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Research Paper

Determining the Illuminance Limits for Providing Visual Comfort in Patients with Eye Lesion (Cataract) in Medical Building of Tehran

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Abstract
Given the crucial role of medical buildings in emergency situations, health maintenance, and disease control, as well as the importance of ensuring user comfort, recent architectural studies have emphasized the need to revise design criteria. One of the key considerations for creating comfortable environments in hospitals is managing undesirable lighting. Although research underscores the importance of sufficient and appropriate natural light in reducing patients' length of stay, reliance on general standards may not adequately address the needs of specific patient groups. To assess visual comfort in an ophthalmic ward while minimizing the potential biases and limitations of human studies, this research utilized an in vivo animal model using rabbits. Rabbits were selected due to their physiological similarities to humans, especially regarding the visual system, making them appropriate subjects for studying cataract-related reactions. Moreover, animal studies offer better control over environmental factors, ethical considerations, and reproducibility compared to human studies, where individual variations and external factors can affect results. In this study, daylight simulation and its effects were analyzed through a point-by-point illuminance comparison using Rhinoceros modeling software, Grasshopper, and HoneybeePlus version 1.4.0. The results demonstrated a 15.19% discrepancy between the visual comfort limits set by international standards and the expectations of patients with cataract eye problems. This inconsistency has led to a 22.44% reduction in the comfort levels within the patients' rooms.

Keywords: *Visual comfort, Eye disease, Medical buildings.*

INTRODUCTION

Nowadays, architecture is more complex than before due to the emergence of more indicators related to indoor qualities and sustainability. After decades, it is demonstrated that finding solutions for indoor problems that occupants encounter primarily comes from a sustainable approach. Daylight and the dissatisfactions it causes are among the most critical issues that architects, building constructors, and even occupants are aware of today (Wienold & Christoffersen, 2006). Views and daylight through windows in buildings are recognized as important factors in increasing Indoor Environment Quality (IEQ).

The architecture of hospitals can improve the health of patients (Husein et al., 2020). Findings show that natural light and dark rhythms help control the biological clock and regulate important hormones (Englezou & Michael, 2020). This significance means that lighting greatly influences health, alertness, and sleep quality. These effects are also noticeable in mental and psychological conditions (Amleh et al., 2023). Proper lighting reduces visual stress, resulting in better efficiency in work and life environments. Cortisol (the stress hormone) and melatonin (the sleep hormone) are two hormones that play crucial roles in alertness and sleep control. Cortisol increases blood sugar and body energy. However, when cortisol levels remain too high over a long period, the body begins to

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feel tired and ineffective. High cortisol levels keep the body ready for daily activities, while it is expected that melatonin levels drop in the morning, and the release of this hormone at night can ensure healthy sleep (Wang et al., 2020).

The physical environment of a building significantly affects the therapeutic process and well-being of the occupants (Chen et al., 2023). For optimal daylighting performance, the external facade should be designed to maximize daylighting to assist in patient health care and comfort. However, uncontrolled solar radiation can increase thermal loads during summer, placing extra demands on air-conditioning systems (Ochoa & Ã, 2006). Therefore, balancing the diffusion of light and eliminating undesirable lighting is crucial.

In the ophthalmic ward, due to patients' inability to change their clinical conditions, providing visual comfort by controlling light quality in the treatment environment during the post-surgery period is important (Edwards & Torcellini, 2002). Uncontrolled daylight can have detrimental effects in ophthalmology wards, such as glare and eye strain for both patients and staff. By carefully managing daylight within the architectural scope, ophthalmology wards can create environments that enhance patient care, improve staff performance, and promote overall well-being while minimizing potential negative effects. Investigating the preferences of specific groups of optic patients may further clarify their needs.

Eye lesion

Impaired vision encompasses a range of diseases affecting individuals of various ages and can significantly disrupt personal and social aspects of life. Individuals with vision impairment often require assistance with daily tasks and interpersonal interactions (Isawumi et al., 2006). According to the latest estimates by the World Health Organization, 161 million people globally suffer from vision impairment, with approximately 37 million being completely blind. Additionally, around 135 million people have other vision disorders. The prevalence of blindness, particularly among individuals over the age of 50, is higher in rural areas and especially among women (Resnikoff et al., 2004).

Cataracts are the leading cause of blindness worldwide, with statistics indicating that about 47.8% of blindness cases are due to severe cataracts. Other significant causes of blindness include glaucoma (approximately 12.3%), age-related retinal problems (around 7.8%), corneal opacity (about 5.1%), and diabetic retinopathy (approximately 4.8%). Additionally, childhood blindness (about 3.9%), trachoma (around 3.6%), and onchocerciasis (about 0.8%) contribute to global blindness rates (Isawumi et al., 2006).

Cataracts are highly prevalent, particularly among the elderly, and account for a substantial portion of eye surgeries. Providing visual comfort after cataract surgery is crucial in environmental design due to the extreme sensitivity of these patients to light. Addressing this disease and ensuring visual relief is a major concern for the medical community, given the high volume of patients and the critical sensitivity of this group.

Cataract

A cataract refers to the presence of any opacity in the eye's lens and is the most common cause of vision loss. It predominantly affects elderly individuals aged 65-74, with prevalence rates increasing by approximately 50% in this age group. Cataracts can be categorized into several types:

1. Age-Related Cataract: This type involves the loss of lens transparency, leading to diminished vision quality. It typically results from an increase in the lens's focusing power, causing a shift in refractive power towards myopia.

2. Traumatic Cataract: Often caused by damage from foreign bodies, this type of cataract generally causes the lens to turn white shortly after the foreign object penetrates. The white appearance is due to the rupture of the lens capsule, allowing aqueous humor and sometimes vitreous humor to enter the lens structure.

