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Simulation-based assessment of morning daylight performance and study period recommendation in Tahfidz Classroom

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Abstract.
This study investigates morning daylight performance in a Tahfidz classroom to identify the recommended study period for visually intensive learning activities. Tahfidz learning requires sustained reading and memorization, making stable daylight conditions with adequate illuminance and improved illuminance uniformity essential for visual performance. A quantitative descriptive approach was employed using daylight simulation in DIALux Evo from 07:00 to 09:00 at 30-minute intervals. Illuminance levels were evaluated based on minimum, maximum, average, and illuminance uniformity (U_0) values and compared with the recommended classroom lighting standard of 350 lux. The results show that average illuminance exceeds the standard after 08:30, indicating adequate daylight availability for learning activities. However, significant differences between minimum and maximum values reveal uneven daylight distribution across the classroom. Temporal analysis indicates that daylight conditions become more stable after 08:30, providing sufficient illumination with relatively reduced contrast compared to earlier intervals. Based on simulation-derived illuminance and illuminance uniformity indicators, the period after 08:30 is recommended for visually intensive learning activities. The study concludes that daylight performance depends not only on illuminance level but also on the balance between intensity, distribution, and time.
Keywords: daylighting, illuminance, Tahfidz classroom, recommended study period, illuminance uniformity

Introduction

Natural lighting plays an important role in creating effective learning environments, particularly in educational spaces that rely heavily on visual activities (Ghiai & Rashid, 2026; Liu et al., 2023). Adequate daylight supports reading performance, visual comfort, concentration, and psychological well-being, while insufficient or excessive lighting may reduce learning efficiency and increase visual discomfort (AL-Mowallad et al., 2024; Tabadkani et al., 2021). In classroom environments, lighting quality is commonly assessed through illuminance level, distribution uniformity, glare control, and the relationship between spatial orientation and sunlight exposure. These factors become increasingly important in spaces where students perform sustained near-vision tasks for extended periods (AL-Mowallad et al., 2024; Hao et al., 2024; Shamseldin, 2025).

Tahfidz classrooms have distinctive learning characteristics compared with general classrooms. Students regularly engage in reading, memorizing, repeating, and reviewing Qur'anic texts, often using small, printed scripts that require continuous visual focus. Such activities demand stable lighting conditions to maintain legibility and concentration. Inadequate daylight during early school hours may hinder reading performance, while excessive direct sunlight may produce glare and visual distraction

(AL-Mowallad et al., 2024; Chauca et al., 2024). Therefore, the design and timing of natural lighting become essential components in supporting the effectiveness of Tahfidz learning spaces.

Previous studies have demonstrated that adequate classroom lighting contributes positively to student performance and user comfort (Aghajari & Chen, 2025; Çelik et al., 2025; Syafi'i et al., 2023; Zaky et al., 2023). Research in educational environments has reported that sufficient illuminance levels are associated with improved reading accuracy, faster visual recognition, reduced eye strain, and better task performance during learning activities. Conversely, insufficient lighting may lower concentration and create discomfort, particularly in tasks requiring prolonged near-vision focus (Chiou et al., 2020; Gao, Fu, Gao, & Gao, 2025; Kristanti & Rezalti, 2022; Zhou & Pan, 2023). Beyond illuminance quantity, researchers have also emphasized the importance of daylight uniformity, since uneven light distribution often creates excessive contrast between window zones and deeper classroom areas. Such conditions may reduce visual comfort and force continuous visual adaptation during reading activities (Gao, Fu, Gao, Liu, et al., 2025; Kristanti & Rezalti, 2022). In addition, daylight availability is strongly affected by building orientation, window placement, surrounding obstructions, and hourly solar movement (Desiana et al., 2025). North, south, east, and west-facing classrooms may experience different daylight patterns throughout the day, resulting in varying visual conditions during learning sessions.

Despite the growing interest in daylighting performance in educational buildings, limited studies specifically discuss Tahfidz classrooms and their temporal learning suitability based on morning illuminance conditions. Most research focuses on general classrooms, offices, or residential spaces, while learning environments with intensive memorization and repeated reading activities remain underexplored. In addition, practical recommendations regarding the most suitable morning study hours based on daylight availability are still rarely addressed.

