Lighting Design for Visual Comfort and Energy Efficiency Considerations: A Patient Room Case Study

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Abstract

Discomfort glare causes unease and distraction, significantly affecting patients, staff, and visitors. Achieving visual comfort is essential for glare reduction, as it is primarily influenced by artificial lighting in the workplace. This study examines the probability of visual comfort and the unified glare rating (UGR) as measures of discomfort glare. UGR calculations compare three types of artificial lighting sources in a hospital patient room, considering both visual comfort and energy efficiency. This study analyzes different lighting installations with a focus on surface properties and their relative height as critical factors for enhancing visuals and reducing energy consumption. The results show that increasing the reflection coefficient can reduce energy consumption while improving visual comfort. Although LED lighting generally outperforms traditional lamps, the latter can still achieve significant performance improvements with increased surface reflectance.

Keywords: artificial illumination, visual comfort, energy saving, LED, medical care

1. Introduction

To bear witness to external existence, the requisite for any visual perception is, undeniably, light. Many studies have investigated and demonstrated the effects of light on humans, both visually and biologically. In addition to influencing the circadian rhythm and sleep-wake cycle, light can also be effective in reducing pain and depression, increasing alertness, improving employee performance and energy, and shortening hospital stays. Beyond these advantages, scientific evidence suggests that light can assist in the treatment of dementia, which is significantly beneficial to geriatric studies.

One of the fundaments of building design is providing occupants with a sense of peace and security, and creating visual comfort is crucial to achieving this goal. Visual comfort refers to using light sources to create an environment where individuals feel at ease and are not fatigued [1]. In contrast, visual discomfort can significantly impact health, causing eye strain and migraines. The context is substantial when determining whether a lighting installation renders visual comfort or discomfort. A lighting design may be considered uncomfortable in one context but comfortable in another. Unlike visual performance, visual comfort is not limited to a specific room area; visual discomfort can be experienced anywhere in a lit space [2].

One of the parameters used to achieve visual comfort is control glare, which is an integral part of evaluating visual comfort. Glare can be dichotomously classified into two types: discomfort glare and disability glare. Discomfort glare is primarily generated by bright artificial lighting used in the workplace, whereas disability glare is characterized by a loss of vision induced by powerful light sources, which inhibits visibility. Given discomfort glare cannot be objectively defined, the glare factors possess certain difficulty integrating and being correctly measured.

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Therefore, the unified glare rating (UGR) and visual comfort probability (VCP) are utilized to assess discomfort glare induced by artificial lighting in an indoor environment. The VCP, which ranges from 0 to 100, shows the percentage of people who experience discomfort glare from artificial lighting in interior spaces. The VCP was designed mainly for fluorescent lighting systems and cannot be used to analyze glare from sunshine, metal halide fixtures, incandescent lights, or compact fluorescent downlights. The UGR, on the other hand, rates glare on a scale of 10 to 30. It is intended to measure glare caused by artificial lighting systems and is inappropriate for analyzing glare in daylight settings. Besides, currently, it is critical to achieve a sustainable lighting design, especially when a typical hospital in the United States could use approximately 31.0 kWh of electricity per square foot, according to Business Energy Advisor. Lighting, space, and water heating consume 65% of total energy consumption, indicating that using appropriate and low-consumption lamps in the lighting sector can significantly reduce energy consumption [3].

Due to the importance of visual comfort and energy saving, many studies have investigated herein. Researchers tried to offer solutions to control energy and reduce energy consumption or visual comfort in different ways in their research. In a study by Hassouneh et al. [4], the researchers demonstrated the potential of new technologies to reduce energy consumption in an educational building. Their findings, showing that dimmer devices can adjust the amount of lighting in different spaces and reduce energy consumption by 10 to 60%, offer the potential for energy efficiency for future investigations.

The recent research conducted by Mahmoud et al. [5] presented new standards of strategic lighting design for residential space in Dubai, United Arab Emirates. This article aims to promote a healthy lifestyle by simulating natural lighting changes during the day to match people’s circadian rhythms. The article emphasizes the role of lighting parameters such as light intensity and color temperature in influencing the performance of people’s moods and relaxation. To achieve this goal, specialized lighting technologies such as photocatalytic ultraviolet A LED (UV-A LED) and anionic LED have been used, along with intelligent control systems, to provide flexible, hygienic, and natural-simulating lighting solutions tailored to the needs and functions of each home space.

In addition, a myriad of research has focused on the architectural features of the building, such as the properties of the glass, the orientation of the windows, the ratio of the windows to the wall, etc., on the distribution of natural light in the interior environment in the discussion of optimizing the building design regarding lighting energy demand [6]. Furthermore, studies show that interior surface characteristics affect the interior environment’s lighting and quality. To furnish optimal visual perception, the emphasis lies on horizontal lighting in the indoor environment and vertical lighting, which includes surfaces such as walls, ceilings, and other surfaces considered in lighting design [7].

A study by Jafarian et al. [8] has shown that if the wood is chosen to cover the surfaces of the interior space, the type of color and the position of the interior wooden panels can affect the uniformity of light and the quality of lighting in the space. Additionally, a study by Michael et al. [9] Suggests using bright and reflective furniture materials to improve interior light distribution. Moreover, research by Makaremi et al. [10] demonstrates that the reflection characteristics of internal surfaces, particularly walls, play an essential role in improving lighting uniformity. The results of these prior studies have promoted the present research, which hypothesizes that the reflection of reflection coefficients from surfaces can improve indoor lighting. However, numerous studies on daylight and artificial lighting have focused on either energy consumption or visual comfort, but not both factors simultaneously. Additionally, while LED technology has been widely used in lighting design research, traditional lamps are still commonly used in many countries due to their availability and lower initial cost.

