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INVESTIGATING WINDOW DESIGN IMPACT ON OTTV THROUGH BIM MODELING IN WARM-HUMID CITIES

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Abstract
Introduction: Fenestration design is critical for building energy efficiency in warm-humid climates, where solar radiation through windows significantly affects the overall thermal transfer value (OTTV). Many buildings in Indonesia do not adequately address location-specific envelope design, potentially due to limited experimental research on appropriate designs for Indonesia's diverse climates. **Purpose of the study:** This study aims to examine the impact of different window design strategies on building thermal transfer across Indonesian cities. **Methods:** A sensitivity analysis was conducted to evaluate the influence of window design on the OTTV in three geographically distinct Indonesian cities: Banda Aceh (Northern Hemisphere), Pontianak (Equator), and Yogyakarta (Southern Hemisphere). Using a building information modeling (BIM)-based OTTV calculator in Autodesk Revit and Dynamo, 3,600 window variations were generated and represented in 180 line graphs. Variations included window-to-wall ratio (WWR), glazing properties, and shading devices. **Results:** The analysis indicates that WWR has a more significant effect on the OTTV than the shading coefficient (SC), with reductions of up to 46 W/m² when WWR decreased from 65 % to 25 %. Shading dimensions proved more influential on the OTTV than glazing properties, highlighting the critical role of shading configuration in thermal performance. Optimizing WWR and implementing standardized shading systems can significantly enhance energy efficiency and thermal comfort, especially in tropical climates with high solar exposure. These findings encourage early design-stage exploration of WWR and shading combinations to achieve compliance with energy standards while maintaining design flexibility.

Keywords: fenestration design, energy efficiency, OTTV, sensitivity analysis, warm-humid climate buildings, Indonesian buildings.

Introduction

The design of a building's envelope is critical to its energy consumption (Albatayneh, 2021; Mushtaha et al., 2021; Natephra et al., 2018; Tong et al., 2021). To avoid inefficient energy use and the subsequent need for costly retrofits, it is essential to prioritize the initial design phase. Therefore, a strategic and systematic approach during this phase is vital for optimal decision-making (Al-Homoud, 2005). In countries with warm and humid climates, building envelopes face unique challenges, as they require adequate fenestration for natural ventilation and daylighting, particularly in daytime-use buildings such as schools. Proper natural lighting is necessary not only to achieve energy efficiency but also to prevent mold growth due to high humidity. Although facade design is one of the most critical factors influencing building performance, not all elements of the building envelope contribute equally. According to the Indonesian National Standard (SNI) 6389:2020, three values represent the amount of heat transferred through the building envelope by conduction and radiation: conduction through opaque walls, conduction through glass, and solar radiation through glass (BSN, 2020). The SR value comprises solar factor (SF), window-to-wall ratio (WWR), shading coefficient (SC), and glass shading coefficient (SC_G). Previous studies in tropical climates showed that SR-related variables significantly impact the overall thermal transfer value (OTTV) (Chow and Chan, 1995; Gondal et al., 2019; Habibi, 2019; Kusumawati et al., 2021; Pathirana et al., 2019; Syafutri et al., 2023a).

Previous studies also revealed that many mid- to high-rise buildings in Indonesian cities exceed the OTTV standard of 35 W/m^2 set by SNI 6389:2020. For instance, research on educational buildings in Lampung (Sani et al., 2019) and Yogyakarta (Octarino and Feriadi, 2021; Syafutri et al., 2023a) demonstrated a trend of surpassing the maximum allowable value. The same trend was observed in other studies: a study focusing on a church in Jakarta (Imran, 2019; Widhayaka and Rilatupa, 2021), and a study addressing a church in Semarang (Purwanto and Tichelmann, 2021). Likewise, Rahmanda and Suriansyah (2020) investigated a hotel building in Lampung, providing further evidence that many buildings in Indonesia exceed the recommended OTTV values due to inadequate envelope design. Nasrullah et al. (2024) studied two hotels in Makassar and showed through simulation that proper building envelope design could significantly reduce energy consumption. Collectively, these studies suggest applying a smaller WWR and using glazing with superior thermal properties. The findings indicate that the buildings analyzed were not designed to respond effectively to the SF specific to each city, which determines the intensity of solar radiation in different areas (BSN, 2020). Each building orientation in Indonesian cities experiences a distinct SF, requiring careful window design. Therefore, poorly designed building envelopes can increase the cooling load, leading to energy inefficiency.

The initial review of literature indicates a lack of specific window designs in many buildings across Indonesian cities, which could help reduce heat transfer through windows. Despite the thermal properties of the glass used, the diverse SF values across Indonesia significantly affect the OTTV. This study aims to address this issue by examining how window components influence the OTTV in three Indonesian cities: Banda Aceh, Pontianak, and Yogyakarta. The study focuses on factors such as window-to-wall ratio (WWR), shading device shading coefficient (SC), and glass shading coefficient (SC_G), as outlined in SNI 6389:2020. The analysis will be conducted using statistical models generated through BIM-based applications, namely Autodesk Revit and Autodesk Dynamo. This method accelerates the analysis process and reduces the risk of human error, as demonstrated in previous studies (Bahdad et al., 2021; Eid et al., 2022; Lim et al., 2019; Seghier et al., 2017, 2022; Syafutri et al., 2023b; Tantisevi and Sornsuriya, 2010). By analyzing building envelope variables using BIM-based applications, the study intends to provide practical design recommendations for architects and policymakers to improve building energy efficiency across different regions of Indonesia.

Methods

The objective of this research is to investigate the influence of window variables on the OTTV across different locations in Indonesia. Previous research on this specific topic remains limited; therefore, three geographically distinct cities were selected as case studies: Banda Aceh in the Northern Hemisphere, Pontianak on the Equator, and Yogyakarta in the Southern Hemisphere.

Table 1 presents the SF values according to SNI 6389:2020 for the case study cities. Banda Aceh, located in the Northern Hemisphere, exhibits a significantly higher SF on the south side compared to Pontianak and Yogyakarta. The south SF value of Banda Aceh is even higher than the east SF value of Pontianak, despite the east side generally experiencing high SF values. Fig. 1 illustrates the sun path diagrams of the three case study cities (Tukiainen and Gaisma.com, 2024).

To further analyze the performance of window design variables in relation to the OTTV, an experiment was conducted using an educational building: Nahdlatul Ulama University (Universitas Nahdlatul Ulama, UNU) in Yogyakarta, Indonesia, as shown in Fig. 2. Fig. 3 presents a simplified model of the building created using Autodesk Revit 2021. Tables 2 and 3 provide the variable data of the case study building extracted from the Revit model. The UNU building has nine floors, most of which are air-conditioned. Table 4 details the dimensions of the building's windows.

OTTV Equation

The OTTV equation, based on the SNI 6389:2020 standard, is employed to determine the value of thermal transfer through the building envelope. According to SNI 6389:2020, OTTV consists of three components: (a) heat conduction through opaque walls, (b) heat conduction through transparent walls, and (c) solar radiation through transparent walls. The equation is expressed as follows:

$$OTTV = [(\alpha \times (1 - WWR) \times U_W \times TD_{EQ}) \times A] + [WWR \times U_F \times \Delta T] + [WWR \times SF \times (SC \times SC_G)]. \quad (1)$$

In the equation, α represents the absorptance value of exterior paint. The term (1 – WWR) expresses the ratio of wall area to window area, accounting for heat conduction through opaque walls. U_W represents the thermal transmittance of the wall material, while TD_{EQ} is the equivalent temperature difference of the material. U_F denotes

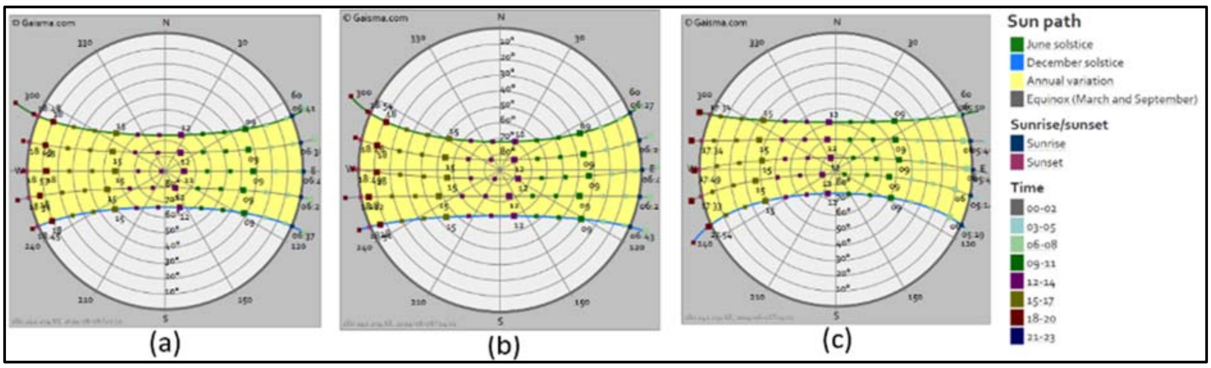


Fig. 1. Sun path diagrams for each city: (a) Pontianak, (b) Banda Aceh, and (c) Yogyakarta (Tukiainen and Gaisma.com, 2024)

