BESt: Journal of Built Environment Studies
P-ISSN: 2746-9077 E-ISSN: 2746-9069
Journal Home Page: https://journal.ugm.ac.id/v3/BEST

BETTER SPACE BETTER LIVING

BUILDING INFORMATION MODELING (BIM) APPLIED TO DAYLIGHT SIMULATION & ANALYSIS: COMPARISON OF SHADING DEVICE

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ABSTRACT

Improving environmental quality in architectural design is crucial in energy efficiency, health, and comfort, directly impacting occupant productivity. In tropical regions, high exposure to solar radiation significantly contributes to increased energy consumption in the building sector, accounting for 36% of total global energy usage. Shading devices are employed as a passive strategy to minimize solar heat gain, maintain thermal comfort, and evenly distribute natural light, reducing reliance on artificial lighting. This study analyzes the impact of different louver types on daylight optimization in shading devices, designed with the same module across various scenarios (louvers at ∠90°, ∠45°, and ∠150°). The research methodology involves computational simulations based on BIM, using Autodesk Revit for prototype modeling, parameter determination, scenario setup, and the Insight Plugin for simulating daylight illuminance (lux) and daylight factor (DF). The results show that the shading device with a 90° louver angle performs optimally in meeting the daylight illuminance standard (300–3000 lux) across various representative dates, achieving a daylight factor (DF) of 3.2%, in line with global standards. The louver angle significantly influences the overall distribution of natural light. This study's limitation is its focus on a single location (Surabaya) and its restriction to three shading device scenarios.

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Keywords:
Daylight Illuminance, Daylight Factor (DF), Natural Lighting

1. Introduction

Environmental quality is crucial in architectural planning as it contributes to energy efficiency and creates spaces that significantly impact well-being and comfort, ultimately enhancing occupant productivity. Several factors must be considered to maintain good environmental quality in design, including climate, context, building massing, orientation, materials, services, and vegetation. In each region, climatic factors such as air temperature, humidity levels, rainfall intensity, irradiation, illuminance, and cloud cover vary due to the influence of geographical location (Koenigsberger et al., 2013 in Dev & Saifudeen, 2023). In tropical regions, solar radiation exposure tends to be high, increasing energy consumption. In the construction sector, buildings account for 36% of global energy consumption. If this trend continues without measures to reduce energy consumption, the percentage could reach 50% by 2050 (according to projections from the International Energy Agency) (Koc & Kalfa, 2021).

Although it generates solar radiation, leading to increased energy consumption, natural lighting is an essential factor influencing indoor environments' physical and psychological aspects (Michelon et al., 2024). It offers multidimensional benefits that have been extensively studied in various literatures (Zuhri et al., 2021). The quality of natural lighting directly impacts a building's performance (Al-Rudainy & Mahjoob, 2024). Integrating visual connection with natural elements and the balance in natural lighting (both quantity and quality) are essential indicators in optimizing daylight. It also emphasizes aspects such as even light distribution, glare reduction, and controlling light intensity for occupant comfort (Michelon et al., 2024).

Based on the issue, a design strategy is needed to reduce excess heat while optimizing natural lighting. Implementing passive design strategies with an exterior shading device system is recognized as an effective and efficient approach compared to interior shading devices, as it can control heat gain and glare outside the building and reduce the building's energy consumption for artificial lighting (ultimately saving operational costs), especially in tropical climates (Zuhri et al., 2021).

Determining the optimal design parameters for shading devices and natural lighting factors is crucial. Simulation methods have proven highly effective in addressing challenges associated with shading devices. Using simulation tools enables an in-depth exploration of complex interactions among various design aspects, such as design characteristics, incorporating climate factors, and analyzing daylighting.

Although extensive research exists on shading devices, studies specifically examining the impact of louver types on daylight optimization in tropical buildings remain limited. This study addresses this gap by analyzing their effects and offering efficient design guidelines.

2. Literature Review

The shading device, an integral part of the building's facade, is designed to control the heat inside the room caused by high levels of natural light intensity, while also helping to reduce the overall energy consumption of the building system (Heidari et al., 2021). As the primary natural light source, sunlight provides significant light and heat energy. Natural lighting through openings such as windows can improve light distribution uniformity and provide high illuminance. However, without proper control, excessive light entry can lead to glare that disrupts user comfort.

The study by Lee et al. (2022) emphasizes the importance of using climate modeling, simulation methods, and measurable metrics to evaluate natural lighting in buildings. This highlights the need for further research to optimize the potential benefits of natural lighting (Lee et al., 2022, in Michelon et al., 2024).

Meanwhile, another study by Rastegari et al (2023) emphasizes the critical role of reflectance distribution and geometry in enhancing natural lighting, influencing occupant comfort, and building energy efficiency. Natural illumination can be maximized by utilizing the reflectance of building surfaces, such as walls, and reducing dependence on artificial lighting. Additionally, this research develops an occupant well-being index that demonstrates the impact of natural lighting on occupants' physical and psychological health (Rastegari et al., 2023).

The effectiveness of natural lighting can be measured using two primary methods. (1) The intensity of light outside is measured through illuminance levels, and the total lumen falling on surfaces inside the space is calculated. (2) By using the average daylight factor (the result of the ratio between the light level inside the building and the light level outside, which is influenced by clear sky conditions), this comparison remains constant under all conditions (Handika & Utami, 2023). Therefore, integrating an effective shading system with natural lighting analysis can create energy-efficient and comfortable spaces for occupants. To assess the optimization of daylight illuminance in spaces influenced by shading devices, it is essential to use metrics that define boundaries for daylight illumination.

The study by Li et al. (2023) highlights the importance of using Climate-based Daylight Metrics (CBDM) to assess natural lighting performance in building design, while emphasizing the challenges in CBDM calculations that require complex simulations (Li et al., 2023). In general, the application of metrics such as Daylight Autonomy (DA), Useful Daylight Illuminance (UDI), and annual daylight factor, which fall under the scope of climate-based daylight metrics (CBDM), plays a role in exploring more accurate and efficient methodologies for creating optimal natural lighting designs (Li et al., 2023).

