

Optimization of Louvre Façade for Thermal Comfort and Daylighting in Office Units in Surabaya

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Abstract

This study explores the optimization of louvre facade configurations for west-facing office units in Surabaya's tropical climate, focusing on enhancing thermal comfort and daylighting performance. Using generative design integrated with Rhinoceros, Grasshopper, Honeybee, and Ladybug, various louvre angles and spacing combinations were simulated and analyzed based on key metrics: Glare Autonomy (GA), Illuminance, and Thermal Comfort Percentage (TCP). Results show that configurations with steeper angles (45°–60°) and tighter spacing (0.4–0.5 m) significantly reduce glare and heat gain, but at the expense of daylight availability. Conversely, flatter angles (0°–30°) increase natural light but compromise comfort. A 45° angle with 0.5 m spacing offers the most repetitive configuration, being able to achieve an average illuminance of 173 lux at 10:00, an average of 95% thermal comfort percentage, an average illuminance of 251 lux at 14:00, and an average glare autonomy of 92.86%, while using a configuration of spacing between 0.25 - 0.40 m and angle of 0° - 25° is also an alternative to achieve a balanced performance. The study highlights the potential of data-driven generative design in creating adaptive, energy-efficient facades suitable for tropical urban settings.

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INTRODUCTION

Over the years, global warming and climate change have become urgent and critical issues that affect human life. On the other hand, the phenomena of urbanization and overpopulation are driving cities to grow vertically due to limited land availability, making high-rise building development a viable solution. This has also led to the vertical development of buildings, resulting in the emergence of buildings such as apartments and offices (Murbaintoro et al., 2009; Romli, 2024). However, while vertical buildings are considered an innovative solution, they also face new challenges in terms of thermal comfort and daylighting (Budiman & Anisa, 2023). With a very large building surface area and exposure to sunlight for almost the entire day, vertical buildings often experience excessive heat and lighting, which disrupts user comfort. This condition not only reduces the quality of living but also increases dependence on cooling and artificial lighting systems, ultimately resulting in high energy consumption.

Amidst the rapid urbanization of a city, quality of life tends to improve sharply, which indirectly provides a better means of opportunity for work. With limited space, traditional working space tends to grow vertically, creating office towers within a city. However, due to excessive heating and lighting, this disrupts the performance and productivity of the workers inside the building. Based on recent research, spaces that receive enough daylight and have thermal comfort can enhance the performance of building occupants (Marigo et al., 2023; Mebarki et al., 2021).

The application of sustainable design approaches has become a major trend in the architectural world, and high-rise buildings—while being among the biggest contributors to global warming—are also significant consumers of energy (Mba et al., 2024). Facade design is a crucial aspect in building design, especially in the context of energy efficiency and user comfort (Christianto & Damayanti, 2021). The facade not only functions as a physical barrier between the external and internal environments but also plays an active role in regulating thermal energy flow and the distribution of natural light into the space. Therefore, design decisions made for facade elements will directly impact the building's thermal performance as well as the quality of natural lighting experienced by occupants.

Louvres have become a facade that is commonly used on a building, as it also serves as a shading device for the building (Eltaweel, 2019). Louvres has also been proven to be a very high-performance facade system that drastically reduces thermal influences, whilst being able to control daylighting within a room in a significant manner (Meitadevi et al., 2025; Misawa et al., 2016). However, creating louvers requires precise design planning, as although it may improve thermal comfort within the building, however reduce the daylighting within the building and the view of the user within. Therefore, designing louvers optimally will sharply improve the performance of the user while reducing the energy consumption of the building (Marigo et al., 2023).

Recent facade research has highlighted the strategic importance of vertical louvres, particularly for buildings with east- or west-facing openings, where sunlight arrives at a low angle during morning and afternoon hours. Horizontal louvres—although effective for high-angle sun on north or south facades—perform poorly in blocking low-angle radiation typical of tropical east–west orientations. According to the *Facade Tectonics Institute* (Fordham, 2018), vertical louvres are significantly more effective at intercepting low-angle sunlight for east- and west-facing facades, reducing direct glare and heat gain while still allowing controlled daylighting. This advantage becomes even more relevant in tropical climates, where intense low-angle solar radiation in the late afternoon can cause severe overheating, particularly in west-facing office units such as those commonly found in Surabaya. Given that this research focuses on a west-oriented office unit, vertical louvres provide the most context-appropriate shading strategy. Their orientation aligns with the direction of incoming solar rays, enabling them to block excessive heat and glare without excessively reducing daylight. This makes them an ideal subject for performance testing and optimization in tropical high-rise building design.

The strength of this approach lies in its ability to integrate performance simulations—such as thermal comfort analysis and daylighting simulations—into the design exploration process, resulting in solutions that are not only aesthetically innovative but also quantitatively validated. Additionally, this approach opens up opportunities to discover design solutions that might not be conceived manually by designers. Several studies have demonstrated the significant potential of generative design in reducing cooling and artificial lighting loads in tropical and subtropical buildings (Zhang et al., 2021). However, the integration of this approach in facade design remains relatively new and requires further exploration, particularly regarding the selection of relevant design parameters, simulation calibration processes, and the implementation of optimization algorithms suited to the local context.

This study aims to determine the optimal configuration of louvres, specifically through angle and spacing, by evaluating their combined effects on thermal comfort and daylighting performance within a west-facing office unit. Rather than examining these parameters independently, the research applied a generative design approach to explore and identify configurations that achieve a balanced performance across multiple criteria, including glare autonomy, illuminance, and thermal comfort percentage. Through this multi-objective optimization process, the study seeks to establish performance-driven design guidelines and demonstrate the potential of generative methods in determining efficient and climate-responsive facade systems.

LITERATURE REVIEW

Louvre

Louvre has been widely researched as a system for passive facade strategies to improve daylighting and thermal performances. Previous studies consistently show that steeper louvre angles are effective in reducing glare and mitigate solar effect at the cost of reduced daylight penetration (Misawa et al., 2016). This also means that a shallower angle may improve indoor illuminance at the cost of higher glare and thermal discomfort. Many studies have proved that louvre contributes to a massive reduction in solar heat gain, while being able to control the amount of light in a significant manner (Meitadevi et al., 2025). These findings are accompanied by an unavoidable trade-off between daylight availability and thermal regulation in louvre design. To solve this issue, many designs have incorporated adaptive louvre design where they can adjust the angle as controlled or depending on the surrounding environment. However, many studies have evaluated daylighting and thermal performance independently, lacking the identification of a balanced performance facade configuration.

Daylight

Lighting is one of the important factors in space design that supports user comfort. A space with a good lighting system can support the activities carried out in it (Fleta, 2021). According to SNI 03-6197-2000 Energy Conservation of Lighting Systems in Buildings, daylight is lighting that comes from natural sources, generally known as sunlight. Daylight is influenced by several variables such as the design of window openings, room geometry, and external

factors. According to Thojib & Adhitama (2013), an office as a work area requires an adequate level of natural lighting comfort so that users in it can carry out activities smoothly and have good work productivity (Fleta, 2021).

Illuminance

According to SNI 03-6197-2000 Energy Conservation of Lighting Systems in Buildings, illuminance is the luminous flux incident on a surface or the result of dividing the luminous flux by the illuminated surface area expressed in lux. The guideline illustrates that a workspace requires a lighting level, or minimal illuminance, of approximately 350 lux. The recommended illuminance of a working space is stated to be around 300 lux internationally, mostly in the case of computer-based work, with an upper limit of 500 lux for paperwork. In Australia and New Zealand, the recommendation ranges from 320 lux to 500 lux (Preto & Gomes, 2019). Over-illumination occurs when the illuminance of the room exceeds 1500 lux.

