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ARTICLE

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IMPACT OF LIGHT ON HUMAN HEALTH - A BRIEF REVIEW

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This paper deals with biological and health impact on public caused by artificial light. The primary aim of a lighting layout is to provide efficient light for visual phenomenon. On the other hand, non-visual functions integrate and control our organic activities like circadian rhythm, myosis, melatonin secretion, intellectual ability, memory, temper and locomotion, to name a few. The use of light emitting diodes has significant impact on our biological processes and photodynamic therapy instead of metal-halide luminaries or compact fluorescent bulbs. The considerations for sports lighting, hospital lighting and photonics for affordable health-care along with the health hazards of artificial lighting have been discussed to strive for a healthy human life.

Introduction

Light is considered to be the nucleus for human beings and it functions as the physical as well as psychological influencer[1-3]. Renowned physicist, J.C. Maxwell, defined light as an electromagnetic wave (visible range from 400 to 780 nm for an adult human eye) passing through space that covers a wide range, from radio waves having higher wavelength with wave shaped behaviour, down to x-rays with very less wavelength where the behaviour of electromagnetic radiation is particle shaped. Similar to the electromagnetic radiation, the light waves also impede amongst others; bends slowly while passing through an edge and likely to be directionally polarized. These features permit light to be refined by wavelength or escalated coherently when subjected to a laser beam[4].

In the study of radiometry, the proliferating wave-front of light is modelled since it propagates in the form of tiny wave particle namely, photon. Recent studies demonstrate that there is a correlation between light and its impact on human health. Light not only provides mere visual particulars rather constitutes a dominant modulator of circadian entrainment and various non-visual features including state of attentiveness and analytical performance[5]. As per the Illuminating Engineering Society (IES), "Day light refers to the art and practice of admitting sunlight beam, diffuse skylight, and reflected light from the exterior into a building to facilitate lighting requirements and energy saving through the use of electric lighting controls"[6]. In comparison with natural light, the artificial sources have no restriction to provide uninterrupted light. There are two concepts, namely Correlated Colour Temperature (CCT) and Colour Rendering Index (CRI). A high valued CRI of light source transliterates to an object colour nearer to its natural colour seen under daylight and having same colour temperature[7]. The sun is capable of generating a wide spectrum of light having ample wavelength (CRI = 100)[8]. Various studies have proven the multitude of benefits between natural light and artificial light, which will be discussed in different sub-sections along with their impact on human health.

All these are general optical properties of light. We, however, concentrate at present on the geometrical and physical properties of artificial light rather than natural light.

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Before going to the text of our thrust area, a few words about 'Basic Principles of Light' is illustrated as follows:

Basic Principles of Light

Inverse Square Law: This law establishes the association between point source irradiance and distance, which defines per unit area intensity to vary inversely with the square of distance.

$$E = I/d^2 \quad \text{(i)}$$

Alternatively, it can be expressed as

$$E_1\, d_1^2 = E_2\, d_2^2 \quad \text{(ii)}$$

Distance 'd', is measured to the first laminating surface, which can be either filament of a transparent bulb or glass envelope of a frosted bulb. Interestingly, Inverse Square Law assumes light as a point source and it should be much greater than the dimensions of the source. Also, the surface at the point of incidence is normal to the direction of the incident light.

Lambert's Cosine Law: This law states that illuminance falling on a surface varies with cosine of incident angle. The assessed measurement surface area that is orthogonal to incidental flux reduces at oblique angle rather than perpendicular to measurement plane. This causes light to disperse over a broad area.

$$E_\theta = E * \cos\theta \quad \text{(iii)}$$

Artificial Source of Light

The idea of flame oriented lamps introduced first as artificial light at night (ALAN)–time environment gets priority demand matching with the population intensification as well as need of technological demand which extends to electric powered lamps at the grass-root levels for producing artificial lights. This derives from diversity of sources namely, incandescent and luminescence lamps. Luminescence lamps can further be classified into discharge / fluorescence lamps (FL) and solid state lighting devices (SSLD) respectively[9-11]. ALAN upsets natural light patterns that take the form of two principles[12]. Primarily, lights are fixed in public places at different urban centres and marine sites with immense demographic diversity[13]. Secondly, ALAN is introduced as light spectrum unlike natural sources e.g., sun light, moon light and star-light[12]. Next, comes the era of high intensity discharge light and light emitting diode (LED). Thus, in time, the dominance technology tends to vary in a heterogeneous manner satisfying local conditions. There is a tendency to use white light source. However, coloured LEDs are used in the sense of performing architectural and beautiful spectrums[14].

