Evaluating Natural Lighting Performance in Vernacular Mosque Architecture: A Case Study of the Masjid Tuha Indrapuri

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Abstract. The historic mosque of *Masjid Tuha Indrapuri* (Indrapuri Old Mosque), originally an ancient palace and temple from the 12th-century Lamuri Kingdom, continues to serve daily religious activities. The mosque features a unique three-tiered roof, with each tier separated by openings that facilitate both ventilation and natural lighting. This study evaluates the performance of these openings, specifically clerestory windows, in terms of natural lighting quality and distribution. This study employed a combination of quantitative and qualitative methods. Quantitative data were obtained through field experiments measuring the intensity and distribution of daylight. Meanwhile, qualitative data were collected using a questionnaire to evaluate user satisfaction with daylight availability. Field measurements showed that the average illumination intensity inside the mosque was 186 lux, slightly below the Indonesian standard of 200 lux (SNI 6197:2011). However, user perceptions indicated that the lighting conditions were satisfactory. Factors such as lighting distribution and visual comfort received positive feedback, with over 60% of users expressing satisfaction with the mosque's lighting performance. The level of visual comfort satisfaction based on mosque users' perceptions indicated that users felt the interior of the mosque was bright, non-glare, and comfortable for worship. Regarding the lighting distribution in the mosque's interior, users felt it was even, although field measurement data analyzed with Surfer showed that the lighting distribution varied and was uneven. This highlighted the relationship between lighting intensity and respondents' visual comfort. Therefore, it could be concluded that a sufficiently bright space, according to respondents' perceptions, did not cause glare, thus achieving comfort.

Keywords: Vernacular Architecture, Masjid Tuha Indrapuri, Natural Lighting, Clerestory Windows, User Perception.

1 Introduction

Lighting plays a crucial role in architecture, especially mosque architecture. The placement of light openings significantly contributes to creating good quality natural lighting

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[1]. Beyond aesthetics, proper lighting supports the functionality of the space, shapes visual impressions, and enhances comfort and safety for occupants [2].

In mosque planning, especially for those with vernacular designs featuring clerestory windows, the design of natural lighting adheres to illumination standards. It also considers user activities, which can impact light [3]. Mosques are recognized as "houses of light" and reflections of the divine in Islamic architecture, emphasizing light as a central focus [4].

Factors such as community spirituality, psychological influence, and reflective perception contribute to congregants' visual comfort through natural lighting [5]. Evaluating elements like orientation, window placement, materials, and glass quality helps optimize natural lighting. Assessing glare within the space ensures occupant comfort, and visual satisfaction is measured by considering both glare and direct illumination [6] [7] [8].

The issue addressed in this research pertains to the performance of natural lighting systems in vernacular mosque architecture, specifically those with three levels of clerestory and multilateral lighting. Despite its significance, there has been limited research on this topic. Therefore, this study aims to explore the performance of natural lighting systems in mosques, focusing on optimizing natural illumination [9].

The novelty lies in examining the impact of natural lighting on user visual comfort in historical mosques or vernacular mosques with high historical value. The chosen research object is Masjid Tuha Indrapuri, known for its unique features and historical allure. This mosque has radiated grandeur since the reign of Sultan Iskandar Muda (1607–1636). Originally an ancient palace and temple from the Lamuri Kingdom in the 12th century, it later became a symbol of Acehnese civilization during the pre-Islamic era and the golden age of Islam [10].

Masjid Tuha Indrapuri boasts a distinctive three-tiered roof, with each level separated by openings that facilitate ventilation and natural lighting. The study aims to evaluate the performance of these openings, particularly the clerestory windows, in terms of light quality and distribution. Through this research, we hope to gain valuable insights into natural lighting in historical mosques.

2 Research Method

2.1 Research Approach: Quantitative Through Survey and Field Measurement

The research was conducted using a quantitative approach, combining surveys and direct field experiments. The experimental measured the intensity of natural lighting using a Lux meter. Meanwhile, the survey was carried out through questionnaires to assess natural lighting and visual comfort based on user perceptions. Reliability testing used SPSS software to determine whether the questionnaire statements were reliable or not.