3. Complicated Cataract: This type arises as a direct consequence of intraocular diseases affecting lens physiology.

4. Medication-Induced Cataract: Prolonged use of certain medications can lead to lens opacities.

5. Childhood Cataract: Cataracts in children can impact physical, emotional, and social development. They are classified into two groups: congenital cataracts, which are present at birth or shortly thereafter, affecting 3 to 10 children per 10,000 births, and acquired cataracts, which develop later and are usually associated with specific causes. While acquired cataracts are less urgent, congenital cataracts require immediate attention due to their impact on the developing visual system.

Given the prevalence of cataracts, patients are a significant demographic in treatment spaces and ophthalmology clinics. Due to their sensitivity to light, it is crucial to provide these patients with environments that ensure visual comfort.

Indicators

According to the increasing number of indicators related to visual quality and suitable daylight conditions, it is essential to evaluate these indicators based on inspection and usage standards or the specific conditions of projects. Despite the growing number of visual comfort indicators over the years, they can be categorized into two main groups: static and dynamic indicators. Static indicators aim to assess visual comfort at a particular moment or during a specific period, while dynamic indicators analyze light conditions and visual comfort over a longer period, such as a year, accounting for changes and fluctuations (Bellia et al., 2016).

Among the static and dynamic indicators in the field of visual comfort, glare rate and illuminance have been extensively investigated.

Illuminance index

Illuminance (measured in lux) is a crucial factor affecting visual comfort and provides basic information for calculating various indicators. The illuminance index represents the amount of light flux received per unit area, measured in lumens per square meter or lux. In almost all analyses and research related to daylight, the initial step is to evaluate the quality and quantity of illumination (Rastegari et al., 2023).

The required amount of lighting in a space depends on factors such as the type of work, its duration, and whether it occurs during the day or night, as well as the age of the users. Lighting regulations and standards have evolved over time. The maximum tolerable illuminance level in treatment spaces is 300 lux (Sherif et al., 2017).

Site analysis

The city of Tehran, the capital of Iran, has been selected for investigation and research in this project. Located at a latitude of 35 degrees 41 minutes 21 seconds and a longitude of 51 degrees 23 minutes 20 seconds within the Alborz mountain range, Tehran's elevation ranges from 900 to 1800 meters above sea level. According to software analysis, Climate Studio 6 categorizes Tehran's climate as Csa, or moderate with hot and dry summers, according to the Köppen climate classification.

Considering Tehran's latitude and the sun's path, which extends a considerable distance during summer, architectural measures to mitigate the effects of prolonged sunlight exposure are essential for climate compatibility in Tehran (Figure 1). Conversely, during winter, harnessing the solar energy can help reduce the need for heating.

Iran is a country with significant solar exposure. The Caspian region, however, experiences relatively low radiation due to its location between the mountain range and the sea, coupled with frequent cloudy conditions. In contrast, most of the country enjoys over 270 sunny days annually. Detailed analysis from satellite images reveals the following about solar radiation in Tehran:

- **Diffuse Solar Radiation**: The diffuse horizontal irradiance (DHI) in Tehran is approximately 600-700 kWh/m² per year (Figure 2).
- **Direct Normal Irradiance**: The direct normal irradiance (DNI) in Tehran is estimated at around 1600-1800 kWh/m² annually (Figure 3).
- **Global Solar Radiation**: Tehran receives an average annual global solar radiation of approximately 1800-2000 kWh/m² on horizontal surfaces (Figure 4).

Due to its significant elevation, Tehran experiences low cloudiness and substantial levels of both diffuse and direct solar radiation.

