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Analysis of Natural Lighting Distribution and Visual Comfort in Tahfidz Classrooms

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ABSTRACT

Natural lighting plays an important role in classroom design because it influences students' visual comfort and learning performance, particularly in Tahfidz classrooms where reading and memorization activities are carried out intensively. However, adequate illuminance levels do not always ensure visual comfort when lighting distribution within the room is uneven. This study aims to analyze the distribution of natural lighting in a Tahfidz classroom and evaluate its implications for students' visual comfort. A quantitative approach was employed through field measurements using a lux meter at multiple points arranged in a grid pattern at a working-plane height of 84 cm from the floor. The measurements were supported by direct observations of classroom visual conditions during learning activities. The collected data were analyzed descriptively using minimum illuminance (E_{min}), maximum illuminance (E_{max}), average illuminance (E_{avg}), and lighting uniformity values, then compared with the classroom lighting standard based on SNI 6197:2020. The results indicate that illuminance levels ranged from 175 lux to 497 lux, with an average value of 320 lux, which is below the recommended minimum standard of 350 lux. The lighting uniformity ratio was 0.35, indicating non-uniform light distribution across the classroom. Areas near openings received higher illuminance, while deeper zones experienced insufficient lighting. Although no glare complaints were identified, uneven lighting distribution may increase visual adaptation load and reduce students' visual comfort. The study concludes that

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improving classroom lighting quality should prioritize distribution strategies, including spatial configuration, reflective materials, and integrated natural-artificial lighting systems.

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1. INTRODUCTION

Natural lighting is a fundamental aspect of classroom design that directly affects visual comfort and the effectiveness of the learning process (Chiou et al., 2020; Giang & Duong, 2024; Mahgoub et al., 2025). In educational settings, lighting quality functions not only to support visual tasks but also as an environmental factor influencing concentration, visual perception, and students' learning performance (Karlicek et al., 2017; Mahgoub et al., 2025; Setiati & Budiarto, 2021; Sleegers et al., 2013; Wang et al., 2025; Zaky et al., 2023). Adequate lighting can create stable visual conditions, reduce eye strain, and support sustained learning activities over extended periods (Çelik et al., 2025).

The quality of lighting in learning environments is determined not only by illumination levels but also by the uniform distribution of light throughout space. Proper lighting distribution helps maintain consistent visual conditions and prevents significant luminance contrasts between different areas within a room (Cui & Ahn, 2025; Dang et al., 2023; Panggabean et al., 2025). Uneven lighting distribution forces the eyes to continuously adapt to varying brightness levels, which can lead to visual strain. Therefore, lighting uniformity is considered a key indicator in designing optimal learning environments (G. Liu et al., 2020; T. Liu et al., 2020). According to SNI 6197:2020, the minimum illumination level required for classrooms is 350 lux to effectively support reading and writing activities. However, meeting this quantitative standard does not necessarily guarantee visual comfort if the lighting distribution is uneven.

In practice, natural lighting is often used as the primary light source in classrooms, particularly in educational buildings located in tropical regions where sunlight is abundant throughout the year (Costanzo et al., 2017; Saraswati et al., 2023). Natural lighting is considered more energy-efficient and capable of providing a more dynamic light quality compared to artificial lighting. However, its dynamic characteristics, influenced by weather conditions, time of day, and solar position, make the control and distribution of light within indoor spaces a significant challenge in architectural design (Costanzo et al., 2017; Meng et al., 2023; Syafi'i et al., 2023).

Previous studies have shown that natural lighting significantly contributes to visual comfort and students' learning performance. Research on classroom lighting quality highlights that uneven light distribution can lead to visual strain due to continuous visual adaptation to varying light intensities within the same space (Aghajari & Chen, 2025; G. Liu et al., 2020; Syafi'i et al., 2023). Furthermore, architectural factors such as building orientation, direction of incoming light, opening configurations, and spatial depth influence lighting distribution patterns and the perceived visual quality (Karlicek et al., 2017; Meng et al., 2023). Other studies indicate that non-uniform lighting in classrooms can reduce visual comfort and potentially increase visual fatigue, particularly during activities that require prolonged concentration (Utamisari & Refranisa, 2024; Wang et al., 2025).

