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Human & Environmental Factors in Lighting Services Design

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Abstract: This study has been undertaken to investigate the determinants of human and environmental factors in the design of lighting services. The determinants will not only enhance the visual performance but also help in assessing the overall comfort, reducing glare. The study emphasizes the non-visual effects of light. Good lighting is both a science and an art, weighing various factors and circumstances that are different for every project, combining knowledge of engineering, design and physiology, and psychology. Scotopic and photopic lumens for lamp power spectral distribution are often neglected as important determinants in lighting design and considerations; the quantities are not even shown by manufacturers. This study tries to figure out the determinants concerning human and environmental factors that play an important role in lighting design and selection. The research provides insights into the observations, barriers, and risks associated with these determinants in lighting design.

Index Terms **– Environmental factors, Human factors, Indoor lighting quality**

I. INTRODUCTION

Basic requirements, such as lighting level, contrast, light distribution, and color rendering, must be considered for each situation in general and the activities that are taking place. Good lighting does not come by itself. It requires weighing various factors and circumstances that are different for every project. Human factors in lighting is the study of the interaction between people and light, which is influenced by how people respond in terms of perception, performance, behavior, and health. The research describing the main approaches to the impact of lighting on the environment and humans was carried out at the Department of Lighting (Kirschbaum and Departamento de Luminotecnia, Luz y Vision, Universidad Nacional de Tucumdn 2016). Measurements of environmental and physiological parameters, and psychological responses through a summer survey containing 952 questionnaires, show that short-stay occupants' lighting and thermal environment comfort requirements are more sensitive to indoor air temperature and illuminance changes (Hu et al. n.d.). A survey with 1015 questionnaires on people's perception of coziness, liveliness, tenseness, and detachment, depicts that average illuminance of 500 to 1250 lux could improve the coziness and liveliness perception, and color temperature under 4800k decreases the tenseness in public areas of commercial buildings (Nataša Lukić, Frank M. Schurr, Tanja Trifković 2023). Illuminance levels that exceed the appropriate illuminance standard increase the occupants' satisfaction (Kim and Lee 2024). Potential health problems with exposure to light at night negatively impact circadian rhythms and sleep patterns. Nighttime darkness and bright daytime light are essential for circadian entrainment and maintenance at home (Ticleanu 2021). The complex nature of light affecting psychological functioning was addressed through theories (de Kort 2019).

Lighting Quality

Lighting quality is much more than just providing an appropriate quantity of light. Other factors that are potential contributors to lighting quality are Illuminance uniformity, luminance distributions, light color characteristics, and glare. Many physical and physiological factors can influence the perception of lighting quality. The following are the aspects of lighting quality:

- visual aspect - judged according to the level of visual comfort and performance required for our activities.
  long-term effects of light on our health, which are related either to the strain on our eyes caused by poor lighting.
- psychological aspect - assessed based on the pleasantness of the visual environment and its adaptation to the type of room and activity.
- non-visual aspects - Effects of light on the human circadian system

2. METHODOLOGY

Several research papers and manufacturers' data have been collected to formulate the factors concerning both luminous environment and human performance and productivity for appropriate lighting quality. Opportunities in terms of striking a

balance between human productivity and lighting quantity are the need of the hour. Potential risks due to ignorance towards human factors lead to serious health concerns and productivity issues.

3. THEORETICAL FRAMEWORK

Lighting Quality comprises visual, psychological, and non-visual aspects of light.

3.1 VISUAL ASPECTS:

- Visual Performance
  Visibility is defined by our ability to detect objects at given distances and with a given contrast against the background. In buildings, typical applications include lighting, conditions for writing, typing, reading, communicating, and viewing slides and videos, or performing detailed tasks like sorting products
- Visual performance is defined by the speed and accuracy of performing a visual task.
- Visual performance is improved with increasing luminance. Yet, there is a level above which further increases in luminance do not lead to improvements in visual performance.
- The visual performance aspect and consumption of electricity for lighting should be in balance to increase energy efficiency, not, of course, forgetting the lighting quality aspects.
- Ensuring adequate and appropriate light levels (quantity of light) is an elementary step in creating comfortable and good-quality luminous and visual environments.
- It can be agreed that bad quality lighting does not allow people to see what they need to see and/or it can cause visual discomfort.
- Lighting that is adequate for visual tasks and does not cause visual discomfort is not necessarily good-quality lighting.
- Also, depending on the specific application and case, both insufficient lighting and too much light can lead to bad-quality lighting.

