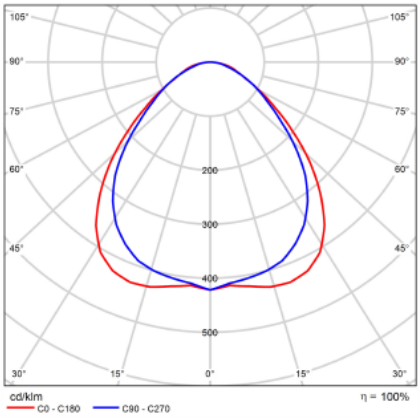
ρ Tavan	70	70	50	50	30	70	70	50	50	30
ρ Duvarlar	50	30	50	30	30	50	30	50	30	30
ρ Zemin	20	20	20	20	20	20	20	20	20	20
Oda büyüklüğü X Y	Bakış yönü enlemesine Lamba eksenine					Bakış yönü boylamasına Lamba eksenine				
2H 2H	15.3	16.1	15.8	16.6	17.3	17.4	18.2	18.0	18.8	19.4
3H	15.3	16.0	15.9	16.6	17.3	17.5	18.2	18.1	18.8	19.5
4H	15.3	15.9	15.9	16.5	17.2	17.5	18.1	18.1	18.8	19.4
6H	15.2	15.8	15.9	16.5	17.2	17.4	18.0	18.1	18.7	19.4
8H	15.2	15.8	15.8	16.4	17.1	17.4	18.0	18.0	18.6	19.3
12H	15.1	15.7	15.8	16.3	17.1	17.3	17.9	18.0	18.6	19.3
4H 2H	15.3	16.0	15.9	16.6	17.3	17.3	17.9	17.9	18.5	19.2
3H	15.4	16.0	16.1	16.6	17.4	17.4	18.0	18.1	18.6	19.4
4H	15.4	15.9	16.1	16.6	17.4	17.4	17.9	18.1	18.6	19.4
6H	15.4	15.8	16.1	16.5	17.3	17.4	17.8	18.1	18.5	19.4
8H	15.3	15.7	16.1	16.4	17.3	17.4	17.8	18.1	18.5	19.3
12H	15.3	15.6	16.0	16.4	17.2	17.3	17.7	18.1	18.4	19.3
8H 4H	15.4	15.8	16.1	16.5	17.3	17.3	17.7	18.1	18.4	19.3
6H	15.4	15.7	16.1	16.4	17.3	17.3	17.6	18.1	18.4	19.3
8H	15.3	15.6	16.1	16.4	17.3	17.3	17.6	18.1	18.4	19.3
12H	15.3	15.5	16.1	16.3	17.2	17.3	17.5	18.1	18.3	19.2
12H 4H	15.3	15.7	16.1	16.4	17.3	17.3	17.6	18.0	18.4	19.2
6H	15.3	15.6	16.1	16.4	17.3	17.3	17.6	18.1	18.3	19.2
8H	15.3	15.5	16.1	16.3	17.2	17.3	17.5	18.1	18.3	19.2
Işıklık aşikârları S için gözlemci konumunun değişimi										
S = 1.0H S = 1.5H S = 2.0H	+2.4 / -2.6 +3.7 / -3.7 +5.4 / -4.8					+1.4 / -1.5 +2.5 / -3.1 +4.2 / -4.4				
Standart çizelge	BK01					BK01				
Düzeltme için toplanacak değer	-1.9					0.2				
Düzeltilmiş kamaşma indisi suna dayanır 3840lm Toplam ışık akısı										

UGR-şeması (SHR: 0.25)

Ürün bilgi föyü

Regent - Recessed ceiling luminaire Geo 4 Office L2 33W 3600lm CRI >

Ürün No.	2005.9924 - GEO4 CR596x596 CLD LED3600-830 WH ONF
P	33.0 W
Φ_{Lamba}	3600 lm
$\Phi_{Işıklık}$	3600 lm
η	100.00 %
Işık verimi	109.1 lm/W
CCT	3000 K
CRI	90



