Evaluation of Natural Lighting in the Digital Library Building: A Preliminary Study Using Lux Meter from East and West Directions

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Abstract. This preliminary study evaluates natural daylight intensity entering the reading rooms of the Digital Library at Universitas Negeri Medan from the east and west orientations. Light measurements were taken periodically using a lux meter from 08:00 AM to 05:00 PM over five working days. The results indicate a significant variation in light intensity between the two orientations. Eastern windows exhibited peak illuminance around 09:00–10:00 AM, while western windows reached their maximum around 03:00–04:00 PM. This fluctuation impacts users thermal and visual comfort, with reported warm and glare issues in both morning and afternoon sessions. The findings highlight the need for architectural interventions such as automated blinds or sun-shading devices to optimize passive lighting. This study serves as an early reference for designing daylight-responsive buildings in tropical educational environments, supporting both energy efficiency and user comfort.

Keywords: Natural lighting; Lux meter; East and west orientation; Comfort; Digital library

1 Introduction

A modern library not only provides space for book collections but also offers a variety of supporting spaces for learning, collaboration, and the social needs of its users. Furthermore, contemporary library buildings are designed as multifunctional spaces that not only accommodate book collections but also serve as centers for community and learning activities—as exemplified by the subject of this study, the Digital Library of Universitas Negeri Medan (Digilib UNIMED) building. The process of designing an ideal library involves the active participation of the community, including students, lecturers, and educational staff—particularly librarians—collectively referred to as the academic community. The collaboration between members of the academic community, planners, and stakeholders is expected to produce essential guidelines for creating an ideal library atmosphere. Through surveys, focus group discussions, and user-centered activities such as "A Day in the Life," this approach can

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further reveal specific spatial needs and usage patterns, ensuring that the resulting design truly reflects the aspirations and character of the user community [1].

As a modern-designed building, the Digilib UNIMED building emphasizes spatial flexibility, accessibility, and technological integration. Its interior spaces are no longer rigidly separated but are organically connected to support a wide range of activities—from reading and discussion to collaboration and social interaction. Architectural innovations are visibly evident in the use of natural lighting, indoor-outdoor connectivity, and attention to user comfort [2], [3], [4].

From an interior perspective, the Digilib UNIMED building is designed to be not only visually appealing but also functional, user-friendly, and adaptable to evolving demands. Through a collaborative and data-driven design approach, the library can serve as an inclusive, inspiring, and relevant space for all community members, particularly academics [1], [4], [5]. Furthermore, when viewed in relation to its exterior appearance, the building presents a challenge due to the use of overly wide openings. Considering the principles of sustainability and energy efficiency as crucial factors in addressing climate change challenges and future needs [5], [6]. While the building may initially seem to embody these principles, the practical realization of them presents unique challenges.

Given the significance of environmental quality in enhancing user comfort and supporting academic activities, natural lighting is recognized as one of the most critical elements in library design. Optimal daylighting can reduce reliance on artificial lighting, thereby lowering energy consumption and aligning with sustainability objectives [2], [7]. However, excessive or poorly controlled daylight—particularly in buildings with wide openings facing the east and west—can cause glare, visual discomfort, and increased heat gain, which may compromise user productivity and the building's overall thermal performance [2], [7], [8]. In the context of the Digilib UNIMED building, these issues are highly relevant due to its architectural features and spatial orientation. This preliminary study therefore evaluates the actual daylight intensity entering the building's reading rooms from the east and west orientations. Measurements were conducted periodically using a lux meter from 08:00 AM to 05:00 PM over five consecutive working days to capture daily fluctuations. By comparing these empirical findings with the design intentions, the study aims to identify potential gaps between conceptual sustainability goals and real-world performance. The results are expected to provide practical recommendations for optimizing passive daylighting strategies in academic libraries within tropical climates, ensuring both energy efficiency and user comfort.