2.2 Study Object

The research object was Masjid Tuha Indrapuri, located in Desa Kede, Kecamatan Indrapuri, Kabupaten Aceh Besar, Aceh 23363. Its coordinates were 5.4154°N 95.4466°E. The mosque covers an area of 353.44 square meters and stands on a land parcel of 33,875 square meters. It features 36 pillars and is situated approximately 150 meters from the edge of the Krueng Aceh River. Masjid Tuha Indrapuri could accommodate approximately 216 worshippers.

2.3 Research Procedure

The measurement points using a Lux meter instrument were taken inside Masjid Tuha Indrapuri, with measurement intervals set at every 5 meters (see Fig. 1). This aligns with the reference guidelines specified in SNI 03-2396-2001 for measuring light intensity. Given that the mosque's span length is 14.43 meters, a total of 9 measurement points were obtained.

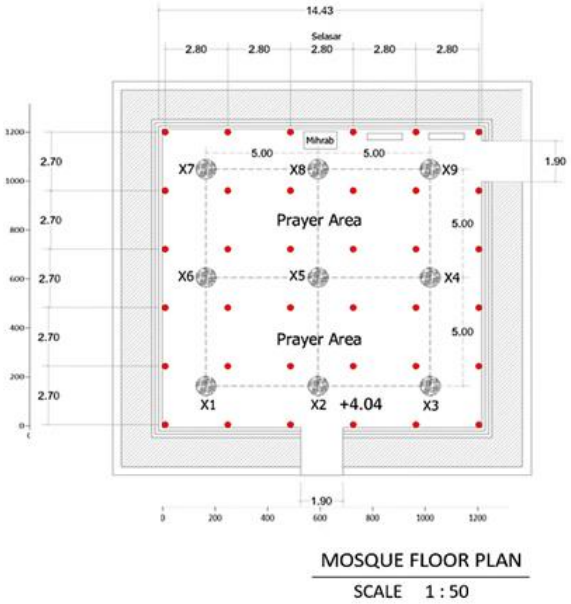

Fig. 1. Measurement Point

The measurement of light intensity using a Lux meter was conducted in March over 7 days at 4 different times: 09:00-10:00 AM (morning), 11:00-12:00 PM (noon), 13:00-14:00 PM (afternoon), and 15:00-16:00 PM (late afternoon). These time intervals align with the Sun Path diagram, considering that the sun's position during this month is along the equator. The measurement parameter focused on both the quality and distribution of light within the room, expressed in lux (lx). Lux is the standard unit for measuring light intensity, often referred to as "illumination." The data collected in this study pertains to light illumination measured in lux.

The sampling technique used for the questionnaire in this research is the Accidental Sampling method, which is one of the nonprobability sampling techniques. It is called nonprobability sampling because everyone does not have an equal chance of being selected as a sample. Samples are drawn from anyone who happens to encounter the researcher at Masjid Tuha Indrapuri, and individuals encountered by chance are considered suitable data sources. In accidental sampling, the sample is not predetermined. In this study, a total of 30 respondents were included in the sample.

The data analysis method used in this research is quantitative descriptive analysis, which processes survey data from respondents regarding the distribution of lighting and visual comfort indicators at Masjid Tuha Indrapuri. The analysis output includes both measurement data and questionnaire data. The illumination level measurements are taken using a Lux meter and processed using software like Surfer and Microsoft Excel. The results of the analysis will be presented in the form of lighting color mapping, tables, and diagrams to compare the measurement results with recommended lighting levels. For analyzing the questionnaire, Microsoft Excel is used to understand the respondents' visual comfort based on a Likert scale, which includes five alternative levels: strongly agree (SS), agree (S), neutral (N), disagree (TS), and strongly disagree (TSS).