- Visual Comfort:
- too much variation in luminous distribution,
- too uniform lighting,
- number of lighting-related factors that may cause visual discomfort,
- annoying glare,
- veiling reflections,
- too strong shadows and
- flicker from light sources.

Attention also needs to be paid to the elimination of veiling reflections and to the formation of shadows in the space. The recommendations and guidelines concern mainly the elimination of visual discomfort.

- Visual Comfort & Productivity
- Visual comfort is how easily we can view tasks.
- How well the right amount of illumination is distributed.
- The higher a workers visual comfort, the higher the productivity.
- High levels of discomfort glare, disability glare and veiling reflections result in visual discomfort and lower productivity

- Lighting Contrast
- If luminance contrasts are too low, the result will be a dull and flat visual scene with no point(s) of interest.
- Too high contrasts, are distracting and give rise to adaptation problems for the eye when changing from one visual target to the other.
- Well-balanced contrasts give a harmonious visual scene, which gives satisfaction and comfort.

3.2 PSYCHOLOGICAL ASPECTS OF LIGHT

People perceive their luminous environment through their eyes, but they process this information with their brains. The luminous environment can be appreciated in many ways e.g.,

- more or less agreeable,
- more or less attractive,
- more or less appropriate to the function of the space,
- more or less highlighting the image.

- A lighting installation that does not meet the user's expectations can be considered unacceptable even if it provides the conditions for adequate visual performance.
- Unacceptable lighting conditions may impact on task performance and thus productivity through motivation.
- Beside cones and rods, the retina also contains light sensitive ganglion cells.
- They influence our biological clock that in turn regulates the daily and seasonal rhythms of a large variety of physiological processes, including the body's hormonal system.

- Photopic Lumens vs. Scotopic Lumens

In lighting design, there are two distinct kinds of lumen output produced by lamps. Photopic lumens represent the relative sensitivity of the eye under intense lighting, such as full outdoor sun. It is the amount of light registered by the cones in the human eye and is measured by standard lumens and foot-candle meters. Scotopic Lumens represent the sensitivity of the eye under typical interior lighting conditions and cannot be measured directly with a standard light meter. It is the amount of light registered by the rods of the human eye and also controls pupil size, directly affecting visual acuity for tasks

- Mesopic Vision

- In medium light intensity area the eye's spectral sensitivity lies somewhere in the area between night vision and day vision.
- This is often true at dusk and dawn or under street lights and in our homes.
- The eye responds not only to brightness, but to the spectral distribution of incoming light when deciding when to shift between the Photopic and the Scotopic statesIn medium light intensity areas the eye's spectral sensitivity lies somewhere in the area between night vision and day vision.
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3.3 NON–VISUAL ASPECTS OF LIGHT

Light also has effects that are fully or partly separated from the visual system. These are called the

- non-visual,
- non-image forming (NIF) or biological effects of light, and are related to the human circadian photoreception

4. Results

4.1 VISUAL COMFORT:

Visual comfort system is the most common evaluation. This is expressed as a percentage of people considering an installation comfortable as viewed from one end. If VCP (Visual Comfort Probability) ≈ is approximately 70%, then the system is considered glare-free. For true visual comfort, humans don't just need the right amount of illumination. Light needs to be well distributed to avoid discomfort. A study in clerical office work indicated that an increase in illuminance from 500 lx to 1500 lux could increase the performance of office workers by 9%. A field study in an industrial environment measured direct productivity increases in the range from 0 to 7.7% due to changes in lighting.

Lighting Contrasts:

If luminance contrasts are too low, the result will be a dull and flat visual scene with no point(s) of interest.

Too high contrasts, are distracting and give rise to adaptation problems for the eye when changing from one visual target to the other. Well-balanced contrasts give a harmonious visual scene, which gives satisfaction and comfort.

As a general rule in interior situations, it can be taken that for satisfactory results, the luminance contrast ratio (= ratio between highest and lowest luminance) in the field of view should not be larger than 3 and not smaller than 1/3.

(1/3. < luminance contrast ratio <3)

Color characteristics:

The color characteristics of light in space are determined by the spectral power distribution (SPD) of the light source and the reflectance properties of the surfaces in the room. The color of light sources is usually described by two properties, namely correlated color temperature (CCT) and general color rendering index (CRI).

Glare:

The degree of glare restriction attained depends very much on the optical quality of the luminaires used in combination with the type of lamp used. Fluorescent lamps have lower luminances than high-intensity gas discharge lamps, and it is therefore easier to limit glare with these lamps.