No comprehensive study exists regarding ideal illuminance values for tropical regions like Indonesia. The illuminance levels recommended in Indonesian National Standards (SNI), such as SNI 03-6197 (2000), SNI 6197 (2011), and SNI 6197 (2020) for various functional spaces range from 100-750 Lux, which represents the minimum average standard for artificial lighting. Meanwhile, in SNI 03-2396 (2001), which addresses natural lighting design methods for buildings, there is no specification regarding daylight illuminance standards. As a result, this study utilizes the UDI (Useful Daylight Illuminance) metric. UDI is a metric to determine the lower and upper limits of insufficient lighting conditions. The lower limit (UDI <100 Lux, inadequate), (100-2000 Lux, sufficient), and (UDI >2000 Lux, excessive light). The adequate light range has since been updated to 100-3000 Lux (Mardaljevic et al., 2012 in Atthaillah & Bintaro, 2019; Attahaillah et al., 2019; Lakhadari et al., 2021) (see table 1).

Table 1. The Boundaries of Illuminance in the UDI

Illuminance (Lux)	Category
<100	Insufficient lighting conditions
100-300	Lighting conditions that require additional artificial lighting
300-3000	Optimal natural lighting conditions without the need for additional artificial lighting
100-3000	Combining two categories of sufficient natural lighting
>3000	Indicating excessive lighting, which may lead to glare

Source: Mardaljevic et al (2012)

Table 2. Zones Based on the Daylight Factor

Zones	Category
Perimeter zone	DF > 5%, no artificial lighting required
Middle zone	DF 2% - 5%, artificial lighting partially supplements natural daylight
Inner zone	DF < 2%, requires permanent artificial lighting

Source: Sun et al (2018)

The Daylight Factor (DF) recommends a minimum value of 2% for office space buildings (this value is based on the British Standards, American IESNA Standards, and Chinese Standards for natural lighting design in buildings). Spaces are divided into three zones based on the daylight factor, as shown in Table 2 (Sun et al., 2018). Another study related to shading devices by Dev & Saifudeen (2023), explores dynamic facade systems (sliding type, rotating type, and folding type) and their impact on natural lighting, focusing on the calculation of azimuth, Horizontal Shadow Angle (HSA), and Vertical Shadow Angle (VSA) with a case study of an existing building in Kerala (Dev & Saifudeen, 2023). Meanwhile, the survey by Al-Masrani & Al-Obaidi identified the potential and limitations of dynamic shading systems in enhancing building performance through integrated design. This

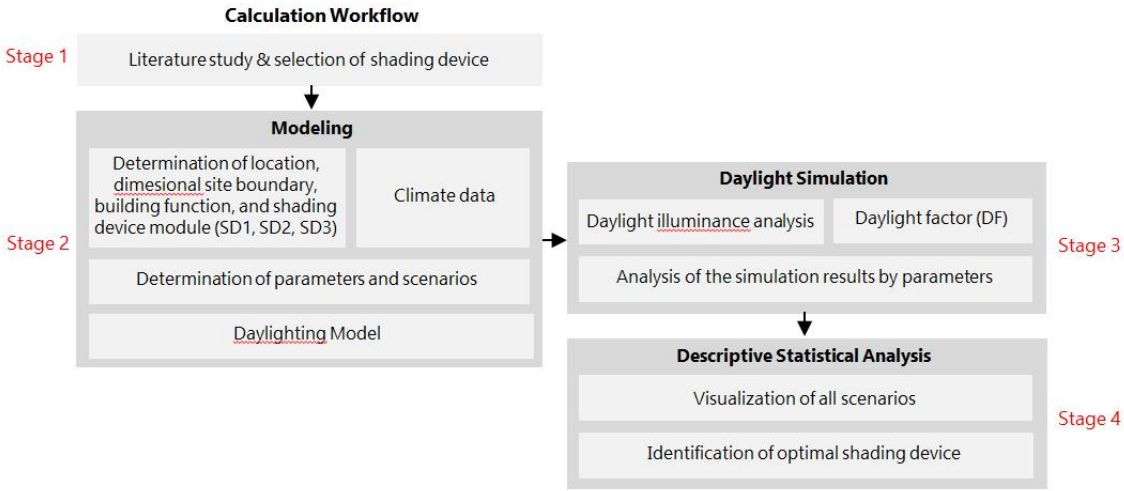


Figure 1. Methodology
Source: Author (2024)

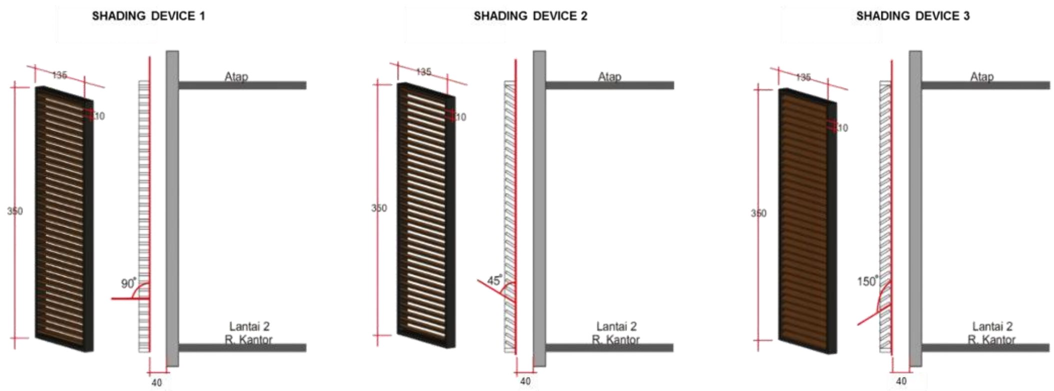


Figure 2. Shading Device Scenarios
Source: Author (2024)

involved analyzing design elements, evaluation strategies, and approaches based on geometry and performance in response to environmental parameters (Al-Masrani & Al-Obaidi, 2019).