Despite these findings, most previous studies have primarily focused on illumination levels as the main parameter of lighting quality, without thoroughly examining the spatial distribution of natural lighting under real classroom conditions. Existing approaches are generally quantitative and based on point measurements, with limited integration of spatial analysis and actual user activities. In addition, studies specifically addressing classrooms with intensive visual activities, such as Tahfidz classrooms, remain limited. In fact, the learning characteristics of Tahfidz classes, which involve prolonged reading and memorization activities, require more stable and evenly distributed lighting conditions compared to typical classrooms.

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Based on these considerations, there is a need to examine natural lighting distribution more comprehensively by incorporating spatial aspects and real classroom conditions. This study proposes an analytical approach that not only focuses on illumination levels but also emphasizes lighting distribution patterns as part of overall lighting performance. By integrating field measurements, spatial analysis, and observations of visual conditions, this research aims to provide a more comprehensive understanding of natural lighting quality in classroom environments.

The novelty of this study lies in the spatial analysis of natural lighting distribution in real Tahfidz classroom settings, as well as its evaluation of students' visual comfort within the context of intensive learning activities. This approach offers a more practical perspective in understanding the relationship between spatial design and users' visual experience, particularly in educational environments. In addition, recent developments in lighting design strategies indicate that optimizing light distribution does not solely depend on the size and number of openings, but also on the use of light-directing elements such as light shelves, high-reflectance materials, and the integration of natural and artificial lighting systems. These strategies aim to improve lighting uniformity and reduce luminance contrast within spaces, thereby enhancing visual comfort (Giang & Duong, 2024; Idrus & Latif, 2025). However, the application of these strategies in real classroom settings, particularly in intensive learning environments such as Tahfidz classrooms, has not been widely explored empirically.

The research problem addressed in this study is how natural lighting is distributed within the classroom and how this condition potentially affects students' visual comfort. Accordingly, this study aims to analyze the distribution of natural lighting in Tahfidz classrooms and identify its implications for students' visual comfort.

2. RESEARCH METHOD

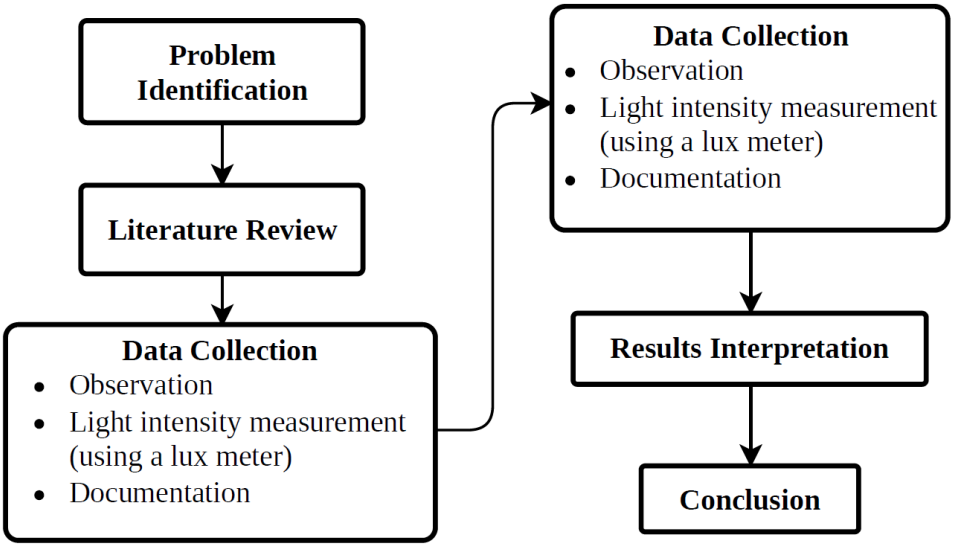

Figure 1. Research Methodology Flowchart
(Source: Developed by the author, 2026)