Strategies for Reducing unwanted glare:

Indirect lighting that throws more light upward than downward, diffusing the light and reducing glare on computer screens

- Parabolic louvers, special lenses or other diffusing media on fixtures that diffuse the fixture's light output
- In an office, it may be possible to de-emphasize the ambient lighting system with reduced light output and diffusing media, while providing adjustable task fixtures at workst**ations**
- Relocating the light source
- Relocating the task or changing its orientation until the glare is removed
- Changing the surface reflectance of the task
- Use blinds or shades on windows to control the amount or transmittance angle of sunlight entering the space
- It is prevented by curtains, blinds, louvers.
- Opening of windows can be reduced.
- Shift the work plane away from offending windows. i.e. normal field of view no light enters from the offending window on the work plane.

For the visual comfort in spaces, it is necessary to pay more attention to the shadowing, especially for the comfort of elderly people and visually impaired

Flicker:

- Flicker from light sources can be minimized by stable supply voltage or by using high frequency electronic ballasts with fluorescent and high intensity discharge lamps.
- Some people experience headaches because of the flicker of fluorescent lamps operated on conventional ballasts (50 Hz).
- Fluorescent lamps running on modern high-frequency electronic ballasts (around 30 kHz), however, do not exhibit this flicker phenomenon and incidents of headache are found to be significantly lower when electronic ballasts are used.
- Electronic high-frequency ballasts are also recommended because they're more efficient and result in longer economic lamp life than lamps operating with conventional ballasts.

4.2 PSYCHOLOGICAL ASPECTS OF LIGHT

They influence our biological clock that in turn regulates the daily and seasonal rhythms of a large variety of physiological processes, including the body's hormonal system. Light of the early hours of the day, in particular, synchronizes internal body clock to environmental time or the Earth's 24hour light-dark rotational cycle.

Photopic Lumens vs. Scotopic Lumens (S/P Ratio)

- It is the ratio of scotopic luminous quantity to photopic luminous quantity for the lamp spectral power distribution.
- Natural daylight has an S/P ratio of close to 2.5 which means that it is highly scotopically enriched.
- Both vision and brightness are enhanced with scotopically enhanced lighting.
- Adoption of light sources with high S/P ratios can also lead to substantial energy savings if vision and brightness are maintained at the same levels as achieved with standard lighting.
- The LED light source produces high levels of Scotopic lumens.
- The highest sensitivity of the cones occurs at an average wavelength of 555 nm or orange wavelengths.
- This is under daylight level and changes at low light levels when the rods become dominant
- Rods are sensitive only to black and white.
- The rods function under low light levels.
- They are only responsible for night vision or during low light intensity conditions, as well as the detection of motion.
- Rods are about 1000 times more sensitive to light than cones.
- Rods are most sensitive at a wavelength of 507 nm or blue/green wavelengths. In conditions of low light intensity entire vision is due to rod cells
- Sources with larger S/P ratios (such as high color temperature fluorescent lamps) can be expected to permit a greater depth of field and better acuity than those with smaller S/P ratios.
- They are independent of light level and express a property of the light or lamp spectrum and express the extent to which a lamp favors scotopic effects.
- When both cone and rod photoreceptors are active, mesopic vision takes place. In medium light intensity areas, the eye's spectral sensitivity lies somewhere in the area between night vision and day vision. This is often true at dusk and dawn or under street lights and in our homes. The eye responds not only to brightness, but to the spectral distribution of incoming light when deciding when to shift between the Photopic and the Scotopic states.
- As the light level is reduced, different photoreceptors are active in different parts of the retina. Specifically, as the adaptation luminance falls below about 3 cd/m^2.
- The rod photoreceptors escape from the grip of the cone photoreceptors and begin to become influential. Their influence continues to grow until the adaptation luminance falls below about 0.001 cd/m^2, state of continual change as the balance between rod and cone photoreceptors, changes with light level and eccentricity, until either rods dominate, as in scotopic vision, or cones dominate as in photopic vision.
- This implies that it would be possible to use lower illuminances with scotopically enhanced lighting and get the same visual acuity.
- Lamps with high S/P ratios can result in faster reading time, reduced visual fatigue, reduced glare, a reduction in task orientated errors, and improved human performance.

4.3 NON–VISUAL ASPECTS OF LIGHT

Light is the primary stimulus for regulating the human body clock and can therefore influence how well we rest.