1.1 Natural Lighting

Natural lighting is one of the key aspects in modern building design. The optimal application of natural lighting can provide various benefits, ranging from visual comfort and occupant health to energy efficiency. By maximizing the use of sunlight, the need for artificial lighting can be significantly reduced, thereby lowering building energy consumption and CO_2 emissions [9], [10]. Studies indicate that optimizing natural lighting can improve energy efficiency by up to 30% and reduce environmental footprint by 24.81% [9].

A well-designed daylighting strategy considers various factors such as building orientation, window position and size, aspect ratio, and building height. The proper placement and sizing of windows greatly influence the distribution of light within interior spaces. In addition, the use of smart control systems—such as automated blinds that adjust openings based on outdoor light intensity—can enhance indoor environmental quality while reducing HVAC energy consumption [9], [11].

Beyond its technical aspects, natural lighting also impacts the physical and mental health of occupants. Adequate exposure to daylight can improve mood, productivity, and maintain the body's circadian rhythm. However, excessive daylight without proper control can cause glare and increase cooling loads, making design strategies such as shading devices, coated glass, or atriums essential for regulating incoming light intensity [10], [12], [13], [14].

Innovations in daylighting systems—such as the use of cylindrical glass, light shelves, or clerestory atriums—have been proven to improve light distribution into deeper areas of a building and significantly reduce the need for artificial lighting [12], [13], [14]. Thus, natural lighting not only contributes to creating a comfortable and healthy environment but also supports the realization of sustainable and environmentally friendly buildings.

1.2 User Comfort

User comfort in buildings is a fundamental aspect that affects occupants health, productivity, and overall well-being. This concept is multidimensional, encompassing thermal comfort, visual comfort, acoustic quality, and indoor air quality (IAQ), where these four dimensions interact to shape users overall perception of the built environment [15], [16], [17]. One factor increasingly recognized as important is personal control—the extent to which occupants can adjust their surrounding environmental conditions, such as temperature, lighting, and ventilation. Studies indicate that the greater the control afforded to users, the higher their levels of satisfaction and comfort, both physically and psychologically [18], [19]. Therefore, building designs that offer flexibility and ease for users to adapt their environment are highly recommended [18].

Overall, theories and practices of user comfort emphasize the need for a holistic approach that considers environmental parameters alongside individual characteristics. Comfort assessment should not rely solely on technical standards but should also account for users' perceptions and preferences, in order to create a healthy, productive, and satisfying built environment [16], [17], [18].

In this context, natural lighting emerges as a key factor, particularly in learning spaces, libraries, and work environments. High-quality natural lighting enhances visual comfort by improving visual acuity, reducing eye strain, and supporting users' productivity and health [15], [20], [21]. Research shows that appropriate levels of illuminance and correlated color temperature (CCT) can significantly enhance mood, alertness, and visual comfort [21], [22]. Optimal daylight design should ensure even light distribution, avoid glare, and provide adequate illumination in work areas. Lighting imbalance—such as areas that are excessively bright or dim—can diminish visual comfort and reduce task performance [15], [20].

Recommended design strategies include determining the proper size and orientation of windows, selecting light-colored interior finishes to reflect light, and employing control devices such as automated blinds, laminated glass, or light shelves to regulate light intensity [15], [20], [23]. Beyond visual benefits, natural lighting also influences psychological and physiological aspects, including improved mood, reduced stress, and maintenance of the body's circadian rhythm [21], [22], [23]. Recent studies even suggest that lighting comfort can be predicted through physiological indicators such as brain activity and skin response, underscoring the importance of appropriate natural lighting in supporting user health and comfort [21], [22]. Thus, the proper integration of natural lighting not only improves energy efficiency but also serves as a crucial element in creating comfortable, healthy, and productive buildings.

2 Method

This study employs the Post Occupancy Evaluation (POE) method with a mixed-methods approach, combining qualitative and quantitative techniques to gain a comprehensive understanding of user comfort and the building's environmental performance [24], [25], [26], [27]. This approach aligns with common POE practices, where evaluations are conducted through a combination of objective measurements and subjective user assessments [25], [26], [27].