This study aims to investigate whether the modification of surface reflection coefficients can be utilized as an appropriate solution to improve the performance of both traditional and LED lighting systems, to enhance energy efficiency and visual comfort in hospital environments. These lighting design options have been designed and evaluated based on their UGR values and energy consumption properties to assess the visual quality of the indoor patient room environment. The study is particularly significant given the considerable dependence of buildings, including hospitals, on artificial lighting, which accounts for approximately 40% of global annual electricity consumption [11]. As high-energy-consuming units, hospitals have a considerable impact on the environment due to the large number of hospital buildings and their continuous operation [12].

Proper energy management in hospital environments is vital because these buildings witness continuous human activity, and many people are present [13]. Inefficient energy management in hospitals results in environmentally detrimental effects and increased operational costs. Besides, apart from the energy issue, patients and staff are the typical subjects in the hospitals. Research shows that the physical environment in which patients receive care significantly impacts treatment outcomes, patient satisfaction, and safety. Providing appropriate lighting to satisfy patients is one of the critical principles in creating such an environment. For staff, having the right light is essential for productivity and performance and for creating a favorable working environment where they feel comfortable and calm. Inappropriate lighting can cause eye fatigue, headaches, and stress, which attests to the importance of proper lighting for their well-being [14]. Therefore, optimizing energy consumption and lighting quality in hospital environments is very important.

2. Materials and Methods

This research aims to investigate the effect of familiar lighting sources, i.e., compact fluorescent lamp (CFL), LED, and incandescent lamps, on glare and energy consumption in the hospital environment. To achieve this, DIALux version 11 software was used, which enabled the calculation of the UGR index and the energy consumption of artificial lamps. The research design was experimental-analytical, with the type of lighting source and the reflection coefficients of the ceiling, walls, and floor as independent variables.

To evaluate these variables, two different scenarios were considered:

(1) Scenario 1 with low reflection coefficients: ceiling = 0.7, walls = 0.5, and floor = 0.2

(2) Scenario 2 with high reflection coefficients: ceiling = 0.9, walls = 0.8, and floor = 0.4

In this analysis, the "Reflection Factor" feature in the DIALux software was utilized. This feature allows for independent adjustment of the level of light reflection from surfaces without changing their color, providing a way to control light reflection while testing different lamp types. Additionally, several fixed parameters were considered, including the room's dimensions (height 2,800 mm) and the type of space (hospital treatment room). A patient room in Iran was used for the simulation. Since the focus was on the performance of different lamps in indoor environments and energy optimization, the effect of natural light was not further investigated.

2.1. Hospital artificial lighting requirements

Table 1 Various light sources

Lamp type	Lumens/Watt	Avg.Lumens/Watt	CRI	Life (Hrs)
Incandescent	8-18	14	100	1,000
T12 fluorescent	40-70	55	92	8,000
T8 fluorescent	60-80	70	85	6,000
T5 fluorescent	100-105	102.5	85	9,000
Mercury	44-57	50	50	24,000
High-pressure sodium (HPS)	66-121	90	21	50,000+
Low-pressure sodium (LPS)	101-175	150	10	60,000+
LED	75-200	137.5	100	50,000+

The four basic parameters utilized in lighting system design are luminous intensity, luminance, luminous flux, and illuminance. Table 1 lists various lamp types utilized in lighting system design, including their luminous efficiency and service life [14]. To define, glare is a condition that could cause discomfort or reduce a person's visual performance. In addition to the crucial aspect of glare control and reduction within hospital environments, several factors, such as lighting levels, color rendering index (CRI), and reflection factor, necessitate thoughtful consideration when designing suitable artificial lighting for medical care settings to attain optimal visual comfort. Each aspect contributes significantly to creating a visually appealing and peaceful environment, improving patients' overall well-being and satisfaction. Therefore, when designing artificial lighting systems for medical care environments, it is imperative to address these factors comprehensively to provide an environment conducive to healing and comfort.

2.1.1. Glare

The UGR system, developed by the International Commission on Illumination (CIE) [15], assesses the discomfort glare generated by lighting sources in indoor lighting applications. Discomfort glare is quantified by the UGR derived using the formula below.

$$UGR = 8\log_{10}\frac{0.25}{L_b}\sum\frac{L_s^2 3}{P^2} \tag{1}$$

where L_b is the background luminance (cd/m^2), excluding the contribution of the glare sources, L_s is the luminance of the luminaire (cd/m^2), 3 is the solid angle subtended at the observer's eye by the luminaire (steradians), and p is the Guth position index.

This equation calculates the UGR value based on background luminance, luminaire intensity, solid angle, and position index. The UGR values range from 10 to 30, with higher values indicating more discomfort glare and lower numbers indicating a low level of glare [16], as shown in Table 2. An acceptable UGR value can be determined for different lighting installations.

Table 2 UGR values

Subjective ratings	UGR value
Imperceptible	10
Just perceptible	13
Perceptible	16
Just acceptable	19
Unacceptable	22
Just uncomfortable	25
Uncomfortable	28

2.1.2. Color rendering index (CRI)

The CRI measures the ability of a light source to accurately represent the colors of surfaces, maintaining color accuracy in lighting design. The International Commission on Illumination (CIE) uses the General Color Reproduction Index to quantify this ability, emphasizing the importance of precision in the field. CRI compares the color reproduction of different types of lamps. If a higher temperature is required, the eight test colors are illuminated by a reference source, either a 5000 K blackbody or artificial daylight. Subsequently, the test lamp lights up the same eight colors. By measuring the average color difference between the colors rendered by the reference source and the test lamp, the color reproduction characteristics of the test lamp are determined. Therefore, CRI serves as a valuable design tool, enabling lighting designers to select light sources that meet specific color quality standards [17].

