A Review based on OLED Lighting Conditions and Human Circadian System

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ABSTRACT

Light is a form of energy that affects the human sleep cycle, working hours, alertness, productivity, and well-being. As one of the essential environmental factors, lighting requires extensive research to understand the human-environment interaction. Earlier studies reveal that various artificial lighting technologies are utilized to investigate the human circadian system; experiments employing solid-state lighting (SSL) sources are still being conducted to determine how the human circadian system is affected. Due to the advantages of OLED (organic light-emitting diode) lighting, there is a need to enhance this form of artificial lighting in an indoor environment. This paper focuses on a literature review on artificial lighting sources, particularly OLED lighting, used from the past to the present. This article also discusses how OLED lighting can influence the human circadian system in terms of different characteristics of lighting in an indoor environment.

KEYWORDS OLED Lighting, Human Circadian System, Lighting Technologies, Human-Environment Relationship, Lighting in an Indoor Environment

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1. Introduction

Light is radiant energy that ranges from gamma rays to radio waves. The human eye responds to this energy within the limits of the visible spectrum from ultraviolet to infrared. Lighting technologies act as substitutes for natural light. Lighting history might be defined as the evolution of efficient technologies for producing visible light in the required spectral area.

Several lighting fixtures have been produced over the centuries. They have been manufactured to meet the needs by modifying their shape, color, temperature, intensity, and rendering of light. They provide general illumination and are classified into three groups: incandescent, discharge, and solid-state lighting (SSL). Figure 1 shows the evolution of artificial lighting technologies. Incandescent lamps produce light by heating a tungsten filament to incandescence. Discharge lamps have light through an electric discharge in gas and require control gear between the lamp and the power supply.

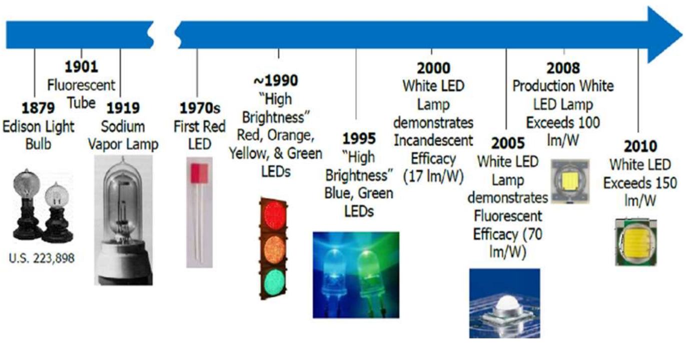

Fig. 1. Evolution of artificial lighting technologies (De Almeida et al. 2014: 32).

The term 'solid-state lighting' is also called 'electroluminescent lighting' since it produces electromagnetic radiation in response to power current; this process does not require heat and electric discharge via gas. As a result, they are cooler and smaller than other lighting sources (Innes, 2012). With the advent of new green SSL technology, the general concepts of artificial lighting sources have been changing (Kar and Kar, 2014). Due to task performances, human comfort, and production of high-quality lighting, researchers have focused on high-tech lighting sources that use more efficient SSL devices, have very long lifetime, resulting in lower maintenance costs, and have good physical robustness and compactness compared to other lighting sources (De Almeida et al., 2014).

Earlier studies indicate that various artificial lighting technologies are used to explore the human circadian system; experiments employing solid-state lighting sources (SSL) (i.e., light-emitting diode [LED]) are still being undertaken to understand how the human circadian system is affected. However, due to the advantages of organic light-emitting diode (OLED) lighting, there is a need to use this form of artificial lighting in an indoor environment. Due to the advantages of OLED lighting, it has been a matter of curiosity why it is not used indoors more than other lighting technologies. It aims to expand the indoor-oriented use of OLED lighting technologies and shed light on the studies carried out in different areas by considering the user profile. Specifically, this paper focuses on a literature review of artificial lighting sources, particularly OLED lighting, which also discusses how OLED lighting can be utilized to alter the human circadian system in an indoor environment. Most importantly, it has also the potential to change the design approaches by providing fresh knowledge for architects, interior designers, industrial designers, lighting designers, and lighting companies on how to effectively approach indoor lighting design with newer technologies for all users. Creating optimal surroundings is predicted to reduce stress and enhance visual satisfaction and well-being, having a considerable influence on the human circadian system and greatly boosting the user's quality of life.

