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A study of patient-centered, energy-efficient lighting design for hospital wards

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Abstract. As one of the most critical areas in a hospital building, the rationalization of the lighting environment is crucial for both patients and healthcare workers. This paper presents findings from field research and questionnaire interviews conducted in the Taiyuan ward, which reveal several issues with the current lighting setup, including low illuminance value, poor light uniformity, color temperature not meeting standard requirements, inappropriate selection and arrangement of light sources, and high proportion of lighting energy consumption. By analyzing factors influencing the humane and energy-saving aspects of the ward lighting environment, we explore a comparative simulation of the window-to-wall ratio and the form of shading inside the windows in the natural lighting system of the wards. Additionally, we consider the selection, placement, and control methods of lamps and lanterns for the artificial lighting system. Based on these findings, we propose a method for designing the light environment of hospital wards that accounts for both humane and energy-saving aspects, providing a technical means for optimizing the ward's lighting environment.

Keywords: ward, light environment, patient-centered, energy efficiency, software simulation.

1. Introduction

The ward, as the primary service area for patients, holds the utmost significance in a hospital building. It is where patients spend the most time, especially the weakest ones, and it directly impacts their recovery. Additionally, it serves as the routine treatment area for medical staff to conduct daily care and examinations for patients. Being a crucial component of the indoor physical environment in hospitals, the ward's lighting environment significantly influences the visual experience and health status of patients. Numerous studies have demonstrated that a well-lit ward environment effectively reduces patients' depression, enhances their mood, and leads to a decreased usage of painkillers. Moreover, appropriate illumination can reduce healthcare workers' error rates and alleviate their stress [1].

When designing hospital buildings, special consideration should not only be given to functionality but also to reflect humane design concepts. As people's living standards improve, patients' demands for comfort in the medical environment during treatment have significantly increased. Research on patient-centered ward design has primarily focused on evidence-based design [2], healing environment [3], humanization interventions [4] and factors affecting staff satisfaction in hospital wards [5]. Some literature has summarized 66 evidence-based design guidelines for wards, encompassing entrances, clinical areas for patients, bathrooms, family areas, and storage areas for patients and visitors [2]. Additionally, scholars have developed post-occupancy evaluation (POE) tools to assess the effectiveness of ward designs [6]. Within the context of ward humanization, a comfortable light environment represents the fundamental level of a well-designed physical environment. It not only influences physiological rhythms and patients' health through its effects on melatonin secretion but also helps alleviate negative emotions among healthcare workers due to burnout, reducing work error rates, and improving work efficiency [1]. Robert et al. have emphasized the value of investing in innovative lighting methods and technologies for studying ward light environments through questionnaire surveys.

The International Energy Agency (IEA) has emphasized the vital role of the building sector in achieving clean energy transitions, with buildings already accounting for 30-40% of global energy consumption [7]. Consequently, buildings become a key area in achieving carbon neutrality and energy transition [8–11]. However, most literature on energy conservation has focused on residential, office, and commercial buildings, with little attention given to hospital buildings [12]. Hospital buildings, which consume 1.6-2.0 times more energy than other public buildings, necessitate significant efforts to reduce energy consumption in alignment with the goal of curbing global warming and alleviating energy shortages. Despite being the most common and spacious areas in hospital buildings, wards' energy efficiency has been limited to window size [13] and glazing type [14], with minimal research conducted on the lighting environment in wards.

In general, existing research on the light environment in wards predominantly focuses on the comfort of the lighting environment or explores energy-saving effects from the perspective of external window research. However, there is a notable absence of simultaneous consideration for both light environment comfort and energy saving. This paper centers on the ward as the research object, drawing from the author's involvement in actual projects. The objective is to ensure that the ward's lighting environment meets humane requirements catering to different patient needs while exploring the balance between energy-saving and humanization. By finding this equilibrium, the paper provides valuable insights for future ward design and application.

2. Analysis of the current state of the light environment in the ward

To address the existing lighting issues in hospital wards, the author conducted research on 12 comprehensive tertiary hospitals in Taiyuan City, Shanxi Province. The ward configurations in these hospitals predominantly featured a combination of three main types: single rooms, three-bed rooms, and multi-bed rooms with two, four, or six beds. Triple rooms constituted over 70% of the total number of wards. The ward population primarily comprised medical and nursing staff, patients, and their families. Medical and nursing staff conduct room visits to understand the medical history, symptoms, and laboratory test results of undiagnosed patients. For diagnosed and recovering patients, staff mainly monitor their condition changes and perform simple treatments and visual operations. Patients usually spend their time lying down and resting, with occasional reading needs.