Glare

According to SNI 03-6197-2000 Energy Conservation of Lighting Systems in Buildings, Glare is a condition where the eye is no longer able to receive the intensity of light emitted from a light source, which can be caused by the high intensity of the light. Glare could be classified as disability glare and discomfort glare. Disability glare occurs when a bright light source in the field of view produces a loss of contrast in the retinal image (CIE TC 3-13, n.d.; Jones, 2019). Discomfort glare causes visual irritation but not impairment; it may become disability glare as the light source grows in area or brightness (Hopkinson, 1972; Jones, 2019). To evaluate the presence and impact of glare within a space, the concept of glare autonomy (GA) is used.

This research uses glare autonomy as a metric to measure how much percentage of the day receives glare. Glare Autonomy (GA) is a metric describing the percentage of occupied hours that each sensor is below the glare threshold (in DGP). In this scenario, the glare threshold follows the daylight glare probability (DGP), which is 0.4. Daylight glare probability (DGP) is an indication of the percentage of people who would be disturbed by glare. The value will be classified as one of the following four categories: Imperceptible: less than 35%, Perceptible: 35% - 40%, Disturbing: 40% - 45%, Intolerable: greater than 45% (Monteliva et al., 2021; Jones, 2019; Larson & Shakespeare, 1998; Wienold, 2009).

Thermal Comfort

According to Fanger (1970) and ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Standard 55, thermal comfort is defined as a condition in which a person feels satisfied with their thermal environment—in other words, it is the absence of thermal discomfort. Similarly, ISO Standard 7730 (2005) describes thermal comfort as a state of mind that expresses satisfaction with the thermal environment (Muhaling et al., 2017). In thermal comfort theory, thermal sensation—felt as cold or heat by the human body—is actually a response of sensory receptors in the skin to the temperature stimuli from the surrounding environment (Amin et al., 2004; Muhaling et al., 2017). According to the standards of ASHRAE 55 and ISO 7730, an acceptance of at least 80% of occupants satisfied is generally considered comfortable, while being able to achieve a 90% of occupants satisfied is considered comfortable according to ISO7733.

To assess the thermal comfort level of a particular space, one common metric used is the Thermal Comfort Percentage (TCP), which represents the percentage of time spent where thermal conditions are considered acceptable or comfortable (Wu et al., 2025). Thermal comfort percentage is based on hourly timestep, where each timestep is then evaluated to be either comfortable or uncomfortable within a specific timestamp. This metric allows thermal performance to be evaluated in an average manner of a single day instead of a single time condition (for example, 10:00, or 12:00), allowing a more concrete evaluation of thermal comfort.

METHODS

This research uses a quantitative experimental approach based on simulation and algorithmic optimization to evaluate and generate the optimal configuration of louvre facades for a single office unit using thermal comfort and natural lighting simulations. The methodological framework consists of four main stages: 1. Model development, 2. Parameter Definition, 3. Performance Simulation, and 4. Optimization. Software was used for the sample modeling and simulation: Rhinoceros for modeling, which was then connected to the simulation process through the Grasshopper plug-in. Thermal comfort simulations were conducted using computational tools such as Honeybee and EnergyPlus Weather, while natural lighting simulations were performed using Ladybug Tools and Honeybee. The

simulations were then integrated with generative algorithms to explore the highest-performing under defined criteria effective design solutions with the help of Opossum. Optimization in this study is defined as the identification of louvre configurations that achieve the best trade-off between thermal comfort (TCP), glare autonomy (GA), and illuminance performance. For this simulation, vertical louvre is used as it is more suitable when facing an eastern-western oriented opening.