3 Result and Discussion

3.1 Intensity and Distribution of Light In The Mosque Area

The measurement of natural light intensity at Masjid Tuha Indrapuri was conducted over 7 days, from April 17, 2024, to April 23, 2024, under partly cloudy sky conditions. Four measurement times were chosen: 09:00-10:00 AM, 11:00-12:00 PM, 13:00-14:00 PM, and 15:00-16:00 PM. Within the mosque area, 9 measurement points were established, each spaced 5 meters apart. A Lux meter was used for measurements, positioned at a height of 75 cm above the floor surface to determine the light intensity at each point. Below are the average light intensity results for the mosque area over the 7-day period.

Table 1. Average Total Light Intensity of Mosque

Day	Time				Avg Total
	09.00-10.00	11.00-12.00	13.00-14.00	15.00-16.00	
Day 1 (17/4/24)	207,14	224,79	31,56	52,12	128,90
Day2 (18/4/24)	210,94	307,18	189,87	216,13	231,03
Day 3 (19/4/24)	235,68	257,29	183,04	120,09	199,03
Day 4 (20/4/24)	225,17	279,57	59,30	95,69	164,93
Day 5 (21/4/24)	190,51	198,62	161,61	90,19	160,23
Day 6 (22/4/24)	210,08	173,70	191,83	162,83	184,61
Day 7 (23/4/24)	294,63	221,57	202,07	227,38	236,41
TOTAL	**224,88**	**237,53**	**145,61**	**137,78**	**186,45**

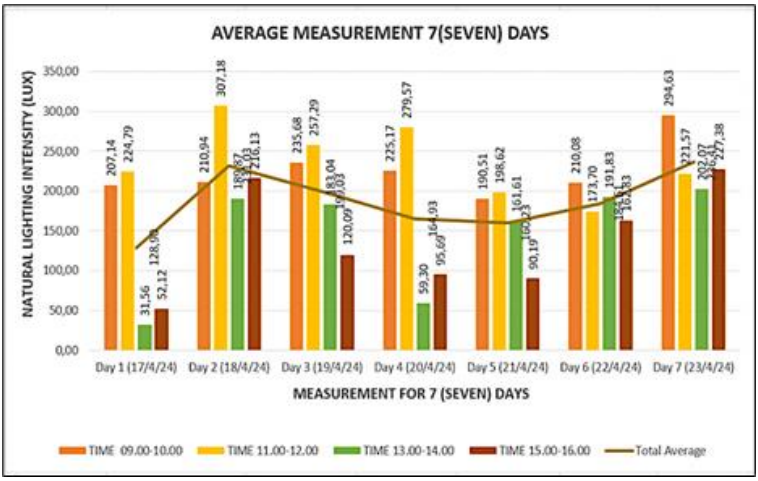

Fig. 2. Average Light Intensity Graph of Mosque Area

Table 1 and Fig. 2 show the average light intensity measurements over 7 days within the mosque area, taken at four different time intervals. Based on the measurement results, variations in light intensity are evident from 09:00 AM to 04:00 PM. Notably, the highest average light intensity occurs during the 11:00-12:00 time slot, with an illuminance value of 237.53 lux. In contrast, the 09:00-10:00 interval records a lower average of 224.88 lux. Subsequently, the 13:00-14:00 interval shows an intensity of 145.61 lux, followed by 137.78 lux during the 15:00-16:00 interval.