LEDs are Changing the World of Light

The light from LEDs at present continues to grow in demand that exceeds the values of halogen and filament lamps. It has an extended lifetime that results in a paradigm shift with respect to the design and development of lighting. In case of interior decoration, headlights of two to four wheelers and even in traffic indicators, LEDs have very fast changed the orientation of the lighting model and established components of general lighting concepts.

LEDs emit nearly monochromatic radiation having multi-dominance colour of wavelengths viz., red, orange, yellow, green, indigo, violet and blue. It almost contains neither ultra-violet (UV) nor infrared (IR) radiation. Hence, they can be employed on food industry and on the illumination of sensitive art museum works. The semiconductor crystals are electrically excited to produce the light of LEDs in n-conducting space having a plethora of electrons and also in p-conducting space having a deficiency of electrons and the intermediate space is known as the p-n depletion layer. Here, light is produced to the crystal with bright lumination flux that allows heat sensitive materials—regardless of display windows, malls, VIP palaces, corridors and showrooms, even streets or highways.

Hospital Lighting

A Green Hospital building improves patient's wellness, assists in the remedial process and utilizes the natural sources in a systematic eco-friendly technique. A quality hospital should maximize the daylight and cut down the artificial lighting demand. Daylighting is the administered allowance of inherent light from the airspace towards a building to bring down the requirement of artificial energy sources for lighting. It has progressive impact on patients and decreases the mental pressure of the employees to give worthy healthcare with optimum efficacy. It has been observed that if the staffs are introduced under natural light, they are less susceptible to suffer from seasonal disorders. However, artificial lights are required for installation in critical sectors of a hospital, although, an amalgamation of both the types of lighting can turn down the functional expenses of hospital lighting considering the increasing energy price and huge capital expenditure[15-16].

Some Considerations to Increase Impact of Natural Lighting in Health Centres:

a. Glazed facades are to be designed to have dual view and sunlight.

b. Translucent skylight panels are to be installed possessing gentle colours.

c. Translucent and possible entrance to courtyards and ledge-seating area at the windows may be provided.

Some Considerations to Increase Impact of Artificial Lighting in Health Centres:

a. Use of occupancy sensors in corridors, store rooms, laboratories, etc.

b. Installation of energy efficient LED devices to minimize operational energy expenses.

c. Use of task specific lights to provide local lighting tasks like consultation rooms, laboratories, wards, etc.

Sports Lighting

The latest mandate on energy efficacy thrives for decrease in energy utilization. The recent trend is to replace the conventional lighting solutions (e.g. metal halide and fluorescent lamps) with LED, having an evolutionary lighting characteristic with highest energy efficacy. Apart from trimming of energy requirement, LEDs require lesser number of luminaries with minimal operational as well as maintenance cost in comparison with high-powered floodlights with metal-halide (MH) lamps or luminaires with compact fluorescent lamps (CFL). Although, capital expenditure to LED floodlights is significantly high, leading to proportionally increased payback period unless it is used extensively. Anyhow, prior to the selection of luminaries one should undergo comprehensive lighting analysis based on illumination intensity, glare, safety, health impacts, etc. to confirm that technological lighting requisites are also maintained[17-18].

Photonics in Healthcare

The technology of photonics has a significant role to play in affordable healthcare, therapeutics, medicinal delivery and even in prevention of disease. This technology can curtail hospital stays, cut down side-effects and slash the hospital expenses. Biomedical imaging is an emerging application domain to understand the condition of a patient and remedial measures to be taken. Biomedical photonic sensors are miniaturized, safe, robust, cost-effective, bio-compatible, sterilization free, precise and attain all the criteria to be applied in biomedical measurements. When a photonic sensor comprises of additional intelligence, apart from sensing or actuation signal, it becomes 'Smart'. During this Covid-19 pandemic, optical technology (infrared) based 'vital-sign monitoring' devices to measure body temperature, respiration rate, pulse rate, blood pressure and others have gained wide popularity[19-20].