Based on field research and specific measurements conducted in numerous wards, ceiling lamps were found to be the main lighting tools used. In more recently constructed inpatient buildings, the position of the lamps generally corresponds to the beds to illuminate the entire ward. In older wards with two rows of four and six beds, a single lighting fixture is usually centrally located in the room aisle, while two and three-bed setups often lack uniform lighting fixtures. Localized illumination is typically provided through table lamps or bedside lamps near the head of the bed, and there may be a small ceiling light or recessed light at the ward entrance. Semi-structured in-depth interviews were conducted with patients, and 200 questionnaires were distributed, with 196 being returned. The reliability of the questionnaires was analyzed using SPSS software, resulting in a Cronbach Alpha of 0.872 and a KMO of 0.86, confirming the questionnaires' accuracy and validity. Through the measurement of illuminance, color temperature, and average brightness in different time periods using professional measuring instruments, as well as statistical research and analysis of lamp types and

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related parameters, the following problems with the ward lighting environment in general hospitals in the Taiyuan area of Shanxi Province were identified:

1) The illuminance value falls far below specification requirements. The Building Lighting Design Standards (GB 50034-2013) stipulate an illuminance standard value of 100 lx for the ward floor. However, based on the field research data, the average ground illuminance value is between 15-36 lx, primarily due to aging lamps or an insufficient number of lighting fixtures;

2) Ward light uniformity is poor. The large depth of the room leads to beds near windows requiring curtains to block excessive sunlight on sunny days, while beds away from windows often need artificial lighting to meet illuminance requirements due to the attenuation of natural light. Ceiling lights directly above the bed can have surface luminous intensities of up to 3500 cd/m^2, resulting in visual fatigue and a contrast of up to 600, leading to dazzling light.

3) The light source has a high color temperature biased towards white light, with an average color temperature of about 5600 K, creating a colder environmental experience. The "Architectural Lighting Design Standards" recommend a warmer color temperature (<3300 K) for the ward environment, which is not currently considered to meet patients' psychological needs.

4) The selection and arrangement of light sources and lighting fixtures are unreasonable. Some older ward buildings still use incandescent lamps, which have low efficiency with only 2% of energy converted into light. Most ceiling lamps are too bright and fail to effectively prevent the generation of dazzling light. Lamp positions often fall within patients' main line of sight, with 49% of bedridden patients experiencing eye discomfort due to light shaking. In wards without bedside lamps, 68% of patients feel the need for additional localized lighting, while in wards with bedside lamps, 29% of residents suggest improvements in lamp height and illumination angle.

5) Lighting energy consumption accounts for a high proportion, averaging 16-20% based on research data.

The current research indicates that the light environment conditions in wards fall short of meeting humane requirements for patients and fail to meet global energy-saving and emission reduction standards. Thus, urgent research is required to explore the light environment in wards that considers both humane and energy-saving aspects.

3. Analysis of humane and energy-saving design of ward light environment

3.1. Humanized design of the ward light environment

1. Quantitative Standards for Humane Design of the Light Environment

In today's rapidly changing society with advancing science and technology, economic development, and improved living standards, the concept of "patient-centered healthcare services" has gained prominence internationally, as reflected in the 6th edition of the Hospital Accreditation Standards released by the Joint Commission of the United States Healthcare Organizations in 2021. To quantitatively analyze the qualitative index of "patient-centered design," which is not directly measurable, the concept of "comfort" is introduced as an evaluation index of humanization. According to the Standard for Architectural Lighting Design (GB 50034-2013), factors influencing perceived comfort in the light environment include appropriate illuminance, light uniformity, appropriate color temperature, and glare avoidance [15].

1) Appropriate illuminance: In terms of illumination standards, the standard value for ward illumination is 100 lx, using a combination of primary and secondary lamps, multiple dispersed lamps, and a multi-level space atmosphere to achieve the "see the light but not the light" experience.