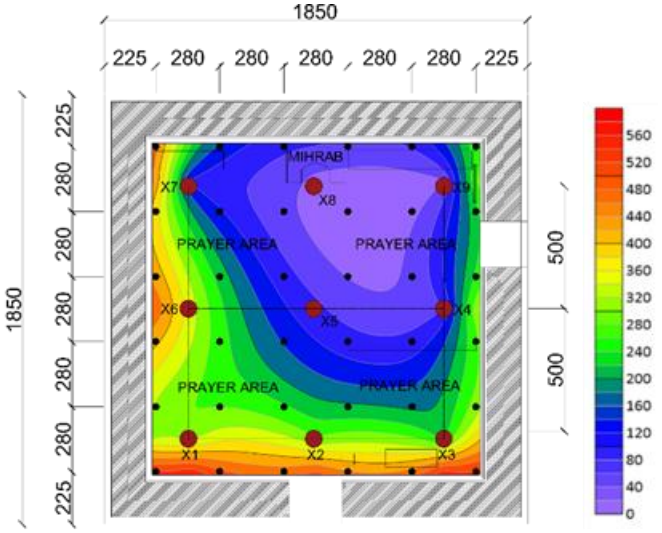

Fig. 3. Distribution of Lighting in the Mosque Area for 7 (Seven) Days from 09:00 to 10:00 AM (WIB)

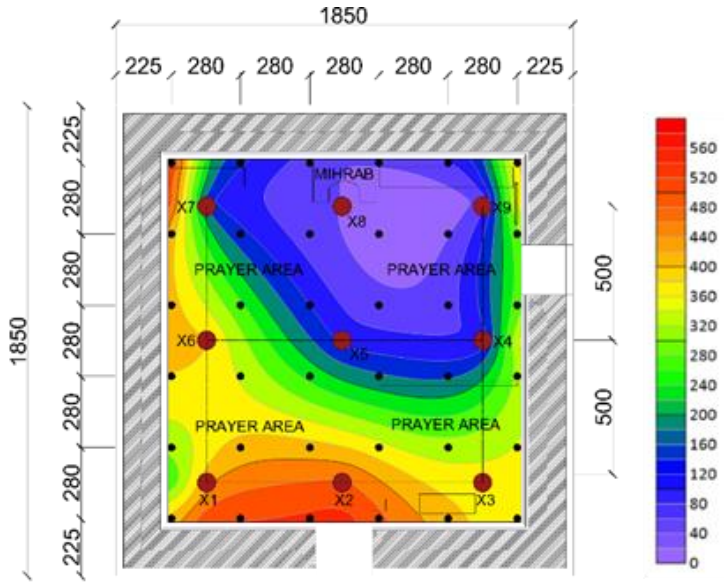

Fig. 2. Distribution of Lighting in the Mosque Area for 7 (Seven) Days from 11:00 to 12:00 AM (WIB)

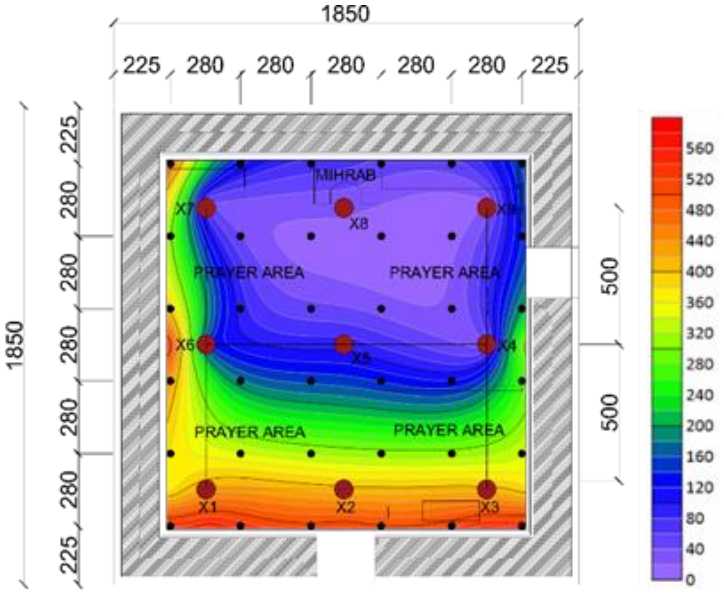

Fig. 3. Distribution of Lighting in the Mosque Area for 7 (Seven) Days from 13:00 to 14:00 AM (WIB)