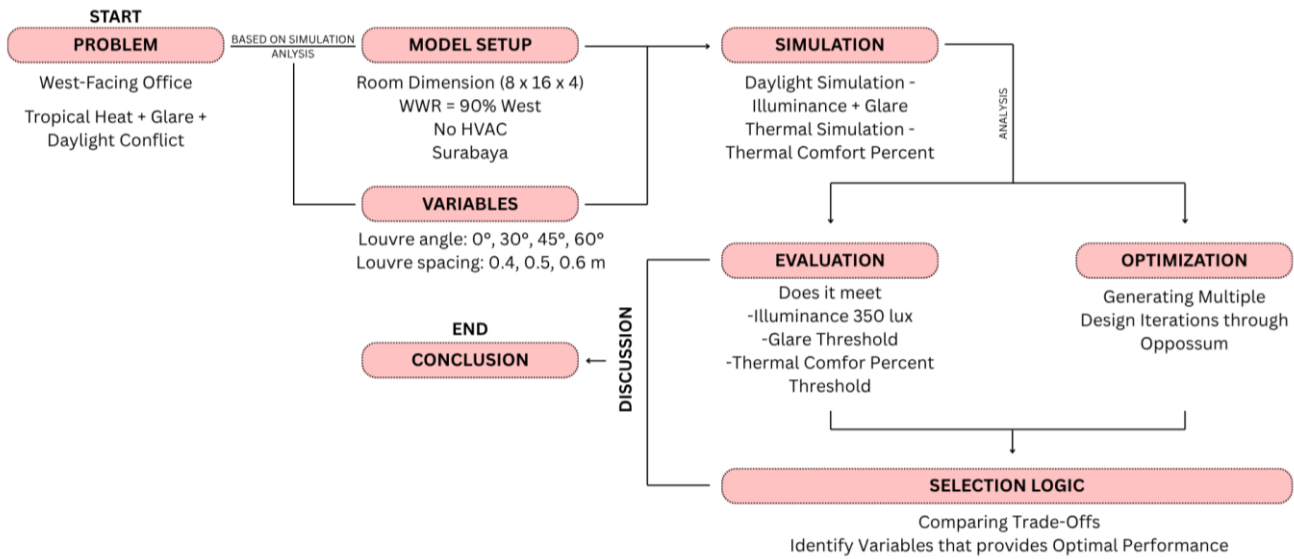


Figure 1. Step-By-Step Flowchart of Research

Room Model Development

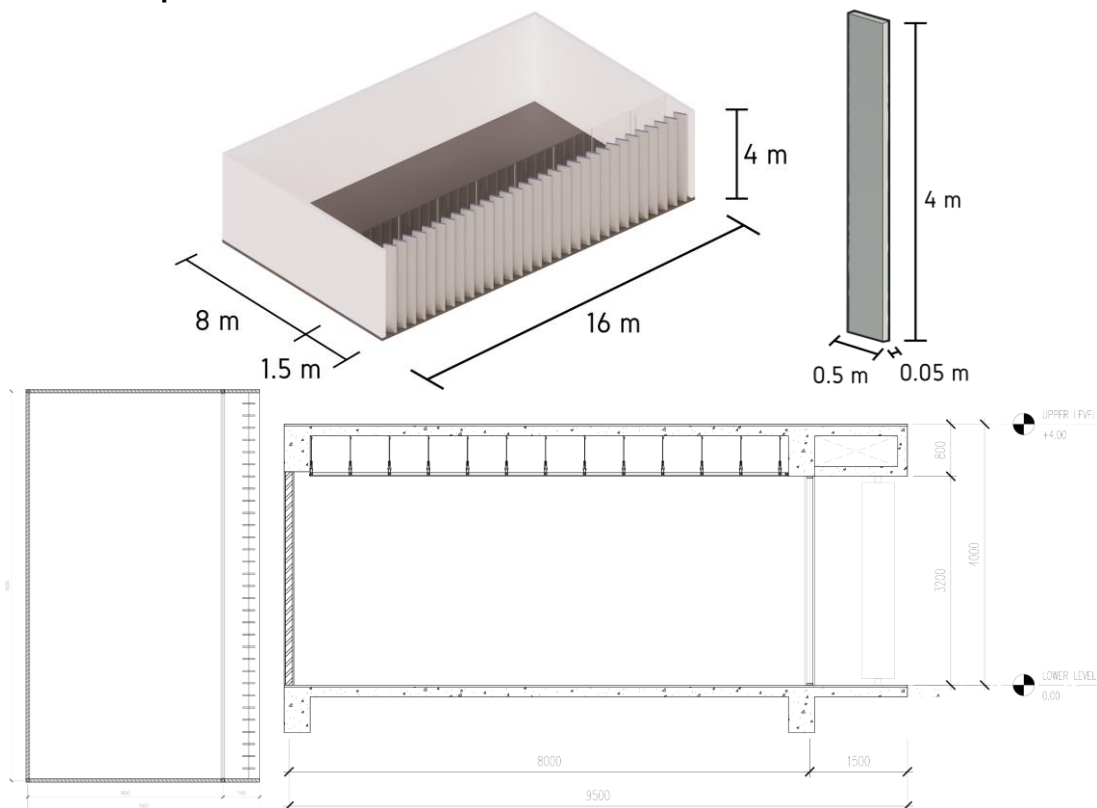


Figure 2. Sample Office Room Model for Simulation

The room model for the office has a dimension of 8 x 16 x 4 meter dimension with a louvre with a distance offset from the window of the office room being 1.5 meter. The louvre by itself has a thickness of 0.05 m, with a width of 0.5 m and the louvre covers the entirety of the height of the room, being 4 meters in height. The simulation excludes material properties, HVAC systems, and other mechanical factors affecting indoor thermal conditions so that the research can solely focus on the impact of the louvre geometry. The context of the room is also considered

to be an individual room, where the room has not been placed within a tower nor have the surrounding buildings been included during the entirety of the simulation. The weather data of the simulation is conducted and used from the weather data of Surabaya, Indonesia, specifically at the Gedangan area.

Parameters and Variables

The simulations evaluate two main performance parameters: daylight performance and thermal comfort. Daylight performance is assessed using illuminance levels during 10:00 and 14:00 and glare autonomy, which indicate the adequacy and visual comfort of natural lighting within the space. Thermal comfort is evaluated using the Thermal Comfort Percentage derived from the Universal Thermal Climate Index (UTCI) map, providing an understanding of outdoor–indoor thermal stress conditions as influenced by the facade design.

Several model variables are adjusted to examine their impact on the simulation results. The changed variables include the angle of the louvre, which is tested at 0°, 30°, 45°, and 60°, as well as the distance between each louvre, set at 0.4 m, 0.5 m, and 0.6 m. These variations are intended to analyze how different shading configurations affect daylight penetration and thermal performance.

Other variables are kept constant to ensure controlled comparison across simulations. The building location is fixed in Surabaya, Indonesia. The louvre thickness is maintained at 0.05 m. The window-to-wall ratio is set at 90% on the west façade and 0% on all other façades. The room openings are oriented toward the west, and the window transmittance value is fixed at 0.55. The reflectance value of the ceiling is 0.8, the wall being 0.5, and the floor 0.2. The U-value of the wall is 0.6 W/m²K, and the U-value of the window is 3.0 W/m²K. These fixed parameters establish a consistent baseline for evaluating the effects of the louvre configurations.

RESULTS AND DISCUSSION

Glare Autonomy (GA) Analysis

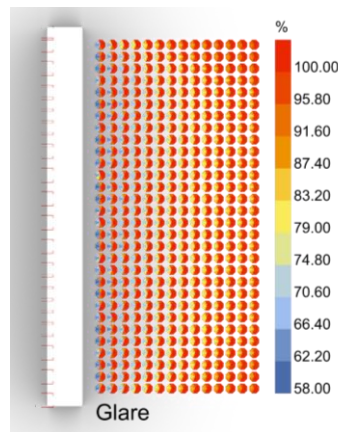
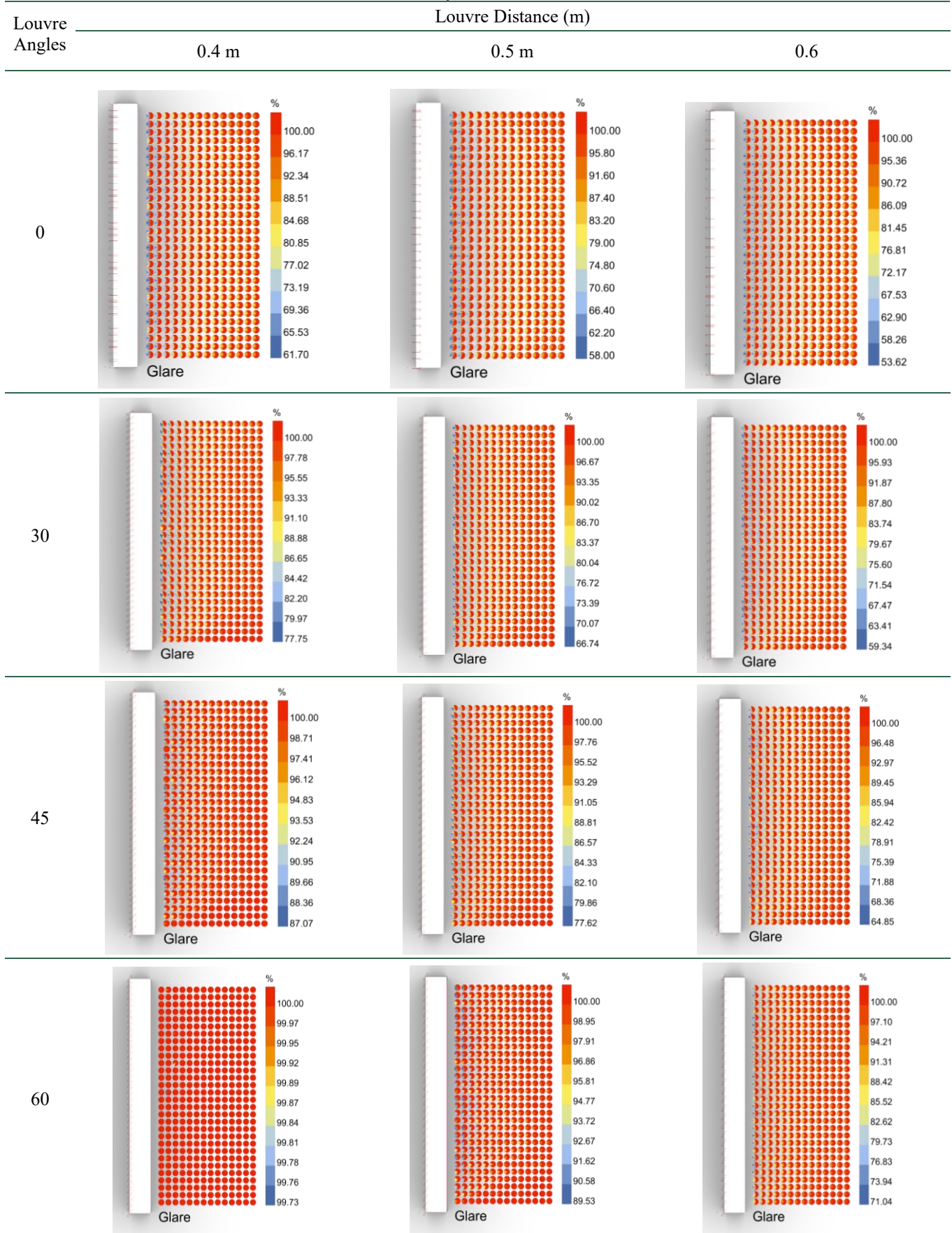


Figure 3. Heatmap Glare Autonomy Simulation - 0,5 Louvre Gap, 0° Louvre Angle

The image above is a heatmap generated from a Rhino simulation for glare autonomy analysis. Glare autonomy (GA) refers to the percentage of occupied hours that each sensor is below the glare threshold (in DGP). This means that, for example, a 90% glare autonomy means that 10% of the day, people will be disturbed by glare or 10% of the day the DGP will be above 0.40. The simulation was conducted under conditions of 0.5 m louvre spacing with the louvre angle set to 0°. On the left side of the heatmap, the outdoor area and the position of the west-facing louvre are shown. Each circle represents a sensor point in the simulation grid, and each circle is divided into eight directional segments, indicating the view orientation. Segments facing east (away from the opening) consistently show 100% glare autonomy, meaning that views directed away from the opening are glare-free. The heatmap illustrates that the closer the sensors are to the opening, the higher the probability of glare, particularly when facing toward the west-facing opening. This is visualized through the color gradient: areas near the opening show lower values (blue tones), which gradually transition into yellow–orange tones further into the space, indicating decreased glare exposure when facing the opening.