This study employs a quantitative approach supported by field observations to analyze the distribution of natural lighting and its implications for students' visual comfort. The study was conducted in a Tahfidz classroom at Madrasah Ibtidaiyah Ma'arif NU Assa'adah. This location was selected because it represents a primary education environment in which students engage in intensive learning activities such as reading, memorizing, and writing. In such conditions, lighting quality should be carefully considered to support visual comfort and

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maintain students' visual health from an early age. Data collection was carried out in the morning between 09:00 and 10:00 WIB, to represent natural lighting conditions during learning activities, when the classroom was actively used by students.

Illuminance measurements were conducted using a lux meter at multiple points distributed evenly according to desk positions and student activity areas within the classroom. The measurement points were arranged in a grid pattern to represent the spatial distribution of lighting throughout the room. Measurements were taken at a height of approximately 84 cm above the floor, corresponding to the students' working plane during reading and writing activities. Prior to data collection, the measuring instrument was checked to ensure proper functioning and stable readings.

During the measurement process, classroom openings, window conditions, and the surrounding environment were maintained in their normal daily condition to capture actual daylight performance. Weather conditions during measurement were relatively stable, allowing the recorded values to represent common natural lighting conditions during the study period.

The collected data consisted of illuminance values at each measurement point, which were then processed to obtain minimum, maximum, and average illuminance levels. Furthermore, lighting uniformity was calculated as the ratio between the minimum and average illuminance values to reflect the quality of light distribution within the space (Kruisselbrink et al., 2018).

Data analysis was conducted using a descriptive quantitative approach by examining key lighting parameters, namely minimum illuminance (E_{min}), maximum illuminance (E_{max}), average illuminance (E_{avg}), and lighting uniformity. This approach was used to identify variations in lighting distribution within the space and to evaluate its compliance with applicable standards. Although no inferential statistical tests were applied, this analysis provides a representative quantitative description of the actual lighting conditions in the classroom.

Furthermore, the measurement results were compared with classroom lighting standards based on SNI 6197:2020, which specifies a minimum illuminance level of 350 lux. Spatial lighting distribution analysis was performed to identify light distribution patterns within the classroom through graphical and heatmap visualization. As a complementary approach, observations of visual conditions were conducted, including the identification of potential lighting imbalance, glare indications, and students' visual responses during learning activities. The measurement and observational results were then integrated to identify the relationship between natural lighting distribution and students' visual comfort.

3. RESULTS AND DISCUSSION

3.1 Distribution of Natural Lighting Intensity

Table 1. Summary of Lighting Measurement Results

Parameter	Value
Minimum Illuminance (E_{min})	175 lux
Maximum Illuminance (E_{max})	497 lux
Average Illuminance (E_{avg})	320 lux
Standard (SNI 6197:2020)	≥350 lux
Uniformity $\left(\frac{\mathbf{Emin}}{\mathbf{Eavg}}\right)$	0.35