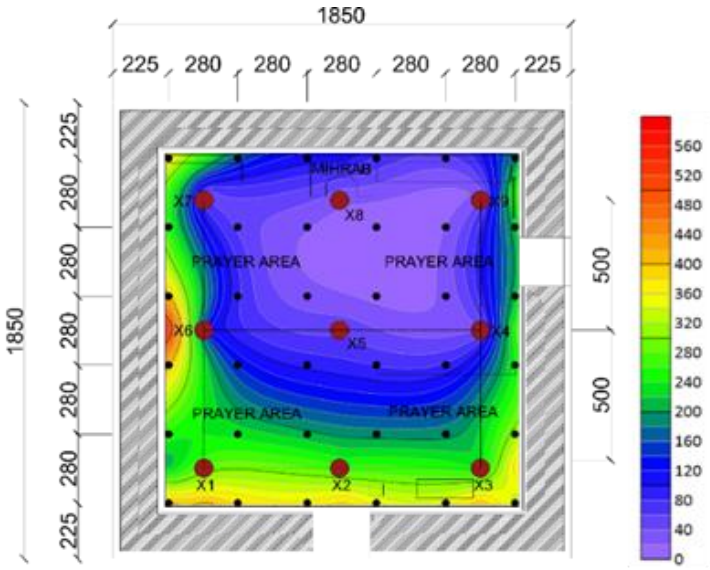

Fig. 4. Distribution of Lighting in the Mosque Area for 7 (Seven) Days from 15:00 to 16:00 AM (WIB)

Based on the measurement data plotted using Surfer software as shown in Fig. 3 to Fig. 6, significant variations in light intensity were observed at different times morning, noon, and afternoon. The average natural light illuminance from day 1 to day 7 showed an increase in intensity from morning to noon, followed by a decrease during the transition from noon to afternoon. One contributing factor to this variation is the mosque's clerestory window typology. The clerestory windows surround the building, but their widths differ in each orientation. Specifically: Northern clerestory windows have a width of 62 cm. Southern clerestory windows have a width of 60 cm. Eastern clerestory windows have a width of 53 cm. Western clerestory windows have a width of 58 cm. As a result, the expected distribution of natural lighting becomes uneven due to these window size differences. The radiance image confirms that daytime intensity is higher near the windows and gradually decreases toward the interior of the mosque.

Based on the measurement results, the highest illuminance occurs during the 11:00-12:00 time slot, with a value of 237.53 lux. The brightest areas are near the clerestory windows, particularly those at a height of 60 cm, especially on the eastern side (points X1, X2, X3) and southern side (points X1, X6, X7). Conversely, the darkest areas are in the central part of the room, away from the clerestory windows. However, on the western side (points X7, X8, X9) and northern orientation (points X3, X4, X9), which should be closer to the clerestory windows, the illuminance is low at 58.50 lux. This discrepancy is due to the presence of numerous ornaments and furniture items, such as prayer cabinets, bookshelves, Qur'ans, calligraphy boards, whiteboards, and curtains. Consequently, the light distribution within the mosque area remains uneven and does not meet the recommended mosque lighting standard of 200 lux according to SNI 6197:2011.

Table 2. Summary of percentage of measurement results based on clerestory window orientation

Aperture Placement	Natural Light Intensity (lux)	SNI Compliance (200 lux)
North	58,50	Less than SNI
South	356,46	Exceeding minimum SNI
East	279,05	Exceeding minimum SNI
West	124,81	Less than SNI

Based on Table 2, it shows that the east and south orientations meet SNI 6197:2011 the minimum mosque lighting standard of 200 lux, where the east orientation is the path of the sun, allowing direct sunlight to enter the mosque. Additionally, the east side is the main entrance to the mosque, with a door opening of 1.90 meters without a door leaf and a clerestory window 53 cm wide, allowing optimal light entry. The south orientation also meets the minimum standard, with a window width of 60 cm and no objects obstructing this orientation, allowing optimal light entry. In contrast, the west and north orientations have many pieces of furniture such as pulpits, cabinets, calligraphy boards, partition curtains, and whiteboards, which hinder optimal light entry but prevent glare, which visitors appreciate. Additionally, the north orientation has a two-story stage building and a long canopy, further blocking light entry. The central part of the room tends to have natural lighting below the standard, at 88.13 lux.