2. Organic Light-Emitting Diodes (OLEDs): The Future of Lighting Technologies

Organic light-emitting diodes (OLEDs), one of the most significant advancements in the lighting industry, are unique and revolutionary SSL sources. OLEDs are a type of SSL source; however, they differ from other SSL sources in that they contain electroluminescence in organic compounds (Kunić and Šego, 2012). Following Bernanose and his colleagues' initial innovation, in 1985, Eastman Kodak Company explored many materials to improve this technique, and in 1987, the first OLED devices were introduced. They were later developed by companies including Samsung, LG, Panasonic, and Sony. OLEDs are currently used in various electronic products such as televisions, mobile phones, and automobiles.

OLEDs are composed of multiple organic sandwiched between the cathode and the anode. They are semi-conductive, emit light, and are manufactured on a substrate. The color of the light emitted is determined by the content of the organic layer. Multiple layers (e.g., red, green, and blue) are mixed to produce any color, including white. OLEDs differ in structure, material, and emission type. They are classified into seven classes: passive-matrix OLED (PMOLED), active-matrix OLED (AMOLED), transparent OLED, top-emitting OLED, bottom-emitting OLED, foldable or flexible OLED, and white OLED (WOLED).

OLED lighting offers an entirely new realm of light interaction possibilities. OLED is an SSL technology with numerous advantages over traditional alternatives. Along with its design (i.e., being ultra-thin, featherweight, flexible, cool-to-touch, long-life span, and 90+ color rendering index), health and well-being (no blue light risk, no UV, circadian system friendly, no flicker, naturally diffuse, and glare-free), and sustainability (recyclable, 85% organic and glass materials, does not contain toxic materials, no thermal heat sink, reduced manufacturing footprint, and low power consumption) are among the benefits of OLEDs (Thejokalyani and Dhoble, 2014; Hawes et al., 2012; Why OLED, 2020).

3. Lighting and Human Circadian System

In the 18th century, the term 'circadian' was investigated by French scientist Jean Jacques d'Ortous de Mairan (Rossi, 2019). He notices that the movements of the flowers of plants continue during the day, although they are placed in an indoor environment and not exposed to sunlight. This finding indicates that the movements of the plants are controlled by an internal clock (Vitaterna et al., 2001). Plants, animals, fungi, and cyanobacteria have circadian systems (Edgar et al., 2012). It is a 24-hour cycle internally created and influenced by external factors such as light and temperature. The circadian system has a daily process linked to brain wave activity, hormone production, core body temperature, cell regeneration, and other biological activities. These are all coordinates in the 24-hour cycle of living beings. In addition, the human circadian system influences primary physiological factors such as sleep cycle, changes in body temperature and blood pressure, immune system activities (Rossi, 2019), hormone system, and other psychological factors such as alertness level (Cajochen, 2007), mood, behavior (LeGates et al., 2014), and well-being.

Light is a fundamental human need, providing both vision and non-visual impacts, including regulating the circadian system. It is essential to the human circadian system, accomplished through vision. One of the most complicated senses, vision, is the primary mechanism by which humans perceive their surroundings. The first thing to understand about the visual system is that it comprises more than just the eye. The interaction between the eye and the brain results in vision, in which humans experience lights in their environment. Understanding this process leads to the establishment of such an environment. Understanding the biological context that led to vision requires considering the eye and brain as a unit. The eye governs the physiological effects of light in humans. When light enters the eye, it activates retinal photoreceptors, which convert photic information into neural impulses transmitted to various parts of the brain via ganglion cells. For many years, it was considered that the human retina included just two types of photoreceptors: rods and cones; nevertheless, roughly two decades ago, another distinct photoreceptor type was discovered in the mammalian eye. These retinal photoreceptors are specialized ganglion cells that contain the photopigment melanopsin and are inherently photosensitive, hence being dubbed intrinsically photosensitive retinal ganglion cells (ipRGCs) (Berson et al., 2002; Hattar et al., 2002; Provencio et al., 1998, 2000). When light falls on the retina, photoreceptors and cells transfer the light to the brain's suprachiasmatic nucleus (SCN), which regulates our daily circadian systems. SCN is an organizer for the recurrence of our daily physiological functions and psychological states like hormone secretion, body temperature, mood, well-being, and alertness (Tähkämö et al., 2019). Figure 2 shows the schematic illustration of the neuroanatomical underpinnings of the physiological effects of light.