Source: Author's measurement and analysis, 2026

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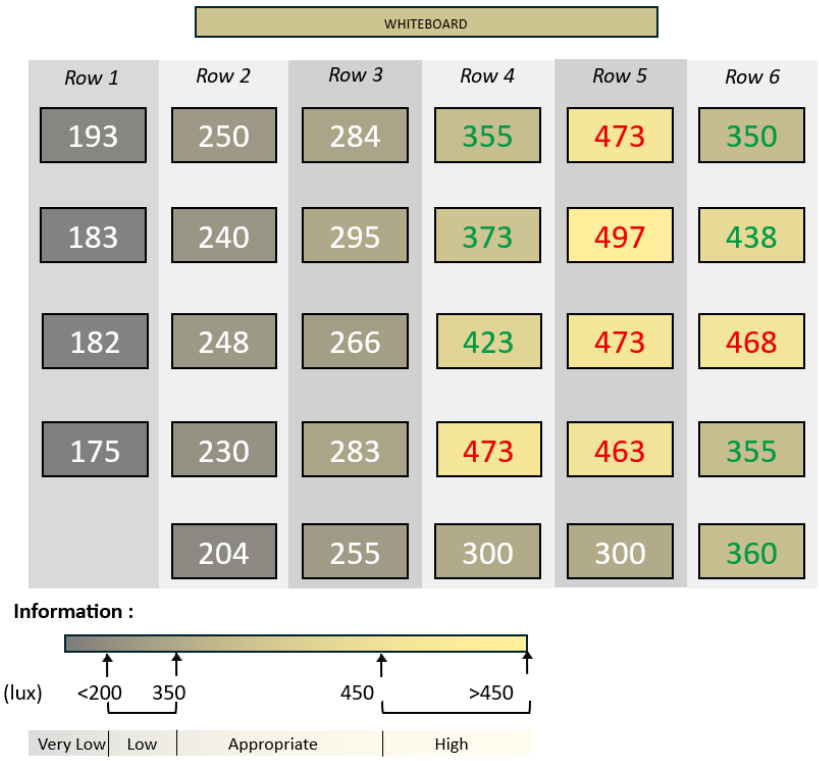

Figure 2. Distribution of Natural Lighting Intensity in the Tahfidz Classroom (Source: Author's observation, 2026)

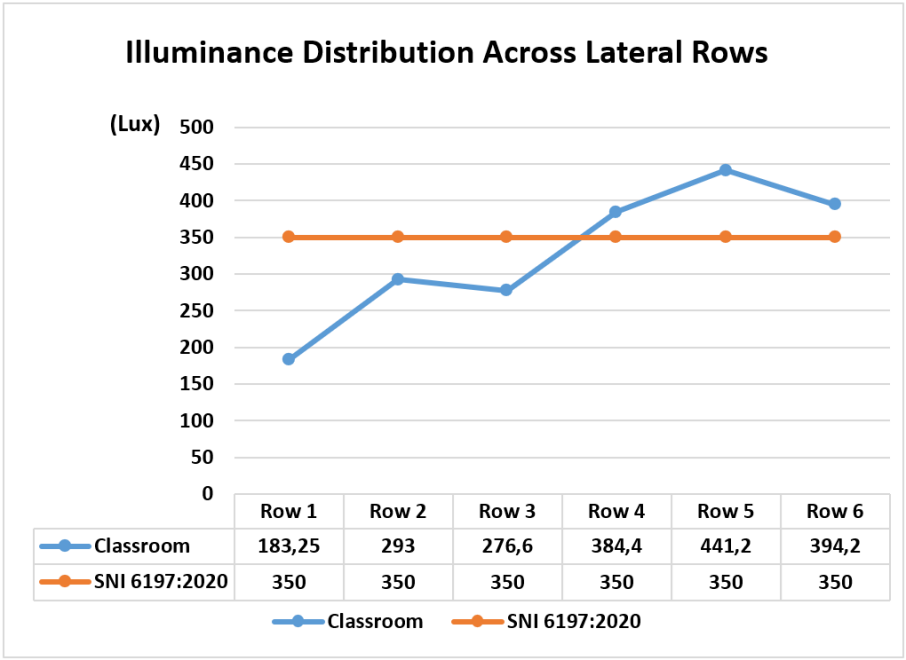

Figure 3. Illuminance distribution across lateral rows compared with SNI 6197:2020 (Source: Author's observation, 2026)

The measurement results presented in Figure 2 indicate that the natural lighting intensity in the classroom ranges from 175 lux to 497 lux. This range reflects a considerable variation in illuminance across different points within the same space. When compared to the classroom lighting standard based on SNI 6197:2020, which specifies a minimum value of 350 lux, it can be observed that not all areas within the classroom meet the required standard, particularly in the middle to rear zones.