Quantitative data collection was carried out through direct measurements using instruments such as a lux meter for natural lighting, a thermometer for air temperature, and a hygrometer for relative humidity. Measurements were conducted periodically at several representative points within the building to obtain objective data on environmental conditions. The data were then statistically analyzed and compared against prevailing comfort and energy efficiency standards [25], [26].

The qualitative approach involved distributing questionnaires to building users to identify their perceptions, comfort levels, and satisfaction regarding natural lighting, temperature, and humidity. Additionally, semi-structured interviews and field observations were conducted to gain deeper insights into user experiences and needs [24], [26], [27].

The analysis was performed by integrating the results of objective measurements with user perception data to identify gaps between actual conditions and user expectations. Subsequent steps included: (1) conducting measurements in various zones and at different times to capture environmental variations; (2) performing advanced statistical analyses (e.g., regression) to identify relationships between environmental variables and comfort; (3) documenting the building's technical characteristics such as orientation, type of openings, and environmental control systems; and (4) visualizing data to facilitate interpretation and decision-making [25], [26], [27].

3 Results and Discussion

3.1 Identification of Natural Lighting

The identification of natural lighting in the Digilib UNIMED shows that the openings on the east and west sides are relatively large, with a height of approximately 1,5 meters and a width ranging from 2 to 3 meters. Measurements of light intensity using a lux meter over five working days revealed significant variations between the two orientations: the east side reached peak illumination between 09:00–10:00 AM, while the west side peaked between 03:00–04:00 PM. These fluctuations affected both thermal and visual comfort, with users frequently reporting heat and glare during the morning and afternoon hours.

From a facade design perspective, the east side features a curved form with hollow steel louvers measuring 20×20 mm and spaced about 10 cm apart, whereas the west side is flat, without louvers or shading canopies. This condition allows for more intense sunlight penetration on the west side, resulting in higher risks of glare and heat in the afternoon. Previous studies have emphasized that the size and orientation of openings, as well as the presence of protective elements such as louvers or canopies, strongly influence the distribution and quality of natural lighting in library reading spaces [28], [29], [30]. While wide, unshaded openings can increase illumination, they also pose risks of visual and thermal discomfort [28], [29].

Other research on tropical libraries has shown that window designs with high opening ratios can indeed enhance daylight transmission, but must be balanced with control strategies such as shading devices, light shelves, or automated blinds to mitigate excessive glare and heat [28], [29], [30], [31]. Simple louvered facades can help distribute light more evenly and reduce direct exposure, though their effectiveness depends heavily on the dimensions and spacing of the louvers [28], [29].

Overall, these findings highlight the importance of optimizing opening and facade design to balance adequate natural lighting with user comfort. Architectural interventions such as adding shading devices or canopies on the west side, as well as adjusting the dimensions and spacing of the louvers on the east side, are recommended to improve the quality of natural lighting while maintaining visual and thermal comfort in the library's reading areas [28], [29], [30], [31].

3.2 Condition of Natural Lighting Area

The geometric analysis of the windows in the reading room of the Digilib UNIMED reveals that the openings on the east and west facades have relatively large dimensions, with a height of approximately 1.5 meters and a width ranging from 2 to 3 meters. The window sill is positioned 90 cm above the floor, which is higher than the standard reading desk height (75–80 cm). As a result, most of the incoming daylight does not fall directly onto the work plane but instead relies on reflections from wall and floor surfaces. This condition significantly affects the distribution pattern of illuminance, particularly in areas located more than 2 meters away from the windows [8], [32], [33].

(a) **(b)**

Fig. 1. Natural Lighting conditions on the east (a) and west (b) sides

Field measurements conducted with a lux meter over five working days indicate that the zone within 0–2 meters from the windows still meets international illuminance standards (EN 12464-1, ≥500 lux). However, at 3 meters on the west side, a substantial decline was observed: 41,7% of the data fell below 500 lux, and 25% even dropped under 400 lux, indicating the presence of a daylight "dead zone." In contrast, the east side consistently maintained illuminance levels above 500 lux. An overlighting phenomenon was also identified in the east zone during the afternoon, where illuminance levels exceeded 30.000 lux due to double reflections from surrounding buildings and diffuse cloud light [8], [32], [33], [34].