- The ipRGC is the main photoreceptor responsible for entraining humans to the environmental light/dark cycle, along with other biological effects.
- Thus, light can be thought of as an external cue that entrains the internal clock to work properly.
- The human biological clock drives most daily rhythms in physiology and behavior.
- When we are active outdoors, it is mainly natural light that helps synchronize our body clock.
- These include sleep/wake rhythm, core body temperature, and hormone secretion.
- Besides the shifting of the phase of the endogenous clock by light, there is evidence of the involvement of the ipRGCs in pupillary reflex, alertness, mood, and human performance
- There is evidence that short-wavelength light is the most effective in regulating the biological clock

The nonvisual effect of light has recently been used for treating affective disorders. The clinical improvement of some depressed patients from the use of evening bright-light therapy may be related to an effect of light on the melatonin-rhythm generating system

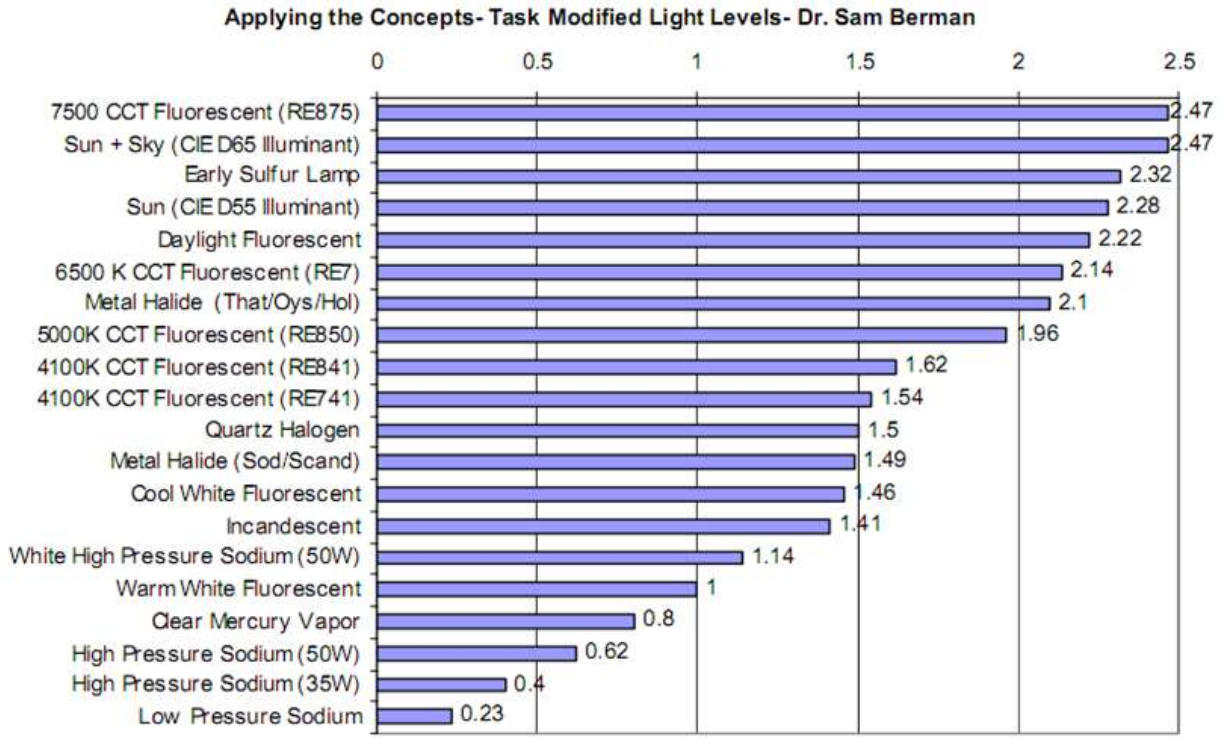

Figure 1: S/P ratios of Light sources available in the market

OBSERVATIONS & BARRIERS

- Any choice in lighting design will therefore have a consequence, which may sometimes be negligible, sometimes essential.
- Increasing the quality of lighting does not mean using more energy.
- With careful consideration of the different lighting factors and with proper lighting equipment, the energy consumption of lighting can still be decreased while improving the quality of lighting.

RISKS

- Reduction of the size of light sources (compact HID lamps, LEDs) may lead to increased risk of glare. Standards and recommendations should be adapted accordingly
- The possible adverse effects of light on health should be understood before using light to increase alertness and productivity
- Energy conservation measures may lead to the risk of poor lighting environment for the office employees.
- Poor lighting conditions can easily result in losses in productivity of employees, and the resulting production costs of the employer can be much higher than the annual ownership cost of lighting.

The newer compact fluorescent light bulbs generate radio frequency radiation as well as ultraviolet radiation. Instead of promoting compact fluorescent light bulbs, governments around the world should be insisting that manufacturers produce light bulbs that are electromagnetically clean and contain no toxic chemicals. Some of these are available (CLED) but are not yet affordable.

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