2.1.3. Illuminance

Illuminance refers to the total amount of light that falls on a surface per unit area or the measured quantity of light on a flat surface. It is typically measured in Lux (lumens per square meter) or Footcandle (lumens per square foot). The range of lighting levels experienced in daily life varies from 0.2 lux, equivalent to moonlight, to 100,000 lux, the brightness of midday sunlight [18]. Illuminance is the foundation for lighting design, which concerns human behavior and spatial characteristics and is crucial for healthy lighting. Proper planning of illuminance levels can have a significant impact on people's comfort and performance. Adequate lighting levels have been found to enhance visual comfort, efficiency, and quality for users. Increased illumination in work and living spaces improves visibility and clarity, enabling individuals to perform better in various settings [19]. It is essential to deploy opposite light sources to improve indoor illuminance. Different areas in a hospital require varying levels of illumination. Higher illuminance is necessary for operating rooms or medical examination areas to enhance visibility and visual acuity Table 3 [20].

Table 3 Lighting specifications for various hospital areas

Hospital areas	Illuminance	Limiting glare index	CRI
General lighting	100	19	80
Waiting rooms	200	22	80
Staff office	500	19	80
Staff rooms	300	19	80
Patient rooms	300	19	80
Examination, treatment wards	1,000	19	80

2.1.4. Reflectance values

The reflectance range is a set of values representing different surfaces' reflectivity or reflecting characteristics. Different materials and surfaces have varying degrees of reflectance, which can influence the distribution of light and the overall appearance of a place. Research on visual comfort and light reflection indicators shows that the reflection coefficient significantly impacts average brightness and UGR. Specific ranges of suitable reflectance are specified for internal surfaces such as ceilings, floors, and walls in indoor workplaces, according to European Standard EN 12464, which establishes the lighting needs of inhabitants. Table 4 contains these recommended ranges [21].

Table 4 Reflectance range recommended values of surface

Surface	Reflectance range
Ceiling	0.7 to 0.9
Walls	0.5 to 0.8
Floors	0.2 to 0.4

2.2. Computer simulation using DIALux

This article used DIALux version 11 simulation software to analyze and design lighting for patient rooms. By employing simulation, one can visually compare conceptual ideas and make informed decisions before the actual construction phase, particularly in lighting design calculations that have a significant visual impact on projects. The advantage is that it eliminates the dependence on employing real-world applications, such as incorporating furniture or placing specific interior elements. Furthermore, this software proffers a convenient approach to calculate required lighting installations and optimize energy consumption.

The analysis herein relies on the implementation of DIALux version 11 simulation software. The accuracy of the outcomes obtained from DIALux software is contingent upon the provided data. Lighting designers opt for DIALux software due to its diverse features, including rendering capabilities, user-friendly interface, and light distribution and intensity optimization, resulting in energy-efficient lighting system designs. This software adheres to CIBSE and IES standards, determining appropriate physical numerical values for the proposed system. Many projects have demonstrated a close correspondence between simulation results and field measurements, supporting this article's recommendation to utilize DIALux version 11 simulation software.

The essential stages for ensuring lighting system integrity through the utilization of DIALux software are outlined as follows:

(1) Inputting project details: This initial step entails entering project information, such as room dimensions (length, width, and height), materials utilized for ceilings, walls, and floors (which impact lighting calculations due to differing reflectance coefficients of each material), light loss factor, and working plane height.

(2) Selection of lighting: The selection and determination of luminaire installation height directly influence the outcomes of lighting simulation. The software encompasses a comprehensive library and an electronic catalog of luminaires.

(3) Placement of lighting, calculation, and result visualization: In this phase, lighting placement can be executed manually or automatically. Designers can flexibly input their desired illuminance values. Subsequently, the software generates simulation results. The proposed design approach enables incorporating values aligned with the standards outlined in Tables 1 to 3.

2.3. Characteristics of the examined room

A patient room in an Iranian hospital was chosen for the case study. The ground area is 38.91 m^2. If considering the restroom and the space in front of the door, the area is 12.43 by 3.58 m^2. In contrast, if not considering the mentioned spaces, it is 9.90 by 3.58 m^2. The room's height is 2.800 m, as shown in Fig. 1. The room is rectangular, and each bed is surrounded by furniture separated by sliding curtains from the other beds. The maintenance factor is estimated to be 0.8. According to the mentioned standards, the amount of illuminance required in a patient room on the work plane at a height of 0.800 m is 300 lux.

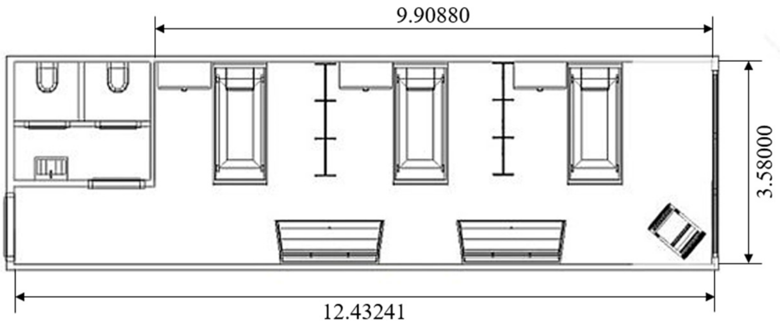

Fig. 1 Dimensions of room

The measurement points for glare are on the patients' beds, where the patients spend time, and the examinations are performed using the UGR surface DIALux measurement method, with 12 measurement points in the vertical direction and 5 points in the horizontal direction, as depicted in Fig. 2. The height of the calculation object is 0.85 m in each bed, and the viewing angles considered are from 0 to 180 degrees, as the patient might want to move their head. Also, uniformity calculation includes the valuable space of the room, except for the corridor in front of the door. The simulation was done with two scenarios of the previously mentioned reflection factors for all three lights.