Polar LDC

Recessed ceiling luminaire Geo 4 Office L2, with LED, system power: 33 W, luminous flux of luminaire 3600 lm, colour rendering index CRI >80, 3000 K, warm white, colour tolerances SDCM 3, lifetime LED L80 50'000 h, office-compatible and glare-free according to EN 12464-1 (UGR < 19; Lmax ≥ 65° ≤ 3000 cd/m²), 230 V, direct light emission, single-part frame in aluminium, white, RAL 9016, with diffuser, office-suitable microprismatic CLD optics (Controlled Luminance Diffusor) for perfect glare control, operating unit included in delivery, ON/OFF, protection class I, ingress protection IP20 / IP40, glow wire test 650 °C, impact strength: IK 08 this product contains a light source of energy efficiency class E module 600, L = 596 mm, B = 596 mm, ET = 85 mm

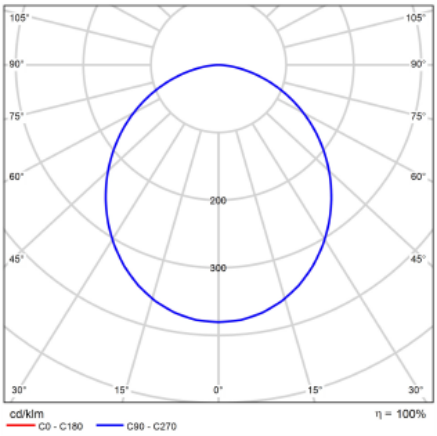
Ürün bilgi föyü

Regent - Recessed downlight Viva 12W CRI > 80 3000K white DALI

REGENT LIGHTING

Ürün No.	2009.2340 - VIVA DL CR155 LED1520-830 105 WH DALI
P	15.0 W
Φ_{Lamba}	1520 lm
$\Phi_{Işıklık}$	1521 lm
η	100.04 %
Işık verimi	101.4 lm/W
CCT	3000 K
CRI	90

Recessed downlight Viva with LED, system power: 12 W, standby power 0.5 W, luminous flux of luminaire 1520 lm, colour rendering index CRI > 80, colour temperature 3000 K, warm white, colour tolerances SDCM 3, lifetime LED L70 50'000 h, photobiological safety: the luminaire poses no danger (RG0), 230 V, direct light emission, housing in aluminium, with ceiling trim, white, wide beam, 105°, operating unit included in delivery, DALI, protection class I, ingress protection IP20 / IP54, glow wire test 650 °C, impact strength: IK 08 this product contains a light source of energy efficiency class D Ø = 175 mm, DAø = 155 mm, ET = 85 mm