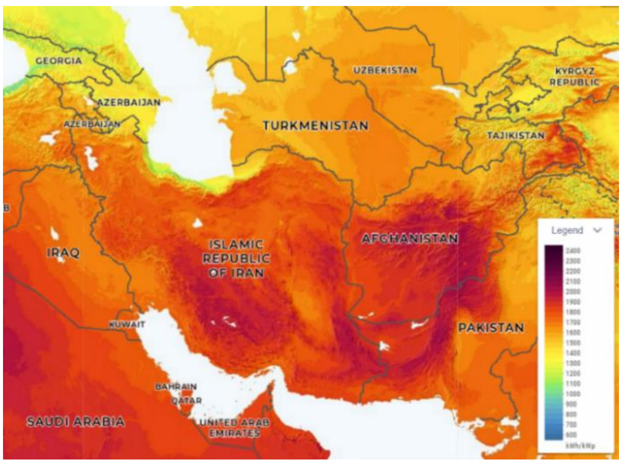

Fig 1. Map of radiation received in Iran
https://globalsolaratlas.info

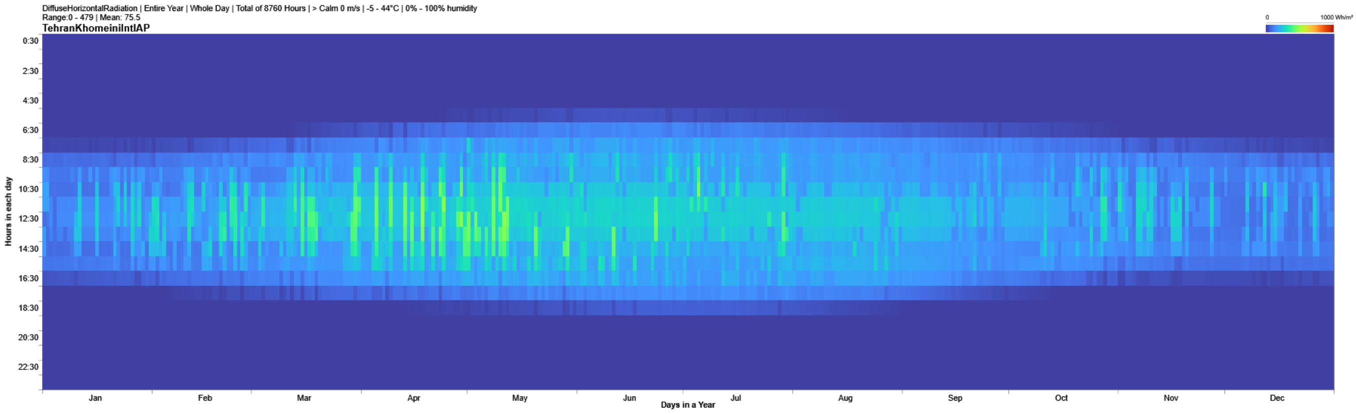

Fig 2. The amount of diffuse radiation in different hours of the year in Tehran (climate studio software).

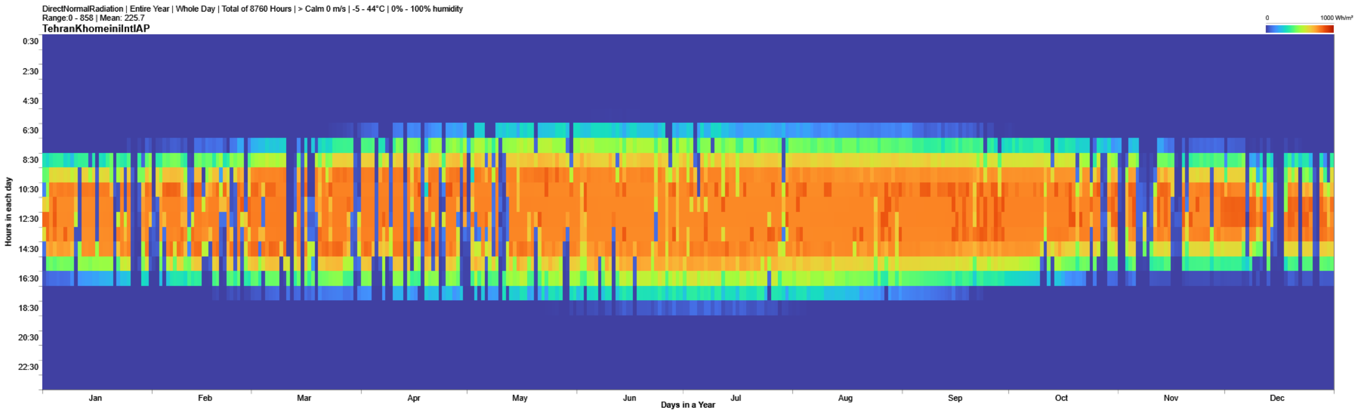

Fig 3. The amount of direct radiation in different hours of the year in Tehran (climate studio software).

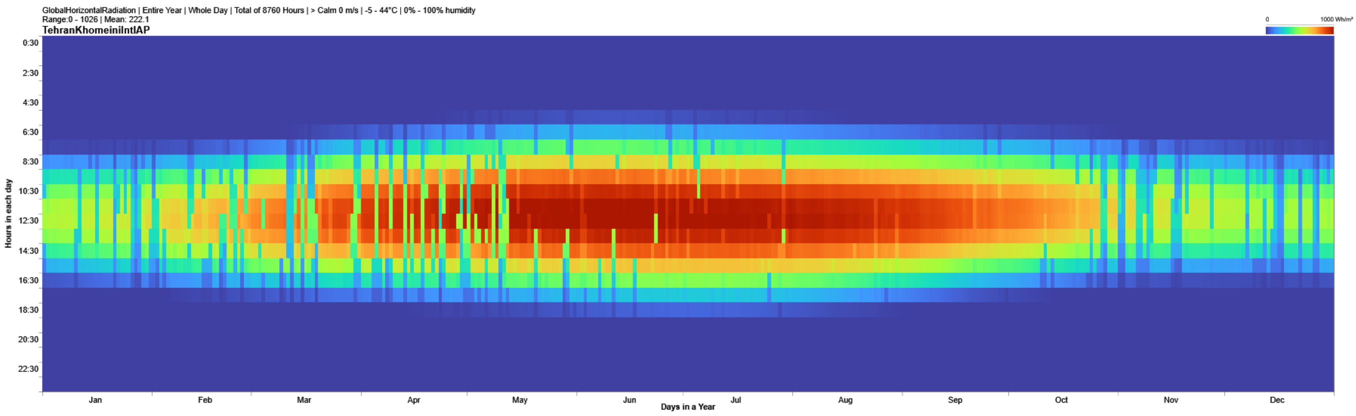

Fig 4. The amount of global radiation in different hours of the year in Tehran (climate studio software).

The above analysis highlights that while the solar radiation received during the summer, particularly around midday, presents significant potential for addressing energy needs, it can also cause discomfort for users. This intense sunlight exposure poses particular concerns for cataract patients, as ultraviolet (UV) radiation is a recognized risk factor for the development and progression of cataracts. Consequently, cataract patients in Tehran may need to take additional measures to protect their eyes from UV radiation. Therefore, it is crucial for medical facilities catering to cataract patients in Tehran to be designed with enhanced efficiency to address these concerns.

METHOD

In vivo test

The study examined differences in light reception between normal and cataract-affected eyes using an animal model. Two groups of albino rabbits (each consisting of six male rabbits) were selected for the tests. Group 1 comprised rabbits with normal eyes, while Group 2 included rabbits with cataracts. The tests conducted included assessments of light tolerance thresholds and latency to analyze light reception for both healthy and diseased eyes.