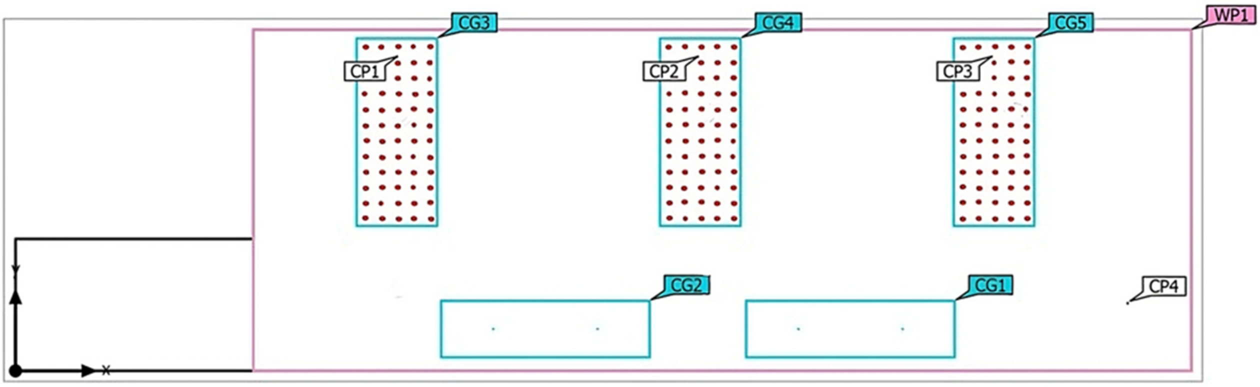

Fig. 2 Measurement points

2.4. Characteristics of the lamps

Product data sheet

FLOS S.p.A - ECOLIGHT TC–DEL/ TEL 2X18W 102°

FLOS

Article No.	03.3452
P	36.0 W
Φ_{Lamp}	2400 lm
$\Phi_{Luminnaire}$	1191 lm
η	2529 lm
Luminous efficacy	33.1 lm/W
CCT	3000 K
CRI	100

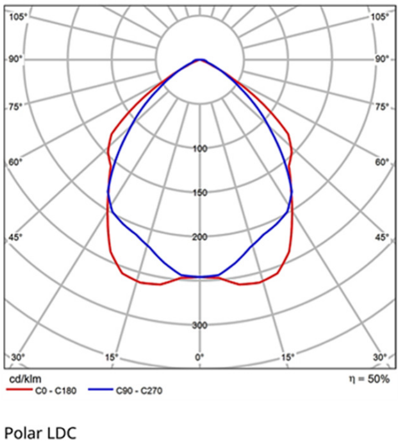

Fig. 3 Product data–Case 1

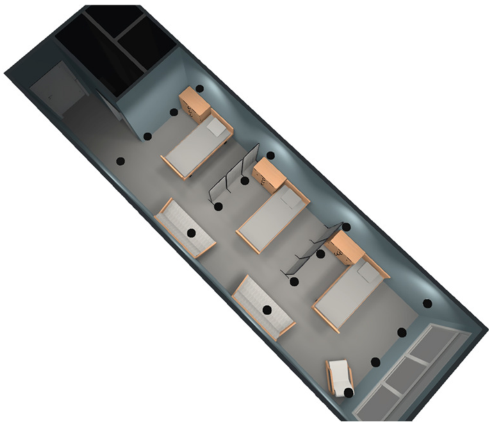

Fig. 4 3D rendering–Case 1

Product data sheet

OPPLE - LED Downlight Rc–P–HG–R200-23W–BLE2-940

OPPLE LIGHTING.

Article No.	540001334700
P	23.0 W
$\Phi_{Luminnaire}$	2529 lm
Luminous efficacy	110.0 lm/W
CCT	4000 K
CRI	90

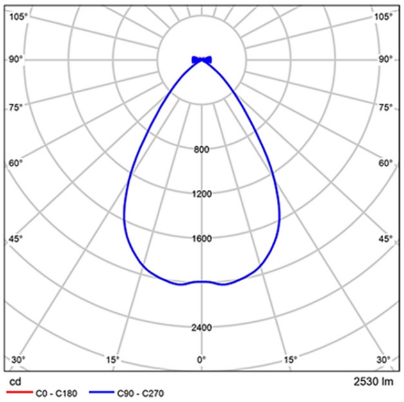

Fig. 5 Product data–Case 2

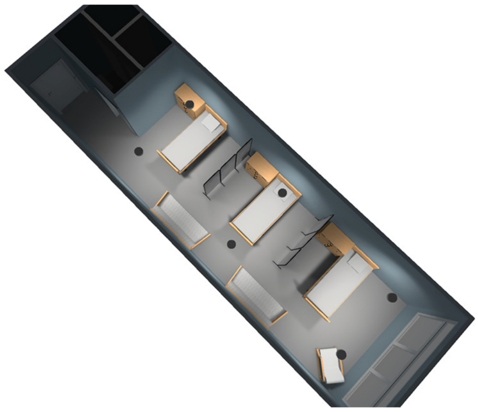

Fig. 6 3D rendering–Case 2

Product data sheet

SCHMITZ | WILA - alphabet spectra Deckeneinbauleuchte, Streuscheibe

SCHMITZ | WILA

Article No.	AS1102119-30-30 + 86206R10_20W
P	22.0 W
Φ_{Lamp}	1460 lm
$\Phi_{Luminnaire}$	1460 lm
η	99.99%
Luminous efficacy	66.4 lm/W
CCT	3000 K
CRI	83