Although previous research has extensively discussed shading devices and their relationship with building energy use and daylighting, studies examining the relationship between louver types in shading devices and daylight optimization are limited. Additionally, while various dynamic shading models have been explored, no study has comprehensively examined the impact of louver types in shading devices on illumination and daylight factor in depth. This gap presents an opportunity for further research to analyze the effects of louver types in shading devices on natural lighting and provide more efficient design guidelines for tropical buildings.

3. Research Method

3.1 Methodology

Our research method is simulation-based, aiming to present empirical field data that reflects real-world conditions in a comprehensive manner, encompassing both location and events. Increasing the amount of input data for a simulation enhances its level of accuracy. The workflow for this research methodology comprises four stages, as illustrated in Figure 1. Stage 1 - The preliminary study begins with a literature review and the selection of shading device types. Stage 2 - involves determining the location, site boundary dimensions, building function, and shading device module. All modeling is performed using Autodesk Revit software alongside the process of collecting climate data. Climate data is verified using Climate Consultant software, utilizing EPW files from the nearest location to represent regional climate conditions accurately. Once the modeling and climate data are obtained, parameters and scenarios will be established to support the simulation. Stage 3 - involves simulating natural daylight, including (1) daylight illuminance (lux) and (2) daylight factor (%) using Autodesk Revit, specifically with the Autodesk Insight plugin based on Building Information Modeling (BIM). Once all simulation results are obtained, a thorough analysis is conducted. Stage 4 involves visualizing and analyzing all scenarios to determine the most effective shading device module in improving indoor daylight performance.

This study has research limitations. The location focuses solely on the meteorological conditions of Surabaya, so the results may not apply to regions with different climates. The shading device design variations are limited to three louver-type scenarios with the same module. Additionally, the study does not account for external factors or non-visual aspects such as thermal comfort or user perception.

3.2 Research Parameters & Scenarios

The building prototype simulated in this study is located in Surabaya, in a tropical climate zone with two seasons (dry and rainy). Based on climate data accessed from the building simulation data repository using the EPW file format input into Climate Consultant software, the overheating occurs between 8:00 AM and 3:00 PM, when the temperature exceeds 27°C throughout the annual cycle. The shading device is an independent variable, with the louver type divided into three scenarios (angles of 90°, 45°, and 150°) (see Figure 2). As a control, the shading device is designed with the exact module dimensions, measuring 1,35 m x 3,50 m, consisting of 8 panels (total area: 37,8 m²). This study analyzes the impact of the shading device (3 scenarios) on indoor daylight illuminance and daylight factor.

The test room has an area of 75 m², with four (4) types of window dimensions: W1 with three window panels measuring 1,5m x 1,2m (total area 1,80 m²), W2 with one window panels measuring 0,6m x 1,82m (total area 1,09 m²), and W3 with three window panels measuring 1,5m x 2,5m (total area 3,75 m²), W4 with one window panels measuring 1,14m x 2,75m (total area 3,13 m²) (see Figure 3). The window glass specifications include a thickness of 4 mm, a Visible Light Transmittance (VLT) of 70%, and an RGB value of 160 (Wintour, 2023). Meanwhile, other simulation properties include wall material reflectance set at 51%, with an RGB value of 130. The daylight illuminance simulation (levels) was conducted in a room with a work plane height of 30 inches (76.2 cm) above the floor. The illuminance settings, set between 300 and 3000 lux, comply with UDI limits, which define this range as representing optimal lighting conditions (Lakhadari et al., 2021). Indoor daylight illuminance is then simulated at specific time intervals over several hours on selected dates, including when the sun is at its northernmost position (June 21), aligned with the equator (September 23), and at its southernmost position (December 22). Simultaneously, daylight factor is also simulated at the same time intervals on the selected dates and times.

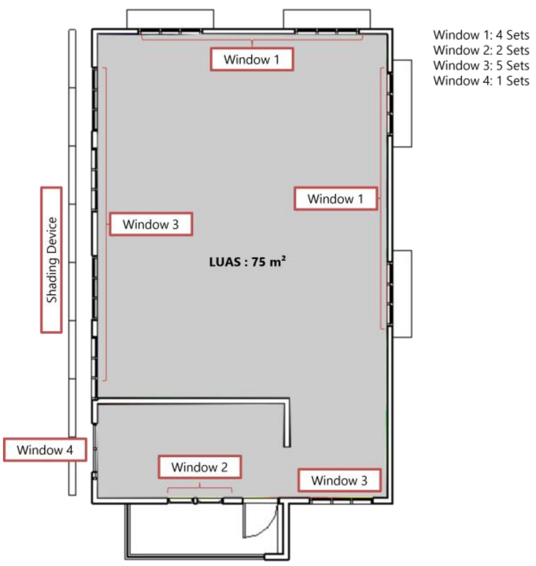


Figure 3. Simulation Test Room Layout (2ND Floor)
Source: Author (2024)

Table 3. Simulation Parameters

Parameters	Values
Louvre angle	SD1: ∠90° ; SD2: ∠45° ; SD3: ∠150°
Shading device dimensions	W: 1,35 m x H: 3,50 m (1 module)
Distance of SD from the outer wall	40 cm
Test room area	75 m²
Building function	Office, test room on the 2nd floor
Window dimensions 1	W: 1,5 m x H: 1,2 m (1,80 m²)
Window dimensions 2	W: 0,6 m x H: 1,82 m (1,09 m²)
Window dimensions 3	W: 1,5 m x H: 2,5 m (3,75 m²)
Window dimensions 3	W: 1,14 m x H: 2,75 m (3,13 m²)
Glass specifications	T: 4mm VLT : 70% ; RGB: 160
Wall material reflectance	51% ; RGB 130
Work plan level	30 inches (76,2 cm)
Illuminance setting	300-3000 lux (UDI standard)
Distance between louvers	10 cm

Source: Author (2024)

Abbrevations

DF	Daylight Factor
SD	shading device
UDI	Useful Daylight Illuminance
TVT	Visible Light Transmittance
DA	Daylight Autonomy

4. Results and Discussions

4.1 Daylight Illuminance Results

In the simulation study, shading devices with three (3) types of louvers were modeled using Autodesk Revit. In each scenario, the center-to-center distance between the louver panels is 10 cm. Figures 4-6 show the percentage of floor area that meets the UDI standard (300-3000 lux) for daylight illuminance simulation under various shading device scenarios based on representative dates (sun positions).