Impact of Day Light on Human Body and Health

Already, we have discussed earlier about light as an electromagnetic wave. Sir Isaac Newton separated visual light to its individual colour components by advancing it through a glass prism. It is an established fact that sunlight comprises of electromagnetic energy spectrum that was referred as photons by Sir Albert Einstein. Apart from the colour, energy level of a photon inversely depends on its wavelength. Various studies exhibited that a highly energised photon of 290 nm wavelength possess the ability to trigger Vitamin D reaction on skin or stimulate hormones for secretion from endocrine glands are formed deeply in brain. The vacuum UV spectrum from the Sun radiates to terrestrial environment and can result in numerous pathological conditions. Human beings require UV wavelength to generate Vitamin D3, even, at lower concentration, it increases risk for heart failure, stroke and sometimes develop cardiac anomalies. The photobiology analysts have proved that the blood pressure as well as serum cholesterol levels get minimized significantly post exposure. Incidentally, day lighting has a natural healing effect to the external world. TABLE 1 indicates the amount of physical and psychological well-being occurring from building day lighting is enormous[21].

Table I: Natural Light and its Impact on Human Beings

Physical Impact		Psychological Impact	
Increase	Decrease	Increase	Decrease
Vitamin-D	Carcinogenic Probability	Temperament	Dejection
Vision	Bone Deformation	Mental Ability	Strain
Circadian Entrainment	-	Attention	Depression
Sleeping Quality	-	Intellect	Violence

Visual and Biological Effects of Lighting

The visual effects regulate the sensory receptors in the retina, cones, and rods of the eye. Light after reaching

those cells initiates a chemical action. A chemical, namely, activated rhodopsin is formulated that produces electrical impulses into the nerves and connect the photoreceptor cells at the cortex region of brain to be explicated as "vision". The rods function in extreme lower level lighting condition that do not allow colour vision. On the other hand, cone is liable for sharpness as well as detailed colour vision. The spectral sensitivity of human eye determines the probability of a photon at a certain wavelength to be absorbed and its possibility to be converted to a neural signal depend upon varying wavelength of light for a certain level of intensity. The aforesaid statement is described using Figure 1: spectral eye sensitivity curve V_λ represents for cone system that forms the basis of all lighting units known as the photopic system, whereas, V_λ' illustrates the rod system named as the scotopic system[22]. It can be observed from the figure that the eye is neither sensitive to extreme blue light nor to extreme red light, but possesses optimum sensitivity for green-yellow light.

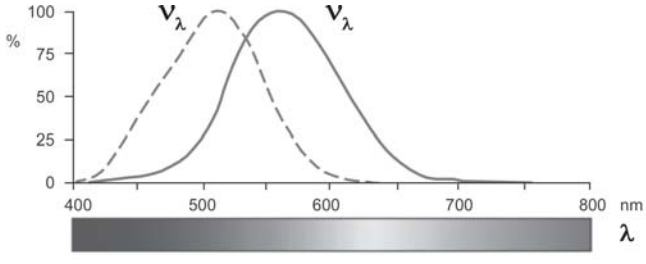

Figure 1. Spectral Eye Sensitivity (SES) Curve for Cone Cells and Rod Cells (dotted).

The photoreceptor cells in the eye retina were initially detected in the year 2002 by Berson et al.[23] which regulate the biological impacts. While light reaches those cells, a chemical reaction takes place (photo pigment melanopsin) and it produces electrical impulses[24-25]. The cells possess their nerve connections for locating in the brain termed as suprachiasmatic nucleus (SNC), also known as the biological clock of brain and to that of pineal gland. We will primarily discuss on visual performance, then gradually possess to biological effects of light.

Visual Performance

Visual performance not only depends upon quality of lighting but also on 'seeing ability' of the observer in respect of age and lens power of eyes. One such is ageing effect on the deterioration of transmission on the lens of eye which means that the transmittance has become lower for the person of interest. It further means that lesser amount of blue light is disseminated. Many studies predict the influence of lighting quality on visual performance in a comparatively strenuous job (like industrial office task or machine task) or an onerous job (like colour inspection or fine assembling). All the jobs indicate enhancement of visual performance with improvement of lighting quality. An escalation in visual performance improves the workability, which is dependent on visual component of the job and reflects in higher threshold with fewer errors.

Apart from visual effect, lights also have significant impact on the environment as well as it has its notion at the workspace[26]. Today, a lot of emphasis is given on the layout of interior design of the workplace. Efficient lighting design can brace up the interior depiction, whereas, a poor lighting design can decline or sometimes shatter the impact of design. Over and above, restricted surface brightness puts a limit on the orientation of the physical space viz. ceiling, wall and floor. Glare and lighting reflections are also unacceptable as it senses the luminosity of the visual spectra which turns out to be appreciably higher than the adapted eye brightness level. It can eventually lead towards reduced visual performance followed by stress and discomfort to human eye.