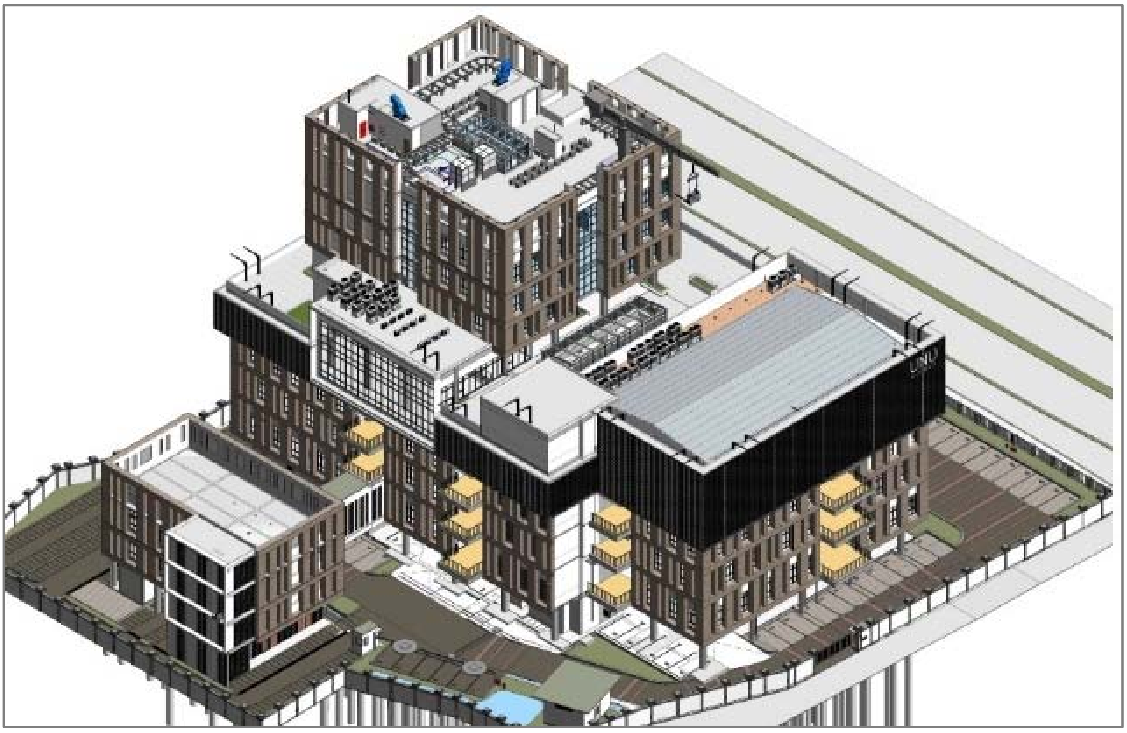


Fig. 2. Window area with minimal shading system on the west facade of the UNU building

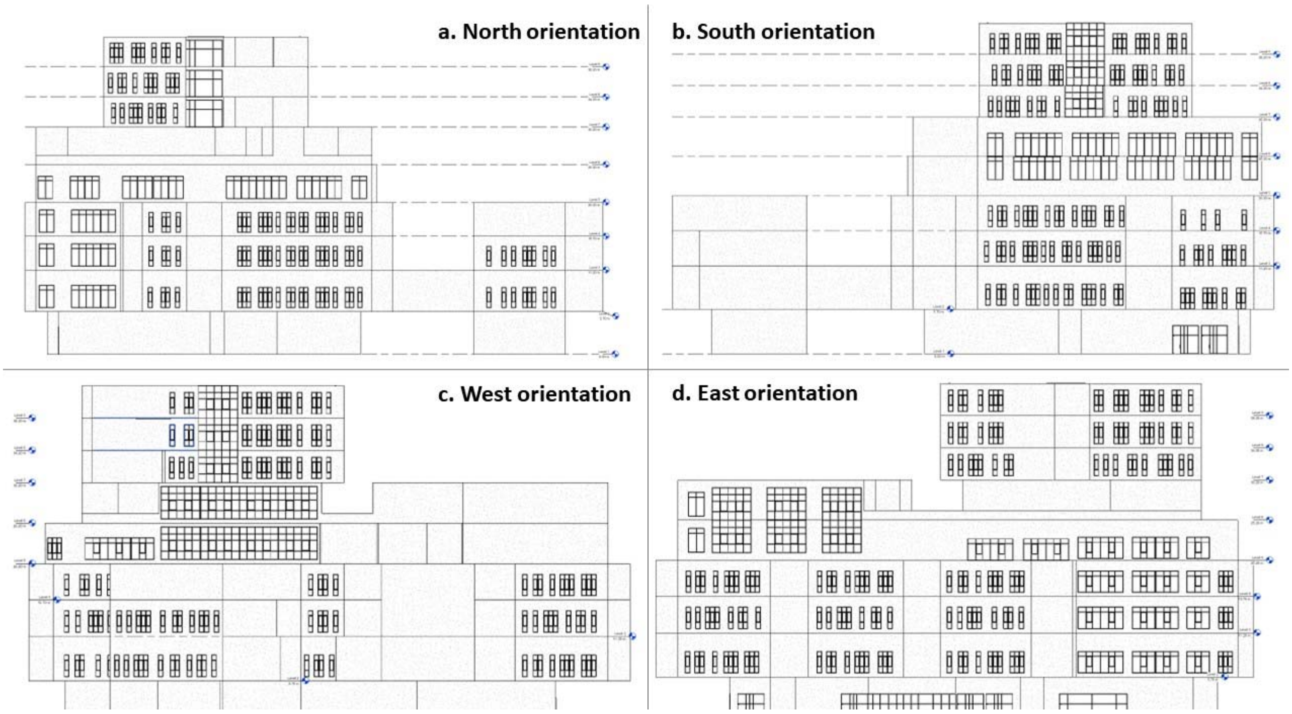


Fig. 3. Facades of the UNU building: (a) north, (b) south, (c) west, (d) east

Table 1. **Coordinates and solar factor of case study locations**

Location		Coordinates	Solar factor			
			North	South	East	West
Banda Aceh	Northern Hemisphere	5.5483° N, 95.3238° E	116	142	166	200
Pontianak	Equator	0.0263° S, 109.3425° E	125	120	139	186
Yogyakarta	Southern Hemisphere	7.8014° S, 110.3648° E	152	105	170	178

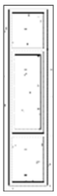
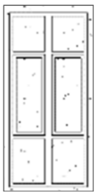
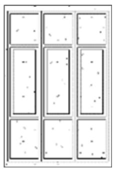
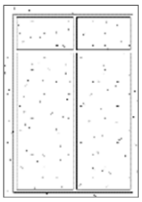
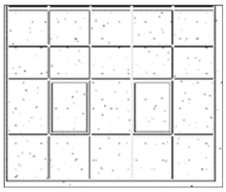
Table 2. **Facade and fenestration area, WWR of each orientation**

Orientation	Opaque wall area	Fenestration area	Total facade area	WWR
North	895.3 m²	499.1 m²	1,394.5 m²	36 %
South	992.2 m²	486.4 m²	1,478.6 m²	42 %
West	1,002.7 m²	742.2 m²	1,744.9 m²	34 %
East	1,519.4 m²	778.2 m²	2,295.6 m²	33 %

Table 3. **Variables of existing case study buildings for OTTV calculation**

Variables required for OTTV calculation	Data
Thermal absorptance value (α)	White exterior painting = 0.21
Thermal transmittance values (U_w & U_f)	• U-value of brick = 3.9 W/m^{2}K • U-value of window glass = 5.7 W/m^{2}K • U-value of door glass = 5.7 W/m^{2}K
Equivalent temperature difference TD_{EQ}	10
Shading coefficient (SC)	• SC of window glass = 0.55 • SC of door glass = 0.55