Latency test

The latency test was performed using a light/dark box setup (Figures 5 and 6). This setup consists of a light box with 100 lux illumination connected through an opening to a dark box. The test measures the time required for the rabbit to place its front limbs or all four limbs on the floor of the light box (Matsuo et al., 2019). Depending on the cognitive test employed, the time taken for the rabbit to escape or enter the dark compartment (passive avoidance test) was analyzed. Figure 6 illustrates the latency test procedure. It is important to note that each test was repeated three times for validation, with a 5-minute interval between each test.

Light tolerance threshold test

To determine the tolerable brightness levels for rabbits with cataracts, the reaction of the rabbits to different light intensities was assessed, focusing on their pain and tolerance thresholds. Rabbits generally keep their eyes open when the ambient light is perceived as comfortable or tolerable. When the light intensity reaches a painful threshold, they tend to keep their eyes partially closed. If the brightness exceeds this threshold, the discomfort becomes unbearable, leading the rabbit to close its eyes completely.

To measure the amount of light (in lux) entering the rabbit's eye under various conditions, a series of 10 smoky filters were used with the examination flashlight. These filters allowed different amounts of light to reach the rabbit's eye at varying distances. Light intensity measurements were taken using a Lutron luxmeter model LUTRON LM-81LX within the animal housing environment. Each brightness measurement was repeated three times at each position to ensure accuracy. The design of the measurement device is illustrated in Figure 7.

In therapeutic settings, numerous factors contribute to the enhancement of these spaces, given the continuous use and patients' inability to adapt to varying conditions. While these factors generally aim to improve the user's quality of life, they can sometimes conflict with one another. Therefore, identifying appropriate and applicable variables and revising existing standards can help minimize these conflicts.

This report analyzes indicators such as brightness levels and glare to assess visual comfort. Daylight penetration into a room, while significantly reducing energy consumption and potentially decreasing patient hospitalization times, can also pose risks. It may increase the likelihood of glare and discomfort for patients who have undergone eye surgery. Despite these concerns, completely blocking daylight is not feasible due to its benefits for energy control and patient mood enhancement.

Indicators like glare, which directly impact user comfort, have been examined in this project because of the heightened sensitivity and vulnerability of patients with eye conditions compared to other users. Reducing glare in patients' visual fields is crucial for improving their comfort.

Additionally, one of the primary objectives of this research is to define visual comfort indicators more precisely for patients with eye issues, particularly cataracts. To achieve this, the study aims to establish more accurate and practical ranges for these indicators through field studies and animal sample examinations, complementing library research and previous studies. The methodology for conducting these tests is detailed in this section.

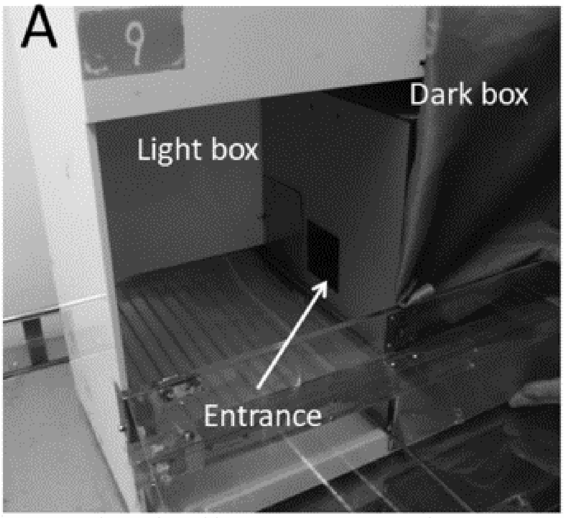

Fig 5. The scheme of light-box (Matsuo et al., 2019)