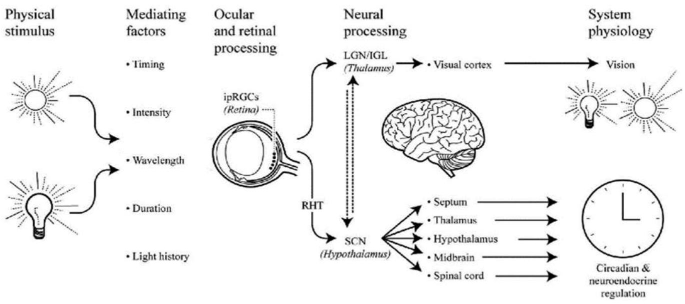

Fig. 2. Schematic illustration of the neuroanatomical underpinnings of physiological effects of light (Vetter et al. 2021: 2).

4. Relationship Between Lighting and Human Circadian System in an Indoor Environment

Most people moved from an outdoor environment to an indoor environment. This has been shown to have a negative impact on our health, productivity, visual comfort, mood, and happiness. However, with the recent discovery of a new photoreceptor in the eye and a better understanding of the process underlying non-visual biological impacts, we may be able to define lighting scenarios that ensure healthy individuals remain healthy even when working in indoor environments. Aside from the benefits to individuals' health and well-being, good lighting contributes to improved job performance (speed), fewer mistakes and rejections, increased safety, fewer accidents, and decreased absenteeism. This all adds up to increased productivity.

Indoor lighting design differs significantly from that of lighting for the circadian system. In general, the latter approach has placed an emphasis on visibility and related issues such as glare and shadow reduction, color rendering, safety, and space appearance. Designing for non-visual impacts of light, such as the circadian system, requires distinct lighting design objectives and, as a result, metrics and parameters related to the physical and psychological effects of light that lighting designers do not currently use.

In the literature, various studies have been carried out within the scope of human-centric lighting by considering the different characteristics of light. Although the studies do not directly address the effect of indoor lighting systems on the circadian system, the topics investigated are related to this field. Kuller and Wetterberg (1993) researched the brain-wave patterns (EEG) of people in a lab set up to imitate an office setting, once with a relatively high illuminance level (1700 lx) and once with a relatively low illuminance level (450 lx). Lower delta waves (the delta activity of an EEG indicates tiredness) are associated with higher illuminance levels of illumination, indicating that bright light has an alerting effect on the central nervous system. Non-visual flicker under fluorescent lighting has been shown to alter performance and mood, with individuals reporting a more pleasant mood under 2000 lx than under 300 lx in office environments (Daurat et al., 1993). Although 500 lx is considered the standard, it has been suggested that lower illuminance levels might be achieved without compromising the user experience (Fotios, 2011). Revell et al. (2006) conducted a study to investigate the non-visual effects (such as mood, alertness) of light of four different wavelengths at 420, 440, 470, and 600 nm on 12 participants. The results indicate that light with a wavelength of 420 nm produced more wakefulness than light with a wavelength of 470 nm or even 600 nm. The effects of illuminance (300 lx or 500 lx) and color temperature (4000 K or 6500 K) were assessed in specially designed office rooms for the study that participants preferred 500 lx and warmer (4000 K) lighting. There were also some impacts of spectral power distribution rather than simply CCT (Islam et al., 2015). In a study, Rossi and Casciani (2018) investigated natural lighting conditions in an indoor environment to explore the contribution to the well-being of the elderly and the invisible effects of lighting. The results sugget that older people might be exposed to low levels of natural lighting in the morning, which is essential for activating invisible responses and, as a result, synchronizing their circadian systems.