Table 4. **Windows dimensions in the Nahdlatul Ulama University**

Window type		
 Window No. 1 Width = 0.6 m Length = 3.6 m	 Window No. 2 Width = 1.2 m Length = 3.6 m	 Window No. 3 Width = 1.8 m Length = 3.6 m
 Window No. 4 Width = 2.8 m Length = 3.6 m	 Window No. 5 Width = 4.8 m Length = 4.0 m	

the transmittance of window glass, and ΔT is a constant value that represents the difference between outdoor and indoor temperatures. This value is simplified to facilitate practical application. SF is the solar factor, SC is the shading coefficient of window glass, and SC_G is the shading coefficient of the shading system. The SC of the shading system depends on the shading system type and dimensions. SNI 6389:2020 defines three types of shading systems: (a) horizontal fins (HF), (b) vertical fins (VF), and (c) eggcrate fins (EF). The dimensions of each shading system determine the R value, which is used to calculate the SC. Fig. 4 shows the shading system types and the variables required to

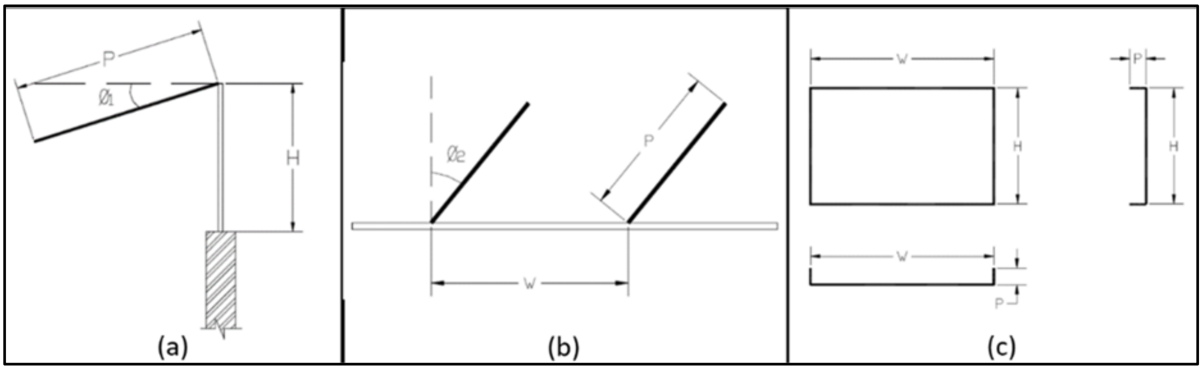


Fig. 4. Shading systems according to SNI 6389:2020: (a) horizontal fins, (b) vertical fins, (c) eggcrate fins

obtain the R value. The R value expresses the ratio between the dimension of the shading device and the corresponding dimension of the window. The calculation differs for horizontal and vertical fins. To obtain the R value of a horizontal fin, the length of the fin is divided by the height of the window frame, as shown in Fig. 4 ($R_1 = \frac{P}{H}$). To obtain the R value of a vertical fin, the width of the vertical shading system is divided by the width of the window ($R_2 = \frac{P}{W}$).

Calculating the OTTV of the existing building is essential for this research. The UNU building is originally located in Yogyakarta, Indonesia. However, for the purposes of this study, three locations were considered: Yogyakarta, Banda Aceh, and Pontianak, representing the Southern Hemisphere, Northern Hemisphere, and Equator, respectively. Accordingly, three sets of OTTV calculations were performed using the original building specifications, with the addition of the solar factor for Banda Aceh and Pontianak. Table 5 shows the OTTV for each case study location.

BIM-Based OTTV Calculator

To accelerate the experiment in this study, a BIM-based OTTV calculator was developed using Autodesk Dynamo within Autodesk Revit 2021. Several previous studies developed similar calculators based on SNI 6389:2020 (Syafutri et al., 2023b), MS 1525:2014 (Abass et al., 2020), and the GreenMark and Green RE rating systems (Seghier et al., 2017), while Lim et al. (2019) proposed a framework to automate decision-making for high-performance buildings. Fig. 5 illustrates the workflow of the OTTV calculator used in this study, based on the validated framework developed by Syafutri et al. (2023b). Furthermore, combinations of various window design elements were configured to conduct the experimental analysis.

In addition to the OTTV calculator, a framework for the experimental configuration was developed in this study using Autodesk Dynamo. This framework enables automation of the experiment. The variables tested included the window-to-wall ratio (WWR), the shading coefficient of glass (SC_G), and the shading coefficient (SC) of the shading systems. The experiment was conducted across three locations with different SF values. The WWR variations used in this study were 25 %, 35 %, 45 %, 55 %, and 65 %. The WWR values below 25 % were considered inadequate, as they restrict natural daylight penetration, while values above 65 % may lead to excessive OTTV (Sayadi et al., 2021). Table 6 presents the variations of the SC values for glass, and Table 7 presents the SC values of the shading systems used in the experiment. Fig. 6 illustrates the experimental framework. The automation tool was developed by implementing the OTTV equation and configuring it with the experimental variables, allowing automatic generation of results for sensitivity analysis.

Fig. 6 shows one of the frameworks used in this study to obtain the OTTV for analysis. The frameworks were adapted for each case study city and followed four stages: data input, data adjustment, experimentation, and result export to Microsoft Excel. At the data input stage, information extracted from the BIM model was compiled and written as a string in a code block to streamline the process. In Autodesk Dynamo, a string is a sequence of text characters used to store and manipulate information, while a code block is a flexible node that allows users to write and execute scripts for efficient data processing. The input data included the SF, WWR, U-value, absorptance (α), TDEQ, ΔT, SC, and SC_G for each building orientation in every city. At the data adjustment stage, the existing SC and SC_G values were multiplied by those corresponding to the glass types defined in Table 6. At the experimentation stage, the adjusted data were processed, and the results were categorized according to different WWR values (25 %, 35 %, 45 %, 55 %, and 65 %). Finally, the experimental results were exported to Microsoft Excel for further analysis. This framework was consistently applied across all cities included in the study.

Sensitivity Analysis Method

The BIM-based OTTV calculator developed for this research generated 3,600 OTTV values, each representing a different window design variation in terms of the WWR, SCG, SC, and SF, varying by location. To achieve the research objectives, a sensitivity analysis was applied to identify trends and synthesize the experimental results. Previous studies employed sensitivity analysis to investigate the impact of design variables on heating and cooling loads in residential buildings, for example in Hungary (Elhadad and Orban, 2021). Additionally, a review of sensitivity analysis methods for high-performance buildings, covering 96 studies from

Table 5. **Pre-experiment OTTV values for each case study location**

Location	OTTV (W/m^2)			
	North	South	East	West
Banda Aceh	32.4	34.5	40.1	57.2
Pontianak	33.6	31.5	35.9	54.3
Yogyakarta	37.6	29.4	40.5	52.7

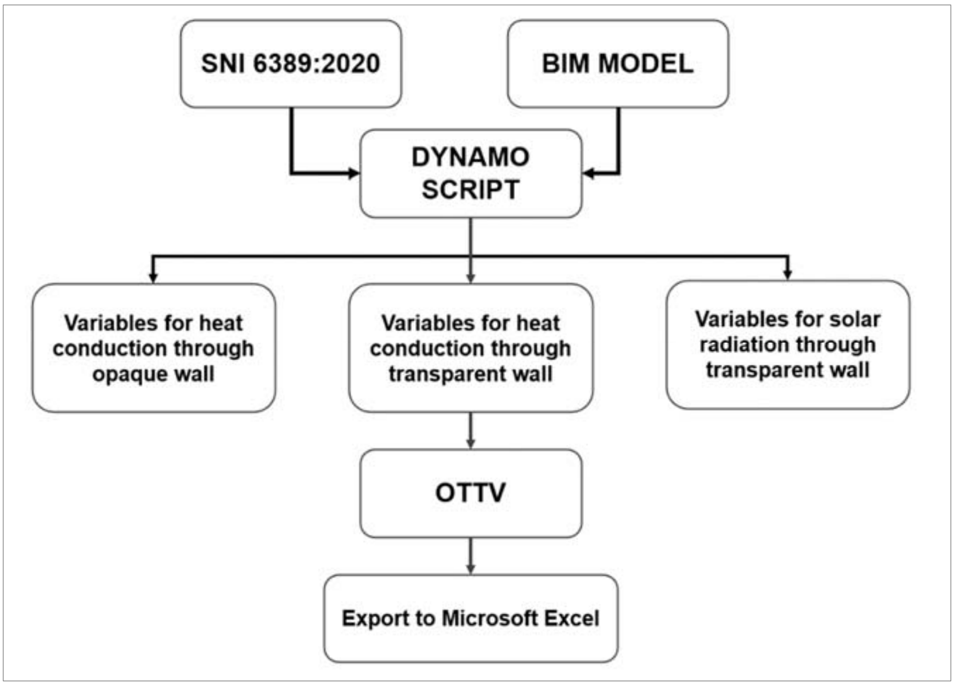


Fig. 5. BIM-based OTTV calculator

Table 6. **Variations of the SC values (PT Asahimas Flat Glass Tbk, 2022)**

Glass type	Thickness (mm)	SC value	U-value (W/m²K)	Image
Panasap *Bronze*	6	0.73	5.7	
T-Sunlux CS-150 #2	6	0.67	5.7	
Stopsol – *Eurogray*	6	0.56	5.7	
Stopsol – *Dark Blue*	8	0.39	5.7	