The simulation results comparing daylight illuminance when the sun is at its northernmost position (June 21) show that when shading device SD1 (90° louver angle) shades the building, 79% of the working area has an ideal daylight illuminance (300-3000 lux) at 08:00 AM, 94% of the working area at 12:00 PM, and 97% of the working area at 03:00 PM. When the shading device SD2 (45° louver angle) shades the building, 70% of the work area has ideal daylight illuminance (300-3000 lux) at 08:00 AM, 88% of the work area at 12:00 PM, and 79% of the work area at 03:00 PM. Meanwhile, when shading device SD3 (150° louver angle) shades the building, 66% of the work area has ideal daylight illuminance (300-3000 lux) at 08:00 AM, 84% of the work area at 12:00 PM, and 96% of the work area at 03:00 PM (see Figure 4).

The comparison of daylight illuminance when the sun is aligned with the equator (September 23) shows that when shading device SD1 (90° louver angle) shades the building 90% of the working area has an ideal daylight illuminance (300-3000 lux) at 08:00 AM, 96% of the working area at 12:00 PM, and 100% of the working area at 03:00 PM. When the shading device SD2 (45° louver angle) shades the building, 91% of the work area has ideal daylight illuminance (300-3000 lux) at 08:00 AM, 96% of the work area at 12:00 PM, and 74% of the work area at 03:00 PM. Meanwhile, when shading device SD3 (150° louver angle) shades the building, 89% of the work area has ideal daylight illuminance (300-3000 lux) at 08:00 AM, 95% of the work area at 12:00 PM, and 100% of the work area at 03:00 PM (see Figure 5).

The comparison of daylight illuminance on the last representative date, when the sun is at its southernmost position (December 22), shows that when the shading device SD1 (louver angle of 90°) shades the building: 90% of the work area has ideal natural lighting (300-3000 lux) at 8:00 AM, 96% of the work area at 12:00 PM, and 99% of the work area at 3:00 PM. When the shading device SD2 (louver angle of 45°) shades the building, 89% of the work area has ideal natural lighting (300-3000 lux) at 8:00 AM, 96% of the work area at 12:00 PM, and 78% of the work area at 3:00 PM. Meanwhile, when the shading device SD3 (louver angle of 150°) shades the building, 88% of the work area has ideal natural lighting (300-3000 lux) at 8:00 AM, 96% of the work area at noon and achieved 98% in the work area at 3:00 PM (refer to Figure 6).

Compared to all representative dates (June 21, September 23, and December 22), the most optimal shading device scenario is SD1 (∠90°) in the daylight illuminance analysis. This scenario demonstrates excellent performance in meeting the ideal natural daylight illuminance standard (300-3000 lux) throughout the day, with a very high percentage of the work area covered.

SD2 (∠45°) performs slightly lower than SD1 and SD3 at 03:00 PM under all conditions. However, it still demonstrates reasonably good efficiency at other times. SD3 (∠150°) generally provides slightly lower natural lighting performance than SD1 and SD2 at 08:00 AM and 12:00 PM, but performs well at 03:00 PM.

The study by Dev & Saifudeen (2023) shows that the foldable dynamic façade system is the most optimal scenario compared to the other two systems (sliding and rotating types) when considering daylight illuminance and daylight factor values on representative dates and times (summer solstice: June 21; autumnal equinox: September 23; and winter solstice: December 21). The daylight illuminance value uses a threshold of > 500 lux (according to the National Lighting Code of India). Using the Autodesk Insight plugin on Autodesk Revit, the study analyzes daylight illuminance values below 500 lux to identify the optimal scenario (Dev & Saifudeen, 2023).

Another study by Akimov et al. (2023) demonstrates that dynamic facades designed with specific geometries (vertically placed louvers with in-plane movement and rotation), as seen in case study 3, significantly enhance natural lighting performance in indoor spaces compared to case study 1 (shading with equilateral triangular unit geometry; vertical and horizontal shading devices) and case study 2 (shading with proper triangular unit geometry; vertical and horizontal shading devices).

The daylight performance results, obtained using Rhino 3D software with various additional plugins and DAYSIM, show that case study 3 yields the highest performance percentages: 85% at a 25% degree of opening, 85% at a 50% degree of opening, and 97% at a 75% degree of opening (based on the UDI threshold standard of 100 lux to 2000 lux). Furthermore, after performing shape-finding on the design, the study revealed a 43% improvement in natural lighting performance compared to the initial façade design (Akimov et al., 2023). Overall, variations in the angles and configurations of shading devices significantly impact natural lighting performance in indoor spaces. These variations enhance light distribution, illuminance efficiency, and compliance with lighting standards under different times and conditions. Furthermore, using a parametric approach, simulation-based analysis proves valuable in assessing and selecting the most optimal device scenarios.

4.2 Daylight Factor Results

The study's Daylight Factor (DF) uses the middle zone category (DF 2%-5%) by global standards. The simulation results show that all three shading device scenarios (SD1, SD2, and SD3) meet the ideal natural lighting criteria for office spaces. However, SD2 (∠45º) demonstrates the highest DF value of 3,4%, indicating the best potential for providing optimal natural daylight distribution. SD1 (∠90º), with a DF value of 3,2%, remains a consistent and efficient choice. Meanwhile, SD3 (∠150º), with a DF value of 2,9%, although meeting the standard, shows lower performance than SD1 and SD2 (see Figure 7).