Polar LDC

UGR'ye göre kamaşma değerlendirmesi

ρ Tavan		70	70	50	50	30	70	70	50	50	30
ρ Duvarlar		50	30	50	30	30	50	30	50	30	30
ρ Zemin		20	20	20	20	20	20	20	20	20	20
Oda büyüklüğü X	Y	Bakış yönü enlemesine Lamba eksenine					Bakış yönü boylamasına Lamba eksenine				
2H	2H	24.7	26.1	25.0	26.3	26.5	24.7	26.1	25.0	26.3	26.5
	3H	26.2	27.4	26.5	27.6	27.9	26.2	27.4	26.5	27.6	27.9
	4H	26.7	27.9	27.1	28.1	28.4	26.7	27.9	27.1	28.1	28.4
	6H	27.1	28.2	27.5	28.5	28.8	27.1	28.2	27.5	28.5	28.8
	8H	27.2	28.2	27.6	28.5	28.9	27.2	28.2	27.6	28.5	28.9
	12H	27.2	28.2	27.6	28.5	28.9	27.2	28.2	27.6	28.5	28.9
4H	2H	25.4	26.5	25.7	26.8	27.1	25.4	26.5	25.7	26.8	27.1
	3H	27.0	28.0	27.4	28.3	28.6	27.0	28.0	27.4	28.3	28.6
	4H	27.7	28.6	28.1	28.9	29.3	27.7	28.6	28.1	28.9	29.3
	6H	28.2	28.9	28.6	29.3	29.7	28.2	28.9	28.6	29.3	29.7
	8H	28.3	29.0	28.7	29.4	29.8	28.3	29.0	28.7	29.4	29.8
	12H	28.4	29.0	28.8	29.4	29.9	28.4	29.0	28.8	29.4	29.9
8H	4H	27.9	28.6	28.4	29.0	29.5	27.9	28.6	28.4	29.0	29.5
	6H	28.5	29.1	29.0	29.6	30.0	28.5	29.1	29.0	29.6	30.0
	8H	28.8	29.3	29.2	29.7	30.2	28.8	29.3	29.2	29.7	30.2
	12H	28.9	29.3	29.4	29.8	30.3	28.9	29.3	29.4	29.8	30.3
12H	4H	27.9	28.6	28.4	29.0	29.4	27.9	28.6	28.4	29.0	29.4
	6H	28.6	29.1	29.1	29.6	30.0	28.6	29.1	29.1	29.6	30.0
	8H	28.8	29.3	29.3	29.7	30.2	28.8	29.3	29.3	29.7	30.2
Işıklık aşıklıkları S için gözlemci konumunun değişimi											
S = 1.0H		+0.1 / -0.1					+0.1 / -0.1				
S = 1.5H		+0.2 / -0.4					+0.2 / -0.4				
S = 2.0H		+0.4 / -0.7					+0.4 / -0.7				
Standart çizelge		BK05					BK05				
Düzeltme için toplanacak sayı		11.3					11.3				
Düzeltilmiş kamaşma indisi şuna dayanır 1520lm Toplam ışık akısı											

UGR-şeması (SHR: 0.25)

A.2 Questions of Survey

OFİSLERDE İNSAN ODAKLI AYDINLATMA TASARIMI
&
HUMAN CENTRIC LIGHTING DESIGN IN OFFICES

Bu anket Kadir Has Üniversitesi Sanat ve Tasarım Anabilim Dalı'nda yürütülen "Ofislerde İnsan Odaklı Aydınlatma Tasarımı" başlıklı tez kapsamında yapılmaktadır. Çalışmaya verdiğiniz katkıdan dolayı teşekkürlerimizi sunarız.

This survey is conducted within the scope of the thesis titled "Human-Centric Lighting Design in Offices," carried out in the Department of Art and Design at Kadir Has University. We appreciate your contribution to the study and extend our thanks.

BAŞLA/START

1. Yaşınız kaçtır? / What is your age?

- ◯ 18-24
- ◯ 25-34
- ◯ 35-44
- ◯ 45-54
- ◯ 55-64
- ◯ 65+

2. Cinsiyetiniz nedir? / What is your gender?

3. Mesleğiniz nedir?/What is your profession?

4. İş yerinizdeki ofis düzeni nasıl? How is the office layout in your workplace?

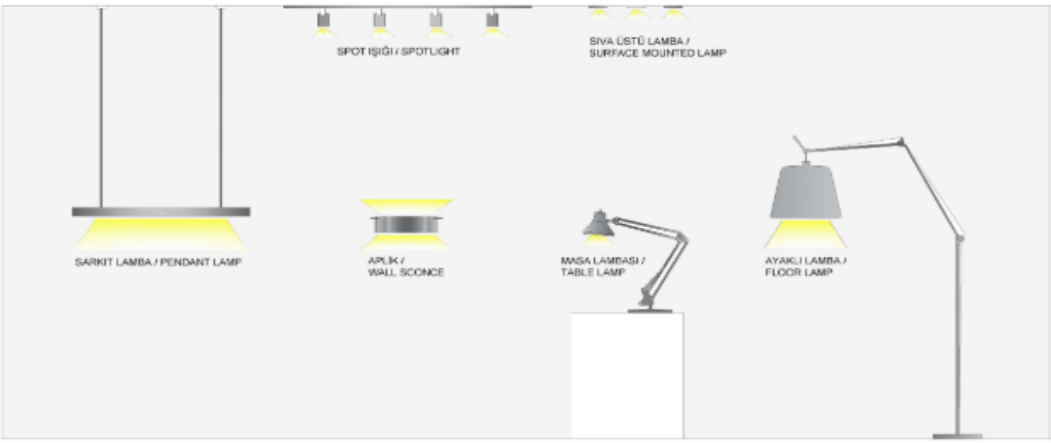
- ◯ Açık Planlı Ofis/Open Plan Office
- ◯ Geleneksel-Kapalı Ofis Planı/Traditional-Close Office Plan
- ◯ Kübik Planlı Ofis/Cubicle Office Plan
- ◯ Ekip Bazlı Ofis Planı/Team-Based Office Plan
- ◯ Karma Planlı Ofis/Mixed Plan Office
- ◯ Evden çalışma/Home Office
- ◯ Diğer(Lütfen belirtiniz.)/Other(Please specify.)