Table 7. **Shading coefficient for each R value of shading systems**

North–South orientation					
Horizontal fin		**Vertical fin**		**Eggcrate fin**	
R1 value	SC value	R2 value	SC value	R1/R2 value	SC value
0.2	0.87	0.2	0.91	0.2/0.2	0.81
0.4	0.76	0.4	0.81	0.4/0.4	0.68
0.6	0.7	0.6	0.75	0.6/0.6	0.66
0.8	0.69	0.8	0.73	0.8/0.8	0.66
1.0	0.68	1.0	0.71	1.0/1.0	0.66
East–West orientation					
Horizontal fin		**Vertical fin**		**Eggcrate fin**	
R1 value	SC value	R2 value	SC value	R1/R2 value	SC value
0.2	0.87	0.2	0.96	0.2/0.2	0.85
0.4	0.77	0.4	0.92	0.4/0.4	0.73
0.6	0.69	0.6	0.89	0.6/0.6	0.65
0.8	0.63	0.8	0.85	0.8/0.8	0.58
1.0	0.58	1.0	0.82	1.0/1.0	0.54

internationally indexed journals, identified the most frequently analyzed variables such as climate, building envelope components, ventilation, HVAC systems, and occupant behavior patterns (Pang et al., 2020).

Experimental Results

The experiment generated 3,600 OTTV values, each corresponding to a specific window design strategy. In this section, the results are discussed according to the variables examined in this study: (a) the impact of the SF and SC on the OTTV, and (b) the impact of the WWR on the OTTV. This division allows for a clear assessment of the influence of each variable on the OTTV. Finally, a synthesis of the results is presented to provide a comprehensive overview of the findings.

Impact of the Solar Factor and Shading Coefficient on the OTTV

The solar factor for the north and south orientations varies significantly depending on geographic location, as shown in Table 1. In Pontianak, located on the equator, the SF is 125 W/m² on the north side

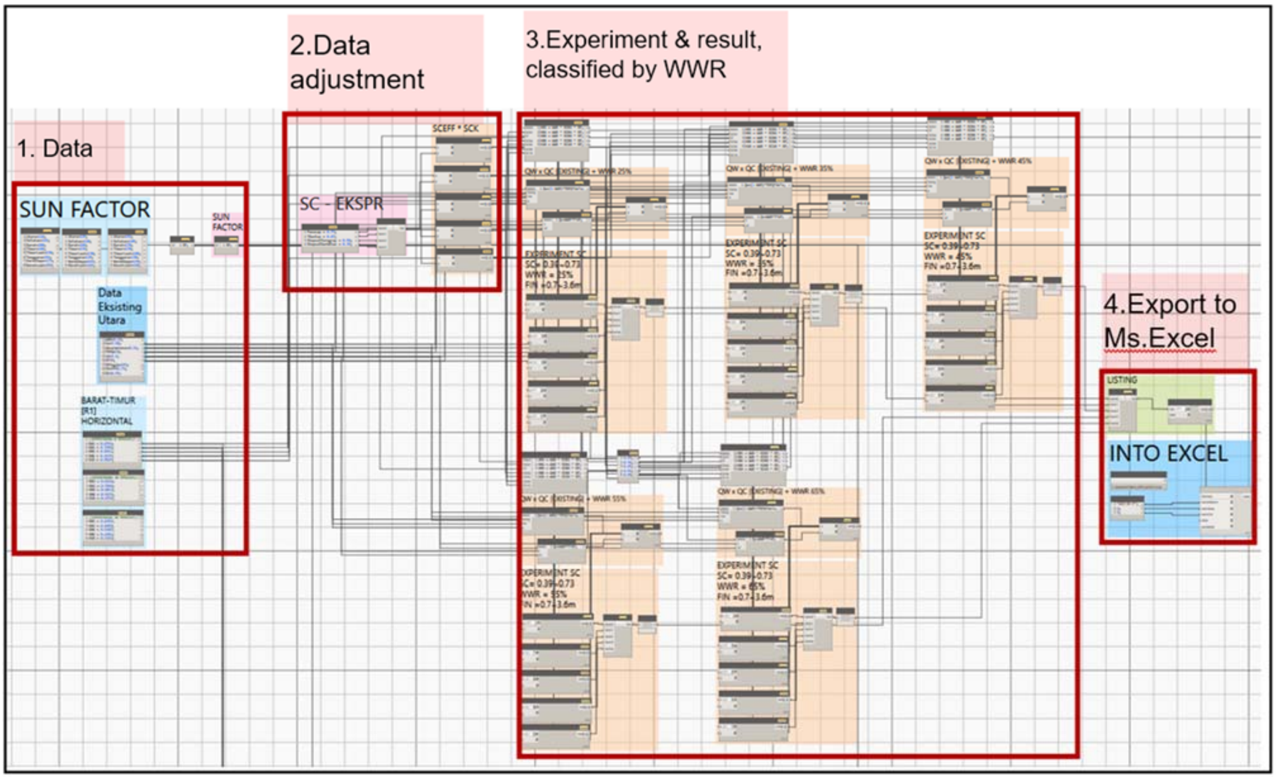


Fig. 6. One of frameworks of the BIM-based OTTV calculator

and 120 W/m² on the south side. In comparison, Yogyakarta exhibits a north SF of 152 W/m² and a south SF of 105 W/m², indicating a substantial variation in solar exposure between these orientations. Conversely, Banda Aceh shows an opposite pattern to Yogyakarta, with a north SF of 116 W/m² and a south SF of 142 W/m². As for the east and west sides, Banda Aceh has the highest SF values, with 200 W/m² on the west side and 166 W/m² on the east side. A similar imbalance is observed in Pontianak, where the east SF is 139 W/m² and the west SF is 186 W/m², which is significantly higher. In contrast, Yogyakarta exhibits more balanced SF values between the west (178 W/m²) and east (170 W/m²) orientations.

Yogyakarta stands out due to its substantial OTTV reduction, attributed to its higher SF on the north side. This higher SF indicates a greater influence of solar radiation, making the location more responsive to shading and glazing strategies aimed at reducing the OTTV. This sensitivity to thermal transfer reduction sets a benchmark for understanding the impact of solar exposure in locations with high SF. Similar trends are observed in other areas with high SF, including the west and east sides of Banda Aceh, the west side of Pontianak, and the east, west, and north sides of Yogyakarta. These variations suggest that higher SF values in specific orientations, such as west and east, amplify the OTTV reduction effect, highlighting the sensitivity of building thermal performance to shading and glazing characteristics.

OTTV Reduction Sensitivity to the Solar Factor and Shading Coefficient

The study further revealed that OTTV differences between Yogyakarta and Pontianak are more pronounced than those between Banda Aceh and Pontianak. A 27 W/m² difference in the SF between Yogyakarta and Pontianak resulted in an OTTV variation of up to 125 W/m² on the north side. Fig. 7 illustrates the substantial OTTV reduction observed across the three locations. This finding indicates that even relatively small increases in the SF can produce disproportionately large effects on the OTTV, highlighting the sensitivity of thermal transfer to solar exposure, particularly on north sides. High SF values also significantly affect the performance of high-quality glazing. As shown in Fig. 8, Stopsol Dark Blue glass with a thickness of 8 mm and an SC value of 0.39 performs differently depending on the location.