In the study by Dev & Saifudeen (2023), a DF threshold of >1,9% is used. The results show percentages below this standard for the dynamic facade systems: sliding type at 0,25%, rotating type at 1,29%, and folding type at 0,2%. Therefore, the folding type dynamic facade system is the optimal scenario, in line with the daylight illuminance percentage values (Dev & Saifudeen, 2023).

Abbrevations

DF	Daylight Factor
sDA	Spatial Daylight Autonomy
SHGC	Solar Heat Gain Coefficient

Sepulveda et al. (2020) conducted a separate study that indicated that the sDA criteria are more stringent. Then, DFmean, while DFmin imposes stricter requirements for residential and office spaces than DFmean, these three parameters were analyzed to identify the optimal criteria for evaluating natural lighting. The study also highlighted that optimal room design requires a combination of lighting and ventilation strategies, with adjustments based on orientation, shading dimensions, and the glass's g-value/SHGC to balance natural lighting with thermal comfort (Sepulveda et al., 2020). Overall, the appropriate combination of shading design (Rana et al, 2021), natural lighting performance evaluation using DF and sDA criteria (Allam et al, 2022), and other factors such as room orientation and openings (Eisazadeh et al, 2024) are crucial for optimal natural lighting and thermal comfort. These findings are essential to be considered in the decision-making process of architectural design (Landgren et al, 2019; Tastemir et al, 2024), especially for achieving the optimal design alternative, such as the design of subsidized housing with its small spaces and limited construction budget characteristics (Abdurrahman et al, (2024).

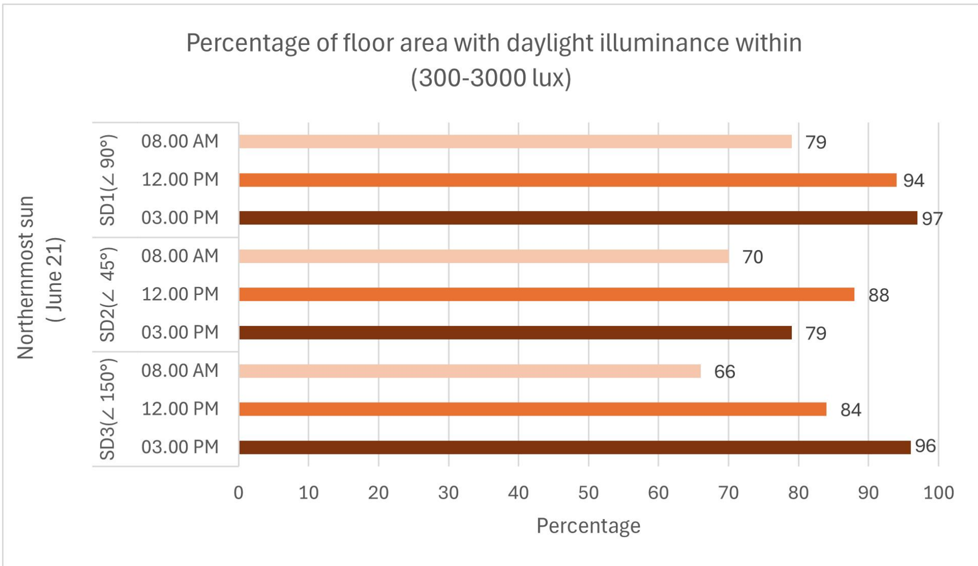


Figure 4. Percentage of Floor Area with Daylight llуminance within Threshold on June 21
Source: Author (2024)

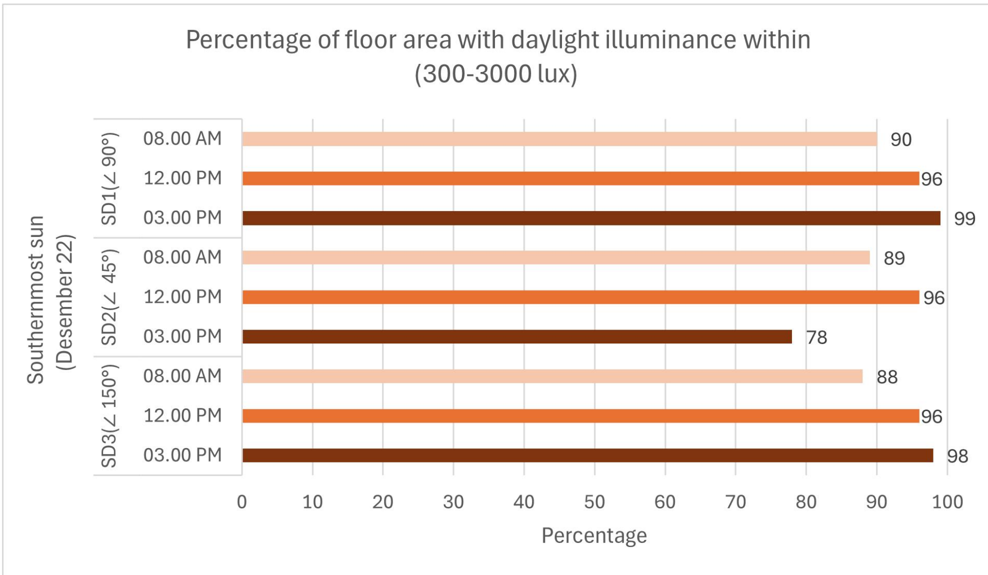


Figure 5. Percentage of Floor Area with Daylight llуminance within Threshold on September 23
Source: Author (2024)

