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The Effectiveness of Lighting Design for Improved Patient Care Considering Energy Conservation †

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Abstract: Unquestionably, hospital patient rooms require a proper lighting design. Dissimilar to cultural and artistic settings, where artistic discourse on light has significant importance, in medical settings, the most crucial conversation refers to standards. Research indicates that light in hospital settings has an impact on a patient's physical and mental health. Effective lighting in medical settings can enhance the hospital's positive experience and the speed at which patients recover from their diseases. It can also increase staff attentiveness and productivity. It is also critical to consider reducing electricity consumption in hospital settings that require lighting 24/7. Due to the high cost of lighting, access to natural light in combination with time-of-day controls minimizes energy consumption when daylight is available and impacts the hospital's bottom line. The effect of light on hospital users was investigated in this article; therefore, it is important to understand both natural and artificial light sources in this regard. Natural light has many benefits for humans, and when it comes to electricity consumption, it is the best method because it is a free source; but, since natural light is not always available and cannot be used throughout the day, there is a need to have an artificial light source that gives the best lighting effect in terms of visual comfort and visual performance for users. Secondly, proper artificial light sources can reduce electricity consumption; hence, these two critical aspects were underlined in this study.

Keywords: patient care lighting; LED; energy savings; daylight; electric light

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1. Introduction

Among the human senses, sight has always been the most powerful for obtaining information about the surrounding world. On the other hand, the visual quality of the environment has a positive effect on the users' feeling of the space. This issue becomes more critical in the case of hospitals and other healthcare centres whose goal is to accelerate the recovery process of patients. In this regard, lighting is one of the aesthetic and practical elements that can provide attractive and pleasant conditions for patients, visitors, and staff. Light plays an essential role in human visual activities; on the other hand, it is very effective in mental and physical health. Multiple research investigations have demonstrated the importance of light in healing disorders such as jaundice in newborns, lowering depression and exhaustion, enhancing alertness, and altering the circadian rhythm [1].

Unlike historical, cultural, etc., areas, where in their lighting design, an artistic view is critical, in hospital areas, the main goal is the implementation of standards and to meet the needs of each hospital area, from office areas to reception and patient rooms, etc. Therefore, lighting should be such that it meets the needs of each healthcare area and has an effect on the improvement of the staff work process and the recovery of the patients.

It should be added that an average hospital in the United States uses about 31.0 kWh of electricity per square foot, according to research conducted by the Business Energy Advisor. Here, 65% of the total energy consumption is dedicated to lighting, space, and water heating, which shows that the use of suitable and low-consumption lamps in the lighting sector can be a great way to reduce energy consumption [2].

2. Importance of Lighting in a Hospital

- For patients: The environment in which patients are cared for in the hospital is related to the patient's satisfaction, patient safety, and the patient's recovery process, and patients need an environment with standard lighting.
- For staff: Facilitating the work of the hospital staff is another goal of lighting the hospital; light with appropriate intensity and standard colour increases the energy of the personnel. Therefore, it also increases the performance and efficiency of these staff. Moreover, the personnel can better attend to the hospital's different departments in sufficient light.
- For visitors: The requirements are different from hospital's staff; they might need to relax and rest at night rather than remain awake [3].

Proper lighting fulfils human needs, puts the mind at ease, and creates a sense of comfort and security. In contrast to this situation, inappropriate lighting can fill the place with an uncomfortable atmosphere or make the residents nervous, worried, and anxious; the person constantly feels that something is not correct or regular. It is even possible that low and inappropriate light can cause headaches, eye fatigue, anxiety, or even collisions due to low vision [4].