3.2 Questionnaire Results

This section explains and outlines the results of the questionnaire survey conducted in Masjid Tuha Indrapuri. Questionnaires were distributed to the worshippers within the mosque. The Likert scale for assessment was applied whre the response value of 1 (strongly disagree) corresponds to disagreement, while a value of 5 (strongly agree) indicates strong agreement. A reliable instrument meant that an instrument used multiple times to measure the same object would produce the same data. A questionnaire or survey was said to be reliable if it had a minimum alpha value of 0.60 [11]. Therefore, the hypothesis of the questionnaire in this study was said to be reliable because its reliability value was 0.8, which was greater than 0.6.

3.3 Respondent Characteristics

The questionnaires were distributed to 30 respondents at Masjid Tuha Indrapuri. The characteristics queried in the questionnaire included gender, occupation, and age. The characteristics of the respondents at Masjid Tuha Indrapuri are as follows: there are 12 female respondents and 18 male respondents. In the occupation category, there are 9 respondents who work in private sectors or as traders, 4 housewives, 4 students, 3 school students, 2 entrepreneurs, 2 teachers, and the rest are 1 person each as a farmer, employee, librarian, nurse, and civil servant who visited Tuha Indrapuri Mosque as congregants. In the age category, there are 27 respondents categorized as adults and 3

respondents categorized as teenagers. This can lead to different opinions or perspectives in assessing visual comfort.

Based on age categories, this study used three age groups: young age, middle age, and elderly. The results showed that the young age group (15-30 years) consisted of 18 people, the middle age group (31-50 years) consisted of 9 people, and the elderly group (51-70 years) consisted of 3 people. As age increases, the eye's ability to adapt to changes in light decreases. The lens of the eye becomes less flexible, and the pupil shrinks, reducing the amount of light entering the eye. This can cause older individuals to require brighter lighting for visual comfort.

3.4 Visitor Perception of Natural Lighting

Table 3 shows the analysis of the visitor perception of the natural lighting intensity in this mosque is sufficiently bright. However, the light distribution is not uniform, and there is no glare. The visual comfort is fulfilled. Based on visitor perceptions regarding natural lighting intensity, the mosque space feels bright, adequate, and optimal, with an average percentage of 49%. According to the interpretation criteria for this percentage score, it falls into the 'sufficient' category. As for light distribution in the mosque space, the percentage is 37%, which falls into the 'low' category, indicating that visitors perceive uneven light distribution.

Regarding visual comfort, visitors tolerate visual disturbances reasonably well, with a 60% satisfaction rate. The mosque space is not glaring, with a negative disagreement rate of 43%. Visitors also feel comfortable with the lighting in the mosque, with a high satisfaction rate of 67%. Overall, visitors find the space well-lit, spacious, and comfortable for worship. The correlation between visitor responses and measurement results can be analyzed by examining the outcomes of various orientations of clerestory windows surrounding this mosque. The natural lighting conditions on the west side tend to have a natural light level that does not yet meet the standard, specifically 124.81 lux. However, visitors' response to this is quite positive; they feel that the west side, which faces the qibla (the direction of prayer), does not need to be overly bright to allow for more focused and tranquil worship. On the other hand, the natural lighting conditions on the east side, based on measurement results, meet the minimum standard (279.05 lux). Visitors also respond favorably to this because, according to their perception, the entrance area should indeed be well-lit, symbolizing that they are entering a sacred and illuminated space, in line with the philosophy of the house of Allah.