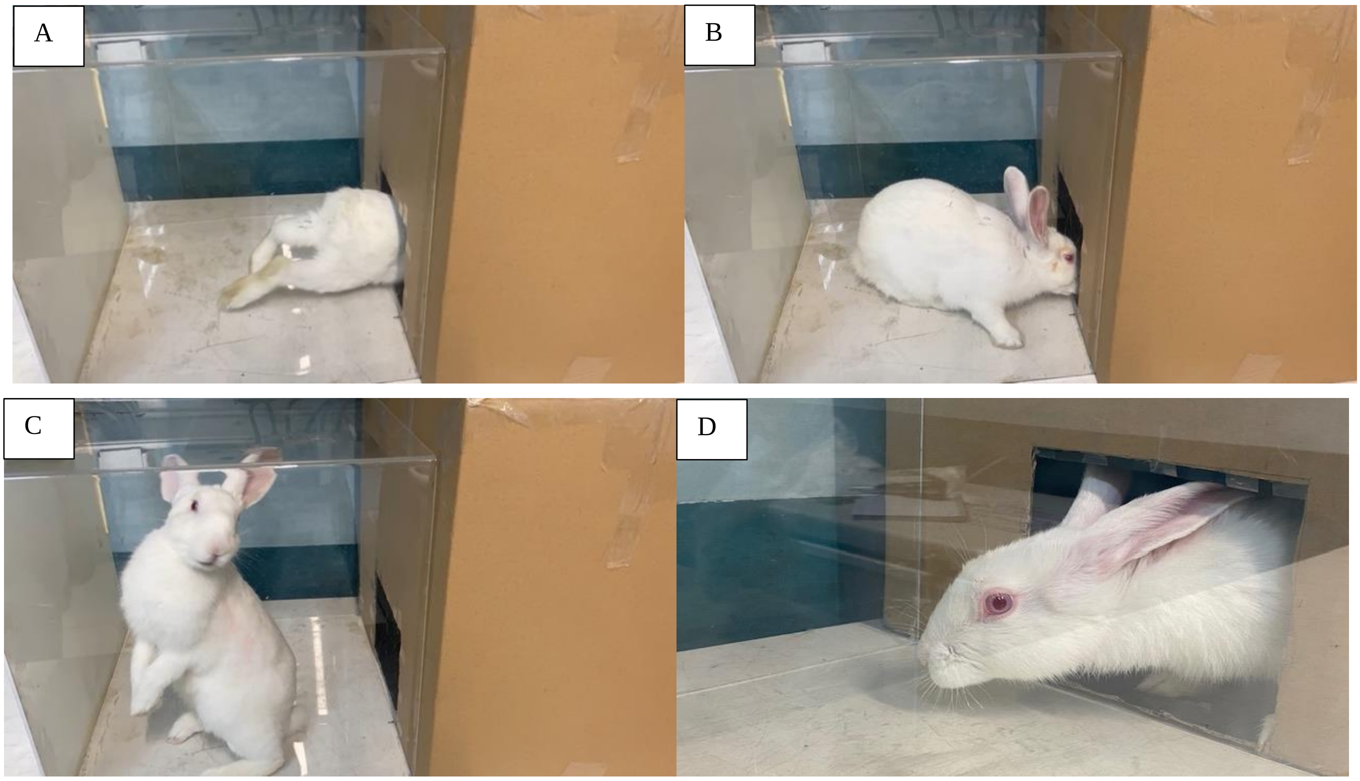

Fig 6. The latency test for healthy and cataract rabbit; A) and B) the entrance of the rabbit in the dark place, C) and D) the exit of the animal from dark-box.

Fig 7. Filtered- Flashlight for tolerance lighting acceptance

Computational Modeling

In our previous study, a virtual room was designed using 3D modeling software Rhinoceros 6.31 and Grasshopper. Point-by-point analysis was performed with Honeybee version 1.4.0. The results of the daylight simulation were tested and validated using in-situ measurements with a luxmeter model LUTRON LM-81L. For the modeling and daylight simulation, the CIE overcast sky model was used based on available horizontal illuminance data (CIE, 2004).

The designed patient room dimensions are 4.8 meters in width, 6.0 meters in depth, and 3.0 meters in height (Brembilla et al., 2017). In contrast, the dimensions of a typical patient room observed in common hospitals in Tehran are 4.2 meters in width, 5.3 meters in length, and 3.2 meters in height.

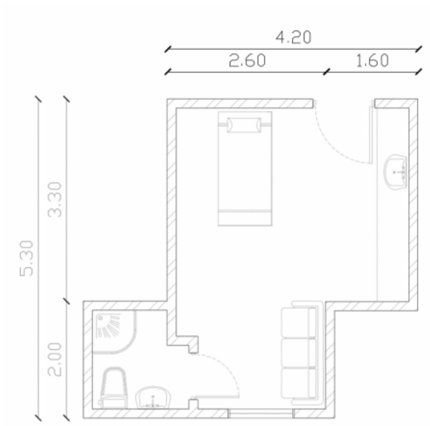

Fig 8. Typical plan of patient room

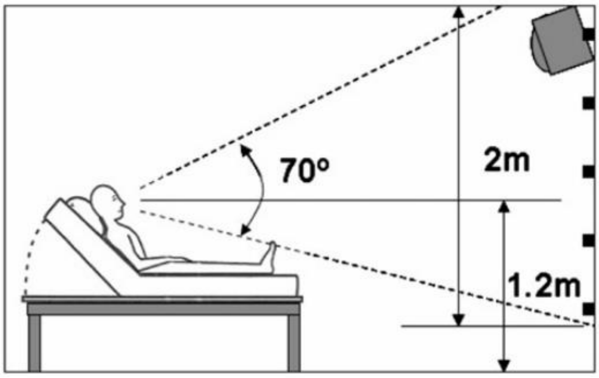

Fig 9. The condition of the patient in the hospital bed (Greenup et al. 2001)

Table 1. Surface reflective index (Greenup et al. 2001)

Surfaces	Reflective index
Wall	0.4-0.6
Floor	0.2-0.4
Ceiling	0.7-0.8
Furniture	0.25-0.45
Refrigerator	0.25-0.45
Blinder	0.25-0.45

According to municipal regulations, patient rooms typically have windows oriented towards the north or south. Due to Tehran's southern location, south-facing windows are generally not preferred.

In terms of ergonomics, patients are positioned lying down on the bed with their head tilted at a 45-degree angle to the horizontal. Consequently, the height of the test plate is set at 1.2 meters, and the distance between measurement points is 0.25 x 0.25 meters, based on similar studies and research (Greenup et al., 2001).

Since the light requirements for normal and cataract-affected eyes differ, this parameter significantly impacts user comfort, building design, and energy efficiency. Optimizing the light received from the environment can enhance patient treatment outcomes.

RESULT AND DISCUSSION

This study examined the impact of illuminance levels on cataract disease, revealing that patients with cataracts exhibit significantly different light sensitivity compared to individuals with healthy eyes. Specifically, the amount of light that cataract patients can tolerate is considerably lower than that of individuals with healthy vision.

Due to practical and ethical limitations associated with medical investigations on human subjects, animal models are often used. Among these models, rabbits are genetically closest to humans regarding eye diseases. Therefore, the use of albino rabbits in this research provided valuable insights, despite some limitations inherent in animal studies. The data obtained from these rabbit models are relevant due to their genetic similarity to humans.