This study addresses this gap by analyzing morning daylight performance in a Tahfidz classroom from 07:00 to 09:00 using DIALux Evo simulation. The analysis evaluates average, minimum, and maximum illuminance, as well as daylight uniformity, and compares the results with the recommended classroom lighting standard (SNI 6197:2020, 350 lux). By examining temporal lighting patterns, the study aims to identify the most appropriate study period for visually demanding learning activities.

In Tahfidz learning, which involves sustained reading and memorization of small Arabic text, visual performance is highly dependent on stable daylight conditions. While previous studies have shown that both insufficient and excessive illuminance can reduce reading efficiency and may increase visual demand, limited research has examined the temporal dynamics of daylight in this context. Therefore, this study integrates daylight performance with temporal learning suitability, highlighting that visual performance is influenced not only by illuminance level, but also by the temporal stability and spatial distribution of daylight.

Methods

This study employed a quantitative descriptive approach to evaluate the morning daylight performance of a Tahfidz classroom and identify the recommended study period based on illuminance standards. The research focused on natural daylight conditions during the morning learning period, when reading, memorization, and review activities are commonly conducted. The analysis was limited to the time range of 07:00 to 09:00 Western Indonesian Time (WIB) at 30-minute intervals.

The selected time range of 07:00 to 09:00 represents the primary learning period in Tahfidz classrooms, during which intensive reading and memorization activities are typically conducted. This period is critical because it coincides with the early morning daylight transition, where rapid changes in solar position significantly influence illuminance levels and distribution. Despite its importance, limited studies have examined how these temporal variations affect visual conditions and learning suitability, particularly in Tahfidz educational settings.

The overall research procedure is illustrated in Figure 1. The study began with problem identification and literature review, followed by classroom data collection, daylight simulation, and data analysis to determine the recommended study period.

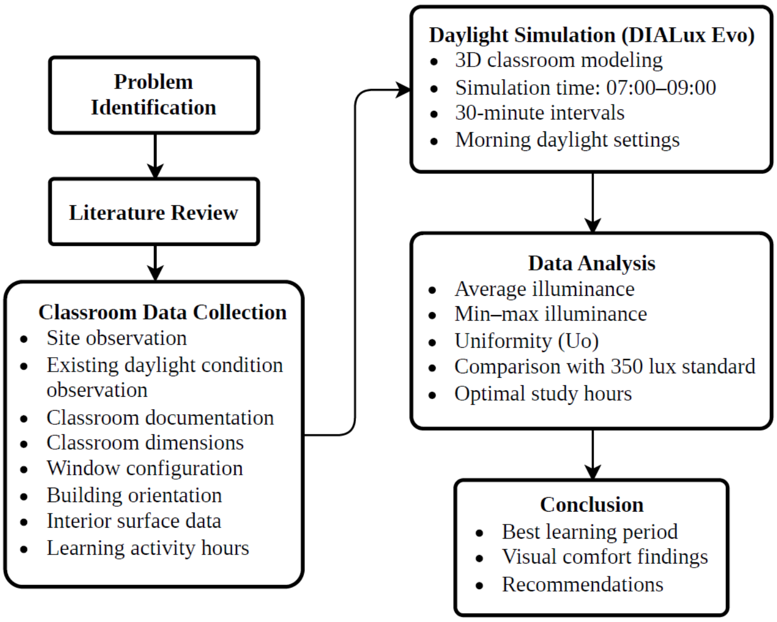

Figure 1. Research Flowchart of Morning Daylighting Analysis in Tahfidz Classroom
Source: Author’s elaboration, 2026

The research procedure consisted of problem identification, literature review, classroom data collection, daylight simulation, data analysis, and conclusion formulation. The literature review was conducted to establish the theoretical framework, identify relevant daylighting indicators, and determine the recommended classroom illuminance standard used in this study. As illustrated in Figure 1, the research framework is structured as a sequential process, beginning with problem identification and literature review, followed by classroom data collection, daylight simulation, and descriptive analysis to determine the recommended study period.

Classroom data collection included site observation, existing daylight condition observation, classroom documentation, and recording of physical room characteristics. The collected data consisted of classroom dimensions, window configuration, building orientation, interior surface characteristics, and morning learning activity hours. These variables were used as the primary inputs for the simulation model.

The case study was conducted in a Tahfidz classroom located in Bungah District, Gresik Regency, Indonesia (latitude: −7.0539993; longitude: 112.5738455). The classroom has a rectangular configuration with dimensions of approximately 7 m × 9 m × 3.5 m. The main openings are positioned on two opposite sides of the classroom, with the primary facade oriented towards the west based on the applied north alignment (261.29°).