Table 2. Glare Autonomy Table without Value Restriction

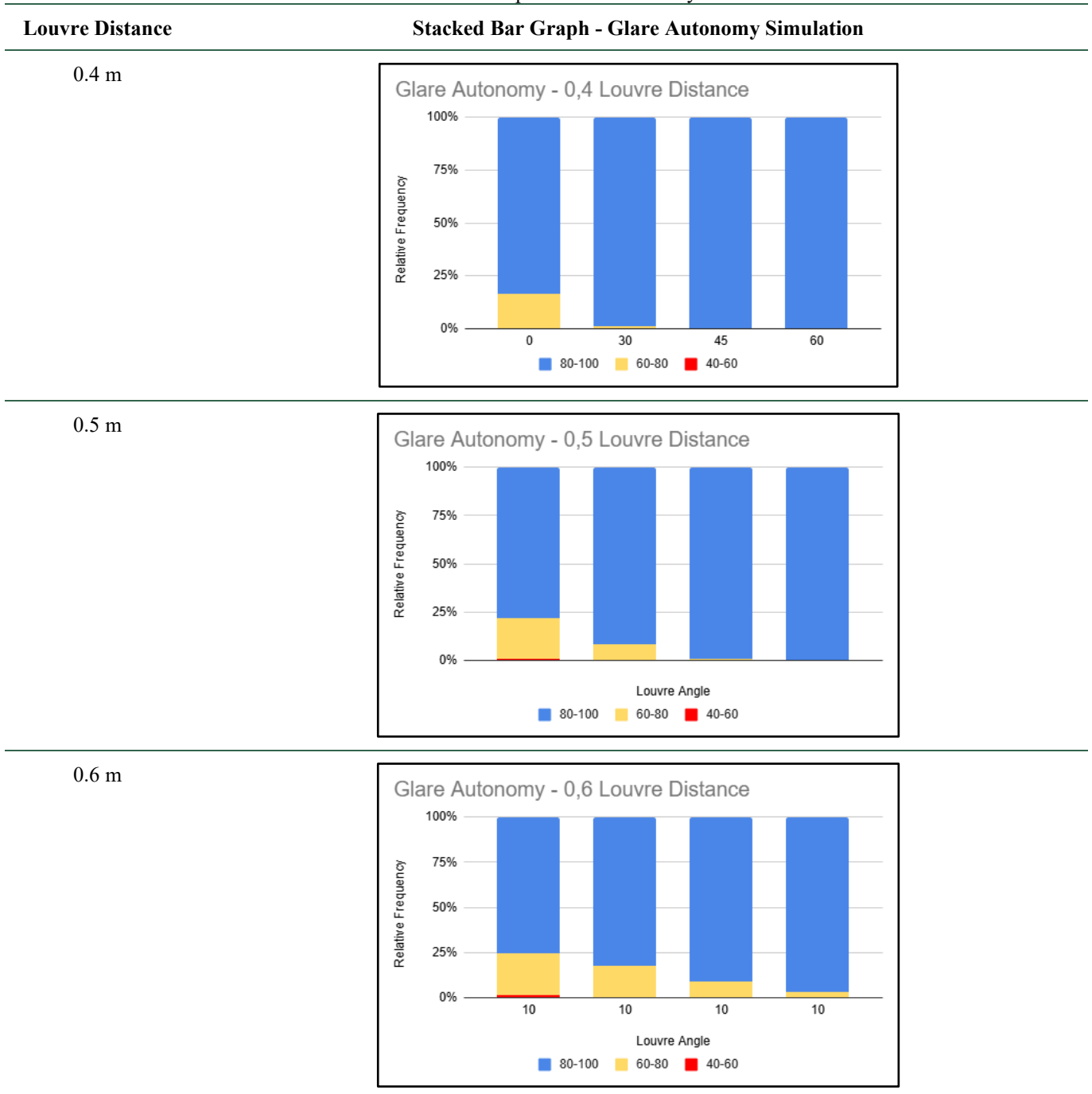


The glare autonomy (GA) analysis reveals a direct relationship between louvre geometry and the mitigation of glare. Configurations with low angle (0°) and wider spacing (0.6 m) show lower GA values, meaning glare occurs more frequently during occupied hours. This is especially problematic in the west-facing office, which is exposed to

intense solar radiation in the afternoon. As the louvre angle increases to 30°, 45°, and 60°, and as the spacing decreases to 0.4 m, the simulations show a significant improvement in glare control. These adjustments reduce the exposure of the glazing surface to direct sunlight, creating a more visually comfortable working environment. Thus, the best GA performance is found in configurations combining steep louvre angles with minimal spacing. However, it is important to note that such setups could affect daylight availability, which should be a consideration when designing and attaching a louvre to a building.

Based on the simulation, a change in the distance between each individual louvres in 0.1 m does not show a significant impact on the glare experience within the room when the angle is still 0°, however as the angle is increased, the glare experience faced when the distance between the louvre is changed for every 0.1 m shows a much more significant impact, nearing around 10 percent for each change in the distance gap. However, each individual change in the angle of the louvres, the impact on the percentage of glare autonomy also shows a significant impact, with an interval nearing 10 percent for each change of the angle of the louvres. The impact shows a huge reduction when the gap between each louvre is 0.6 m. This may be due to the width of the louvre being smaller than the gap itself.

Table 3. Stacked Bar Graph - Glare Autonomy Simulation



The results of the glare autonomy analysis show clear differences between the three louvre distances. At a spacing of 0.4 m, the performance is the highest-performing under defined criteria effective, with almost all sensors falling into the 80–100% glare autonomy range across all angles. The only noticeable weakness occurs at 0°, where a portion of the sensors shift into the 60–80% range, indicating a slight increase in glare. At a distance of 0.5 m, the overall performance decreases, particularly at 0°, where both 60–80% and a small fraction of 40–60% values appear, suggesting higher glare risks. However, as the angle increases to 30° and beyond, the performance improves again, approaching the higher range of glare autonomy. At 0.6 m spacing, the performance is the weakest, as glare levels remain higher across all angles. Even at steeper angles, a majority of sensors still fall within the 60–80% range, with some even dropping to 40–60%, meaning that glare is consistently present and less controlled. Overall, the analysis indicates that smaller louvre spacing (0.4 m) provides the best glare control, while wider spacing (0.6 m) allows more glare penetration and significantly reduces glare autonomy. Note that the graphs use the simulation data, with some of the orientation facing away from the opening (facing east) tends to be glare-free that should be taken into consideration, therefore the significance of each individual parameter change is more significant than what is shown in the chart above.