The results from the in-vivo tests demonstrated distinct behavioral differences between healthy rabbits and those with eye diseases. As shown in Tables 2 and 3, the latency test results indicated that a healthy rabbit takes approximately 8.80 seconds to exit a dark environment. This data underscores the significant difference in the time spent by healthy and cataract-affected rabbits in a dark environment.

Table 2. The duration of a healthy rabbit's exit from the dark environment

	First Time (seconds)	Second Time (seconds)	Third Time (seconds)
A1	20	8.9	3.81
A2	8.37	6.8	2.54
A3	19.3	7.7	1.36
A4	17.5	7.4	2.94
A5	27.1	8.9	1.72
A6	11.18	4.8	3.2

Table 3. The time when the rabbit with cataracts leaves the dark environment

	First Time (seconds)	Second Time (seconds)	Third Time (seconds)
A1	38.3	20.7	5.5
A2	39	21.9	7
A3	35.8	22.3	5
A4	38.2	22.1	5.4
A5	40.6	19.8	6.1
A6	38.1	21.2	6.9

The comparison of results reveals a significant difference in the tendency of the animals to exit the dark box. On average, rabbits with cataracts delay their departure from the dark box by 59.93% compared to healthy rabbits. This extended duration indicates that the light exposure significantly impacts the comfort of the cataract-affected rabbits, highlighting the importance of determining their light tolerance threshold. Given the absence of similar studies, this research was designed to establish the light tolerance threshold for rabbits with cataracts.

The study evaluated light tolerance in both healthy rabbits and those with cataracts, following the methodology outlined in the methods section. To ensure adherence to animal testing standards and reproducibility, light tolerance tests were conducted at three specific distances from the rabbits' eyes: 2 cm, 5 cm, and 10 cm. The results offer a comparative analysis of light sensitivity between the two groups, providing insights into the effects of cataracts on light tolerance in rabbits. All experiments were conducted in accordance with ethical guidelines for animal research.

The amount of light passing through different filter layers is detailed in Table 4. The exit times for both healthy and cataract-affected rabbits are reported in Tables 5 and 6, reflecting reproducibility. The examination of pain thresholds in healthy rabbits indicates that they can tolerate up to 34 lux of light without exhibiting a strong reaction when exposed to a flashlight at a distance of 2 centimeters. In contrast, cataract-affected rabbits demonstrated a painful tolerance threshold of approximately 29.67 lux under the same conditions. This comparative analysis reveals that the light tolerance of rabbits with cataracts is approximately 12.735% lower than that of healthy rabbits.

Table 7 reports the illuminance levels that have passed through various filter layers. The pain threshold reactions of healthy rabbits and cataract-affected rabbits at a distance of 5 cm are compared in Table 8.

The comparison reveals that healthy rabbits can tolerate approximately 30.33 lux of light intensity at this distance. In contrast, rabbits with cataracts exhibit a 15.199% lower tolerance for light intensity. This significant difference underscores the importance of incorporating these findings into design considerations.

Table 4. The amount of light (lux) in the pet environment despite different filters at a distance of 2 cm

The number of filter layers	Illuminance- First time (lux)	Illuminance- Second time (lux)	Illuminance- Third time (lux)	Average illuminance- (lux)
1 layer	98	102	89	96.33
2 layers	76	75	80	77.00
3 layers	68	73	71	70.76
4 layers	64	60	68	64.00
5 layers	53	55	55	54.33
6 layers	50	47	52	49.67
7 layers	45	45	49	46.33
8 layers	40	38	42	40.00
9 layers	35	35	38	36.00
10 layers	30	28	35	31.00

Table 5. The amount of tolerance of a healthy rabbit to the light of a flashlight at a distance of two centimeters

	Reaction	Half closed eye	closed eye
A1	7 layers filter	3 layers filter	1 layer filter
A2	6 layers filter	5 layers filter	3 layers filter
A3	6 layers filter	4 layers filter	2 layers filter
A4	6 layers filter	3 layers filter	1 layers filter
A5	6 layers filter	5 layers filter	2 layers filter
A6	5 layers filter	4 layers filter	2 layers filter

Table 6. The amount of tolerance of a rabbit with cataracts to the light of a flashlight at a distance of 2 cm

	Reaction	Half closed eye	closed eye
A1	7 layers filter	4 layers filter	2 layer filter
A2	7 layers filter	4 layers filter	1 layers filter
A3	7 layers filter	5 layers filter	2 layers filter
A4	6 layers filter	5 layers filter	2 layers filter
A5	7 layers filter	5 layers filter	1 layers filter
A6	5 layers filter	4 layers filter	2 layers filter

Table 7. The amount of tolerance of a rabbit with cataracts to the light of a flashlight at a distance of 5 cm

The number of filter layers	Illuminance- First time (lux)	Illuminance- Second time (lux)	Illuminance- Third time (lux)	Average illuminance- (lux)
1 layer	45	58	53	52.00
2 layers	44	41	31	38.67
3 layers	25	31	35	30.33
4 layers	20	35	28	27.67
5 layers	16	18	24	19.33
6 layers	15	18	22	18.33
7 layers	12	17	17	15.33
8 layers	10	12	15	12.33
9 layers	9	10	6	8.33
10 layers	4	6	6	5.33

Table 8. Comparison of the amount of light luxury in the pet's environment despite different filters at a distance of 5 cm

	Reaction	Half closed eye	closed eye
A1	6 layers filter	3 layers filter	1 layer filter
A2	6 layers filter	4 layers filter	2 layers filter
A3	5 layers filter	4 layers filter	3 layers filter
A4	5 layers filter	3 layers filter	2 layers filter
A5	5 layers filter	4 layers filter	3 layers filter
A6	5 layers filter	3 layers filter	2 layers filter