The classroom is equipped with multiple window openings distributed along both sides of the space. Each window has an approximate dimension of 0.75 m × 0.70 m, with a sill height of 1.20 m above floor level. The glazing material is clear glass; however, field observations indicate that the window surfaces are not perfectly clean, which may slightly reduce light transmission and influence indoor illuminance levels.

The classroom is located within a relatively dense educational complex surrounded by adjacent buildings and vegetation. These surrounding elements partially obstruct direct solar penetration into the classroom, resulting in indoor lighting conditions that are predominantly influenced by diffuse daylight rather than direct sunlight.

Interior surface reflectance values were estimated based on field observations and commonly adopted values reported in daylight simulation literature. The ceiling was assigned a reflectance of 0.70, the painted walls 0.60, the ceramic floor 0.30, and the wooden furniture 0.20 to represent the existing classroom materials in the DIALux Evo simulation (Fontana, 2023).

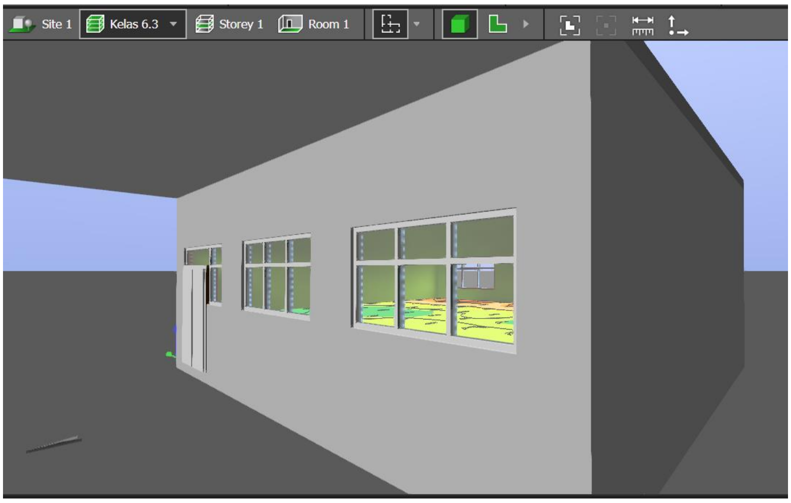

Figure 2. Three-dimensional classroom model used for daylight simulation in DIALux Evo
Source: Author's simulation using DIALux Evo, 2026.

Daylight data corresponding to morning conditions (07:00-09:00) were generated through simulation using DIALux Evo. A three-dimensional classroom model was developed based on the actual spatial configuration to represent realistic daylight conditions. The simulation incorporated key parameters including geographic location, classroom orientation, opening configuration, ceiling height, glazing properties, and interior surface reflectance.

The simulation was conducted under an overcast sky model on 2 April 2026. Although field observations were carried out under generally clear weather conditions, the presence of surrounding buildings, vegetation, and window surface conditions reduces direct sunlight penetration. Therefore, indoor lighting conditions are dominated by diffuse daylight, and the overcast sky model was selected to better represent actual classroom conditions and achieve closer agreement between simulated and observed illuminance distribution.

The daylight simulation was performed using the CIE Standard Overcast Sky model, which represents diffuse daylight conditions with minimal direct solar radiation. This sky model is widely applied in daylighting research because it provides stable and reproducible lighting conditions for evaluating indoor daylight distribution (Aghimien et al., 2025; Tregenza & Wilson, 2011).

Although field observations were conducted under generally clear weather conditions, the investigated classroom receives limited direct sunlight due to surrounding buildings, vegetation, relatively small window openings, and partially contaminated glazing surfaces. Consequently, the indoor lighting environment is predominantly influenced by diffuse daylight rather than direct solar penetration.

The simulation date was selected to represent a typical morning learning period during the study, while the CIE Standard Overcast Sky was adopted to evaluate daylight distribution under consistent boundary conditions. Compared with the Clear Sky model, the Overcast Sky model reduces the influence of highly variable direct sunlight and provides a more representative assessment of indoor daylight distribution for this classroom configuration. However, this study did not perform a sensitivity analysis using alternative sky models, and this is acknowledged as a limitation of the research.