Illuminance

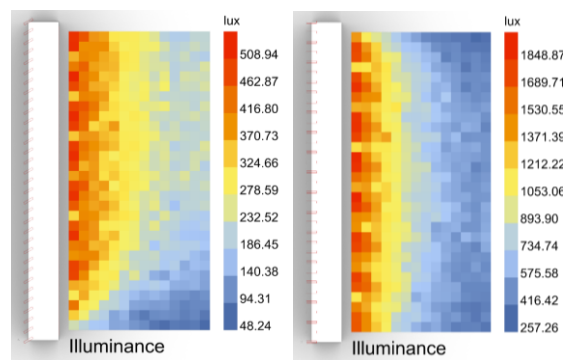
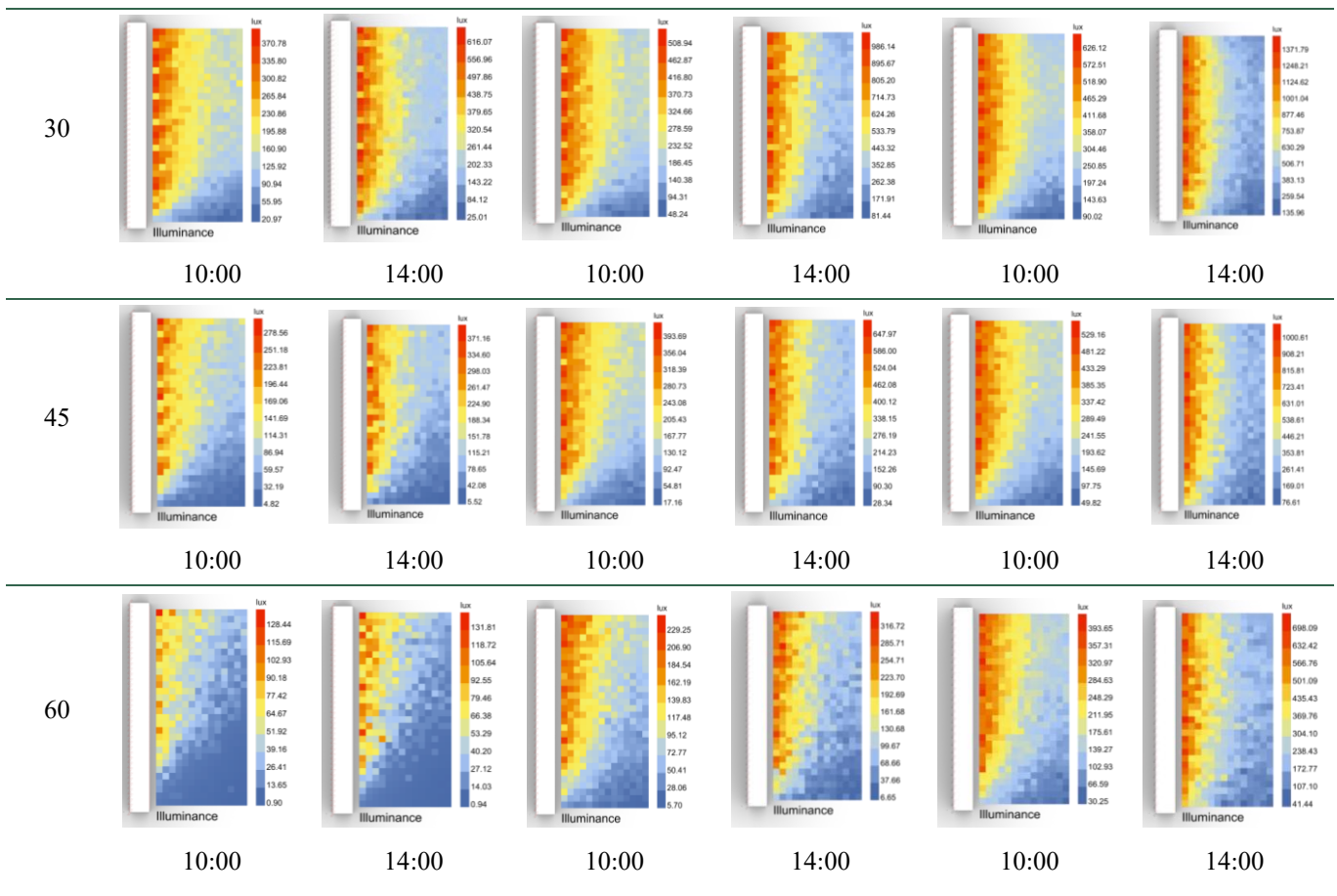


Figure 4. Heatmap Illuminance Simulation - 0,5 Louvre Gap, 0° Louvre Angle (Left 10:00, Right 14:00)

Both heatmaps visualize how daylight illuminance is distributed across the space. The vertical white strip on the left side likely represents the window or opening. In both cases, the regions closest to the opening show the highest illuminance levels, represented by the red and yellow tones, which then gradually transition to cooler blue tones as distance from the opening increases. On the left heatmap, the distribution shows a more balanced gradient, where illuminance decreases steadily with distance. On the right heatmap, however, the contrast is much stronger, with significantly higher illuminance levels concentrated near the opening and a more abrupt shift into lower values deeper into the space. This suggests that the second condition produces stronger daylight penetration but also a higher risk of over-illumination near the opening, while the first condition results in a more controlled and even distribution of daylight. Overall, both simulations highlight the expected daylight gradient effect, but the second scenario emphasizes intensity near the opening, whereas the first leans toward a more uniform distribution.

Table 4. Illuminance Table without Value Restriction

Louvre Angles	Louvre Distances (m)					
	0.4 m		0.5 m		0.6 m	
0						
	10:00	14:00	10:00	14:00	10:00	14:00



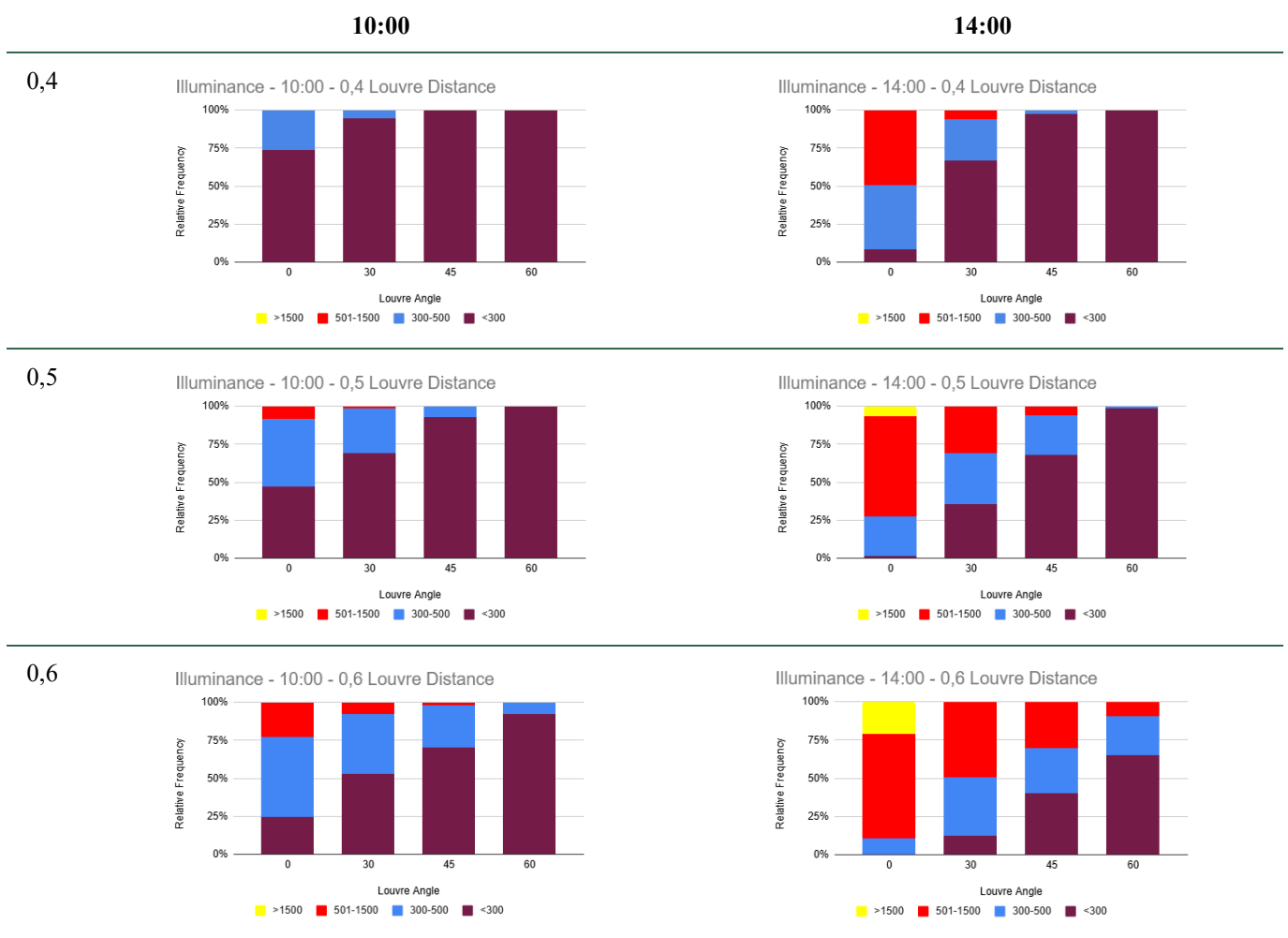
Illuminance analysis was conducted at 10:00 and 14:00, two critical times that reflect varying solar conditions throughout the day. As expected, vertical louvres at 0° permit the most daylight penetration across all distances. While this maximizes natural light, it also correlates with a high potential for glare and thermal discomfort, particularly in the afternoon. As the louvre angle increases, a gradual decline in daylight levels is observed, with the most pronounced reduction occurring at 60° with 0.4 m spacing. However, some mid-range configurations—particularly 30° and 45° louvres with 0.5 m spacing—maintain daylight levels above the 350 lux threshold recommended by SNI for office workspaces. These configurations offer a balanced performance, allowing adequate daylight while mitigating glare, and can be considered optimal in achieving energy-efficient and visually comfortable indoor environments.