Table 9. The amount of tolerance of a healthy rabbit to the light of a flashlight at a distance of 5 cm

	Reaction	Half closed eye	closed eye
A1	5 layers filter	3 layers filter	1 layer filter
A2	6 layers filter	5 layers filter	3 layers filter
A3	6 layers filter	5 layers filter	2 layers filter
A4	6 layers filter	4 layers filter	3 layers filter
A5	5 layers filter	5 layers filter	3 layers filter
A6	6 layers filter	3 layers filter	1 layers filter

Table 10. Comparison of the amount of illuminance in the pet environment despite different filters at a distance of 10 cm

The number of filter layers	Illuminance- First time (lux)	Illuminance- Second time (lux)	Illuminance- Third time (lux)	Average illuminance- (lux)
1 layer	45	49	51	48.33
2 layers	35	38	42	38.33
3 layers	35	32	35	34.00
4 layers	30	28	31	29.67
5 layers	24	23	26	24.33
6 layers	20	19	17	18.67
7 layers	13	17	11	13.67
8 layers	8	9	8	8.33
9 layers	6	4	3	4.33
10 layers	2	6	0	0.67

Table 11. The amount of tolerance of a healthy rabbit to the light of a flashlight at a distance of 10 cm

	Reaction	Half closed eye	closed eye
A1	5 layers filter	2 layers filter	1 layer filter
A2	5 layers filter	3 layers filter	2 layers filter
A3	5 layers filter	3 layers filter	2 layers filter
A4	4 layers filter	2 layers filter	1 layer filter
A5	4 layers filter	2 layers filter	1 layer filter
A6	4 layers filter	2 layers filter	1 layer filter

Table 10 illustrates the light penetration at a distance of 10 cm. The reactions of healthy rabbits are reported in Table 11, while Table 12 details the responses of cataract-affected rabbits. To ensure accuracy, all tests were repeated three times. The comparison reveals that while the tolerance range for healthy rabbits at this distance is from 0 to 74.89 lux, cataract-affected rabbits exhibit a pain threshold that is 7.197% lower. In other words, rabbits with cataracts have approximately 7.2% less light tolerance.

Illuminance (lux) is a crucial parameter in this study. The recommended lighting level in hospital environments for patients typically ranges between 100 and 300 lux. Simulations conducted for various solar times, including equinoxes, summer solstices, and winter solstices, confirm this conventional range.

Figure 10 highlights the areas where cataract patients experience discomfort compared to other patients. On December 21 at noon, the minimum and maximum light lux values were reported as 5.66 and 6.54 lux, respectively. These values are significantly below the standard comfort level of 300 lux. The research findings indicate a 15% difference in visual comfort levels between healthy rabbits and those with cataracts. Consequently, if cataract patients' comfort levels decrease by 15%, the area exceeding the comfort threshold increases.

Modeling daylight in the patient room for the winter solstice reveals that assuming a light tolerance threshold of 300 lux, approximately 4.59 square meters of the room—about 23% of the total space—falls outside the comfort zone. Considering the increased sensitivity of cataract patients, this non-comfortable area expands to 6.14 square meters, or 32% of the space.

During the winter solstice, it is crucial to assess the hours when the sun is at its lowest elevation angle. Although light intensity is minimal during the early morning and late afternoon, the slanted sunlight can penetrate deeper into the room. Therefore, evaluating the comfort conditions, particularly at the patient’s bed, remains essential to ensure adequate visual comfort during these times.

Table 12. The amount of tolerance of a rabbit with cataracts to the light of a flashlight at a distance of 10 cm

	Reaction	Half closed eye	Closed eye
A1	4 layers filter	2 layers filter	1 layer filter
A2	5 layers filter	3 layers filter	2 layers filter
A3	5 layers filter	4 layers filter	1 layer filter
A4	5 layers filter	4 layers filter	2 layers filter
A5	4 layers filter	3 layers filter	2 layers filter
A6	5 layers filter	3 layers filter	1 layer filter

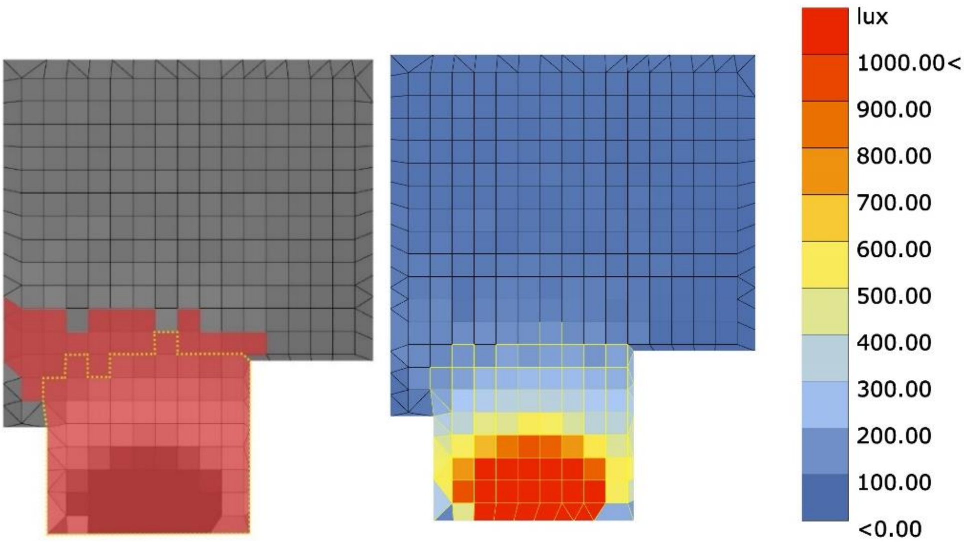

Fig 10. Light intensity (left image) comfort range of cataract patients (right image) at noon on December 21 (Climate Studio software)

Figure 11 illustrates the comfort range for cataract patients compared to other patients on June 21, the summer solstice. On this day, the lighting in the room is significantly higher than the comfort range for cataract patients, with light levels varying from 18.68 lux to 35,468.88 lux and an average illumination rate of 516.55 lux. This level of illumination is approximately twice the recommended comfort level. Such excessive and uneven lighting can lead to discomfort, glare, and difficulty with visual tasks for cataract patients, and it also increases the cooling load on mechanical systems.