2) Light uniformity: Illumination uniformity refers to maintaining the lowest value of illumination in the room and ensuring that the average value of illumination throughout the space should not be less than 0.6 compared to the specification of the ward space illumination average. Brightness uniformity is crucial for object visibility, where the brightness of work surfaces and their background should be clearly differentiated. A significant difference in brightness between the work surface and surrounding environment can cause visual discomfort. Factors affecting brightness uniformity include the size of

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natural lighting holes, intensity of external sunlight, form, number, and location of artificial lighting fixtures, as well as the reflection coefficient of indoor surface materials.

3) Appropriate color temperature: Different color temperatures evoke different feelings in people. For wards, a relaxing and warm environment is desirable, using warmer light with a color temperature of less than 3300 K. Additionally, the color rendering index of indoor light sources should not be less than 80 to reduce color differences under artificial lighting.

4) Avoid glare: Glare refers to extreme brightness contrast within the line of sight, causing visual discomfort or even blindness. The indoor glare situation can be assessed using the Uniform Glare Value (UGR) or Uncomfortable Glare Index (DGI) formulas in the indoor environment.

2. Humanized Analysis of Common Lighting Forms in Wards

To comprehensively address the diverse needs of patients in different situations, the lighting forms in the ward area are divided into four categories: general lighting, diagnostic lighting, reading lighting, and night lighting.

1) General lighting: General lighting creates a comfortable resting environment for patients. Through intelligent illuminance meters and patient interviews in various general hospitals, it was determined that the standard 100 lx is sufficient to meet the requirements. To avoid discomfort, lamps should be placed above the end of the bed, using large area and low-intensity light sources or indirect lighting to create a soft light. Warm, low color temperature light sources are preferable to provide patients with a warm and comfortable feeling.

2) Diagnostic lighting: To facilitate medical staff during patient treatment and care, the bed surface requires local illumination of 300-500Lux. High color rendering light sources are necessary to minimize the impact of light on diagnosis, and a color temperature close to natural light assists healthcare workers in accurate diagnosis.

3) Reading lighting: To cater to patients' reading needs, bedside lamps or wall lamps can be individually installed for each bed. Wall lamps are usually installed 1.4-1.6m from the ground, or sensor-controlled beam reading lamps can be used.

4) Night lighting: Night lighting serves the dual purpose of promoting better sleep for patients and attending to their needs at night. It also facilitates nurse room checks during nighttime hours. Footlights are commonly used to maintain low illumination levels, typically installed at a height of 0.2m-0.3m from the ground, often placed near the entrance or bathroom of the ward. Research suggests an ideal brightness of 2-5Lux. [16]

3.2. Energy-efficient design of ward light environments

Meeting the diverse lighting needs in wards, including general lighting, diagnostic lighting, reading lighting, and night lighting, requires various artificial lighting sources. However, a substantial number of artificial lights can lead to increased energy consumption. Studies indicate that lighting accounts for about 14% of the electrical energy consumption in a 500-bed hospital during normal operation, contributing to approximately 52% of the building's energy consumption [17]. Balancing energy efficiency with a humane light environment is a critical concern, yet it remains inadequately addressed in architectural design research. The challenge now is to explore methods for achieving humane ward light environments while promoting energy efficiency.

1. Basic Principles for Ward Light Environment Energy Savings

According to the building energy consumption equation 1:

$$Q = \frac{\int L dt}{\eta} \tag{1}$$

Where Q - building energy consumption, L - building load, t - time, η - energy conversion efficiency. The fundamental approach to building energy savings lies in three key factors:

a) Reducing building load: Employ design strategies to reduce the power consumption of electrical equipment, prioritize passive energy-saving methods, decrease high-power lighting equipment, and limit its usage frequency.

b) Reducing the time of energy consumption: Enhance passive building design, optimize window-to-wall ratios, shading, and orientation to introduce natural lighting, and adopt a proper lamps and lanterns control method to reduce the duration of artificial lighting.

c) Improving lamp and lantern efficiency: Utilize high-efficiency light sources to directly reduce energy consumption.

2) Evaluating Lighting Energy Saving

Evaluating lighting power density value of general lighting (LPD) is essential for lighting energy saving. LPD represents the installed power of lighting tools per unit area, measured in watts per square meter (W/m2). The current standards for wards require a current value ≤ 5.0 and a target value ≤ 4.5 [15].