Based on the simulation, a change in the distance between each individual louvres in 0.1 m shows a significant impact on the illuminance within the room when the angle is still 0°, however as the angle is increased, the illuminance within the room for every 0.1 m change in the distance between the louvre shows a gradual decline in significance for each change in the distance gap. However, each individual change in the angle of the louvres, the impact on the illuminance within the room shows a significant impact, with an interval nearing 100 lux at 10:00 and nearing 300 lux at 14:00 for each change of the angle of the louvres. The impact shows a huge reduction when the gap between each louvre is 0.6 m. This may be due to the width of the louvre being smaller than the gap itself, therefore creating a sharp change when under the circumstance of 0.6 m gap between each louvres.

The illuminance analysis shows that louvre spacing and time of day significantly influence daylight distribution. At 10:00, the 0.4 m spacing produces a relatively balanced result, with a noticeable portion of values falling within or close to the comfortable daylighting range. At the same time, some areas shift toward higher illuminance, particularly at shallower louvre angles. The 0.5 m spacing displays a broader distribution, with both comfortable levels and higher illuminance present, while the 0.6 m spacing shows a stronger tendency toward higher daylight penetration, including some instances of excessive illuminance.

At 14:00, the distribution shifts across all spacing conditions. For the 0.4 m spacing, the results indicate an increase in higher illuminance levels compared to the morning, although some values remain in the comfortable range depending on louvre angle. The 0.5 m spacing shows a larger share of values above the target range, reducing the proportion of areas in the comfortable daylight zone. In the case of the 0.6 m spacing, the afternoon results are dominated by higher illuminance levels, with fewer areas remaining within the desired range.

Table 5. Stacked Bar Graph - Illuminance Simulation



Across both times, a general trend is visible: narrower louvre spacing tends to reduce the share of excessive illuminance, while wider spacing allows more daylight penetration but with a greater risk of overexposure. Each spacing presents trade-offs between maintaining daylight levels within the target range and admitting higher amounts of daylight, which may or may not be desirable depending on the priorities of the space, such as maximizing daylight availability or minimizing glare risk.

Thermal Comfort Percentage

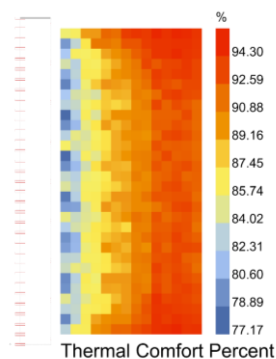


Figure 5. Heatmap Thermal Comfort Percentage Simulation - 0,5 Louvre Gap, 0° Louvre Angle

The heatmap illustrates the distribution of **thermal comfort percentage (TCP)**, which indicates how often the thermal conditions are within an acceptable or comfortable range. The color gradient transitions from cooler blue and yellow tones on the left to warmer orange and red tones on the right. This suggests that areas nearer to the boundary or opening experience lower percentages of thermal comfort, while conditions improve progressively deeper into the

space. Overall, the map shows that most of the evaluated area achieves relatively high levels of thermal comfort, with only localized zones at the perimeter showing reduced performance. The steady shift from lower to higher comfort percentages across the space highlights the influence of external exposure near the boundary, whereas the interior zones maintain more stable and favorable thermal conditions.

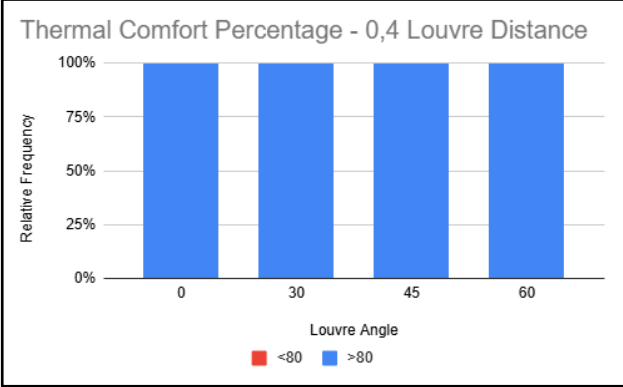
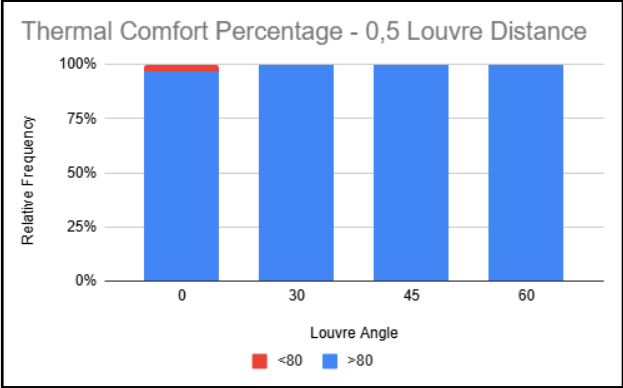
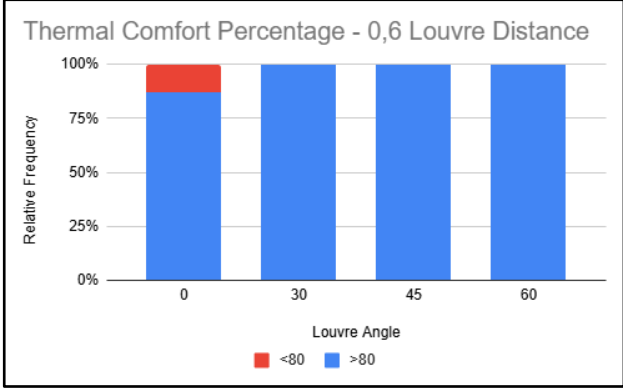
Table 6. Thermal Comfort Percentage Table without Value Restriction

Louvre Angles	Louvre Distance (m)		
	0.4 m	0.5 m	0.6
0	<p>Thermal Comfort Percent</p>	<p>Thermal Comfort Percent</p>	<p>Thermal Comfort Percent</p>
30	<p>Thermal Comfort Percent</p>	<p>Thermal Comfort Percent</p>	<p>Thermal Comfort Percent</p>
45	<p>Thermal Comfort Percent</p>	<p>Thermal Comfort Percent</p>	<p>Thermal Comfort Percent</p>
60	<p>Thermal Comfort Percent</p>	<p>Thermal Comfort Percent</p>	<p>Thermal Comfort Percent</p>

The Thermal Comfort Percentage (TCP), assessed through Universal Thermal Climate Index (UTCI) simulations, reinforces the critical role of louvre geometry in regulating passive heat gain. Configurations with 0° louvres, particularly when paired with wider fin spacing, allow substantial solar heat into the room, resulting in low thermal comfort percentages. In contrast, increasing the angle to 45° or 60° and reducing the spacing to 0.4 m or 0.5 m significantly enhances thermal performance by minimizing direct solar radiation on glazing and interior surfaces. Notably, configurations around 45° at 0.5 m spacing appear to provide the optimal trade-off configuration between daylighting and thermal control. These findings support the importance of climate-responsive facade design, especially in tropical cities like Surabaya, where excessive indoor heat can increase reliance on cooling systems and energy consumption.