Illuminance values were evaluated on a horizontal working plane positioned at 0.84 m above the floor, representing desk height. Calculation points were automatically generated using the default

DIALux Evo measuring grid across the classroom analysis area. The default grid spacing displayed by the software was 1.0 m × 1.0 m, providing evenly distributed calculation points covering areas near the windows, the central zone, and the rear of the classroom.

To verify the simulated daylight distribution, field illuminance measurements were conducted on 2 April 2026 between 09:00 and 10:00 WIB using a digital lux meter. Measurements were taken at 15 points on the same working plane (0.84 m). The comparison was limited to verifying the similarity of spatial daylight distribution patterns rather than performing a full numerical validation between simulated and measured illuminance values.

For each simulation interval (07:00, 07:30, 08:00, 08:30, and 09:00), the outputs included minimum, maximum, and average illuminance, as well as daylight uniformity (U_o). These values were compared with the recommended classroom lighting standard (SNI 6197:2020), which specifies a minimum illuminance of 350 lux.

Data analysis was conducted descriptively by comparing temporal changes in illuminance and evaluating spatial distribution patterns. The findings were used to determine the most appropriate study period for visually demanding Tahfidz learning activities, considering both illuminance adequacy and distribution uniformity.

Result and Discussion

This section presents the key findings of the daylight simulation, focusing on temporal variation and spatial distribution of illuminance in the Tahfidz classroom. The results show a dynamic daylight pattern, with illuminance increasing in the early morning, peaking around 08:00, and gradually decreasing afterward. Although average illuminance consistently exceeds the recommended standard of 350 lux, large differences between minimum and maximum values indicate uneven daylight distribution. This suggests that adequate illuminance alone does not ensure balanced daylight conditions, as excessive brightness and spatial imbalance remain critical issues.

As shown in Figures 3 and 4, supported by Table 1, the findings reveal both temporal and spatial patterns of daylight performance. The discussion interprets these patterns in relation to illuminance intensity, distribution, and their implications for daylight performance during learning activities.

Temporal Variation of Daylight Illuminance

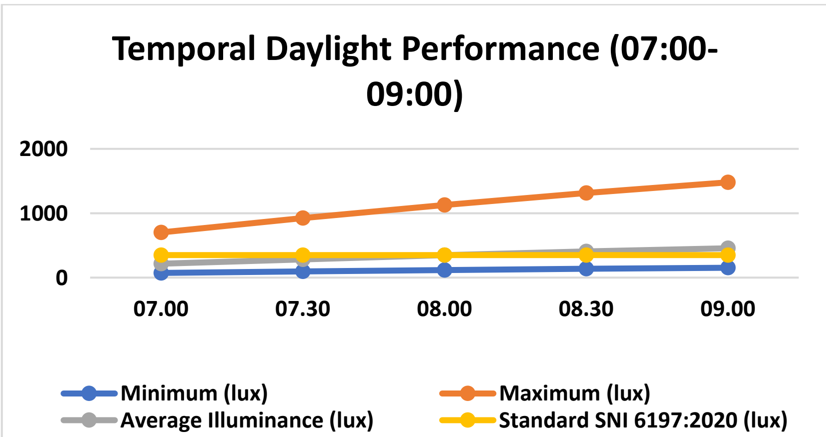

Figure 3. Temporal Changes in Illuminance Levels and Compliance with Recommended Classroom Lighting Standard
Source: Author’s analysis based on DIALux Evo simulation, 2026.

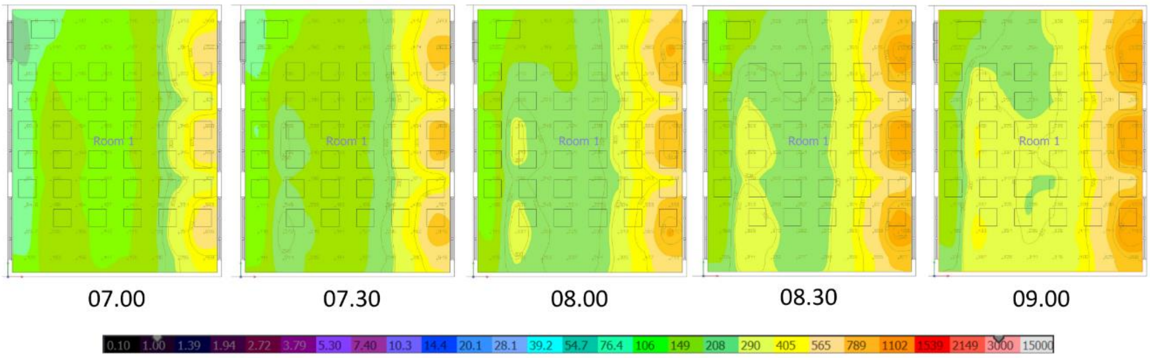

Figure 4. Daylight Penetration Pattern and Illuminance Distribution Across Classroom Space (07:00-09:00)
Source: Author's analysis based on DIALux Evo simulation, 2026.