Important Factors for Evaluating the Quality of the Lighting System

- Visual Comfort: Visual comfort means not feeling tired by being in the environment. Factors that are effective in achieving visual comfort include good colour rendering and uniform brightness distribution.
- Visual Performance: The environment's lighting should be such that it meets the needs of the human eye to see objects. This means that the environment should be bright enough, and the factors that cause glare should be limited.
- Visual Ambience: One of our goals in placing a lighting system is to obtain a visual ambience. Visual ambience means that by choosing the right direction of light and choosing the right light colour, we can recognize objects in three dimensions.
- Glare: Glare is one of the aggravating factors in lighting that limits the field of vision and causes fatigue for people, which should be limited as much as possible. Factors that can cause glare include use of inappropriate lights, placing lights or windows in an inappropriate position, and the high reflection of different surfaces.
- Uniformity: If there is a significant difference between the luminance of the environment that the person's eyes are constantly dealing with and the surrounding environment, the person becomes tired. In general, it is recommended that the brightness of a person's surrounding environment should be at least one-third of the brightness of the work surface. On the other hand, if there is no significant difference between the brightness of different points in an environment, the environment looks uniform and causes a person to feel tired [5].

3. Lighting System Design

3.1. Different Aspects Taken into Consideration When Designing Hospital Lighting Systems

3.1.1. Natural Illumination

Increasing the quality of natural light in a space, access to windows, and creating suitable conditions for seeing objects have obvious effects on people's emotions and moods. Research results show that light affects people in two ways, direct and indirect; its immediate effect is through changes in the quality of vision, and its indirect impact is on emotions, mood, and even body hormones. Natural light radiation and visual communication with

the outside environment reduce anxiety, improve behaviour and personality, and maintain and increase health and comfort [6] (Table 1).

Table 1. The Influence of Natural Light on Humans.

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

By passing visible light through a glass prism, Sir Isaac Newton famously demonstrated the division of visible light into its constituent colors. It is a well-known fact that sunlight contains a spectrum of electromagnetic energy known as photons, which was discovered by Sir Albert Einstein. A photon's energy level is inversely related to its wavelength, in addition to colour. Numerous investigations have demonstrated that highly energetic photons with a wavelength of 290 nm can trigger the secretion of hormones from deep inside the brain's endocrine glands and induce a Vitamin D reaction in the epidermis. The sun's vacuum UV spectrum reaches the Earth's surroundings and can cause a variety of pathological illnesses. Although UV wavelengths are required for humans to create Vitamin D3, excessive exposure, even at moderate levels, can raise the risk of heart failure, stroke, and the development of cardiac abnormalities. Researchers in photobiology have shown that exposure to daylight can considerably lower blood pressure and serum cholesterol levels. Surprisingly, daylighting has a natural healing effect on the surrounding environment [7].

Much research demonstrates that not only does access to daylight improve patient outcomes, but it can also bring restorative advantages to other users in their particular surroundings, such as medical staff. As a result, daylight should be incorporated in hospital lighting design not only because it is helpful to patients and workers, but also because it is free. As a result, it can take the lead in energy conservation, contributing to sustainability. We should also mention that the penetration of the sun should be limited so as not to cause thermal and visual discomfort.

3.1.2. Artificial Illumination

With all the advantages of natural light, it is impossible to use natural light 24 h a day. Even when there are certain weather conditions, such as cloudy and rainy days, the possibility of using daylight is lost, and even in situations in different parts of the hospital, it may be necessary to move the light; for example, light is needed in one position and not in another region. With the advancement of technology, it is possible to be inspired by day and night circulation and create similar natural light through appropriate artificial lights. Since the tops of the opposing walls and the ceiling are the patients' common lines of sight in the hospital, the design should minimize glare for patients while maintaining good visibility for medical staff. For every application, a limited glare index is advised [8].

3.2. Three Main Parameters to Be Considered in an Artificial Source of Lighting Design for the Hospital

3.2.1. Lighting Level or Illuminance

Illuminance is the total luminous flux incident on a surface per unit area or the amount of light measured on a planar surface. Lighting intensity is expressed in either footcandles (Lumens per square foot) or lux (Lumens per square meter). Lighting levels have been issued by numerous international standards organizations and standardized for a range of

applications and occupancies, including The British and European Standard BS-EN12464 and the Illuminations Engineers Society of North America (IESNA) [9] (Table 2).

Table 2. List of lighting levels in some hospital areas.

Location	Lighting Level
Lobby Area	50 lx (5 fc)
Waiting Area	100 lx (10 fc)
Patient Ward Rooms	300 lx (30 fc)
Medical Laboratory	500 lx (50 fc)
Operating Room	3000–10,000 lx (300–1000 fc)
Critical Care Areas (Examination)	500 lx (50 fc)

3.2.2. Colour Rendering Index (CRI)

The CRI represents the lighting source's capability to realistically and naturally depict the colors of objects, which has a scale between 0 and 100 percent; the excellent light sources are those with a CRI above 90 (Tables 3 and 4).