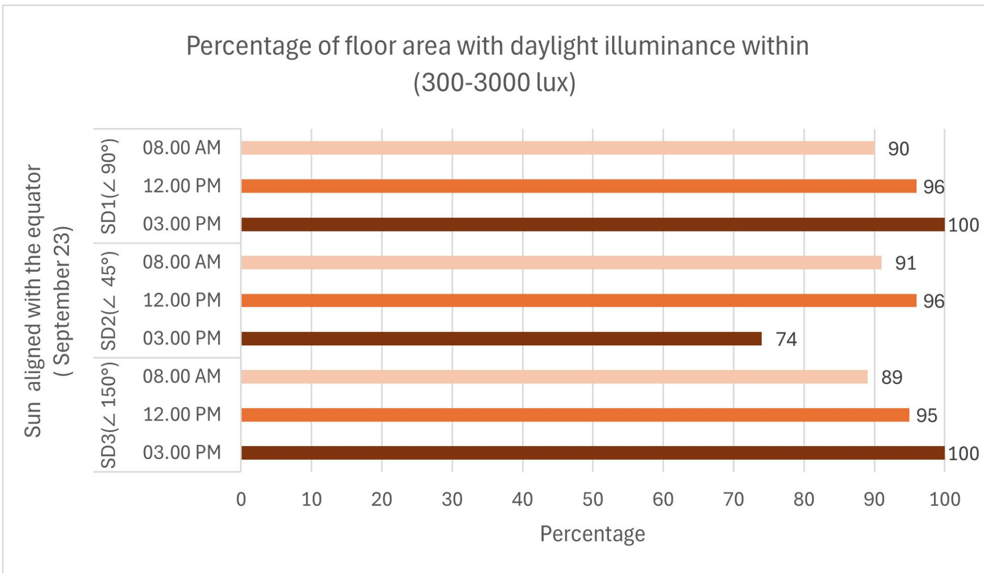
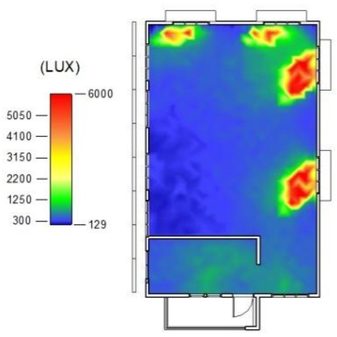


Figure 6. Percentage of Floor Area with Daylight Illuminance within Threshold on December 22
Source: Author (2024)

Table 4. Simulation Results of Daylight Illuminance on Northernmost Sun (June 21)

A



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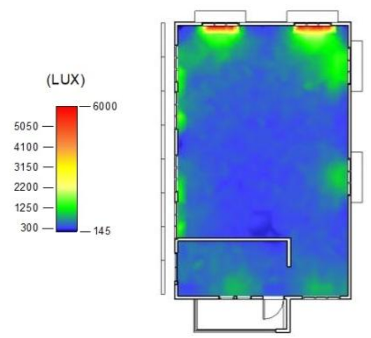

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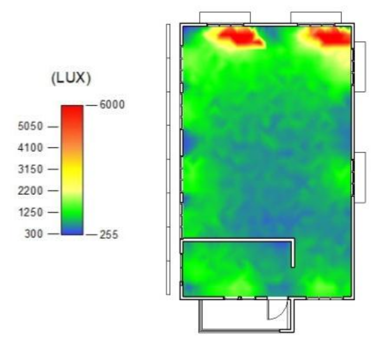
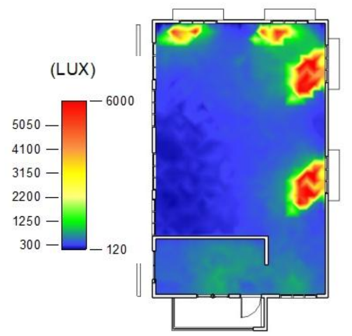
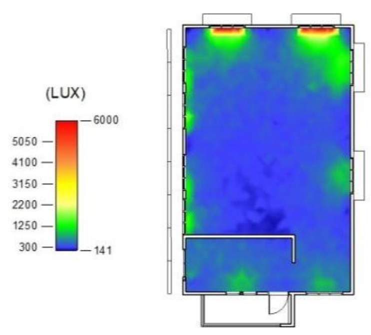
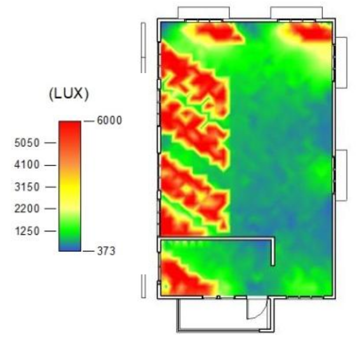


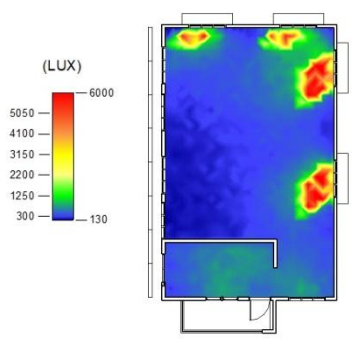
SD1 (∠90°); Time : A-08.00 AM, B-12.00 PM, C-03.00 PM

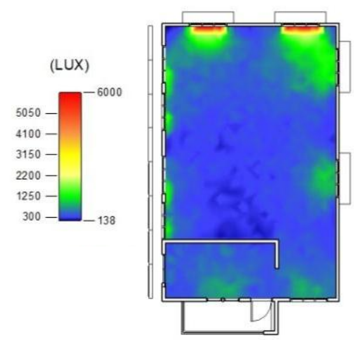


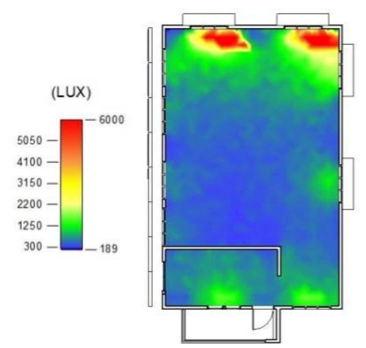




SD2 (∠45°); Time : A-08.00 AM, B-12.00 PM, C-03.00 PM







SD3 (∠150°); Time : A-08.00 AM, B-12.00 PM, C-03.00 PM

Source: Author (2024)