With regard to the OTTV calculation, the SF difference between Banda Aceh and Yogyakarta on the south side is similar to the SF difference between Banda Aceh and Pontianak on the west side (Table 8). This is notable because east and west orientations receive predominantly direct sunlight, while north and south orientations receive mainly diffuse sunlight. Typically, these differences in sunlight type would result in varying solar heat

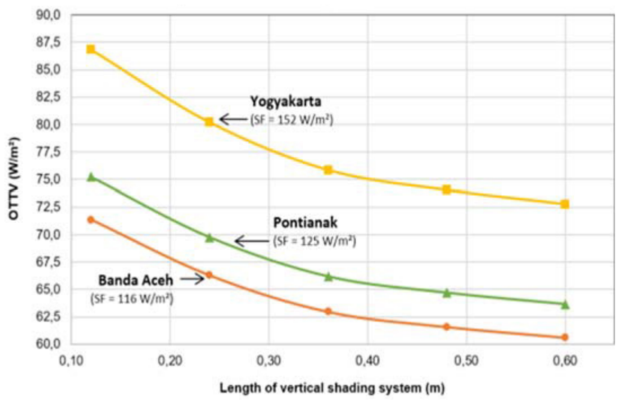


Fig. 7. Comparison of the OTTV in the north orientation of Pontianak, Banda Aceh, and Yogyakarta

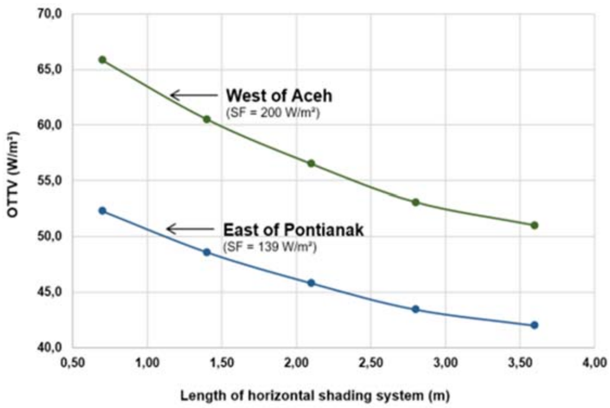


Fig. 8. Performance of high-quality glass (SC = 0.39) in the different locations (e.g the west side of Banda Aceh and the east side of Pontianak)

gains. However, in this case, the OTTV values are similar due to the consistent SC of the horizontal fin shading systems on all sides. The primary reason for this similarity is the uniform ratio of shading dimensions to window size across different orientations. Regardless of whether the orientation is north–south or east–west, maintaining the same shading ratio leads to comparable OTTV values despite variations in sunlight type and intensity. This trend is consistent for horizontal, vertical, and eggcrate shading systems.

In warm-humid climates, these findings suggest that shading devices can be standardized across orientations by maintaining a uniform ratio of shading dimensions to window size, achieving comparable OTTV results for all orientations. Although eggcrate shading systems exhibit larger SC differences between north–south and east–west orientations, they still follow a similar OTTV pattern as horizontal and vertical fins when the same shading-to-window ratio is applied. This insight provides a practical approach to shading device design for buildings in tropical regions, regardless of whether

Table 8. **Comparison of OTTV differences between west and south orientation for different locations**

WWR = 65 %; SC_G = 0.79									
	Location	SF (W/m²)	OTTV (W/m²)			Location	SF (W/m²)	OTTV (W/m²)	
			Fin = 0.7 m	Fin = 3.6 m				Fin = 0.7 m	Fin = 3.6 m
West – horizontal fin	Banda Aceh	200	104.51	76.75	South – horizontal fin	Banda Aceh	142	80.54	67.00
	Yogyakarta	178	95.37	70.67		Pontianak	120	71.39	59.94
	Difference	22	9.14	6.08		Difference	22	9.15	7.06

WWR = 65 %; SC_G = 0.79									
	Location	SF (W/m²)	OTTV (W/m²)			Location	SF (W/m²)	OTTV (W/m²)	
			Fin = 0.7 m / 0.12 m	Fin = 3.6 m / 0.6 m				Fin = 0.7 m / 0.12 m	Fin = 3.6 m / 0.6 m
West – eggcrate fin	Banda Aceh	200	101.94	72.81	South – eggcrate fin	Banda Aceh	142	76.20	65.77
	Yogyakarta	178	93.09	67.16		Pontianak	120	67.71	58.90
	Difference	22	8.85	5.65		Difference	22	8.48	6.87

they are located near the Equator, in the Northern Hemisphere, or in the Southern Hemisphere.

Moreover, the experiment demonstrated that OTTV reduction is less pronounced for lower SC values. For instance, on the south side of Banda Aceh, a combination of the highest WWR (65 %) and an SC value of 0.79 resulted in a 13.15 W/m² reduction in the OTTV when the fin R value increased from 0.2 to 1.0. In contrast, with the same WWR but an SC value of 0.39, the OTTV reduction was only 7 W/m². This comparison is summarized in Table 9. A similar pattern was observed across all orientations and locations. These findings indicate that using window glass with a lower SC value decreases the impact of shading system performance.

Substantial Role of the WWR Across Different Locations

A 25 % WWR configuration across the north–south orientation resulted in minimal OTTV variation between locations, as shown in Fig. 9. This consistency suggests that a 25 % WWR can serve as an effective baseline for minimizing thermal transfer across diverse Indonesian climates. The finding indicates that building envelopes respond consistently to this WWR configuration regardless of geographic or climatic variations, highlighting that specific WWR values can function as reliable performance standards across different environmental conditions. However, a WWR of 25 % on the north side of Yogyakarta, combined with an SCG of 0.79 and a vertical fin length of 0.6 m, yields an OTTV of 38.5 W/m², which exceeds the recommended limit according to SNI 6389:2020. None of the OTTV values in any orientation with a 65 % WWR configuration dropped below 35 W/m², even with the lowest SC value, as shown in Fig. 10. This indicates a performance limitation for high WWRs, regardless of other design interventions.

In terms of OTTV reduction, the WWR has a more significant impact than the SC value. The data indicate that, on the north side, OTTV reduction can reach up to 30 W/m² when comparing SC values of 0.79 and 0.39 at a 65 % WWR with vertical fins. The most substantial OTTV reduction, up to 46 W/m², occurs when decreasing the WWR from 65 % to 25 % at an SC of 0.79 with the same fin configuration. This finding highlights the critical impact of the WWR on thermal performance, suggesting that strategic adjustments to the WWR are more effective for energy efficiency than modifying the SC values. This trend is consistent across other orientations and locations, with varying reduction percentages. Furthermore, at a 25 % WWR configuration, variations in the SC and R values produce only minor differences in the OTTV across all studied cities.

Table 9. **OTTV margin comparison between vertical fin dimensions and various SC values**

Glass material characteristics			**OTTV by vertical fin dimensions**		**OTTV margin (a)–(b)**	**Percentage**
Glass material	**Thickness (mm)**	**SC value**	**0.12 m** (a)	**0.6 m** (b)		
Panasap Bronze	6	0.73	82.5 W/m²	69.4 W/m²	13.2 W/m²	16 %
T-Sunlux	6	0.67	77.5 W/m²	65.4 W/m²	12.1 W/m²	16 %
Stopsol Eurogray	6	0.56	68.3 W/m²	58.2 W/m²	10.1 W/m²	15 %
Stopsol Dark Blue	8	0.39	54.1 W/m²	47.1 W/m²	7 W/m²	13 %

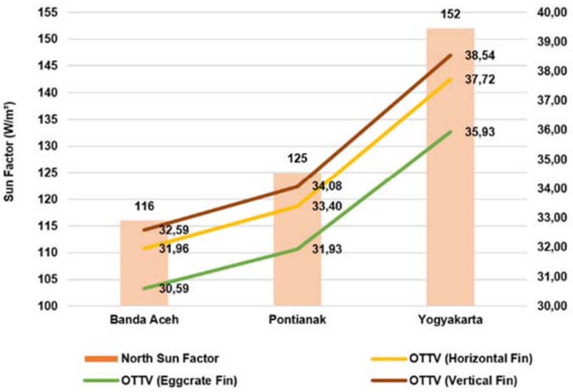


Fig. 9. Correlation of the OTTV with a 25 % WWR in the north orientation

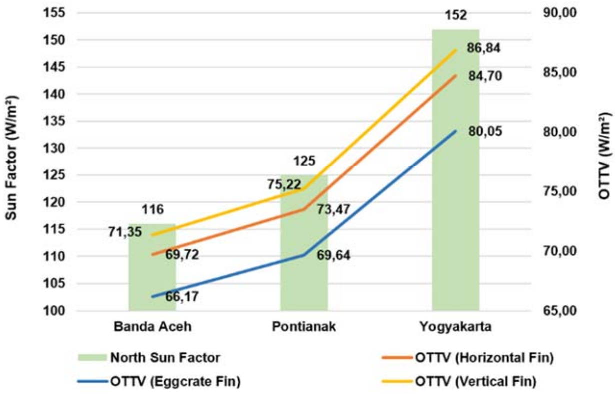


Fig. 10. Correlation of the OTTV with a 65 % WWR in the north orientation

For instance, in Yogyakarta, the OTTV difference in the north orientation (SF = 152 W/m²) with a 25 % WWR reaches up to 9 W/m², as shown in Fig. 9. However, this difference is considerably smaller compared to a 65 % WWR configuration, which exhibited variations of up to 30 W/m². These results indicate that as the WWR increases, the OTTV becomes more sensitive to changes in the SCG values and shading system dimensions, reinforcing the importance of optimizing the WWR for energy-efficient building design.