As shown in Figure 12, at noon, the illumination in the room peaks at 517,992.08 lux, with an average illumination of 1,286.57 lux at this hour.

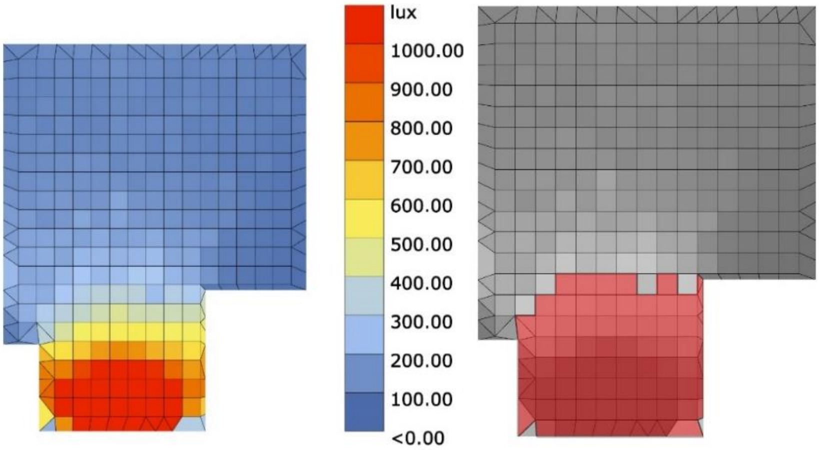

Fig 11. Light intensity (left image) comfort range of cataract patients (right image) at noon on June 21 (Climate Studio software)

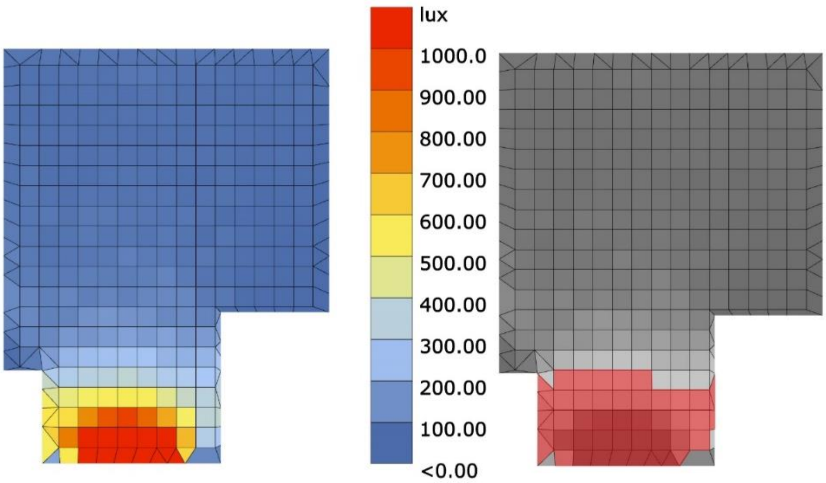

Fig 12. Light intensity (left image) comfort range of cataract patients (right image) at noon on March 20 (Climate Studio software)

Table 13. Analysis of visual comfort conditions in the current situation for patients with cataracts

Average Illuminance (lux)	Minimum Illuminance (lux)	Maximum Illuminance (lux)	The Region of Discomfort	Hour	Day
9.10	0.12	204.26	0%	8	December 21 (Winter Solstice)
2.75.57	5.22	5949.46	15.75% Area	12	
276.56	3.54	5117.9	17.96% Area	16	
156.88	2.88	2740.76	13.07% Area	7	March 20 (Moderate)
1286.57	25.06	51792.08	27.74% Area	12	
976.50	9.62	12899.43	22.44% Area	17	
47.40	0.62	1066.99	14.16% Area	6	June 21 (Summer Solstice)
517.44	19.43	35424.51	22.92% Area	12	
326.05	3.3	7218.39	15.69% Area	18	

Based on the findings of this project, to enhance visual comfort for cataract patients in hospitals with specialized eye departments, it is possible to implement adjustable shading solutions that can modulate light transmission according to the patients' needs.

CONCLUSION

This research investigated the impact of environmental factors on visual comfort for cataract patients in treatment environments. To minimize influencing variables, an animal model was employed, specifically using albino rabbits with cataracts. The study assessed how light intensity affected the reaction times of both healthy and cataract-affected rabbits. Given the significant genetic and immunological similarities between rabbits and humans, this model is recommended for cases where human testing is impractical or impossible. Overall, the results from the rabbit model can be extrapolated to human conditions.

The study found that while the pain threshold difference between healthy rabbits and those with cataracts varied between 7% and over 15.19%, it is prudent to use the highest value for research purposes. The findings suggest that modeling visual comfort in patient rooms can be optimized by implementing smart structures to control light intensity, thus enhancing visual comfort while reducing costs and energy consumption in hospital eye departments.

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