Table 1. Temporal Daylight Performance on Working Plane (07:00-09:00)

Time	Minimum Illuminance (lux)	Maximum Illuminance (lux)	Average Illuminance (lux)	Recommended SNI 6197:2020 (lux)
07.00	72.7	702	216	350
07.30	95.6	923	284	350
08.00	117	1129	348	350
08.30	136	1316	405	350
09.00	153	1480	456	350

Source: Author's analysis based on daylight simulation using DIALux Evo.

Such lighting conditions may require greater visual adaptation because of luminance contrast between brighter zones near the windows and relatively dimmer areas deeper in the classroom. This contrast may increase visual demand during sustained near-vision activities, such as reading and memorization in Tahfidz classrooms.

The simulation results presented in Figure 3 show a clear temporal trend, with illuminance gradually increasing from 07:00 to 09:00. This temporal pattern is further reflected in the spatial distribution shown in Figure 4, indicating that daylight performance is dynamic and influenced not only by illuminance levels but also by the interaction between light intensity, spatial distribution, and time. The classroom geometry and opening configuration illustrated in Figure 2, together with the spatial distribution shown in Figure 4, further support this observation.

As presented in Table 1, the average illuminance exceeds the recommended classroom lighting standard after 08:00. However, the presence of relatively high maximum values and low minimum values indicates a persistent imbalance in lighting conditions across the classroom. The average illuminance increases from 216 lux at 07:00 to 456 lux at 09:00, while maximum values range from 702 lux to 1480 lux. In contrast, minimum illuminance values remain considerably lower, ranging from 72 lux to 153 lux. This disparity indicates that certain areas, particularly those located further from the window openings, continue to receive insufficient illumination compared to areas near the facade.

The coexistence of brighter and dimmer zones within the same space highlights a significant issue of non-uniform daylight distribution. As shown in Figure 4, the daylight distribution forms a clear gradient pattern, with higher illuminance concentrated near the window facade and gradually decreasing toward the interior of the classroom.

From a spatial perspective, this condition reflects directional daylight penetration with limited diffusion within space. As illustrated in Figure 4, the configuration of openings and interior geometry influences how light enters and spreads within the classroom. The contribution of reflected light from interior surfaces, particularly the ceiling, appears insufficient to effectively redistribute light, which contributes to the persistence of uneven lighting conditions.

Additionally, the results highlight the temporal sensitivity of daylight performance. The gradual increase in illuminance over time demonstrates that daylight availability is highly dependent on time and should be understood as a dynamic environmental factor rather than a static condition. From a learning perspective, these variations influence the daylight conditions experienced during learning activities. While conditions after 08:00 provide sufficient illumination, differences in light distribution may still affect visual conditions within the classroom, especially for students seated near the window compared to those in deeper areas.

In the context of Tahfidz learning, which involves prolonged reading and memorization of small Arabic text, daylight performance becomes a critical consideration. Uneven lighting conditions may increase visual demand and require greater visual adaptation during prolonged reading activities. These findings indicate that achieving balanced daylight performance requires a balance between illuminance intensity and spatial distribution. Meeting the recommended illuminance level alone does not guarantee favorable daylight performance. Instead, effective daylight design should aim to improve light distribution while minimizing contrast between different areas of the classroom.

Daylight Adequacy and Learning Implications

As presented in Table 1, the average illuminance values increase progressively across all observed time intervals. When evaluated against the recommended classroom lighting standard of 350 lux, the results indicate that adequate illuminance is achieved after 08:00. The average illuminance rises from 216 lux at 07:00 to 456 lux at 09:00, suggesting that sufficient daylight is available for visually demanding learning activities during the later part of the observation period.

However, adequacy in terms of average illuminance does not necessarily translate into balanced daylight conditions. The presence of relatively high maximum values alongside low minimum values indicates an imbalance in lighting distribution. Maximum illuminance values increase from 702 lux to 1480 lux, while minimum values remain significantly lower, ranging from 72 lux to 153 lux. This disparity indicates that certain areas receive substantially higher illuminance than others, resulting in uneven lighting conditions throughout the classroom.