2. Factors Affecting Ward Lighting Energy Consumption

1) Impact of Different Lighting Forms:

Various window-to-wall area ratios can significantly affect the indoor light environment. While larger open window areas can enhance lighting levels, it may lead to glare and reduced lighting uniformity, prompting patients to use curtains to block direct sunlight and rely on artificial lighting, thus increasing energy consumption. Different forms of window shading can also influence lighting energy consumption, with louvres' varying opening angles controlling natural light transmission.

2) Impact of Lighting Forms:

Traditional fluorescent lamps dominate the ward environment, resulting in fixed illuminance, poor uniformity, and high-power consumption. In contrast, LED lamps offer advantages such as low power consumption, high luminous efficacy, long service life, high color rendering, and flicker-free performance [18]. Energy-saving lighting design focuses on the arrangement, selection, and LPD control of lamps and lanterns.

3) Impact of Luminaire Control Mode:

Lighting energy consumption varies significantly based on control methods. Manual control methods include single switch control of individual lamps or using dimmers for groups of lamps. Automatic control methods encompass motion control, voice control, infrared control, photosensitive control, and intelligent lighting control. The switch control mode of different lamps and lanterns results in varying lighting energy consumption levels.

4. Methodology

As real-life lighting system operation uncertainties involve dynamic processes, traditional methods may not ensure the accuracy of experimental results. To study the relevant factors affecting lighting, qualitatively analyze their interactions, and quantitatively assess their influence, the author employs computer simulation. The south-facing three-room ward at the South Hospital of the Second Hospital of Shanxi Medical University serves as an example. Lighting fixtures are designed to meet human needs, adapting to the requirements of patients and medical staff under different lighting forms. The indoor physical environment is simulated using DIAlux evo modeling combined with DeST simulation. This approach replicates the lighting system's operation process by varying lighting forms, illumination types, and luminaire control modes as variables to simulate their impact on energy consumption and optimize variables for energy-saving.

DIAlux evo is professional and powerful performance simulation software for lighting design in various indoor and outdoor environments. It not only calculates the illuminance of each working plane but also provides visual observations of the scheme's actual effects, aiding designers in optimizing the arrangement of lamps and lanterns to meet human nature requirements while achieving energy-saving and environmental goals. DeST complements DIAlux evo by conducting dynamic simulations of indoor thermal and optical environments for energy-saving calculations.

1) Spatial Model Establishment: The model defines the geographic coordinates as Taiyuan (112.74°E, 37.73°N) and the net size of the interior space as 9.00m (L) * 3.70m (W) * 3.90m (H). Windows, doors, furniture, etc., are added to the ward model based on its actual state. The reflectance

of interior space materials is set as follows: 0.8 for the ceiling, 0.6 for the walls, and 0.3 for the floor. The modeling process is shown in figure. (Figure. 1).

2) Lamp Arrangement: Depending on the different lighting forms and needs, lamps are selected in the software. Three ceiling lamps are arranged corresponding to three beds (height 3.9 m), with an overall color temperature set to 3000 K, providing the option to adjust brightness and color temperature for medical personnel during diagnosis. Three bedside lamps or lighting lamps are used to meet patients' reading needs, with the color temperature set to 4000 K. Additionally, at the entrance to the ward, lamps are set to 4000 K to provide ample illumination. For nighttime, low-level lighting is placed at the entrance to meet patients' needs.

5. Simulation study of lighting environments combining humanity and energy efficiency

The light environment's influencing factors consist of two main components: the natural lighting system and the artificial lighting system. To ensure simulation accuracy, the same meteorological parameters are used for both systems. The natural lighting system significantly impacts lighting and air conditioning energy consumption, as well as the indoor light environment. Direct sunlight can lead to glare and discomfort within the indoor space. Thus, adjustments in the window-to-wall ratio and the form of shading inside the windows are considered as two variables for regulating the indoor natural light environment. For the lighting system, the control is primarily achieved through three variables: lamp selection, lamp location, and the luminaire control method. These variables are adjusted to reduce lighting energy consumption effectively. The pre-modelling process takes into account the diverse lighting needs, and different factors influencing energy consumption are simulated while ensuring human needs are met.