Table 5. Simulation Results of Daylight Illuminance on Sun Aligned with the Equator (September 23)

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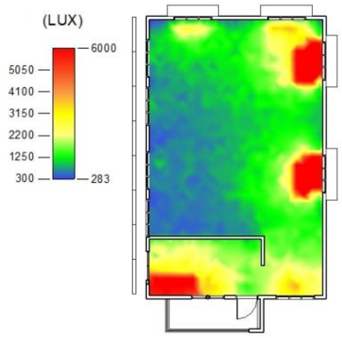

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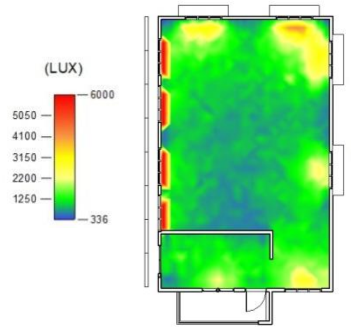

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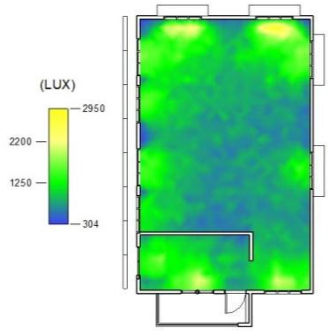
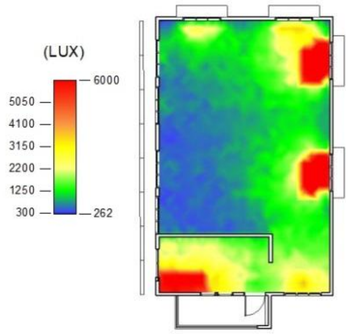
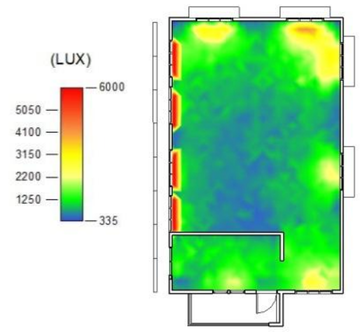
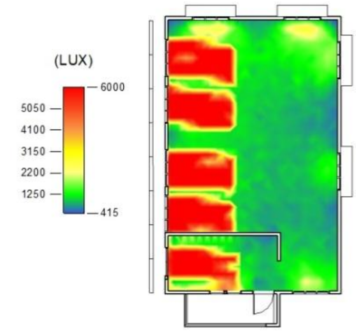


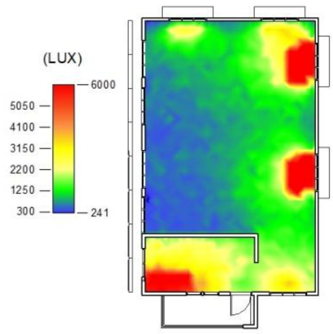
SD1 (∠90°); Time : A-08.00 AM, B-12.00 PM, C-03.00 PM

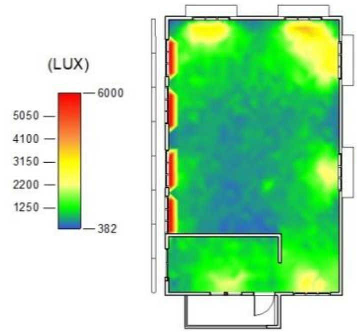


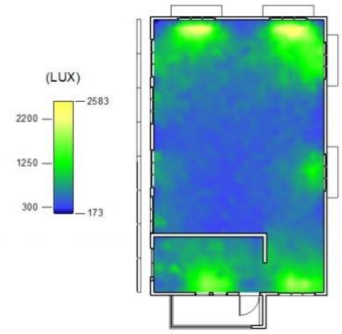




SD2 (∠45°); Time : A-08.00 AM, B-12.00 PM, C-03.00 PM





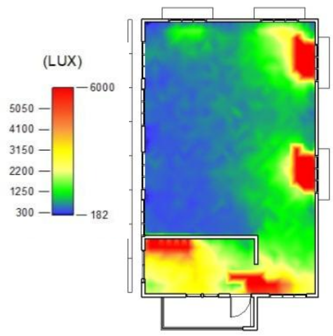


SD3 (∠150°); Time : A-08.00 AM, B-12.00 PM, C-03.00 PM

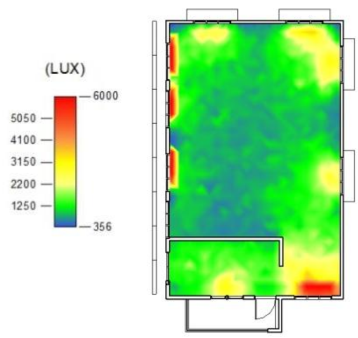
Source: Author (2024)

Table 6. Simulation Results of Daylight Illuminance on Southernmost Sun (December 22)