Table 3. Percentage of Respondents' Answers

NUMBER	QUESTION ITEM	CATEGORIES				
		STS	TS	N	S	SS
1	The mosque space feels bright	0%	17%	10%	53%	20%
2	Natural lighting illuminates the entire space of the mosque	0%	10%	10%	47%	33%
3	The lighting in the mosque room is adequate	0%	13%	10%	47%	30%

4	3-story clerestory windows allow maximum light to enter	0%	17%	10%	57%	17%
5	The mosque's natural lighting has been maximized	0%	23%	10%	43%	23%
6	The distribution of lighting in this mosque space is even.	0%	23%	17%	37%	23%
7	I can tolerate visual disturbances (visual clarity)	3%	17%	10%	60%	10%
8	The reflection of light into the prayer room creates glare (visual clarity)	37%	43%	10%	7%	3%
9	I feel comfortable with the lighting in this prayer room (relaxation)	0%	7%	7%	67%	20%
10	I can't see clearly when reading the Quran here (preference)	30%	43%	7%	17%	3%
11	I feel that this prayer room is spacious and feels roomy.	0%	7%	10%	47%	37%
12	I feel comfortable when praying in this mosque (intimacy)	0%	0%	7%	50%	43%

The natural lighting conditions on the northern side, with an illumination of 58.50 lux, do not meet the standard. However, according to visitor responses, this is not a significant issue. The northern side predominantly serves as the prayer area for female congregants. Visitors believe that during prayer, women do not need overly bright lighting; a slightly dimmer illumination is sufficient for a comfortable worship experience. Moving to the southern side, which serves as the prayer area for men, the illumination level is 356.46 lux. Visitors respond positively to this brightness during midday Dhuhr prayers, as it does not cause glare. The illumination level remains tolerable for visitors, considering that the western and northern sides are relatively darker in the morning, afternoon, and evening. Thus, the southern side, being the brightest, balances the less illuminated areas.

The clerestory windows play a crucial role in implementing natural lighting in historical mosques. Clerestory windows and natural lighting in historical mosques are interconnected in several aspects. Optimal natural lighting is achieved by placing clerestory windows at the upper part of the room's walls, just below the roof or ceiling. This position allows sunlight to enter the space from a higher angle, avoiding shadows from lower architectural elements such as columns or walls. It provides even and gentle natural lighting throughout the room. In terms of light quality, clerestory windows diffuse or scatter light into the mosque more effectively than regular windows at lower levels. This creates a serene and comfortable atmosphere inside the mosque, reducing glare and sharp contrasts. Additionally, from an aesthetic and spiritual perspective, natural lighting from clerestory windows enhances the mosque's interior beauty and imparts a spiritual effect. Sunlight entering from above can create dramatic and inspiring light patterns, adding a profound visual dimension to the worship space.

4 Conclusions

The overall natural lighting intensity in Masjid Tuha Indrapuri still does not meet the standard. The average illumination level is 186.45 lux, whereas according to SNI 6197:2011, the recommended lighting standard for mosques is 200 lux, even though only the east and south orientations meet the minimum standard. This discrepancy is due to obstructive objects in the west and north orientations that prevent sufficient light from entering the room. Additionally, the distribution of light within the mosque's interior area remains uneven. This unevenness may be attributed to measurement points located near the light source, resulting in higher received light intensity. In summary, the natural lighting quality in Masjid Tuha Indrapuri, with its vernacular morphology, can be considered not fully compliant with SNI 03-6197-2011. However, visual comfort in the mosque is satisfactory, as visitors perceive that the natural light during prayer does not cause glare, allowing for a comfortable worship experience. Based on the evaluation results, it can be concluded that the natural lighting in Masjid Tuha Indrapuri, which measures 186.45 lux, does not yet meet the SNI-6197:2011 standard for recommended illumination intensity (which is 200 lux). However, visitors perceive that the illumination level, which is close to the recommended standard, provides satisfactory visual comfort during their time in Masjid Tuha Indrapuri.

Disclosure of Interests. The authors have no relevant competing interests to disclose concerning the content of this article.

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