5.1. Natural lighting system

Adjusting the window-to-wall ratio and window shading form aims to ensure indoor ward comfort while avoiding direct sunlight and maintaining horizontal illuminance below 2000 lx [19]. Four different window-to-wall ratios are compared and simulated, as the windows serve as the main medium for indoor and outdoor heat transfer, impacting both indoor lighting and thermal environment. While larger windows provide ample lighting, they can also lead to negative effects such as glare and thermal discomfort. Therefore, a coupled simulation analysis of the light and heat environment is conducted to guide both humane and energy-saving design aspects.

1. Window-to-wall ratio

Ensure that the number of windows in the ward, the basic situation of the room remains unchanged, only change the window area, the following four ratios of the window-wall ratio were compared and simulated, because the window as the main medium of indoor and outdoor heat transfer, not only affects the indoor lighting, but also has a certain impact on the indoor thermal environment, the windows account for a large percentage of the light is good, but it will also bring about a certain negative impact: on the one hand, direct sunlight, will result in On the one hand, when the sunlight is direct, it will cause glare; on the other hand, it will also cause interference to the comfort of the indoor thermal environment. Therefore, in the simulation of the window-to-wall ratio, it is necessary to carry out a coupled simulation analysis of the light and heat environment, which will provide further guidance for the design of both humane and energy-saving aspects.

The heat transfer coefficient of the windows is 2.0 W/(m2-k), and the shading coefficient is 0.8. The ward is equipped with three 40 W LED ceiling lamps with a colour temperature of 3000 K and a colour rendering index of 80. The calculation of natural light intensity was performed through dynamic simulation throughout the year, and the state of switching on and off the lights and curtains was determined based on the behavioural graphs of patients turning on the lights obtained from the research data. Air conditioning power consumption was calculated based on a COP of 3. The simulation results can be seen in the table below:

Table 1. Comparison of energy consumption for different window-to-wall ratios.

window-to-wall ratio	Energy consumption per unit area /(kW·h(m²·a))			
	illumination	refrigeration	heating	total power consumption
20%	13.3	15.8	7.5	36.6
40%	10.4	16.6	6.2	33.2
60%	9.6	17.9	5.9	33.4
80%	8.8	20.3	4.8	33.9

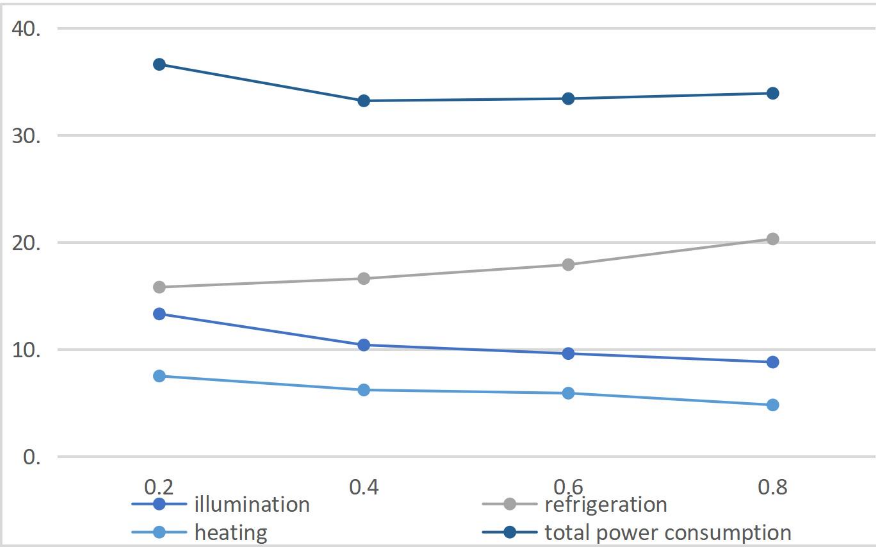

Figure 1. Changes in energy consumption for different window-to-wall ratios.

From the simulation results, as shown in Fig. 1, as the window-to-wall ratio gradually increases, the lighting power consumption gradually decreases and the air-conditioning energy consumption gradually increases, while the total energy consumption of the building decreases and then increases. The results show that too large window-to-wall ratios in pursuit of a good view and too small window-to-wall ratios in pursuit of energy savings by reducing windows are not favorable to energy savings. The difference in total electricity consumption between a 40% and 60% window-to-wall ratio is only 0.4; in this case, a 40% window-to-wall ratio is the most energy-efficient solution under the premise of humane design.