To further examine the variability of daylight performance, the range between minimum and maximum illuminance values was analyzed as an indicator of distribution contrast. The results show a consistently wide gap across all observed intervals, indicating a non-uniform daylight distribution within space.

This condition suggests that students may experience different lighting environments depending on their seating position, with areas near the windows receiving higher illuminance and deeper areas remaining relatively underlit. In the context of Tahfidz learning, which involves prolonged reading of small Arabic text, such imbalance may affect daylight performance, increase visual effort, and increase visual demand during prolonged reading activities.

These findings highlight that achieving adequate illuminance alone is not sufficient to ensure favorable daylight conditions. Instead, a more balanced distribution of daylight is required to support more consistent daylight conditions across all areas of the classroom.

Uniformity and Daylight Performance

Despite the relatively adequate levels of average illuminance, the distribution of daylight within the classroom remains uneven. This is reflected in the consistent gap between minimum and maximum illuminance values across all observed time intervals. The minimum values range from 72 lux to 153 lux, while maximum values reach up to 1480 lux, indicating a considerable level of illuminance contrast within the classroom.

Such disparity suggests low daylight uniformity, where certain areas receive substantially higher illumination than others. In practical terms, this creates uneven daylight conditions in which students are exposed to different lighting environments depending on their position within the classroom.

From a visual ergonomics perspective, low uniformity is associated with continuous visual adaptation. When students shift their gaze between brighter and dimmer areas, the visual system must continuously adjust to changing luminance levels. These conditions may increase visual demand during prolonged reading activities.

In the context of Tahfidz learning, which requires sustained attention and prolonged visual engagement, uniformity becomes an important parameter in evaluating daylight performance. The findings suggest that achieving adequate illuminance alone is insufficient without a balanced distribution of daylight across the learning area.

Spatial Distribution of Daylight

The spatial distribution of daylight as illustrated in Figure 4 reveals a consistent pattern across all observed time intervals. Illuminance levels are predominantly concentrated near the window facade, forming a directional gradient that gradually decreases toward the interior of the classroom. This pattern indicates that daylight penetration is strongly influenced by the position, orientation, and effective opening area of the windows, as supported by the classroom geometry shown in Figure 2.

The observed gradient reflects a typical unilateral daylighting condition, where light enters primarily from one side of the space and diminishes as the distance from the opening increases. As a result, areas located close to the window receive higher illuminance, while deeper zones experience comparatively lower light levels. Although the overall illuminance intensity changes over time, the fundamental spatial distribution pattern remains relatively consistent throughout the observation period.

A closer examination of the heatmap patterns shows that higher illuminance zones are concentrated near the window areas, forming localized regions of increased brightness. These zones are influenced by the directional nature of daylight entering through the openings. In contrast, the central and rear portions of the classroom exhibit more moderate and relatively stable illuminance levels, although still lower compared to the facade zone.

The persistence of this uneven distribution suggests that daylight within the classroom is not evenly diffused across space. The contribution of inter-reflected light from interior surfaces, particularly the ceiling, appears limited in redistributing light toward deeper areas of the room. This condition indicates that while daylight penetration is sufficient, its spatial distribution remains suboptimal.

From a visual perspective, this condition creates noticeable luminance contrast between different zones within the classroom. Students seated near the window are exposed to higher brightness levels, while those located further away experience relatively lower illuminance. Such variation can lead to unequal visual conditions, requiring continuous visual adaptation and potentially contributing to unequal daylight conditions.

This spatial imbalance highlights the importance of integrating architectural strategies that enhance daylight distribution. Factors such as window configuration, glazing properties, interior surface reflectance, and room geometry play a critical role in determining how light is distributed within space. Without adequate diffusion mechanisms, increasing daylight intensity alone may only amplify contrast rather than improve overall lighting quality.

In addition, the findings suggest that effective daylighting design should aim not only to maximize light penetration but also to control and redistribute it. Strategies such as the use of diffusing elements, improved surface reflectance, or optimized window configurations may help reduce contrast and improve uniformity. By addressing both the quantity and distribution of daylight, a more balanced daylight environment can be achieved.