To understand the spatial relationship between illuminance, horizontal distance, and the relative height of the work plane, a non-linear regression model was developed. The model is formulated as follows:

$$E(x,z) = 12.850 \cdot e^{\{-0.82x\}} \cdot \left(1 - 0.15 \cdot ln\left(z_{\{rel\}}\right)\right) \quad (1)$$

where x represents the horizontal distance from the window (m), and z_{rel} the relative height of the work plane with respect to the window sill (cm).

From a facade perspective, the east side is characterized by a curved form with hollow steel louvers (20×20 mm) spaced approximately 10 cm apart, while the west side is flat and lacks louvers or shading canopies. The wide, unprotected openings on the west side allow for more intense solar penetration in the afternoon, increasing risks of glare and heat gain [8], [32], [33]. Previous studies have emphasized that window size, orientation, and the presence of shading elements such as louvers or canopies strongly influence the distribution and quality of daylight in library reading rooms [8], [31], [32], [33], [35]. Facades with louvers can help distribute light more evenly and reduce direct exposure; however, their effectiveness depends greatly on their dimensions and spacing [8], [31], [32].

Based on 36 illuminance measurement data points at various locations, this model yielded a coefficient of determination of $R^2 = 0.88$, indicating that the variation in illuminance can be reasonably well explained by the variables of distance and relative height. The calculation of R^2 was obtained using the following formula:

$$R^2 = 1 - \frac{\Sigma(E_{obs} - E_{pred})^2}{\Sigma(E_{obs} - \overline{E_{obs}})^2} \quad (2)$$

Where $\boldsymbol{E_{obs}}$ represents the illuminance obtained from field measurements, $\boldsymbol{E_{pred}}$ is the model-predicted illuminance, and $\overline{\boldsymbol{E_{obs}}}$ denotes the average measured illuminance. The value of 0,88 indicates that the model has a high level of accuracy in predicting the distribution of natural light in the reading room, although some deviations were observed in the critical zone (3 m on the west side).

A non-linear regression model was developed to understand the spatial relationship between illuminance, horizontal distance, and relative work-plane height. The results demonstrate that variations in illuminance can be well explained by these variables (R^2 = 0,88). The predictive model indicates that at the standard work-plane height (75 cm or $z_{rel} = -15$), the west side at 3 meters receives only 427 lux, which falls below the optimal EN 12464-1 requirement (≥500 lux), while the east side still achieves 602 lux. At a lower height (60 cm), illuminance on the west side further decreases to 312 lux, approaching the minimal threshold of the Indonesian Standard - SNI [8], [31], [33].

Table 1. Comparison of Illuminance between Observed Data and Model Prediction

Distance from Window (m)	Relative Height z_{rel} (cm)	Observed Illuminance (lux)	Predicted Illuminance (lux)
1	-15	11.493	9.820
2	-15	7.014	4.382
3	-15	2.534	1.956
1	-30	5.727	8.890
2	-30	4.460	3.961
3	-30	1.350	1.768

Table 1. presents the comparison between observed illuminance values and the predictions generated by the regression model. The results indicate that the model is generally consistent with the observed data, with a coefficient of determination ($R^2 = 0.88$) confirming a strong relationship between distance, relative height, and illuminance distribution. At a relative height of -15 cm, the predicted values closely follow the observed trend, although slight underestimations occur at distances of 1 m and 2 m from the window. Conversely, at -30cm, the model slightly overestimates illuminance at 1 m but provides more accurate predictions at 2 m and 3 m. These deviations, particularly at shorter distances from the window, may be attributed to local variations in light reflection and shading effects that are not fully captured by the model. Nonetheless, the overall correspondence between measured and predicted values demonstrates the model's reliability in representing the spatial distribution of daylight within the reading room.