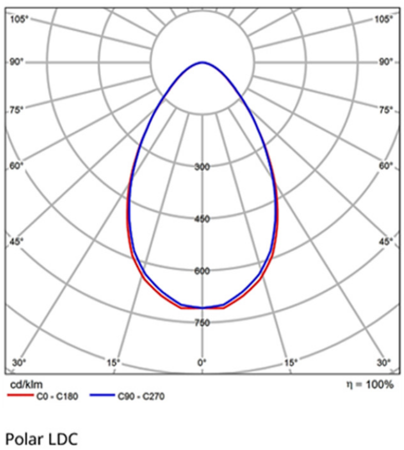

Fig. 7 Product data–Case 3

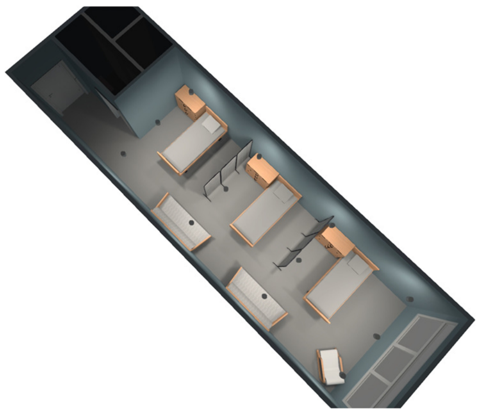

Fig. 8 3D rendering–Case 3

In Case 1, the patient room is illuminated with a 36-watt/ 1,191 lm CFL lamp, ECOLIGHT TC–DEL/ TEL 2X18W 102°, a product of FLOS company. Product specifications are shown in Fig. 3. Color rendering of the room with illuminated CFL lamps is shown in Fig. 4. In Case 2, a 23-watt/ 2,529 lm LED lamp illuminates the patient's room. The lamp is Opple Company's LED Downlight Rc–P–HG–R200-23W–BLE2-940 product. Product data is illustrated in Fig. 5, and color rendering of the space with lighted LED lamps is shown in Fig. 6. In Case 3, a 22-watt/ 1,460 lm incandescent lamp lights the patient's room. The alphabet spectra Deckeneinbauleuchte, Streuscheibe, is manufactured by SCHMITZ | WILA. The product information in Fig. 7 and Fig. 8 displays a color rendering of the room illuminated by incandescent lamps.

3. Results

In this study, simulations were carried out utilizing two different scenarios with low and high reflection factors. In each scenario, the effect of three distinct light types–LED, fluorescent, and incandescent–on glare and energy consumption was investigated. These findings contribute to a profound understanding of how illumination affects patient comfort and energy efficiency in hospital settings.

3.1. The result of the glare simulation

The solid angle, absolute luminance, relative luminance, and the proximity of the glare source to the line of sight primarily influence glare. To assess discomfort glare caused by artificial lighting, metrics are available to evaluate the glare factor. The UGR is commonly used to calculate glare from artificial lighting sources. The UGR value also depends on the observer's position, viewing direction, and ambient luminance. European Standard EN 12464-1 specifies the maximum permissible UGR values for various indoor workplaces, ranging from 10 to 30. A lower value indicates less glare, while a higher value indicates more glare. The results manifested that the different scenarios had varying impacts on glare levels and energy consumption.

3.1.1. Scenario 1

In the Scenario 1, with the reflection factors of walls ρ_{wall} = 0.5, the floor ρ_{floor} = 0.2, and the ceiling $\rho_{ceiling}$ = 0.7, the uniformity of the lighting was obtained throughout the entire room, except for the corridor in front of the door. For Case 1, where CFL was used, the distribution was shown from the minimum lux of 301 and the maximum of 538, with a uniform distribution of 55%. In Case 2, which was done with LED lights, the minimum lux in the room was 255, and the maximum was 395, with an overall uniformity of 64.6% in the room. Then, with incandescent lamps, the light distribution in the room was calculated, and the minimum lux was 212 and the maximum was 384, which gave a uniformity of 55.2%. After the UGR was calculated using the surface method with DIALux, with 5 measurement points on the horizontal axis and 12 points on the vertical axis on the task area, which are the beds in the room, where all care and treatment activities for patients taken on there. This was done for each type of lamp.

Table 5 UGR Results–Scenario 1

Patient number	Light model	Unified glare rating
A1 (Patient number 1)	CFL	19
A2 (Patient number 2)	CFL	19
A3 (Patient number 3)	CFL	19
B1 (Patient number 1)	Incandescent	22
B2 (Patient number 2)	Incandescent	23
B3 (Patient number 3)	Incandescent	23
C1 (Patient number 1)	LED	15
C2 (Patient number 2)	LED	15
C3 (Patient number 3)	LED	16

The simulation results are presented in Table 5, which shows the three patient beds with lighting provided by CFL lamps, and the UGR is 19 for all three beds. With incandescent lamps, one bed has a UGR of 22, while the other two have a UGR of 23. With LED lighting, two beds have a UGR of 15, and another bed has a UGR of 16. According to the standard outlined in Table 3, the UGR value should be equal to or less than 19 for the patient room. This indicates that CFL lighting, with a UGR value of 19, is acceptable but not optimal when compared to LED lighting, which has UGR values of 15 and 16, indicating a promising situation between the perceptible and just perceptible levels. On the other hand, incandescent lighting is deemed unacceptable, as the UGR values are uncomfortable, indicating that glare can be highly disturbing to patients.