The finding shown in Fig. 11 indicate that the Overall Thermal Transfer Value (OTTV) decreases as the shading coefficient (SC) of the glass material is reduced. Among the tested glass types, Panasap Bronze, with the highest SC value of 0.79, produced the highest OTTV of approximately 85 W/m². Conversely, Stopsol Dark Blue, which has the lowest SC value of 0.39, achieved the most significant reduction in OTTV, reaching around 55 W/m². The intermediate glass materials, such as T-Sunlux CS-150 #2 (SC = 0.67) and Stopsol Eurogray (SC = 0.56), showed corresponding OTTV values that fell between these two extremes. This trend confirms that the use of glass materials with lower shading coefficients can substantially reduce OTTV and improve the thermal performance of building envelopes.

These findings collectively underscore the importance of tailored window design strategies that account for specific climatic and geographic conditions to maximize energy efficiency. By understanding the nuanced interactions among the WWR, SC values, and shading systems, architects and designers can make informed decisions that significantly reduce thermal transfer and improve the overall energy performance of buildings in warm-humid climates.

Discussion and Synthesis

This study highlights the critical impact of the solar factor on key building performance parameters, including the WWR, SCG, and SC. The solar factor, representing the intensity of solar radiation on wall surfaces, significantly affects heat transfer through windows, especially in orientations with high SF values. This effect is exemplified by the UNU building case study. As shown in Table 5, the existing OTTV for each city and orientation indicates that only the west orientation in all three locations fails to meet

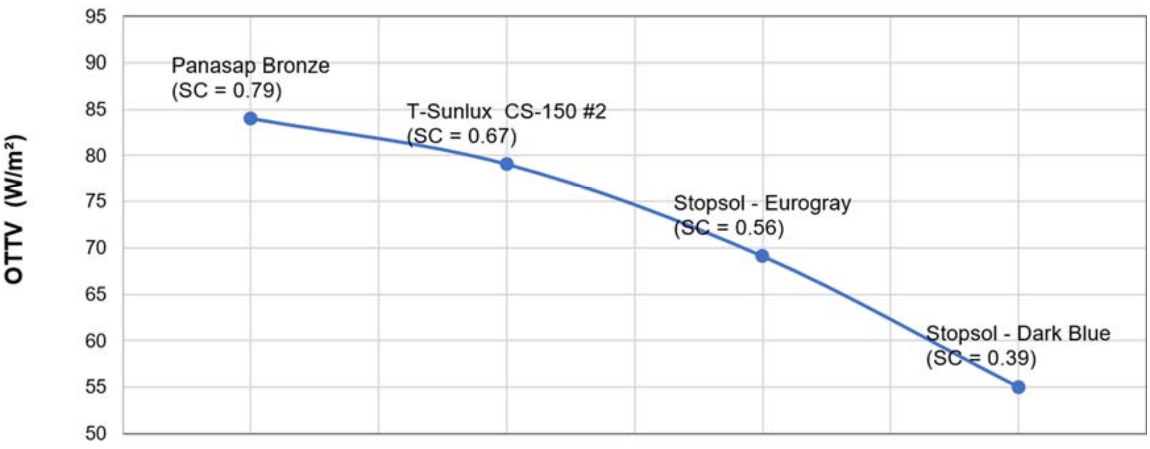


Fig. 11. OTTV reduction with different types of glass materials and SC values

the OTTV standard set by SNI 6389:2020, despite a relatively low WWR of 34 %. The elevated OTTV on the west side of the UNU building results from a combination of the highest SF values among all locations, inadequate shading system, and glass with an SCG value of 0.55. Fig. 12 shows the case study building with an eggcrate shading system, which has a high SC value of 0.877, indicating that approximately 87 % of solar radiation passes through the window. An SC_G value of 0.55 is not optimal for the west orientation in any location. The experimental results demonstrate that glass with an SC value of 0.39 can achieve OTTV values compliant with the SNI standard of 35 W/m².

Table 8 further highlights how orientation-specific shading dimensions yield different OTTV values. In tropical regions such as Indonesia, OTTV variations are relatively consistent between north–south and east–west orientations due to similar distributions of solar heat gain. Among the shading types analyzed, eggcrate systems perform most effectively, corroborating previous research (Sari and Rauzi, 2021), as they efficiently block both direct and diffuse solar radiation. In contrast, vertical and horizontal shading systems demonstrate lower effectiveness.

The study also finds that a high WWR, such as 65 %, is impractical for any orientation in Indonesia, as it fails to meet OTTV standards even when using low-SC glass. Conversely, reducing WWR to 25 % enables compliance with the standards even with an SC of 0.79, while applying an SC of 0.39 at this WWR further minimizes the OTTV. These findings encourage architects to consider WWR and shading system combinations early in design, providing flexibility to achieve energy performance standards without imposing rigid design constraints.

Recommendation as Best Practice

By analyzing building envelope variables using BIM-based applications, the study intends to provide practical design recommendations for architects and policymakers to improve building energy efficiency across different regions of Indonesia. Table 10 summarizes the best-practice window design strategies derived from this study. Orientation and solar exposure are critical factors, with higher WWRs permissible for orientations with lower solar heat gains. For instance, in Pontianak, north-facing windows with SC_G values between 0.67 and 0.73 are recommended to have a WWR below 25 %, reflecting the high solar exposure in that orientation. Conversely, lower SC_G values (0.39–0.56) allow for higher WWRs, such as 35–45 % for north-facing windows in Pontianak and Banda Aceh, indicating reduced heat gain. This table aids in optimizing building energy performance by minimizing unwanted solar heat gain while allowing daylight, tailored to the specific climate and solar exposure of each city.

Conclusion

This study investigates the impact of window design on the OTTV across three geographically distinct Indonesian cities — Banda Aceh, Pontianak, and Yogyakarta — covering a range of latitudes. The analysis

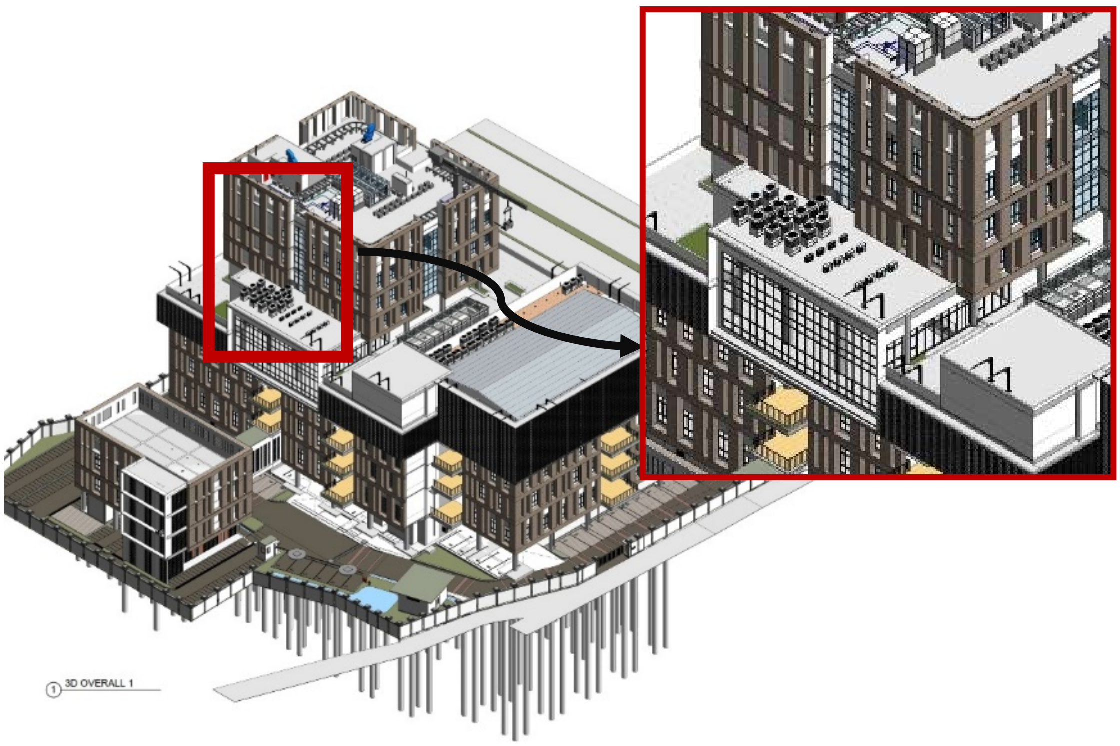


Fig. 12. Window area with minimal shading system on the west facade of the UNU building