Since the millennium, new lighting solutions and advancements have focused on research themes such as light and health, user comfort, and the circadian system. Many studies have been conducted to determine how LED lighting conditions affect visual comfort under various illuminance levels (Avci and Memikoglu, 2017; Fortunati and Vincent, 2014). Light has been demonstrated to have significant non-visual impacts on a variety of biological functions, including the regulation of the human circadian system. In any case, advances in technology can provide useful tools for designing circadian lighting. In this respect, LEDs provide crucial characteristics for manufacturing lighting solutions that previous light sources did not allow for, or only partially allowed for, due to low efficiency and high costs (Rossi, 2019). In the literature, there are many studies related to the effects of LED lighting on the human circadian system from different viewpoints (Cajochen et al., 2011; Chaopu et al., 2018; Figueiro et al., 2018; Nie et al. 2020). However, OLEDs, which emit less blue light than regular LEDs, are considered low-energy and medically friendly artificial lighting. A study by Avci and Memikoglu (2021) found that OLED lighting exposure is more comfortable than LED lighting exposure in terms of some visual comfort criteria in the indoor environment. Ngarambe et al. (2021) investigated the impact of Spectral power distribution (SPD) on visual comfort, work performance, circadian energy, and mood. They used two types of lighting: LED and organic light-emitting diode (OLED). Participants preferred OLED for visual comfort, whereas LED was chosen for improved job performance and mood. However, Park et al. (2020) researched light exposure on circadian system and sleep. Participants were randomly assigned to one of three different light conditions (OLED, LED, and dim light). Melatonin onset was considerably delayed under LED lighting when compared to dim lighting, but did not vary under OLED lighting.

Yamagata University constructed the "Smart Mirai House" to test future lighting and other organic electronic devices. Various lighting conditions may be researched by using different types of OLED lighting displays to identify appropriate lighting for comfortable sleep and a well-controlled circadian rhythm (Sano et al., 2021).

Furthermore, Jo et al. (2021) conducted a study to assess the influence of OLED lighting exposure on sleep quality and the circadian system, which investigates the effects of LED and OLED lighting conditions on the human circadian system at night. Jo et al. (2021) suggest that OLED can be a suitable replacement for LED since its spectrum contains less blue light, which has the most significant impact on melanopsin in intrinsically photosensitive retinal ganglion cells. In addition, the effects of OLED lighting conditions on the human circadian system, visual comfort, and well-being in an indoor office environment have been an interest for the authors of this article, where they have been investigated as part of a scientific research project.

In contrast to earlier studies on the human circadian system, it aims to investigate the effects of OLED lightingas an environmental factor on the circadian system, visual comfort, and well-being of the participants who perform their daily work in an office environment. Finding the physiological and psychological effects of indoor lighting conditions on users is also among the research objectives. The circadian rhythmicity activity during the daytime is monitored using wrist actigraphy (Actiwatch Spectrum/Philips Respironics). The effects of OLED lighting with two different color temperatures (3000 K and 4000 K) on the user were examined. When the results were discussed, 3000 K OLED lighting conditions were generally found to be more positive. This study is intended to contribute to interior architecture by examining the application of OLED lighting in indoor environments (Avci and Akbay, 2021).

5. Conclusion

To conclude, the primary goal should be to design an indoor environment that addresses health, comfort, well-being, and quality. This paper aims to expand the indoor-oriented use of OLED lighting technologies and shed light on the studies carried out in different areas by considering the user profile. Most significantly, it aims to alter the design approaches by offering architects, interior architects, industrial designers, lighting designers, and lighting companies new knowledge on how to properly approach indoor lighting design with modern technologies for all users. The influence of the circadian system should be included in lighting settings. Since OLED lighting technologies are more advantageous than other lighting technologies, their use should be expanded considering the impact on the user's circadian system and other environmental factors.

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7. Conflict of interest declaration

The authors declare that there is no conflict of interest regarding the publication of this paper.

8. Short biography of the authors

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