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Based on Table 1, the average illuminance value of 320 lux indicates that, overall, the lighting level remains below the recommended standard. This average value is derived from all measurement points and therefore provides a more representative description of the actual lighting conditions compared to relying solely on minimum and maximum values. In addition, the lighting uniformity value of 0.35 suggests that the distribution of light within the classroom is not evenly distributed. This value falls below the minimum threshold recommended in previous studies, namely ≥0.5 for acceptable lighting conditions and ≥0.7 for optimal conditions (Idrus & Latif, 2025). In line with this, a study by Lin and Chen (2023) also demonstrates that lighting uniformity significantly influences illuminance distribution and visual comfort within a space, indicating that uneven lighting may reduce the overall visual quality experienced by occupants.

These findings emphasize that lighting quality is not solely determined by the magnitude of average illuminance but also by the level of uniformity in light distribution. Uneven distribution can create luminance contrast between different areas, which may lead to visual discomfort for occupants (Lin & Chen, 2023). To strengthen the analysis of lighting distribution, the measurement data were visualized using comparative graphs and spatial diagrams. These visualizations enable a clearer identification of light distribution patterns, particularly in highlighting intensity differences across measurement rows, as illustrated in Figure 3.

From a spatial perspective, variations in illuminance values indicate a strong dependence on the relative position to natural light sources. Areas located closer to openings tend to have higher illuminance levels, while areas farther away experience a gradual decrease in light intensity (Aghajari & Chen, 2025; Zaky, Dewi, Widyarko, & Sulistiani, 2023). This condition suggests that although natural lighting is sufficiently available, its distribution within the space does not ensure uniform illumination. This finding is consistent with previous studies stating that lighting quality is influenced not only by intensity but also by light distribution within a space (Panggabean et al., 2025), which ultimately affects users' visual comfort.

3.2 Spatial Analysis of Lighting Distribution

Figure 4. Tahfidz Classroom
(Source: Author's documentation, 2026)

The visualization of lighting distribution in the form of a spatial diagram (heatmap) in Figure 2 provides a clear representation of the imbalance in light distribution at each measurement point. Spatially, the natural lighting distribution in the classroom exhibits a non-uniform pattern with a diagonal decrease in intensity, extending from the front-right area toward the back-left area of the room. Based on Figure 2, areas located near the openings on the right side of the classroom show relatively high illuminance levels, ranging from 350 lux

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to 497 lux, with several points classified as high (>450 lux). In contrast, areas on the left side exhibit a gradual decrease in intensity, reaching a minimum value of 175 lux, which falls into the very low category.

This pattern indicates a clear lighting gradient within the space, where light intensity decreases as the distance from the openings increases and as the relative position shifts away from the light source. The distribution tends to form a gradient pattern from areas near the openings toward deeper zones of the room, resulting in variations in illuminance levels across spatial zones (Angelaki & Besenecker, 2026). The graph in Figure 3 further supports this finding by showing an increase in illuminance from the left side toward the right side of the room, indicating the dominance of light sources on the right side. The difference between the maximum value (497 lux) and the minimum value (175 lux) results in a disparity of 322 lux, reflecting a substantial variation in illuminance within a single space. This condition indicates a low level of lighting uniformity, which may affect the visual quality experienced by occupants. Ideally, lighting distribution should exhibit a higher degree of uniformity to support visual comfort. Uneven lighting can create luminance contrast between different areas, increasing the visual adaptation load on the eyes and potentially reducing visual comfort during learning activities.

The imbalance in light distribution can also be identified through differences in lighting categories across spatial zones. Areas near the openings are dominated by “appropriate” to “high” lighting categories, while the middle areas tend to fall into the “low” category, and zones farther from the openings still include “very low” lighting conditions. This indicates that not all areas within the classroom receive equivalent lighting quality, potentially creating unequal visual conditions among users. Moreover, the significant differences in illuminance between points generate high luminance contrast within a single field of view. Visually, this condition may cause the eyes to repeatedly adapt to changes in luminance, particularly when students shift their focus between books, the whiteboard, and the surrounding environment. This serves as an indication that the lighting distribution does not yet meet the principles of optimal visual comfort.