Table 10. **Recommended window design strategies in Pontianak, Yogyakarta, and Banda Aceh**

City	Orientation & SF	SC_G	Recommended WWR for all shading systems
PONTIANAK	North *SF = 125 W/m²*	$0.67 \le SC_G \le 0.73$	WWR ≤ 25 %
		$0.39 \le SC_G \le 0.56$	35% < WWR < 45 %
	South *SF = 120 W/m²*	$0.67 \le SC_G \le 0.73$	WWR ≤ 30 %
		$0.39 \le SC_G \le 0.56$	35 % < WWR < 45 %
	East *SF = 139 W/m²*	$0.67 \le SC_G \le 0.73$	WWR < 25 %
		$0.39 \le SC_G \le 0.56$	30 % < WWR < 40 %
	West *SF = 186 W/m²*	$0.67 \le SC_G \le 0.73$	15 % < WWR < 20 %
		$0.39 \le SC_G \le 0.56$	23 % < WWR < 30 %
YOGYAKARTA	North *SF = 152 W/m²*	$0.67 \le SC_G \le 0.73$	23 % < WWR < 25 %
		$0.39 \le SC_G \le 0.56$	30 % < WWR < 40 %
	South *SF = 105 W/m²*	$0.67 \le SC_G \le 0.73$	WWR < 3 3%
		$0.39 \le SC_G \le 0.56$	40 % < WWR < 50 %
	East *SF = 170 W/m²*	$0.67 \le SC_G \le 0.73$	20% < WWR < 23%
		$0.39 \le SC_G \le 0.56$	30% < WWR < 33%
	West *SF = 178 W/m²*	$0.67 \le SC_G \le 0.73$	WWR < 20 %
		$0.39 \le SC_G \le 0.56$	25 % < WWR < 33 %
BANDA ACEH	North *SF = 116 W/m²*	$0.67 \le SC_G \le 0.73$	25 % < WWR < 35 %
		$0.39 \le SC_G \le 0.56$	35 % < WWR < 45 %
	South *SF = 142 W/m²*	$0.67 \le SC_G \le 0.73$	WWR < 25 %
		$0.39 \le SC_G \le 0.56$	33 % < WWR < 40 %
	East *SF = 166 W/m²*	$0.67 \le SC_G \le 0.73$	WWR < 20 %
		$0.39 \le SC_G \le 0.56$	25 % < WWR < 30 %
	West *SF = 200 W/m²*	$0.67 \le SC_G \le 0.73$	25 % < WWR < 20 %
		$0.39 \le SC_G \le 0.56$	23 % < WWR < 30 %

focused on key factors such as the window-to-wall ratio (WWR), solar factor (SF), glass shading coefficient (SCG), and shading system coefficient (SC), based on the OTTV framework outlined in SNI 6389:2020. The BIM-based OTTV calculator, developed using Autodesk Revit and Dynamo, generated over 3,600 window design variations for this study.

The results indicate that the WWR has a more pronounced effect on the OTTV than the SC, with reductions of up to 46 W/m² observed when the WWR decreased from 65 % to 25 %, regardless of orientation. The influence of the SC was minimal, especially at lower WWR values. Moreover, shading system dimensions had a greater impact on the OTTV than glazing properties alone, emphasizing the critical role of shading configurations in thermal performance. A key insight from the study is that maintaining a consistent shading fin-to-window ratio produces uniform OTTV reductions across all orientations, offering a reliable solution for energy-efficient design in tropical climates. Overall, optimizing the WWR and implementing standardized shading systems can enhance thermal comfort and reduce energy demand in warm-humid regions.

Future Research

A limitation of this study is the exclusion of energy cost calculations associated with the OTTV of the experimental window designs. Future research should incorporate these calculations to better understand the implications of applying different window design elements across diverse locations. Incorporating this analysis would provide a more comprehensive analysis of how the OTTV affects energy consumption and costs, offering valuable insights for optimizing window designs to improve energy efficiency and reduce operational expenses across diverse climatic contexts.

References

Abass, F., Ismail, L. H., Wahab, I. A., and Elgadi, A. A. (2020). Development of a model for OTTV and RTTV based on BIMVPL to optimize the envelope thermal performance. *IOP Conference Series: Materials Science and Engineering*, Vol. 713, 012009. DOI: 10.1088/1757-899X/713/1/012009.

Albatayneh, A. (2021). Sensitivity analysis optimisation of building envelope parameters in a sub-humid Mediterranean climate zone. *Energy Exploration & Exploitation*, Vol. 39, Issue 6, pp. 2080–2102. DOI: 10.1177/01445987211020432.

Al-Homoud, M. S. (2005). A systematic approach for the thermal design optimization of building envelopes. *Journal of Building Physics*, Vol. 29, Issue 2, pp. 95–119. DOI: 10.1177/1744259105056267.

Bahdad, A. A. S., Fadzil, S. F. S., and Onubi, H. O. (2021). Assessment of the thermal performance of vertical green walls using overall thermal transfer value based BIM simulation method: case study of residential buildings in sub-tropics. *Journal of Daylighting*, Vol. 8, Issue 2, pp. 294–312. DOI: 10.15627/JD.2021.23.

BSN (2020). *SNI 6389:2020. Standar Nasional Indonesia Konservasi energi selubung bangunan pada bangunan gedung*. [online] Available at: www.bsn.go.id [Date accessed: May 3rd 2024].

Chow, W. K. and Chan, K. T. (1995). Parameterization study of the overall thermal-transfer value equation for buildings. *Applied Energy*, Vol. 50, Issue 3, pp. 247–268. DOI: 10.1016/0306-2619(94)00023-8.

Eid, A. S., Aboulnaga, M. M., and Mahmoud, A. H. (2022). VPL-based code compliance checking for building envelope design using OTTV calculation. *IOP Conference Series: Earth and Environmental Science*, Vol. 1056, 012033. DOI: 10.1088/1755-1315/1056/1/012033.

Elhadad, S. and Orban, Z. (2021). A sensitivity analysis for thermal performance of building envelope design parameters. *Sustainability*, Vol. 13, Issue 24, 14018. DOI: 10.3390/su132414018.

Gondal, I. A., Syed Athar, M., and Khurram, M. (2019). Role of passive design and alternative energy in building energy optimization. *Indoor and Built Environment*, Vol. 30, Issue 2, pp. 278–289. DOI: 10.1177/1420326X19887486.

Habibi, S. (2019). Improving building envelope performance with respect to thermal, sound insulation, and lighting: a case study. *Building Acoustics*, Vol. 26, Issue 4, pp. 243–262. DOI: 10.1177/1351010X19877280.

Imran, M. (2019). Analisa hemat energi terhadap gedung GPIB Kelapa Gading melalui pendekatan OTTV. *Jurnal Linears*, Vol. 2, No. 2, pp. 79–91. DOI: 10.26618/j-linears.v2i2.3127.

Kusumawati, L., Setyowati, E., and Purnomo, A. B. (2021). Practical-empirical modeling on envelope design towards sustainability in tropical architecture. *Sustainability*, Vol. 13, Issue 5, 2959. DOI: 10.3390/su13052959.

Lim, Y.-W., Seghier, T. E., Harun, M. F., Ahmad, M. H., Samah, A. A., and Majid, H. A. (2019). Computational BIM for building envelope sustainability optimization. *MATEC Web of Conferences*, Vol. 278, 04001. DOI: 10.1051/matecconf/201927804001.

Mushtaha, E., Salameh, T., Kharrufa, S., Mori, T., Aldawoud, A., Hamad, R., and Nemer, T. (2021). The impact of passive design strategies on cooling loads of buildings in temperate climate. *Case Studies in Thermal Engineering*, Vol. 28, 101588. DOI: 10.1016/j.csite.2021.101588.