3.1.2. Scenario 2

In Scenario 2, all strategies proceed according to Scenario 1, only the reflection factors have changed and increased, which are walls ρ_{wall} = 0.8, the floor ρ_{floor} = 0.4, and the ceiling $\rho_{ceiling}$ = 0.9. By distributing the light in the room using CFL lamps, a uniformity of 61% was achieved, with a minimum illuminance of 293 lux and a maximum illuminance of 522 lux in the room. By increasing the reflection coefficient in the room compared to Scenario 1, it increased and improved by about 5%. The LEDs installed in the room reached 70% uniformity in the distribution of light, with a minimum illuminance of 323 lux and a maximum illuminance of 576 lux in the room. The uniformity in the room increased by approximately 4.5%, compared to Scenario 1.

In Case 3, the uniformity that reached 59% with a high reflection factor was measured by installing incandescent lamps in the room. In this case, the minimum illuminance in the room was 285 lux, and the maximum illuminance was 510 lux, which increased by 3.8 percent compared to Scenario 1. Similar to Scenario 1, the UGR was measured using DIALux, the surface measurement method on all three beds with each type of lamp. The simulation result is shown in Table 6.

Table 6 UGR Results–Scenario 2

Patient number	Light model	Unified glare rating
A1 (Patient number 1)	CFL	16
A2 (Patient number 2)	CFL	15
A3 (Patient number 3)	CFL	16
B1 (Patient number 1)	Incandescent	19
B2 (Patient number 2)	Incandescent	20
B3 (Patient number 3)	Incandescent	20
C1 (Patient number 1)	LED	12
C2 (Patient number 2)	LED	12
C3 (Patient number 3)	LED	13

3.2. The result of the power consumption simulation

In addition to the calculations related to visual comfort, another crucial topic highlighted in this article is energy efficiency. Hospitals are among the environments that require high energy consumption due to the 24-hour working hours and the need for many departments for continuous lighting.

A light source's luminous efficacy, which is expressed in lumens per watt (lm/W), is a measurement of how well it transforms energy (watts) into visible light (lumens). It can be calculated using the following formula:

$$\text{Luminous efficacy (lm/W)} = \frac{\text{Luminous flux (lm)}}{\text{Power of lamp (lm)}} \tag{2}$$

where lumens (lm) is a measure of total light output and watts (W) is a measure of power usage.

Traditional incandescent lamps have a luminous efficacy that varies from 8 to 18 lm/W, depending on the manufacturer and kind of lamp. LED lights, on the other hand, range in luminous efficacy from 75 to 200 lm/W. Compared to incandescent lights, LEDs can save up to 70% on energy costs and have a far longer lifespan—up to 50,000 hours, as shown in Table 1 in Subsection 2.1.

This study includes a simulation conducted in a 38.91 m^2 patient room, comparing two lighting conditions with high and low surface reflection factors. According to the requirements, the hospital's patient room requires 300 lux lighting. In Scenario 1 with a low reflection factor, 16 CFL bulbs with a power of 36 W and a luminous flux of 1,191 lm were employed to render the required light for this room. In the following case, 6 LED lights with a power output of 23 W and a luminous flux of 2,529 lm were employed. In Case 3, 12 incandescent lights with a power of 22 W and a luminous flux of 1,460 lm were utilized. By utilizing the previously given formula, the luminous efficacy of CFL, LED, and incandescent bulbs was determined to be 33.1 lm/W, 110.0 lm/W, and 66.4 lm/W, respectively. The findings evince that LED lights use the minimum amount of energy to provide the maximum lumens. The numbers for each kind of lamp are also displayed in the layout diagrams in Figs. 9-11.

In Scenario 2 with a higher surface reflection factor, fewer lamps were required in each of the three lighting cases (LED, CFL, and incandescent) to reach the standard 300 lux lighting level for the patient room. Specifically, concerning LED bulbs, five out of six bulbs were used. As for CFL bulbs, twelve out of sixteen bulbs were employed. Meanwhile, nine out of twelve bulbs were utilized. The findings reveal that, while LED lamps consume less energy than the other two bulb types, with a higher surface reflection factor, the total number of lamps required in each case was lowered. The numbers for each kind of lamp in Scenario 2 are also displayed in the layout diagrams in Figs. 12-14.

This reduction in the number of lamps leads to significant energy savings. For LED lamps, the energy savings with a higher reflection factor reached 15.9%, while for CFL and incandescent lamps, the savings were 25%. These findings demonstrate that, although LED lamps are the most energy-efficient option, higher surface reflection factors can enhance the efficiency of all lamp types. This highlights the importance of optimizing surface reflection in lighting design and energy management to achieve substantial energy savings, regardless of the lamp technology used.