5. Çalışma alanınızda gün ışığından yararlanabiliyor musunuz? Eğer evet ise yeterli mi? / Can you take advantage of daylight in your workspace? If yes, is it sufficient?

- ◯ Evet, yeterli. / Yes, it is sufficient.
- ◯ Evet, yeterli değil. / Yes, it is not sufficient.
- ◯ Hayır. / No.

6. Aydınlatma sistemi bireysel olarak kontrol edilebiliyor mu? / Can the lighting system be individually controlled?

- ◯ Evet/Yes
- ◯ Hayır/No



7. Çalışma mekanınızda yukarıda gösterilen aydınlatma aygıtlarından hangileri bulunmaktadır? Birden fazla seçenek işaretleyebilirsiniz. / Which of the lighting fixtures shown above are present in your workspace? You can choose multiple options.

- ☐ Sarkıt Lamba/Pendant Lamp
- ☐ Aplik/Wall Sconce
- ☐ Spot Işığı/Spotlight
- ☐ Ayaklı Lamba/Floor Lamp
- ☐ Masa Lambası/Table Lamp
- ☐ Sıva Üstü Lamba/Surface Mounted Lamp
- ☐ Diğer(Lütfen belirtiniz.)/Other(Please specify.)

8. Çalışma alanınızda aşağıdaki aydınlatma aygıtlarından hangilerini bir arada kullanmayı tercih ediyorsunuz? Birden fazla seçenek işaretleyebilirsiniz. / Which of the following lighting fixtures do you prefer to use together in your workspace? You can choose multiple options.

- [ ] Sarkıt Lamba/Pendant Light
- [ ] Aplik/Wall Sconce
- [ ] Spot Işığı/Spotlight
- [ ] Ayaklı Lamba/Floor Lamp
- [ ] Masa Lambası/Table Lamp
- [ ] Sıva Üstü Lamba/Surface Mounted Lamp
- [ ] Diğer(Lütfen belirtiniz.)/Other(Please specify.)

9. Çalışırken kullandığınız lambalardaki kişisel ışık rengi tercihiniz nedir? Birden fazla seçenek işaretleyebilirsiniz. / What is your personal light colour preference in the lamps you use while working? You can choose multiple options.

- ◯ Sıcak Işık / Warm Light
- ◯ Günışığı / Daylight
- ◯ Soğuk Işık / Cold Light

10. Çalışma mekanınızda aydınlatma kaynaklı rahatsız olduğunuz bir sorun var mı? Varsa aşağıdakilerden hangisi veya hangileri? Birden fazla seçenek işaretleyebilirsiniz. / Is there any issue with the lighting in your workspace that causes discomfort? If so, which of the following or which ones? You can choose multiple options.

- ☐ Günışığı/Daylight
- ☐ Parlak Yüzey/Shiny Surface
- ☐ Karanlık Alan/Dark Spot
- ☐ Gölge/Shadow
- ☐ Kamaşma/Glare
- ☐ Diğer(Lütfen belirtiniz.)/Other(Please specify.)