2. Forms of internal window shading

Fixed shading usually has a relatively bad impact on ventilation and lighting, winter heating, and landscape views. The internal sunshade can be controlled according to the preference of indoor patients, and the forms are mainly curtains, adjustable roller blinds, and movable blinds.

The model is mainly designed in the following forms:

1) When the illuminance at the calculation point of the ward is more than 2000 lx, the curtains are in full shading state, which can block the direct sunlight, and 20% of the scattered light through the curtains can enter the room; when the illuminance in the ward is lower than 2000 lx, the curtains are in full opening state.

2) The state of roller blinds can be divided into five kinds: fully open, 25%, 50%, 75% of direct sunlight, and all closed. Using automatic control, the modeling will be pre-calculated for each of the five cases. According to the "Architectural Lighting Design Standards", the standard value of indoor

natural light illuminance in the wards is 300 lx, with the average sunrise and sunset time of Taiyuan City as the time period for calculations (see table 2). The state of the roller shutter changes according to the illuminance of the measurement point, and the changes are shown in table 3.

Table 2. Average sunrise and sunset time and lighting hours in Taiyuan city.

Time	Average sunrise time	Average sunset time	Length of daylighting (h)
March, April, May	6:00	19:00	13
June, July, August.	5:30	19:30	14
Sept, Oct, Nov.	6:30	18:00	12.5
Dec, Jan, Feb.	7:30	17:30	10

Table 3. Roller shutter status according to the change of illumination at the measuring point.

Illumination range (lx)	>2000	1000-2000	500-1000	300-500	<300
roll-up state	fully closed	25%	50%	75%	fully open

3) The state of the louvres is analogous to that of a roller shutter, with fully open, slanting up 45°, horizontal, slanting down 45°, fully closed, and simulated in the same way as a roller shutter.

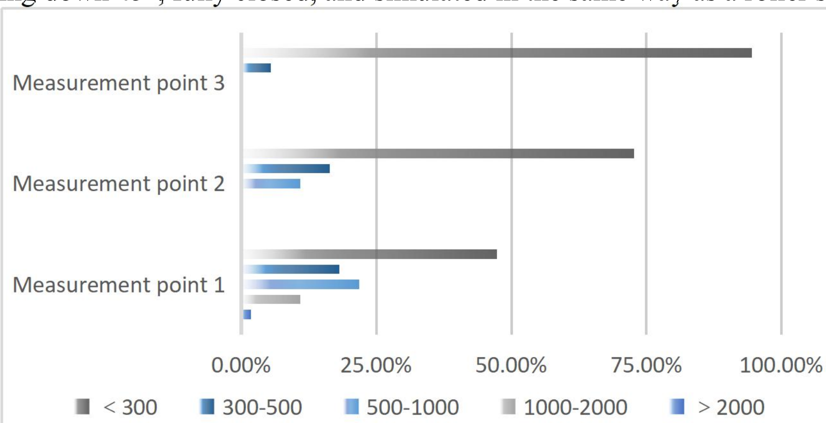

Figure 2. Distribution of light illuminance throughout the year for the curtain programme.

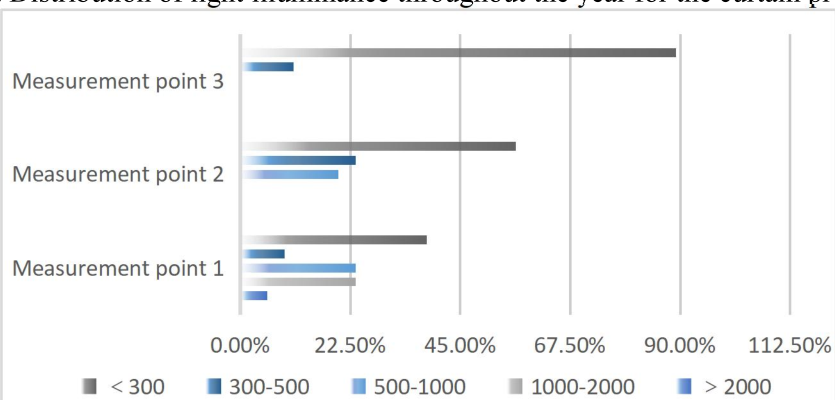

Figure 3. Distribution of light illumination throughout the year for the roller shutter programme.