Temporal Sensitivity and Optimal Study Period

The results demonstrate that daylight performance in the classroom is sensitive to time, particularly within the morning period, where illuminance gradually increases across relatively short intervals. This variation reflects the dynamic nature of daylight availability, indicating that lighting conditions should not be treated as static but as continuously changing environmental parameters.

The highest illuminance levels are observed toward the end of the observation period (around 09:00), when average illuminance reaches its maximum while remaining within a moderate range compared to earlier assumptions of excessive brightness. Although this condition ensures sufficient illumination for visual tasks, it does not automatically correspond to balanced daylight conditions. The presence of relatively high maximum values alongside low minimum values indicates that contrast between different zones of the classroom persists.

In contrast to earlier time intervals, lighting conditions after 08:30 appear more stable, with average illuminance consistently exceeding the recommended standard and changes occurring more gradually. This condition suggests a more balanced lighting environment compared to the early morning period, although spatial distribution remains uneven.

From a temporal perspective, this pattern highlights the importance of identifying not only whether daylight is sufficient, but also when it is most suitable for supporting learning activities. The findings suggest that the period between 08:30 and 09:00 represents the recommended study period, as it provides adequate illumination with relatively more stable conditions compared to earlier intervals.

Furthermore, the observed temporal variation indicates that learning activities may be affected by temporal variations in daylight conditions. Students seated near window areas tend to experience higher illuminance levels, while those located deeper within the classroom remain under comparatively lower illuminance. This variation creates unequal visual environments across the classroom, potentially affecting concentration and visual conditions.

In the context of Tahfidz learning, which involves continuous reading, memorization, and repetition of small-sized Arabic text, stable daylight conditions are essential. Fluctuating daylight conditions, particularly those involving uneven distribution, may require greater visual adaptation and increase visual demand during learning activities. These findings highlight the importance of integrating temporal considerations into both classroom design and learning schedules, as daylight should be understood as a dynamic factor influencing daylight performance during learning activities.

In addition, the results reinforce the need to reconsider conventional approaches that focus primarily on achieving minimum illuminance thresholds. This study demonstrates that adequate daylight levels alone are insufficient without proper spatial distribution. Daylight performance should therefore be evaluated through a balance of intensity, distribution, and timing. However, this study is limited by its reliance on simulation-based analysis, which may not fully represent real-world conditions such as weather variability, user behavior, and dynamic shading effects. Furthermore, the focus on a single classroom configuration may limit the generalizability of the findings. Future studies are recommended to incorporate field measurements and user-based evaluations to further validate and extend these results.

Conclusion

This study demonstrates that daylight performance in the Tahfidz classroom cannot be evaluated solely based on illuminance adequacy but must also consider spatial distribution and temporal variation as critical determinants of overall daylight quality. While the simulation results indicate that average illuminance levels exceed the recommended classroom standard of 350 lux after 08:00, this quantitative adequacy does not necessarily translate into favorable daylight conditions.

The findings reveal that variations between maximum and minimum illuminance values create noticeable contrast across different zones within the classroom. Higher illuminance levels are concentrated near the window areas, while lower values persist in deeper parts of the room, indicating an uneven distribution of daylight. This imbalance results in non-uniform daylight conditions in which students experience different lighting environments depending on their seating position.

From a visual ergonomics perspective, such conditions may require greater visual adaptation, particularly in learning environments that involve prolonged reading and concentration, such as Tahfidz classrooms. The results highlight that achieving sufficient illuminance alone is not enough; balanced light distribution and effective daylight control are equally essential to improve daylight performance.

Furthermore, the study emphasizes the temporal sensitivity of daylight performance. Illuminance levels increase gradually throughout the morning period, indicating that daylight conditions are dynamic rather than static. The recommended study period, based on simulation-derived illuminance and illuminance uniformity indicators, is after 08:30, when illuminance levels remain sufficient and changes occur more steadily, resulting in relatively more stable daylight conditions than during earlier intervals.

These findings suggest that classroom daylighting strategies should not only aim to meet illuminance standards but also address issues of uneven distribution. Design considerations such as window configuration, interior surface reflectance, and daylight control elements should be optimized to achieve more balanced daylight conditions. Additionally, aligning learning schedules with periods of more stable daylight conditions may further improve daylight performance.

In conclusion, this study contributes to a more comprehensive understanding of daylight performance in learning environments by demonstrating that daylight performance is shaped by the interaction between illuminance, spatial distribution, and time. This integrated perspective provides a useful basis for developing classroom daylighting strategies that support favorable daylight performance.

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