Lighting and its Biological Impacts

The eye as a vision organ has photoreceptor cells connected to the brain, which, deals with various health problems. Most importantly it is associated with the control of circadian rhythm and management of few major hormones through light-dark rhythms having dominance over alertness and good health.

Light and Body Rhythms

Light transmits signals through photoreceptor cells and neurotransmitters for regulating the biological clock of a diversified biological process. Cortisol (known as stress hormone) and melatonin (called as sleep hormone) have a significant contribution for attention and nap. Cortisol enhances the blood sugar and gives us the energy and improves the immunity system. But during escalation of cortisol extent beyond a certain limit, the body turns out to be fatigued and incompetent. The cortisol amount rises at the day to prepare our body for the daily routine. They stay over same for the whole day with sufficient activities, falling to minimal level during midnight. In contrast, the level of melatonin hormone minimizes at the day and reduces drowsiness. It enhances only during darkness and permits satisfactory level (as cortisol reaches its minimal value). In case of a healthy person, the rhythms are not disrupted extensively and it is continued everyday.

Normally, morning light synchronizes our biological entrainment with the earth's 24-hour revolving rhythm, in

absence of which it would be free-running causing deviation in body temperature as well as in the cortisol and melatonin level fixed by the environmental clock[27]. Absence of this light-dark rotational rhythm, results in lack of attentiveness, drowsiness during daytime and even insomnia. In case of rotating shifts, workers mostly face these traits at least for two days after their change of schedule due to similar rationale[28].

Lighting Alertness, Stress and Mood

Küller and Wetterberg[29] studied the EEG pattern of people in laboratory turned into an office environment, at times with a comparatively higher illuminance level as well as with a lower illuminance level. The EEG at the upper illuminance level turns out to be indicating drowsiness, which means that intense light influences the central nervous system (shown in Figure 2). In this regard, delta waves are high-amplitude but slowest waves and are associated with sleep or non-aroused condition. They are normally found in infants or in younger children, however, if it is present in an adult one should understand that the person is stressed, unable to think properly and having learning issues.

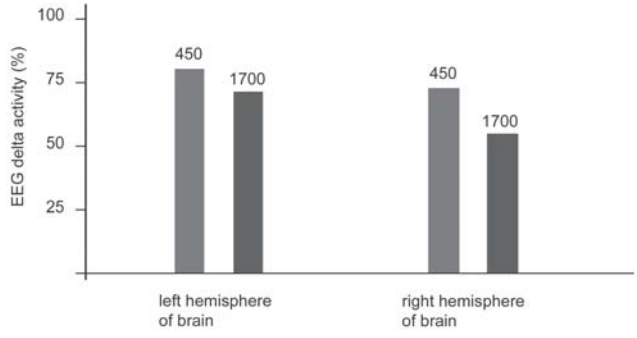

Figure 2. EEG delta-wave analysis of human brain.

Some investigations indicate higher illumination levels to deal with lethargy, and result in higher awareness levels[30-32]. In January (Figure 3), daylight permeation is not adequate while in May, it is sufficient enough to cause any considerable level of stress. An investigation depicts that artificial interior lights having adequate illumination level in winter have a progressive consequence on temperament and vitality[33].

Health Hazards of Artificial Lighting

The impending health risk of illuminating sources is provided by the accessibility of subjection data for public and professional vulnerability due to the stress of emission from different types of lamps[34]. The various hazards include:

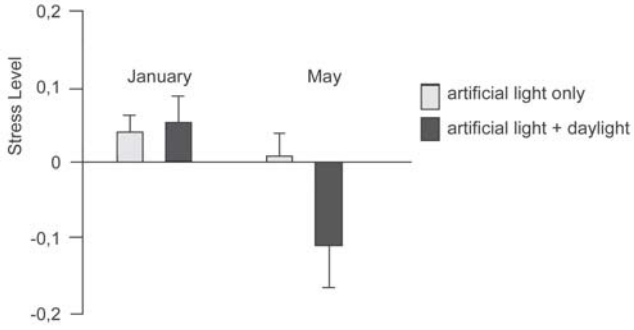

Figure 3. Stress level in various atmospheric and lighting conditions.

a. Ultra-Violet hazard occurring in eyes and skin
b. Blue light risk for eye retina
c. Thermal retina risk
d. Infra-Red hazard for the human eyes