Based on the simulation, a change in the distance between each individual louvres in 0.1 m shows a change in the range of data, making the distribution value of thermal comfort percentage wider, around 4% (TCP) each change in intervals at 0°, while having the effects reduced to around 1% (TCP) when the angle is 60°. The effect can be significantly seen during the change between 0.5 m and 0.6 m, as the width of the louvres are unable to fully close the opening of the room. A change in the angle distributes the value of TCP around the room more evenly, making the range of TCP value lower, creating a more evenly distributed comfort within the room.

Table 7. Stacked Bar Graph - Thermal Comfort Simulation

Louvre Distance	Stacked Bar Graph - Glare Autonomy Simulation															
0.4 m	 <p>Thermal Comfort Percentage - 0,4 Louvre Distance</p> <table border="1"> <thead> <tr> <th>Louvre Angle</th> <th><80 (%)</th> <th>>80 (%)</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>0</td> <td>100</td> </tr> <tr> <td>30</td> <td>0</td> <td>100</td> </tr> <tr> <td>45</td> <td>0</td> <td>100</td> </tr> <tr> <td>60</td> <td>0</td> <td>100</td> </tr> </tbody> </table>	Louvre Angle	<80 (%)	>80 (%)	0	0	100	30	0	100	45	0	100	60	0	100
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45	0	100														
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0.6 m	 <p>Thermal Comfort Percentage - 0,6 Louvre Distance</p> <table border="1"> <thead> <tr> <th>Louvre Angle</th> <th><80 (%)</th> <th>>80 (%)</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>~15</td> <td>~85</td> </tr> <tr> <td>30</td> <td>0</td> <td>100</td> </tr> <tr> <td>45</td> <td>0</td> <td>100</td> </tr> <tr> <td>60</td> <td>0</td> <td>100</td> </tr> </tbody> </table>	Louvre Angle	<80 (%)	>80 (%)	0	~15	~85	30	0	100	45	0	100	60	0	100
Louvre Angle	<80 (%)	>80 (%)														
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The charts present the Thermal Comfort Percentage (TCP) across different louvre distances (0.4 m, 0.5 m, and 0.6 m) under varying rotation angles. Across all configurations, the majority of time remains within the comfortable thermal range (blue bars), indicating that the louvre system is generally effective in maintaining acceptable indoor conditions. At 0.4 m louvre distance, the comfort distribution is consistent across different angles, with minimal variation. At 0.5 m louvre distance, comfort levels remain high, though there is a slight indication of conditions occasionally shifting above comfort (red segment at 0°). At 0.6 m louvre distance, a similar trend appears, with comfort still dominant but with a slightly larger proportion of time spent above comfort conditions at 0°. Overall, the comparison suggests that all three louvre distances maintain high thermal comfort percentages, with only minor differences in distribution. Closer spacing (0.4 m) results in more uniform comfort performance across angles, while wider spacing (0.5 m and 0.6 m) introduces small variations, particularly at zero rotation, where thermal conditions occasionally exceed the comfort threshold.

Performance Trade-Offs and Optimization Implications

The results of the parametric simulations demonstrate a clear performance trade-off between daylighting and thermal comfort driven primarily by louvre angle and spacing. Shallow louvre angles (0°–30°) consistently produce higher morning illuminance values; however, across all spacing variations, these configurations also result in significantly elevated afternoon illuminance and solar exposure, leading to a measurable reduction in thermal comfort percentages. This indicates that improved early-day daylight availability is achieved at the expense of midday thermal performance.

Conversely, steeper louvre angles (45°–60°), particularly when combined with tighter spacing, show a marked reduction in afternoon illuminance and solar gain, which directly correlates with improved thermal comfort outcomes. At the same time, the simulation results indicate that these configurations consistently underperform in morning daylight availability, frequently falling below functional illuminance levels. This confirms that stronger solar-shading strategies, while effective in reducing thermal stress, impose a substantial penalty on daylight performance.

Across the full dataset, configurations with a 45° louvre angle and 0.5 m spacing emerge as a statistically stable compromise rather than an absolute optimum in any single metric. While not maximizing illuminance or thermal comfort individually, this configuration demonstrates the most balanced performance envelope, maintaining adequate morning and afternoon daylight levels while achieving a consistently higher thermal comfort percentage compared to shallower-angled alternatives. The findings suggest that optimal façade performance in west-oriented conditions is not defined by peak values but by minimizing performance loss across competing criteria. This reinforces the necessity of multi-objective evaluation in facade design, where design decisions are guided by trade-off management rather than isolated performance optimization.

The generative design process reveals that no single configuration maximizes all performance indicators simultaneously. Instead, architects and designers must navigate the trade-offs between visual comfort, thermal performance, and daylight sufficiency. For instance, while a 60° louvre angle with 0.4 m spacing may deliver the best glare and thermal control, it risks underlighting the space and increasing dependence on artificial lighting. Conversely, a 0° angle might provide excellent illuminance but compromise both thermal comfort and glare autonomy. The simulation-driven exploration of design alternatives enables a data-informed selection of facade configurations tailored to specific climatic conditions and user needs.