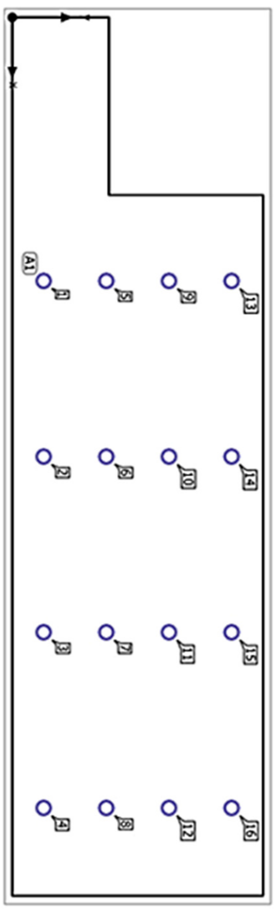

Fig. 9 CFL layout plan and number–Scenario 1

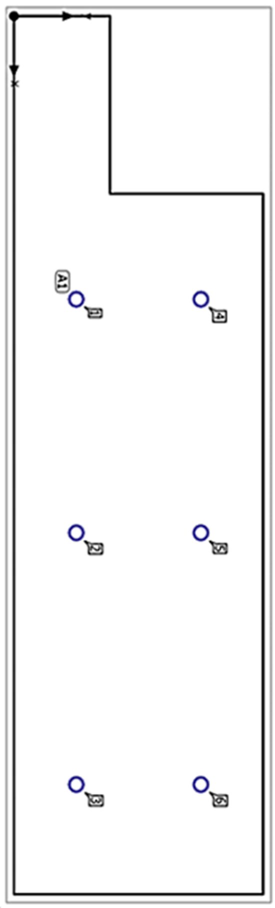

Fig. 10 LED layout plan and number–Scenario 1

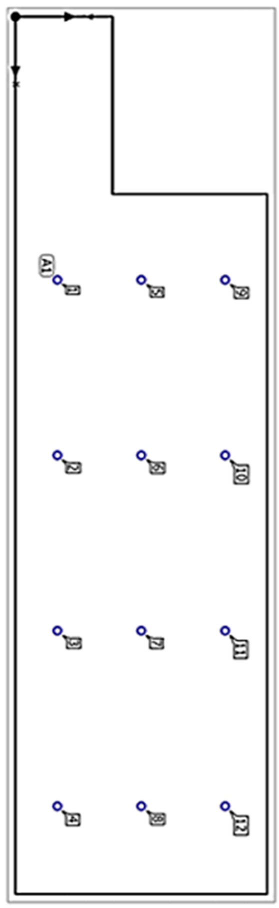

Fig. 11 Incandescent layout plan and number–Scenario 1

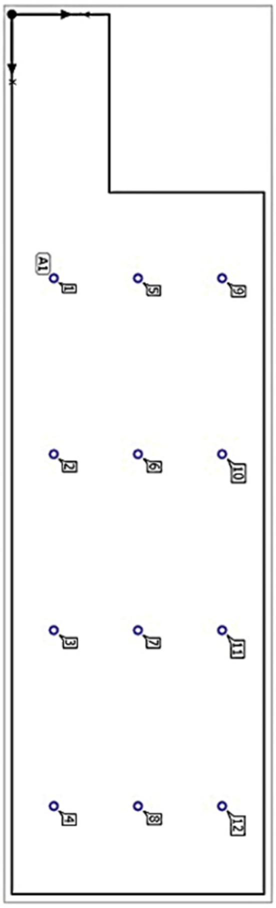

Fig. 12 CFL layout plan and number–Scenario 2

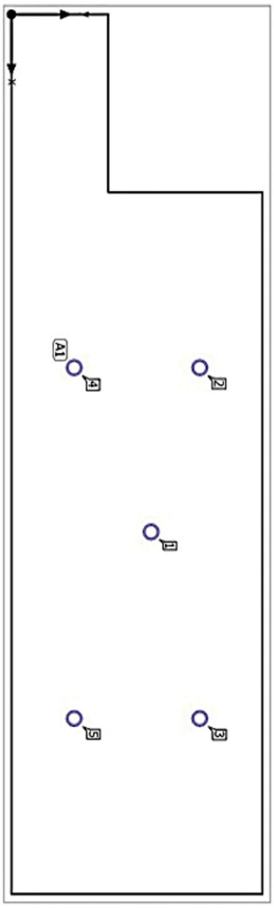

Fig. 13 LED layout plan and number–Scenario 2

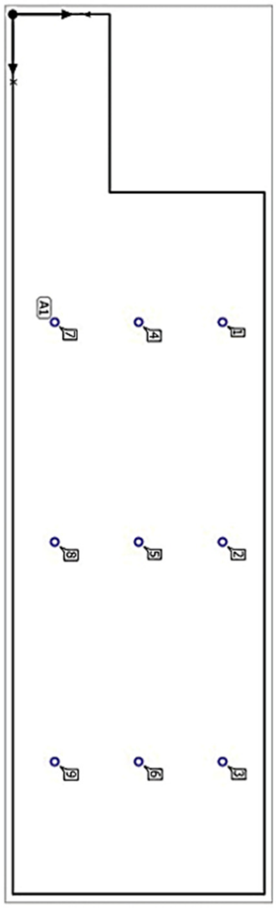

Fig. 14 Incandescent layout plan and number–Scenario 2

4. Discussion

This study aims to determine the most suitable light source for enhancing hospital visual comfort while reducing energy consumption. Lighting is crucial in occupant comfort and productivity, surpassing factors such as temperature, volatile organic compounds (VOC), sound, outside relative humidity, outside temperature, relative humidity, and temperature.

These findings align with previous research highlighting the significance of illumination on occupant visual comfort and productivity [22], with studies also indicating that natural light is preferred for promoting occupant well-being and productivity [23]. However, artificial lighting plays a significant role due to limitations in daylight availability, with studies also identifying the heavy reliance on artificial lighting in office environments due to factors like building design, orientation, and variations in natural light caused by clouds or windows.