Radiant Energy Absorption Effect

The optical radiation has a large impact that is required to be monitored. More simply, it is said that radiant energy is required to be transmitted to the material of interest for observation of the effect. The main mechanisms for the absorbed radiant energy to take place are as follow:

- Radiant energy due to heat is transformed to kinetic energy in terms of molecular motion. In all cases, temperature is enhanced i.e., photochemical impression is developed. The radiant energy (in Joule) is absorbed at unit time with certain volume which determines the temperature increase and is termed as absorption power (J/s) or absorption factor (watt/m^3), it determines how quickly it cools the environment[35].
- **Photochemistry:** The radiant energy can be subsequently utilized in photochemical reaction. This radiant energy emanates as discrete "quanta" or photon that should be equal to the excitation energy. Ultra Violet radiation is photochemically active (means photons convey the utmost energy) and is absorbed in eyes and in organic molecules over diverse processes[36]. Light is photochemically agile in our eyes; ocular perception is initiated with photo-isomerism of opsin proteins. Although, infrared radiation is heat arbitrated and incapable of transmitting the valence electrons to upper energy stages, hence it initiates photochemical

reaction. Few eye tissues absorb light and decrease retina exposure, otherwise, light induces oxidative pressure impairment known as photo-chemical and photo-dynamic damage[37]. UV and IR radiation cause lesions in cornea as well as in the lens of eye although it is repairable. Prolonged UV exposure due to sunlight causes cataract over eye lens. Anyhow, the damages are not for interim or enduring exposure to lighting devices. Retinopathy is normally irremediable and permanent[35].

- **Photobiology:** Here, optical radiation penetrates through our skin or eye, exposure and irradiance are the frequently used photo-biologic metric to enumerate the transmission of radiant energy to human body. Light penetrates through the skin and the body gets pain reflex sensation. Generally, artificial lights intensely do not cause burns but instigate chemical reactions toward detrimental intensities. Our eye retina is specifically endangered to lesser radiation wavelengths (e.g. blue light) and its vulnerability surges with age. Blue light has been found to have a pronounced effect than white light or other colours that are commonly in use[35].

Conclusion

This review work has been performed to search the novelties of a number of original research works. However, this task is undertaken to decipher the benefits of an efficient lighting design for the visual impression as well as the biological impact of light at various spectra (e.g., health, wellbeing and alertness) essential for our daily life. Apart from health and alertness, an elegant lighting installation tends to speedy enactment, optimum security, minimization of accidents and lesser absence. These finally results in better productivity as well as working environment. The considerations for hospital lighting, sports lighting and photonics for cost-effective healthcare have also been discussed.

At present, there is massive use of LED lighting technology and the other artificial sources of light have very highly been outnumbered. Moreover, LED emits light in narrow frequency range. There is a need to study the long-term impact on all biological systems (humans, animals, plants) to ensure health safety. There is also a need to map detailed emission spectra of all major light sources for better understanding of statistically increased health problems using specific light sources.

Summary

Lighting has a positive role to play in the visual performance and in the lighting environment. The lighting arrangement should be designed to maximize the amount of sunlight inflow and requires minimal subjection to artificial light such that the physical and mental health of all the concerned are in better condition. Exposure to sunlight has considerable impact on the physical and psychological health of a human being. Although, prolonged UV and IR radiation causes lesions in cornea leading to cataract and even towards retinopathy. Artificial lights with appropriate illumination level sometimes have a progressive effect on our stress level and mood.

Lights also have a significant role in the secretion of cortisol (stress) and melatonin (sleep) hormone. The cortisol hormone level remains high throughout the day and keeps us active. It minimizes to the lowest value at midnight and prepares us for the next day's activity. But, if the cortisol levels increase beyond a threshold limit, the human body becomes exhausted and inefficient. In contrast, the melatonin hormone remains low during the daytime to reduce drowsiness. It rises at night giving us a sound sleep. It have been observed that dimmed to bright light transformation elevates secretion of cortisol hormone and suppresses melatonin hormone secretion, whereas, bright to dimmed light transformation increases secretion of melatonin hormone and reduces secretion of cortisol hormone. Hence, lighting levels at the workplace and inside our house are to be fixed keeping this in mind.

Nowadays, the MH luminaries and even the CFL technology has been replaced by LEDs with minimal operational expenses. If LED technology is used, the electricity consumption is reduced to a large extent, although, the capital investment may be on the higher side. However, the selection verdict is left upon the consumers keeping in mind all the technical and financial aspects. ❐

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