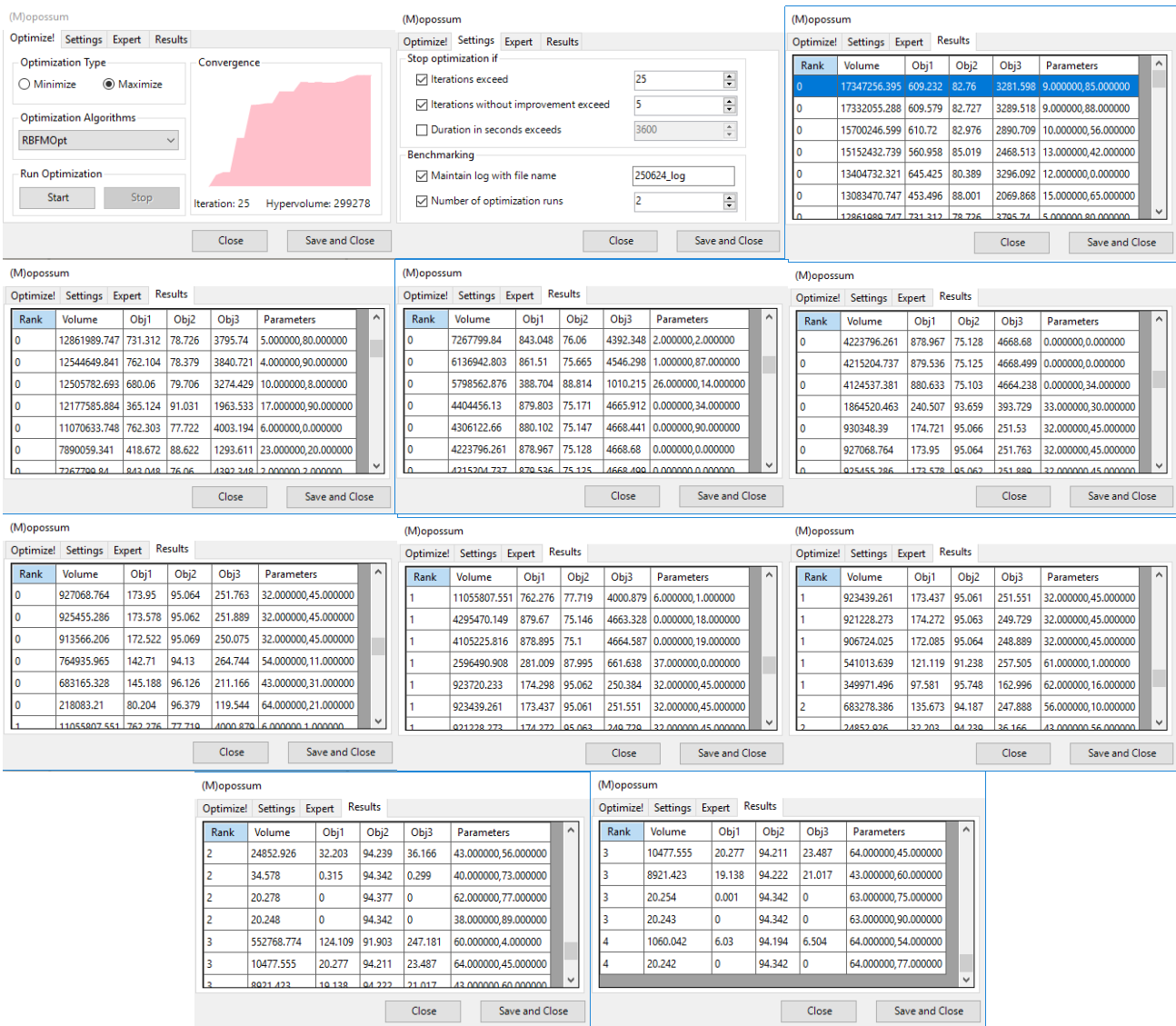


Figure 6. Opossum Setup and Results

The image represents the performance run through Opossum across three variables—illuminance at 10:00 (Object 1), thermal comfort percentage (Object 2), and illuminance at 14:00 (Object 3)—effectively illustrating the inherent trade-offs in louvre facade design. Configurations that perform well in early daylight availability (Object 1), such as 0° or 30° louvre angles, tend to admit excessive solar radiation by midday (Object 3), which compromises thermal comfort (Object 2). In contrast, configurations with steeper angles (45°–60°) and tighter spacing reduce thermal gain and afternoon glare, enhancing thermal comfort but significantly limiting natural light, especially in the morning. This study highlights the challenge of optimizing for a single metric without sacrificing others. Rather than seeking a universal "best" solution, the findings emphasize the importance of identifying a balanced configuration—such as 45° louvres with 0.5 m spacing—which maintains acceptable daylight levels while improving thermal comfort. 45° louvres with 0.5 m spacing is also shown to be the most repeated configuration, proving that this setup can be one of the most optimal configurations. This configuration alone is able to achieve an average illuminance of 173 lux at 10:00, an average of 95% thermal comfort percentage, an average illuminance of 251 lux at 14:00, and an average glare autonomy (excluding the result facing away from the opening as they are guaranteed 100% glare free) of 92.86%.

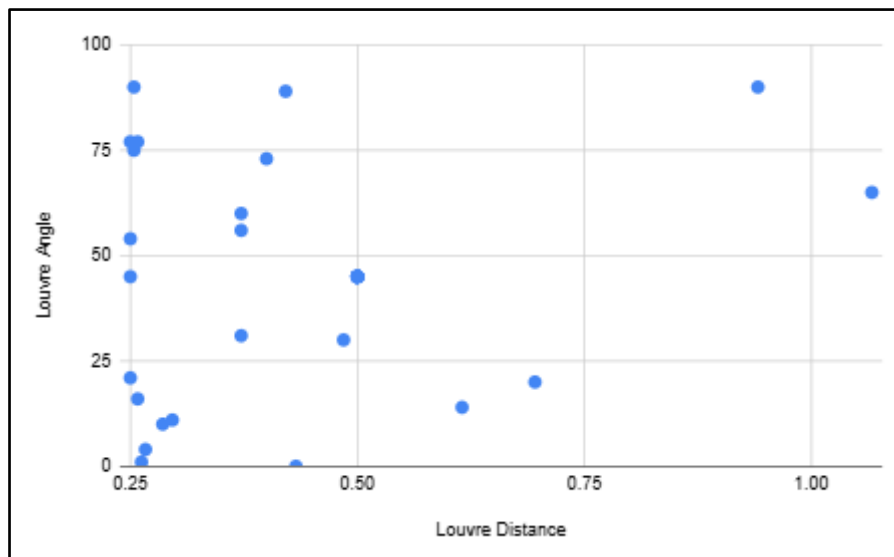


Figure 7. Scatter Graph of the Resulted Opossum

Based on the optimizer used, results suggest that louvre spacing more than 0.5 m is not suggested with the resulting optimizer showing the least result. This indicates that the solar heat gain gained within the room exceeds that of the shading capability. However, a dense clustering is shown throughout the region of 0.25 m - 0.4 m louvre spacing, and 0° - 25° louvre angle. This therefore means that within this range of data regions is a high-performance region, indicating that there are multiple configurations of louvre that can be used to provide a high-performing setup, not just a single optimal configuration. Data shows that the variations of louvre angle can be implemented within a design at a small spacing tends to be more diverse in comparison to a configuration with wider spacing. The graph also shows that the variation of angles to the spacing are inversely proportional instead of being exponentially decayed.

Contextual Considerations and Limitations

Although the results are insightful, several limitations should be acknowledged. The simulation model represents an isolated single room without HVAC systems or real-world thermal mass considerations. It also does not consider external obstructions such as adjacent buildings, which could alter solar access significantly in urban settings. Additionally, only the west-facing facade was analyzed, whereas real buildings may require dynamic facade responses on multiple orientations. Despite these limitations, the findings underscore the value of adaptive, generative facade strategies in shaping high-performance, sustainable office environments.

CONCLUSION

This study investigated the optimization of louvre facade configurations for west-facing office rooms in Surabaya’s tropical climate, aiming to balance thermal comfort and daylighting performance. A generative design method using Rhinoceros, Grasshopper, Honeybee, and Ladybug enabled the evaluation of various louvre angle and spacing combinations based on performance metrics such as Glare Autonomy (GA), critical-time illuminance (10:00 and 14:00), and Thermal Comfort Percentage (TCP) using UTCI. The findings reveal that no single configuration excelled in all aspects; steeper angles (45°–60°) with tighter spacing (0.4–0.5 m) effectively reduced glare and improved thermal comfort in the afternoon but limited morning daylight. In contrast, flatter angles (0°–30°) enhanced daylight penetration but worsened glare and thermal conditions. A 45° angle with 0.5 m spacing emerged as the one of the most multi-objective optimal solution with the most repetitive configuration from the optimizer, offering acceptable daylight while improving thermal and visual comfort, achieving an average illuminance of 173 lux at 10:00, an average of 95% thermal comfort percentage, an average illuminance of 251 lux at 14:00, and an average glare autonomy (excluding the result facing away the opening as they are guaranteed 100% glare free) of 92.86%. While it is the most repeated configuration, the scatter graph shows that within the region of 0.25 m - 0.4 m louvre spacing, and 0° - 25° louvre angle also represents the optimal trade-off solution across evaluated performance metrics. The study highlights the value of data-driven, context-sensitive design and generative algorithms like Opossum in creating sustainable, occupant-friendly facades, suggesting future work on dynamic shading and orientation-specific strategies.

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