Nasrullah, N., Hamdy, M. A., Mustamin, M. T., and Faharuddin, A. (2024). Energy management model for air conditioning energy conservation in hotel buildings of Makassar City, Indonesia. *Civil Engineering and Architecture*, Vol. 12, No. 4, pp. 2755–2771. DOI: 10.13189/cea.2024.120419.

Natephra, W., Yabuki, N., and Fukuda, T. (2018). Optimizing the evaluation of building envelope design for thermal performance using a BIM-based overall thermal transfer value calculation. *Building and Environment*, Vol. 136, pp. 128–145. DOI: 10.1016/j.buildenv.2018.03.032.

Octarino, C. N. and Feriadi, H. (2021). Evaluasi kinerja selubung bangunan gedung agape universitas kristen duta wacana yogyakarta. *Langkau Betang: Jurnal Arsitektur*, Vol. 8, No. 2, pp. 86–97. DOI: 10.26418/lantang.v8i2.45436.

Pang, Z., O'Neill, Z., Li, Y., and Niu, F. (2020). The role of sensitivity analysis in the building performance analysis: a critical review. *Energy and Buildings*, Vol. 209, 109659. DOI: 10.1016/j.enbuild.2019.109659.

Pathirana, S., Rodrigo, A., and Halwatura, R. (2019). Effect of building shape, orientation, window to wall ratios and zones on energy efficiency and thermal comfort of naturally ventilated houses in tropical climate. *International Journal of Energy and Environmental Engineering*, Vol. 10, Issue 1, pp. 107–120. DOI: 10.1007/s40095-018-0295-3.

PT Asahimas Flat Glass Tbk. (2022). *Architectural glass*. [online] Available at: https://luminoindonesia.com/wp-content/uploads/2022/11/katalog-asahi.pdf [Date accessed November 5, 2024].

Purwanto, L. M. F. and Tichelmann, K. (2021). Effects of heat transfer through the walls of a catholic church in Semarang Indonesia simulated with Psi-Therm software and OTTV. *Civil Engineering and Architecture*, Vol. 9, No. 3, pp. 799–806. DOI: 10.13189/cea.2021.090321.

Rahmanda, A. P. and Suriansyah, Y. (2020). Upaya penurunan nilai ottv untuk penghematan energi pada hotel emersia lampung sesuai kriteria greenship. *Riset Arsitektur (RISA)*, Vol. 5, No. 0), pp. 18–35, DOI: 10.26593/risa.v5i01.4415.18-35.

Sani, A. A., Matondang, A. E., Kurniawan, G. K., and Mardiyanto, A. (2019). Kinerja termal selubung gedung kuliah kota bandar lampung ITERA. *Jurnal Arsitektur ARCADE*, Vol. 3, No. 3, pp. 267–273. DOI: 10.31848/arcade.v3i3.303.

Sari, L. H. and Rauzi, E. N. (2021). An evaluation of shading device in tropics utilising the sun-path diagram. ARTEKS: Jurnal Teknik Arsitektur, Vol. 6, No. 3, pp. 373–382. DOI: 10.30822/arteks.v6i3.877.

Sayadi, S., Hayati, A., and Salmanzadeh, M. (2021). Optimization of window-to-wall ratio for buildings located in different climates: an IDA-indoor climate and energy simulation study. *Energies*, Vol. 14, Issue 7, 1974. DOI: 10.3390/en14071974.

Seghier, T. E., Lim, Y. W., Ahmad, M. H., and Samuel, W. O. (2017). Building envelope thermal performance assessment using visual programming and BIM, based on ETTV requirement of Green Mark and GreenRE. *International Journal of Built Environment and Sustainability*, Vol. 4, Issue 3, pp. 227–235. DOI: 10.11113/ijbes.v4.n3.216.

Seghier, T. E., Lim, Y.-W., Harun, M. F., Ahmad, M. H., Samah, A. A., and Majid, H. A. (2022). BIM-based retrofit method (RBIM) for building envelope thermal performance optimization. *Energy and Buildings*, Vol. 256, 111693. DOI: 10.1016/j.enbuild.2021.111693.

Syafutri, R. F., Suryabrata, J. A., and Rahmawati, Y. (2023a). *Analisis sensitivitas elemen dinding selubung bangunan terhadap OTTV dengan kalkulator berbasis kerangka kerja BIM-VPL*. MSc Thesis in Architecture.

Syafutri, R. F., Suryabrata, J.A., and Rahmawati, Y. (2023b). Developing the building envelope thermal transfer value calculator based on BIM-VPL framework. *International Journal of Application on Sciences, Technology and Engineering*, Vol. 1, Issue 1, pp. 343–349. DOI: 10.24912/ijaste.v1.i1.343-349.

Tantisevi, K. and Sornsuriya, K. (2010). Building information model for evaluating the building energy performance: a case study. In: Tizani, W. (ed.). *Computing in Civil and Building Engineering, Proceedings of the International Conference*, June 30 – July 2, Nottingham, UK. Nottingham: Nottingham University Press, 84.

Tong, S., Wen, J., Wong, N. H., and Tan, E. (2021). Impact of façade design on indoor air temperatures and cooling loads in residential buildings in the tropical climate. *Energy and Buildings*, Vol. 243, 110972. DOI: 10.1016/j.enbuild.2021.110972.

Tukiainen, M. and Gaisma.com (2024). *Indonesia - sunrise, sunset, dawn and dusk times*. [online]. Available at: https://www.gaisma.com/en/dir/id-country.html [Date accessed June 6, 2024].

Widhayaka, S. A. and Rilatupa, J. E. D. (2021). Optimalisasi kinerja termal selubung bangunan unit hunian di rusunawa cibesut jakarta timur. *MODUL*, Vol. 21, No. 1, pp. 43–50. DOI: 10.14710/mdl.21.1.2021.43-50.

ИССЛЕДОВАНИЕ ВЛИЯНИЯ ДИЗАЙНА ОКОН НА ОБЩИЙ КОЭФФИЦИЕНТ ТЕПЛОПЕРЕДАЧИ С ПОМОЩЬЮ BIM-МОДЕЛИРОВАНИЯ В ГОРОДАХ С ТЕПЛЫМ И ВЛАЖНЫМ КЛИМАТОМ

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Аннотация
Введение: Проектирование оконных конструкций имеет решающее значение для энергоэффективности зданий в теплом и влажном климате, где солнечное излучение через окна существенно влияет на общий коэффициент теплопередачи. Во многих зданиях в Индонезии особенности проектирования ограждающих конструкций с учетом местного климата не учитываются должным образом, что, вероятно, связано с ограниченным экспериментальным исследованием подходящих проектов в разнообразных климатических условиях страны. **Цель исследования:** изучить влияние различных стратегий проектирования окон на теплопередачу зданий в индонезийских городах. **Методы:** для оценки влияния конструкций окон на общий коэффициент теплопередачи был проведен анализ чувствительности в трех географически различающихся индонезийских городах: Банда-Ачех (северное полушарие), Понтианак (экватор) и Джокьякарта (южное полушарие). При помощи BIM-калькулятора общего коэффициента передачи в Autodesk Revit и Dynamo было сгенерировано 3600 вариантов оконных конфигураций, представленных на 180 графиках. Варьировались следующие параметры: соотношение площади окна к площади стены, характеристики остекления и тип затеняющего устройства. **Результаты:** анализ показал, что соотношение площади окна к площади стены оказывает более существенное влияние на общий коэффициент теплопередачи, чем коэффициент затенения, причем при снижении соотношения с 65 % до 25 % уменьшение общего коэффициента теплопередачи составило до 46 Вт/м². Размеры элементов затенения оказали большее влияние на общий коэффициент теплопередачи, чем характеристики остекления, что подчеркивает важность конфигурации затенения для теплоэффективности здания. Оптимизация соотношения площади окна к площади стены и внедрение стандартизированных систем затенения могут существенно повысить энергоэффективность и комфорт, особенно в тропических климатических условиях с высокой инсоляцией. Результаты исследования подчеркивают необходимость изучения комбинаций соотношения площади окна к площади стены и систем затенения на ранних стадиях проектирования для достижения соответствия энергетическим стандартам при сохранении гибкости проектных решений.

Ключевые слова: проектирование оконных конструкций, энергоэффективность, общий коэффициент теплопередачи, анализ чувствительности, здания в теплом и влажном климате, индонезийские здания.