The diagonal distribution pattern suggests that the direction of incoming light from the right side has a more dominant influence than spatial depth alone. Based on Figure 4, openings are present on both sides of the classroom, indicating that the overall quantity of incoming natural light is relatively sufficient. However, light tends to be concentrated on the right side and is not evenly distributed throughout space. This condition suggests that, despite the presence of openings on both sides, the distribution of light within the classroom remains suboptimal. This may be attributed to the absence of elements that function to redirect and diffuse light more evenly, such as reflective materials or light-directing devices. As a result, areas located farther from the primary light source, particularly on the opposite side, receive lower illuminance levels.

3.3 Implications on Students’ Visual Comfort

The uneven distribution of natural lighting within the classroom has direct implications for students’ visual comfort. Based on the measurement results presented in Figure 2, there is a considerable variation in illuminance across different points within the same space, ranging from 175 lux to 497 lux. This disparity indicates that students are exposed to non-uniform lighting conditions, which may lead to variations in visual experience during the learning process.

The measurements also show that outdoor illuminance reaches approximately 2000 lux, indicating that the availability of natural light is more than sufficient. At the whiteboard area, the recorded illuminance is 372 lux, meeting the minimum lighting standard. However, the

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indoor condition reveals an uneven distribution of light, meaning that not all areas receive optimal illumination. This finding confirms that the primary issue lies not in the lack of light intensity, but in the suboptimal distribution of lighting within the space.

This imbalance in lighting distribution requires the visual system to continuously adapt to changes in luminance. When students shift their focus from books to the whiteboard or to the surrounding environment, the eyes must adjust to relatively high contrasts in brightness levels. This repeated adaptation process can increase visual load, particularly during intensive learning activities such as reading and memorization in Tahfidz classrooms.

Based on Figure 4, classroom learning activities are conducted in relatively static seated positions oriented toward the whiteboard. However, the uneven lighting distribution causes students in different seating positions to experience varying lighting quality. Students seated near the openings tend to receive higher light intensity, while those located farther from the light source experience lower illuminance levels. This condition indicates an imbalance in visual comfort among students within the same classroom. Although seating positions may change over time, the lighting distribution remains constant. As a result, the inequality in visual conditions does not disappear but is instead experienced alternately by students depending on their seating positions.

Although this study does not employ a quantitative questionnaire instrument, observations of students' visual responses during learning activities provide preliminary insights into perceived visual comfort. The observations indicate that no complaints of glare were reported during the learning process, suggesting that excessive light intensity is not the primary issue in the classroom. Therefore, potential visual discomfort is more closely associated with uneven lighting distribution rather than glare. In addition, the fact that only one student wears corrective lenses suggests that visual acuity conditions are not a dominant factor influencing students' perception of the lighting environment.

This condition is closely related to the potential occurrence of visual fatigue, where the eyes must continuously adapt to variations in light intensity within the space. Over time, such conditions may lead to visual fatigue, characterized by reduced comfort, decreased concentration, and diminished visual endurance during learning activities. This is particularly important in the context of Tahfidz classrooms, where learning activities require sustained visual focus over extended periods. Therefore, the findings of this study indicate that students' visual comfort is influenced not only by overall illumination levels but also by the uniformity of lighting distribution within the space. Consequently, efforts to improve classroom lighting quality should consider the distribution of light comprehensively to create more consistent visual conditions and better support students' learning activities.

3.4 Evaluation of Lighting Performance in Classroom Space

The analysis results indicate that the performance of natural lighting in the classroom is not yet optimal, particularly in terms of light distribution uniformity. Although several measurement points meet the minimum illuminance standard of 350 lux, the imbalance in distribution results in overall lighting conditions that fail to provide consistent visual environments for all occupants. In other words, meeting quantitative standards does not automatically ensure comprehensive visual comfort.

Based on Figure 2 and the graphical results in Figure 3, the lighting distribution exhibits a non-uniform pattern with significant variations in intensity across different zones. Meanwhile, Figure 4 shows that the classroom has openings on both sides, which theoretically should support a more even distribution of light. However, the measurement results reveal that light tends to be concentrated in specific areas and is not effectively distributed

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throughout the space. This indicates a gap between the potential availability of natural lighting and the actual performance of light distribution within the classroom.