Table 3. Different CRI.

CRI + 90	CRI + 80	CRI < 65
Excellent	Good	Reasonable

Table 4. Various artificial light sources.

Lamp Type	Lumens/Watt	Avg. Lumens/Watt	CRI	Life (h)
Incandescent	8–18	14	100	1000
T12 Fluorescent	40–70	55	92	8000
T8 Fluorescent	60–80	70	85	6000
T5 Fluorescent	100–105	102.5	85	9000
Mercury	44–57	50	50	24,000
HPS (High Pressure Sodium)	66–121	90	21	50,000+
LPS (Low Pressure)	101–175	150	10	60,000+
LED	75–200	137.5	98	50,000+

3.2.3. Colour Temperature

Measured in Kelvin units, the colour temperature expresses the brightness and colour of light. All lamps emit light with a certain colour. The higher the degree of Kelvin, the cooler and brighter the emitted light will be, and in the same way, the lower degree of Kelvin indicates warm lights such as yellow and red (Table 5).

Table 5. Different ranges of colour temperature.

Temperature (K)	Colour	Description
2000–3500	Orange/Yellow	Ultra-Warm or Warm White
3500–5000	Paper White	Natural/Neutral White
5100–6500	Bluish White	Cool White

A CRI above 90 shows objects very similar to what we see under the natural light of the sun. The suggested colour temperature range is between 3000 Kand 6500 K, according

to the IEC standard 60601-2-41 [10], which provides certain specifications for surgical and diagnostic luminaires. The guideline also stipulates that the Colour Rendering Index (CRI) must be between 90 and 100 percent.

Generally, a 4000 K colour temperature or more is needed in most hospital areas, but for areas where high accuracy is important, such as treatment areas and operating areas, the colour temperature should be 5000 K, with a CRI of 90 to 100 percent, and in areas where patient comfort is important, a colour temperature of 3000 K, which is warmer, and a CRI of 85 to 100 percent are appropriate [11].

4. Results

Two important capabilities in light output, as well as for the requirements of health care environments, are the light colour temperature and CRI; colour temperature creates a balance between comfort and biological effect. According to the mentioned standards, we need a minimum colour temperature range of 3000 K to 6500 K in healthcare environments. The knowledge shows that LEDs with a colour temperature range of 6000 K to 8000 K have the best biological effect, and 3000 K to 5000 K colour temperature ranges are the closest ranges to Daylight White. Also, a high CRI is needed for the comfort of patients and the staff and different environments of health centres. According to Table 3, LED lamps have the highest CRI compared to other lights. For hospital environments that need lighting 24 h a day, 365 days a year, apart from light colour temperature and CRI, it is also a requirement to consider energy savings. The efficiency of a light source is measured in lumens per watt, often known as "luminous efficacy" or "efficacy" (watts converted into lumens). As Table 3 shows, the efficacy of old incandescent lamps is between 8 and 18 lumens/watt, depending on the type of lamp and their manufacture, while LEDs are 75 to 200 lumens/watt. Therefore, LEDs have a longer lifespan of up to 50,000 h and can reduce energy usage by up to 70%.

5. Conclusions

Studies show that proper lighting in hospitals has an unavoidable effect on improving patients and the work process of employees and doctors. In an environment like a hospital, where the main goal is to improve the patient's health, we must achieve a high lighting standard and avoid any visual discomfort caused by lighting for patients and employees, such as glare, the negative effects of which can cause headaches, burning eyes, and fatigue. In hospital environments, we need light sources that are both low consumption to save energy and cost and give us light similar to daylight. LED lamps with a CRI of 98% and a colour temperature range between 3000 and 6800 are the best options for hospital and treatment environments, and at the same time, they are also the most energy-efficient lamps. Natural light also should be used as much as possible, because in addition, patients respond better to lighting that creates a restful atmosphere and best supports their circadian cycle and has other positive effects on staff and patients; also, they can use this light at no cost.

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