11. Aşağıdaki görsellerden hangisini tercih edersiniz?/Which visuals below would you prefer in your office?

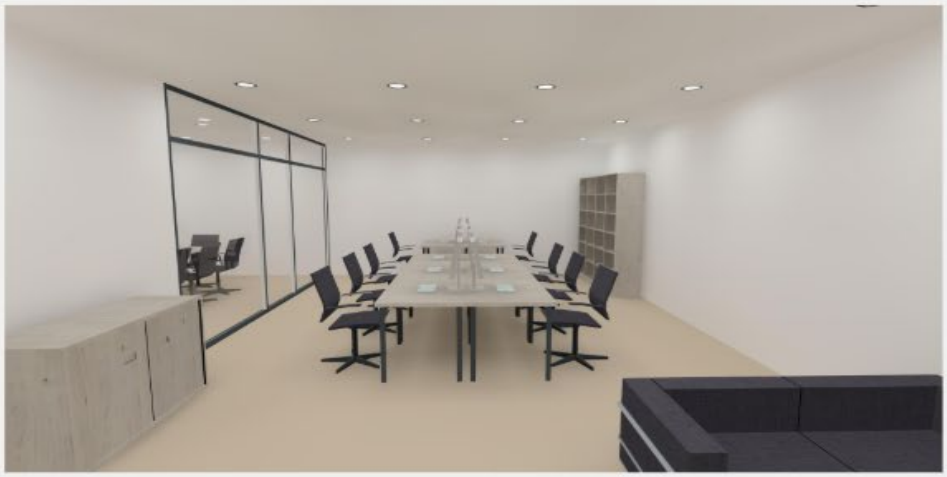
12. Aşağıdaki görsellerden hangisini tercih edersiniz?/Which visuals below would you prefer in your office?

13. Aşağıdaki görsellerden hangisini tercih edersiniz?/Which visuals below would you prefer in your office?

14. Aşağıdaki görsellerden hangisini tercih edersiniz?/Which visuals below would you prefer in your office?

○

○



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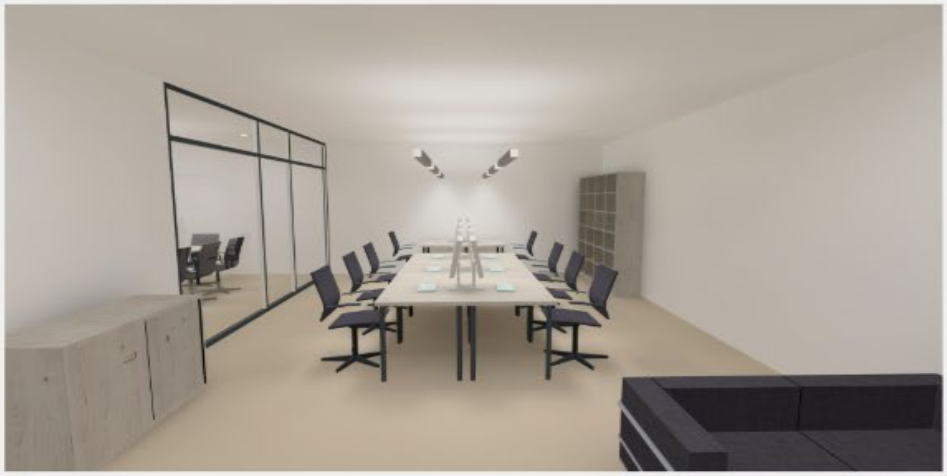
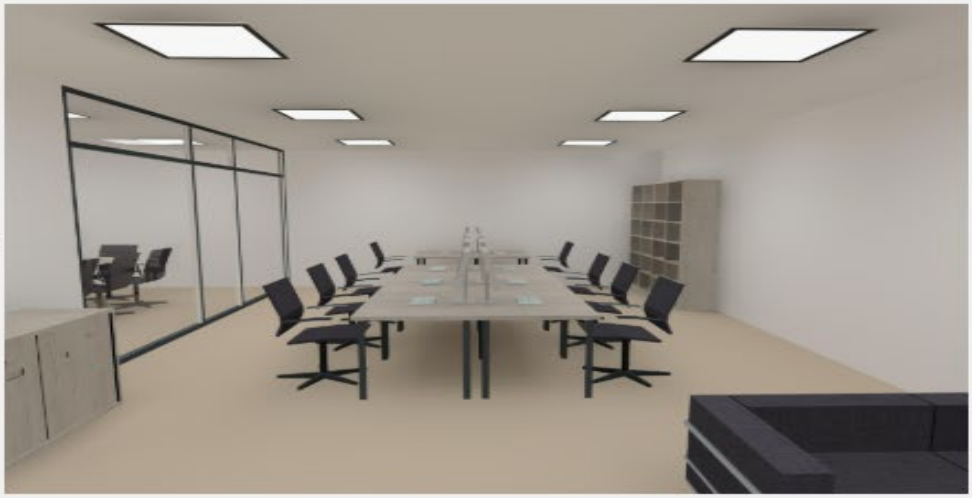