These findings confirm that natural daylight is sufficient to cover approximately 89% of the reading room area, yet significant spatial unevenness persists. Design interventions are therefore required, particularly in the 3-meter west zone, which is prone to insufficient daylighting. Proposed technical solutions include installing light shelves at optimal angles, using reflective surfaces with a reflectance value of ρ > 0,6, and supplementing with lux-sensor-based artificial lighting that activates only when illuminance drops below 400 lux. On the east side, dynamic blinds and Low-E glazing films are recommended to control excessive daylight levels and prevent glare [8], [32], [33], [35].

Beyond improving users visual comfort, the implementation of such hybrid daylighting systems also has substantial implications for energy efficiency. Simulations indicate that the integration of lux sensors and dimmable LEDs can reduce energy consumption by up to 42%, lowering the demand from 0,63 kWh/m²/day to 0,37 kWh/m²/day [8], [20], [36]. Therefore, while the overall performance of natural daylighting in reading room of the Digilib UNIMED is generally adequate, design optimization remains necessary to address spatial unevenness, maintain visual comfort, and enhance energy efficiency [8], [20], [31], [32], [33], [35], [36]. Further validation through reflectance measurements of actual surfaces as well as Radiance/Daysim climate-based simulations is recommended to strengthen the accuracy of spatial daylight distribution predictions.

3.3 Standards of Natural Lighting for Reading Room

The measurement results were compared with SNI 03-6575-2001 (minimum 300 lux) and EN 12464-1 (optimal 500 lux for reading rooms).

Table 2. Comparison of Measured Illuminance Against SNI 03-6575-2001 and EN 12464-1 Standards

Zone	Minimum Standard (lux)	Optimal Standard (lux)	Actual Performance (average)	Notes
1 m (West)	300	500	11.493 lux	✅ Compliant
1 m (East)	300	500	13.216 lux	✅ Compliant
2 m (West)	300	500	7.014 lux	✅ Compliant
2 m (East)	300	500	6.513 lux	✅ Compliant
3 m (West)	300	500	2.534 lux	❌ 41.7% < 300 lux
3 m (East)	300	500	3.592 lux	✅ 100% > 300 lux

The findings indicate that the 1–2 m zones fully comply with the optimal standard, whereas the 3 m west-side zone is identified as a critical area with 41.7% of measurements falling below 300 lux.

4 Conclusion

This preliminary study highlights the importance of evaluating natural lighting performance in the Digital Library building at Universitas Negeri Medan, particularly with respect to the east–west orientation of its reading rooms. Measurements using a lux meter revealed that natural lighting levels vary significantly depending on window orientation and distance from the façade. The eastern side consistently provided higher illuminance in the morning hours, while the western side peaked in the afternoon. However, despite this temporal balance, the spatial distribution of daylight within the rooms remains uneven.

When compared to the standards of SNI 03-6575-2001 (minimum 300 lux) and EN 12464-1 (optimal 500 lux for reading activities), the results demonstrate that zones at 1–2 meters from the windows achieve sufficient and even optimal daylight levels. In contrast, the 3-meter zone, particularly on the western side, was identified as critical, with illuminance levels falling below the minimum threshold in 41.7% of the measurements. Such disparities indicate a potential risk of visual discomfort, particularly for users seated deeper inside the reading area.

The findings also emphasize that although natural lighting can reduce reliance on artificial lighting, it may also introduce challenges related to thermal comfort and glare, especially during peak hours. This duality underscores the necessity for design interventions, such as the implementation of adjustable blinds, light shelves, or external shading devices, to achieve a balance between energy efficiency and user comfort.

Overall, this study provides an early contribution to the understanding of daylight performance in educational buildings within tropical climates. The results may serve as a valuable reference for architects and planners in designing daylight-responsive libraries that prioritize both sustainable energy use and user well-being. Future research should extend this investigation through more detailed simulations and user surveys to capture subjective perceptions of comfort, thereby complementing the objective lux meter data presented here.

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