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As shown in the figure, different internal shading states can be seen in the simple curtain scheme model, so that the efficiency of natural lighting is greatly reduced, increasing the length of time to turn on the lights and further increasing the energy consumption. While roller blinds and blinds have a variety of adjustable states, they can greatly improve the efficiency of the use of natural lighting. Natural lighting is not only beneficial to the patient but also reduces the energy consumption of lighting through the use of self-adjusting roller blinds or louvres, taking into account both the humane and energy savings.

5.2. Artificial lighting system

1. Lighting form variable control

1) Lamp selection

Select the same luminous flux, the power of different light sources, color rendering index, life, and power consumption comparisons. It can be seen that in the humane aspects of the parameters, the color temperature can reach the warm color temperature required by the ward. In terms of color rendering index, LED lamps are slightly inferior to other types of lamps, but they have outstanding performance in terms of energy savings. Not only is their life far better than other lamps, but their power consumption is also very low.

Table 4. Comparison of different light source parameters.

Bulb Type	LED lamps	Fluorescent lamps	Tungsten halogen lamps	Incandescent lamps
Power (W)	10	10	40	80
Luminous efficiency (lm/W)	80	80	20	10
Luminous flux (lm)	800	800	800	800
Colour rendering index	80	85	95	97
Colour temperature (k)	3000	3000	3000	3000
Lifetime (h)	50000	3000	2000	1000
Power consumption (kWh) (based on 10,000 hours)	100	100	500	800

2) Layout position

Ward simulation with three people as an example can be set up by setting the center of the ceiling to place only a ceiling lamp (Scheme I), three beds in the middle of the two (Scheme II), and each bed placed a bed (Scheme III). Three types of arrangements were simulated. To be illuminated surface to reach 100 lx as a benchmark, light efficiency is 80 lm/ w, and general lighting as a light environment state simulation test wards turn on the light time and lighting energy consumption.

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Table 5. Comparison of luminaire layout position options.

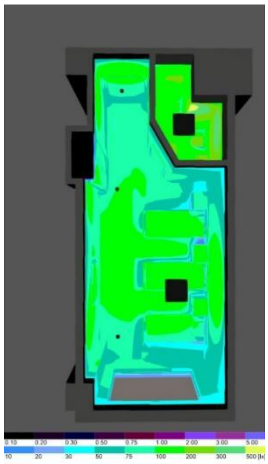
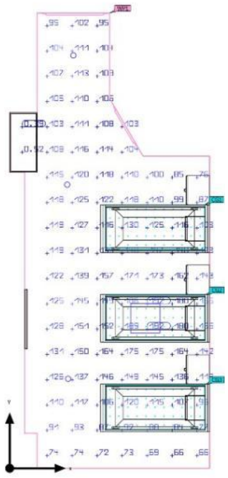
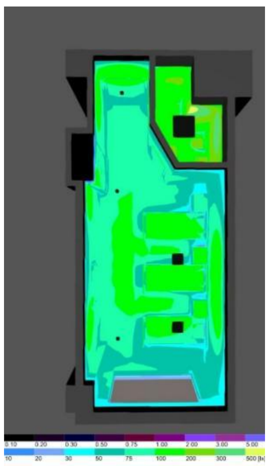
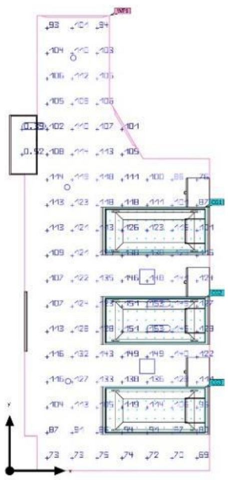
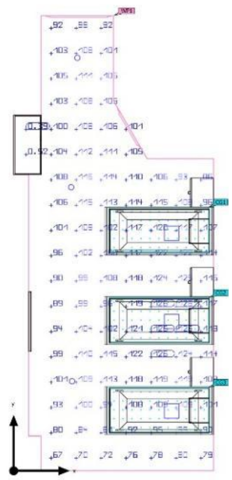
	Power (W)	Luminous flux(lm)	Pseudo-colour map	Work surface Illumination Average	Lamp on Length of time(h)	Lighting energy consumption (kW·h/(m^2·a))
Option 1	36	2880			3942	12.2
Option 2	16	1280			2628	9.6