15. Aşağıdaki görsellerden hangisini tercih edersiniz?/Which visuals below would you prefer in your office?

○



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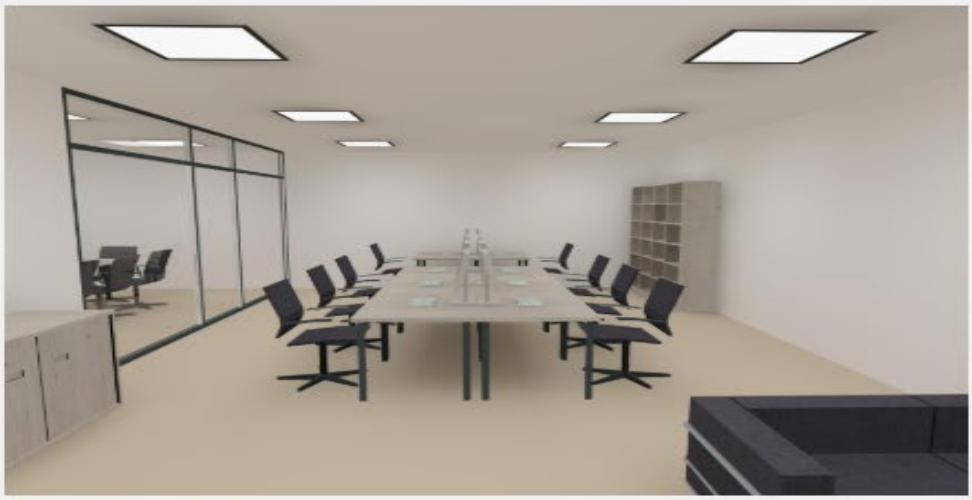

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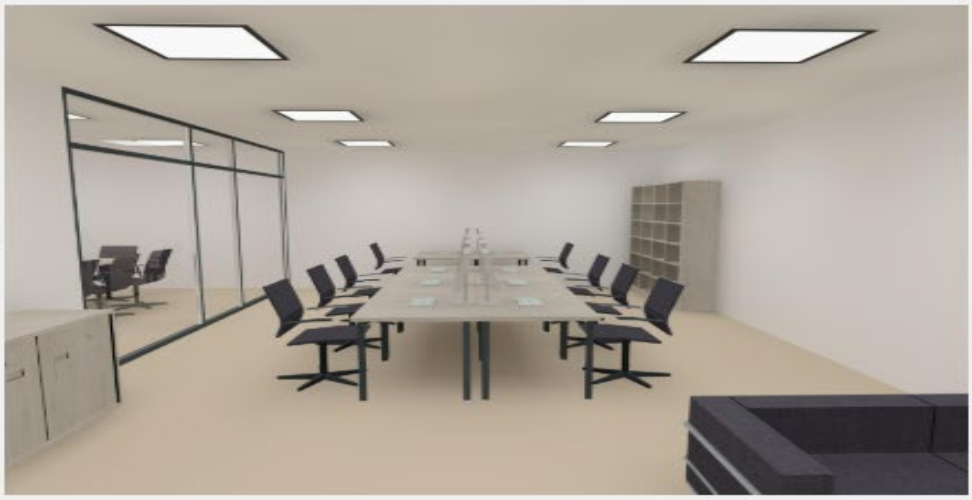

CURRICULUM VITAE

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