From an architectural perspective, this condition suggests that the configuration of spatial elements does not fully support optimal light distribution. Although the number of openings is relatively adequate, their position, orientation, and spatial relationships do not facilitate an even spread of light. Light entering from the right-side openings tends to illuminate nearby areas directly, while deeper areas experience a gradual reduction in intensity. This indicates that lighting distribution is more influenced by the lateral direction of incoming light rather than by an even spatial diffusion throughout the room.

In addition, room depth contributes to the limited reach of natural lighting. The farther an area is from the light source, the greater the reduction in illuminance. Without elements that can reflect or redirect light, such as high-reflectance materials on walls and ceilings, natural light is unable to effectively reach deeper areas of space. As a result, distinct lighting zones with varying quality are formed within the same room.

The absence of light-distribution elements such as light shelves, shading devices, or other light-directing systems also affects lighting performance. These elements can theoretically improve light distribution by reflecting light toward upper surfaces or reducing excessive luminance contrast near openings. Without such elements, natural light tends to enter directly and remains uncontrolled, resulting in uneven distribution.

Furthermore, the variation in lighting distribution indicates that the design has not adequately considered uniformity as a key parameter of visual comfort. In learning environments, lighting uniformity plays a crucial role in maintaining stable visual conditions, which are essential for reducing visual strain. When uniformity is not achieved, users are exposed to varying visual conditions that may negatively affect comfort and visual performance (Giang & Duong, 2024).

From this evaluation, it can be concluded that the primary issue in classroom lighting is not the availability of natural light, but rather the strategy of light distribution. This finding highlights that lighting design should not only focus on the quantity of light or the size and number of openings, but also on how light is effectively distributed within the space. Therefore, a more comprehensive design approach is required to improve natural lighting quality. Several strategies can be considered, including the use of interior materials with high reflectance to enhance light diffusion, the addition of light-directing elements such as light shelves to distribute light into deeper areas, and the optimization of the position and orientation of openings to achieve more even distribution. In addition, integrating natural and artificial lighting systems can help balance illumination in areas that are not adequately reached by natural light. In conclusion, this evaluation confirms that classroom lighting quality is determined not only by light intensity but also by the performance of light distribution in creating consistent and stable visual conditions. The practical implications of this study emphasize the importance of an integrated lighting design approach that optimizes spatial light distribution to support visual comfort and enhance the effectiveness of students' learning activities.

4. CONCLUSION

This study demonstrates that the distribution of natural lighting in the Tahfidz classroom has not yet provided uniform visual conditions for all students. Although several measurement points met the minimum illuminance standard of 350 lux, the overall average illuminance was 320 lux, while the lighting uniformity ratio was 0.35. These results indicate that the main issue lies not in the availability of daylight, but in the uneven distribution of

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light within the classroom. Areas located near the side openings received higher illuminance, whereas deeper and opposite-side zones experienced lower lighting levels, resulting in variations in visual quality across the same learning space.

The findings confirm that lighting quality is determined not only by the magnitude of illuminance, but also by the uniformity of its distribution in supporting students' visual comfort. Uneven lighting conditions may increase visual adaptation load during reading and memorization activities, which are dominant learning activities in Tahfidz classrooms. Therefore, the objective of this study, namely to analyze natural lighting distribution and its implications for visual comfort, has been achieved.

Based on these findings, improving classroom lighting quality should focus on optimizing light distribution strategies rather than merely increasing the number of openings. Practical design recommendations include the use of high-reflectance interior materials, the incorporation of light-directing elements such as light shelves, the adjustment of the position and orientation of openings, and the integration of natural and artificial lighting systems to support underlit areas.

This study contributes to the field of architectural design, particularly in educational space planning, by emphasizing that lighting distribution should be considered a key parameter in creating comfortable and effective learning environments. For future research, it is recommended to conduct measurements under varying time conditions and weather scenarios, as well as to examine the relationship between lighting distribution, visual fatigue, concentration, and students' learning performance using quantitative or mixed-method approaches.

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