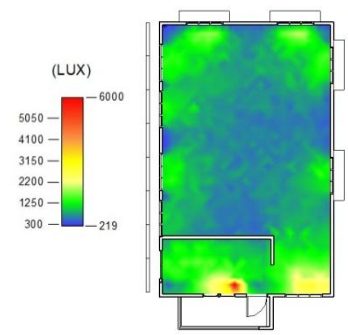
A



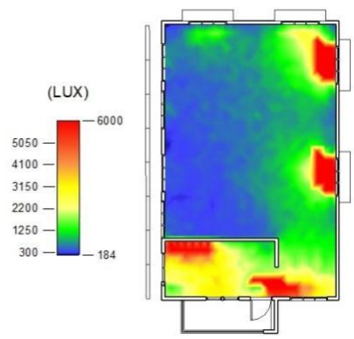
B

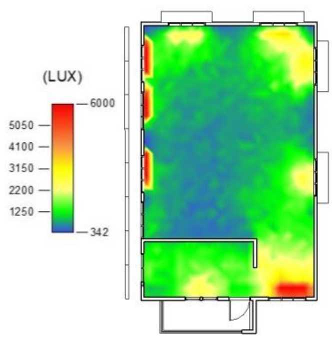


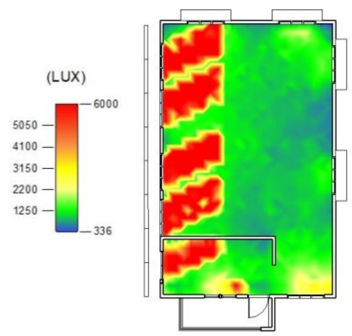
C



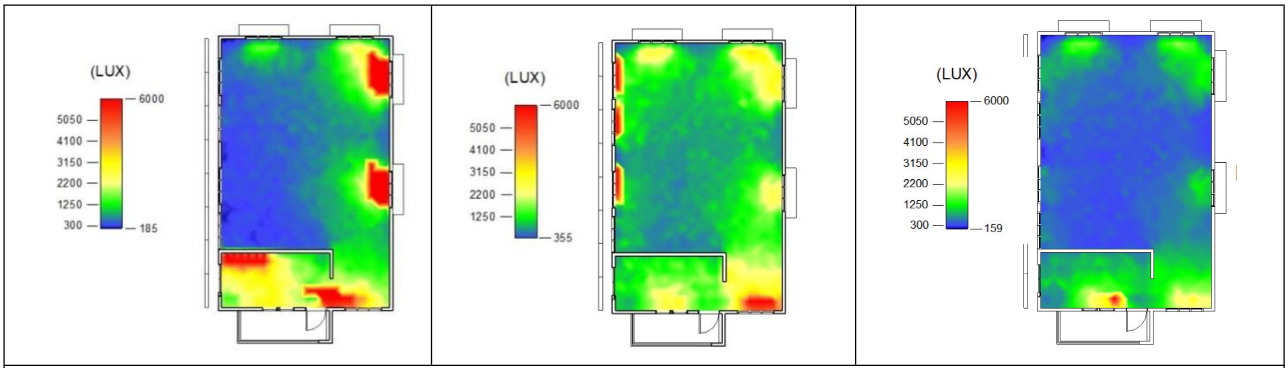
SD1 (∠90°); Time : A-08.00 AM, B-12.00 PM, C-03.00 PM







SD2 (∠45°); Time : A-08.00 AM, B-12.00 PM, C-03.00 PM



SD3 (∠150°); Time : A-08.00 AM, B-12.00 PM, C-03.00 PM

Source: Author (2024)

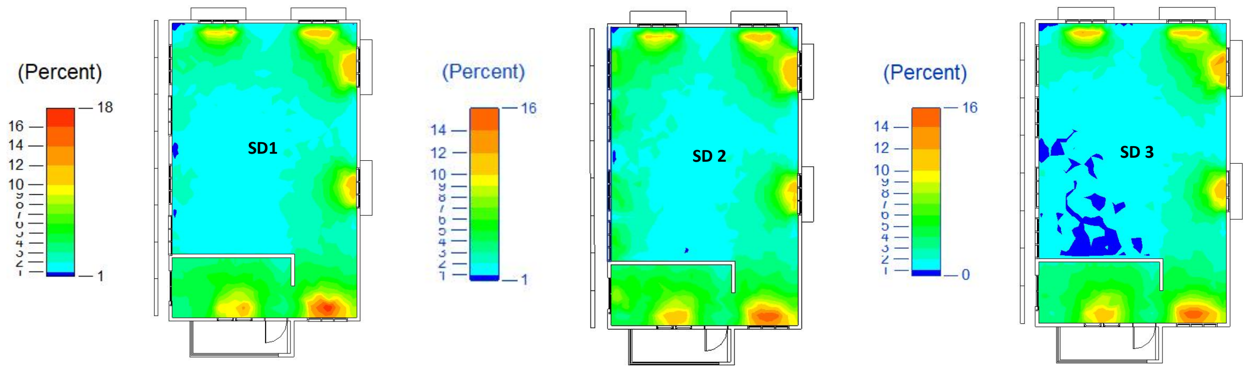


Figure 7. Simulation Results of Daylight Factor SD1(∠90º), SD2(∠45º), SD3(∠150º)
Source: Author (2024)

5. Conclusion

This study analyzes the impact of three types of louver angles (∠90°, ∠45°, and ∠150°) on shading devices on natural lighting performance in indoor spaces, focusing on daylight illuminance and daylight factor. This research aims to address the gap in understanding the relationship between shading device design and natural lighting optimization, while also providing insights for energy-efficient building element design.

The results show that the louver angle significantly affects the overall distribution of natural lighting. Shading device 1 (louver at ∠90°) consistently achieved the ideal illuminance range (300–3000 lux) at different times and across all representative dates. This is supported by a daylight factor (DF) value of 3.2%, which aligns with global standards for office spaces. While shading devices 2 (louver at ∠45°) and 3 (louver at ∠150°) also performed reasonably well, their effectiveness was less consistent throughout the day and across various representative dates. These findings highlight the importance of carefully designing shading devices and considering louver angles to optimize natural lighting.

Although making a significant contribution, this study has limitations. It focuses only on a single location (Surabaya, Indonesia) and is limited to three shading device scenarios. Future research could expand on these findings by exploring different climate regions, incorporating thermal comfort and user perception metrics, investigating other shading devices, or including additional variables (external factors). Such efforts would enhance the generalizability of the results and provide more comprehensive design guidance for optimizing natural lighting in tropical climates.

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