Table 5. (continued)

	Power (W)	Luminous flux(lm)	Pseudo-colour map	Work surface Illumination Average	Lamp on Length of time(h)	Lighting energy consumption (kW·h/(m^2·a))
Option 3	10	800			2190	4.3

Through simulation, it can be seen that only one ceiling lamp is placed in the centre of the ceiling, the light distribution is too uneven, if the middle beds feel comfortable in the light environment and the illuminance can meet the specification requirements, the illuminance of the two beds can not be satisfied; if the whole room meets the illuminance requirements, the middle beds will feel the light shaking the eyes, resulting in discomfort for the patients; the programme of placing two lamps in the middle of the three beds is relatively Uniformity, and because of its position away from the head of the bed, will not cause the patient to lie down on the eyes of the direct light, energy consumption is also lower; three beds corresponding to the position of each put a lamp, illumination distribution is relatively the most uniform, lamps and lanterns independently controlled to meet the patient's personalised needs, energy consumption is also the lowest, and taking into account the actual situation of the ward interior, between each bed there are curtains to ensure that the patient's privacy, so the program The third option is the most energy-saving and humane.

2. Lighting control method variable control

The control mode of lighting fixtures is also an important part of the lighting system. In addition to regulating the indoor light environment, it can also make a certain contribution to energy-saving lighting. Lighting control mode is only considered in manual mode. The room has LED lamps; each bed corresponds to a ceiling lamp; lamp power is 40 W; color temperature is 3000 K; and color rendering index is greater than 80.

Lamp control is all lamps for a switch, and each lamp can be individually controlled. The latter programme, according to the test point throughout the day below 100 lx, is the lamps on, the average number of hours of light, and lighting energy consumption, as shown in table 6.

Table 6. Comparison of lighting control methods and schemes.

Programme	Average number of hours lights on(h)	Lighting energy consumption(kW·h/(m^2·a))
One switch for all luminaires	4189	19.5
Individual control for each luminaire	856	3.9

The results of the calculations show that the control of all luminaires by a single switch consumes significantly more energy than the lighting of the other solution. The reason for this is that if the weather is good, the beds by the window or even in the center can be lit by natural light during the day, and the beds furthest away from the window can be lit only by switching on the lamps in their corresponding positions. If the switch is shared, any one person with a lighting need will need to switch on all the lights. The switch is controlled by only one user, and the probability of three lights being switched on at the same time is much lower than the probability of all lights being switched on by a common switch. So both in terms of energy savings and the use of natural light, the solution where each luminaire is controlled individually is better.

6. Conclusion

This study aimed to explore a ward light environment that considers both human needs and energy efficiency while achieving quantitative analysis. Based on real-world hospital ward situations and engineering practices, the author conducted simulations on the natural lighting system, including window-to-wall ratio and window shading forms, as well as the artificial lighting system, encompassing lighting types and control modes. The goal was to examine their impact on the ward light environment and provide guidance for a balanced humane and energy-saving design.

The following conclusions were drawn from the study:

1. Effective utilization of natural lighting not only enhances patients' connection with nature, reflecting humane design principles, but also significantly contributes to energy saving. For a three-person ward, a 40% window-to-wall ratio with roller blinds or louvres as internal window shading achieves a well-balanced combination of humane and energy-efficient design.

2. Among existing lamp types, LED lamps are a suitable choice for the artificial lighting system, meeting patients' comfort needs while being the most energy-efficient option. Placing a lamp at each corresponding position of the three beds in the ward ensures the most uniform work surface illumination with minimal energy consumption.

3. Lamp control mode plays a vital role in lighting energy consumption. Independent switches for lamps corresponding to the beds in the ward cater to different usage habits of occupants, while allowing energy-saving benefits by turning off lamps in areas with sufficient natural illumination.

By considering both human needs and energy efficiency, this research provides valuable insights for the design and application of ward light environments, fostering a patient-centered, comfortable, and sustainable approach to hospital lighting design..

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