As a result, buildings consume around 40% of the world's annual electricity consumption [7]. Hence, selecting an appropriate light source that provides visual comfort to occupants while reducing energy consumption is crucial. Visual comfort directly affects individuals' comfort, productivity, and health within a building [24]. Adequate lighting is essential for employees to maintain health and work efficiency simultaneously. The productivity and overall work environment significantly impact an organization's processes and financial performance [25].

Glare has been pervasively recognized as a primary cause of discomfort in lighting. It refers to a sensation caused by a light intensity within the visual field that exceeds the eyes' accustomed light intensity, resulting in irritation, discomfort, or reduced vision [26-27]. This study focuses on glare as a critical factor contributing to visual discomfort, which has been highlighted in various research.

Among the lamps analyzed in this study (Table 3), LED lamps are strongly recommended due to their high color rendering index (CRI) of up to 100 and long lifespan exceeding 50,000 hours. The results indicate that LEDs outperform other lamps in energy efficiency, cost-effectiveness, and visual comfort (high CRI). These findings are consistent with a study by Valentová et al. [28], which examined 106 LED tests from 17 European countries and demonstrated an average energy savings of 55% compared to the original installation.

Moreover, LED investments also generally provide a financially justified payback period of less than three years. As for alternative lamp options, CFL and incandescent lamps are considered suitable due to their acceptable lifespan and higher CRI compared to other lamps. Incandescent lamps with a CRI of 100 and CFL lamps with a CRI of 85 are appropriate for patient rooms. However, lamps such as mercury lamps with a CRI of 50, high-pressure sodium (HPS) lamps with a CRI of 21, and low-pressure sodium (LPS) lamps with a low CRI of 10 are not recommended due to their inadequate color rendering.

Despite the domination of LED lamps in developed countries for years, fluorescent tube lamps are still widely used in some developing countries like Iran, in applications such as hospitals, educational centers, and homes [29]. This study emphasizes the importance of finding lighting designs that provide the best visual comfort for occupants, utilizing the potential of each lamp type while minimizing electricity consumption. The research tested all three lamp types (LED, fluorescent tube, and other lamps) in a room with fixed dimensions and height. The preliminary analysis showed that LED lamps are the better choice in both scenarios (low and high reflection factor), as they consume less energy, provide higher visual uniformity, and perform better in terms of visual comfort indices, such as UGR.

In the critical analysis, the results indicate that if each lamp is compared solely within its type in both scenarios, each lamp had better performance with a higher surface reflection factor. In Scenario 1, the LED lamp had a UGR of 16 in the discussion of visual comfort, which was the parameter discussed in this article, even with a low reflection factor. In a medical environment where the UGR standard is 19, the LED failed to reach the standard and caused less glare in the room, incurring visual discomfort for patients and medical staff. The CFL was also at the borderline, passing the standard with a UGR of 19, whereas the incandescent lamps with a UGR of 22-23 did not reach the standard and are not a suitable option for the treatment room, as the glare irritates the occupants.

However, in Scenario 2, with an increase in the reflection factor, the UGR was reduced by about three units as the uniformity in the room increased. LED had the best performance with a UGR of around 12, which is ideal. The CFL had a UGR of around 16, considering all three beds, which, although higher than the LED, is still in an ideal state. The incandescent lamps had a better situation than Scenario 1, whereas it failed to meet the standard, which, in interior design cases, this small amount can still be acceptable or can be covered by other solutions.

Apropos energy consumption, the increase in the surface reflection factor caused more light to be reflected from the surfaces, which in turn increased the light intensity in the environment. This meant that with lighting design using any lamp type, fewer lamps were needed to reach the desired illumination, resulting in energy savings of 15 to 25% in this study. The present study also acknowledges some limitations:

(1) The height was considered as a constant factor, and the variable factor was the reflectance coefficient of the surfaces, while in the research conducted by Ciampi et al. [30], the performance of light in a historical building was investigated, and low-cost solutions for energy saving were provided. The results show that with the decrease in height, the number of lamps required for lighting also decreases, affecting the number of lamps between 19.5 to 23.5 percent. It is suggested that height should be considered a variable factor in future research, and the results should be examined with different heights.

(2) A patient room in Iran was considered, and the results were obtained through DIALux simulation and data analysis. It is suggested that future research results can be examined in the real environment of the hospital and specifically on hospital users.

5. Conclusions

In this study, the effect of lamp type and surface reflectance on visual comfort and the reduction of glare in hospital environments was investigated. The findings demonstrate that both lamp type and the reflection coefficient of surfaces are key factors in enhancing visual comfort and optimizing energy consumption. Specifically, the research identifies four key points, which are outlined in the following paragraphs.

(1) In Scenario 1 with a low surface reflection, LED lights with low UGR values (around 16) are most effective for minimizing glare in hospital environments, outperforming CFL and incandescent options. This demonstrates that LED lamps inherently outperform other lamps.

(2) Increasing the surface reflection coefficient led to improved light uniformity and reduced UGR by about three units, enhancing visual comfort. In high reflectance scenarios, LED lamps achieved a UGR of about 12.

(3) While LEDs are more energy-efficient, increasing surface reflection further reduces the total number of lamps required to achieve the standard 300 lux in patient rooms.

(4) Implementing LED lamps and optimizing surface reflectance can enhance visual comfort and lead to cost savings. Higher surface reflection reduced the number of lamps needed and glare, enabling the performance of CFL and incandescent lamps to be appropriately improved.

Conflicts of Interest

The authors declare no conflict of interest.

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