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The Influence of Shading Devices on OTTV and Natural Daylighting Performance in the Campus Gallery

Fariz Hidayat, Agus Dwi Hariyanto*, Jimmy Priatman

Faculty of Civil Engineering and Planning, Petra Christian University, Indonesia

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Abstract Global warming is increasing, and buildings with glass envelopes are one of its contributing factors. Glass increases visual comfort but can also increase heat gain, which results in increased energy needs. Indonesian National Standard (SNI) 6389:2020 provides energy conservation strategies for building envelopes, including using external shading devices to reduce the Overall Thermal Transfer Value (OTTV). On the other hand, this strategy can reduce the intensity of natural lighting, thereby increasing the energy needed for artificial lighting. Therefore, optimization is required. This study aimed to evaluate the types and configurations of shading devices that can optimize OTTV and natural lighting performance and to identify how much influence the OTTV variables and natural lighting performance have. The method used was quantitative, with experiments using the Ecotect and Ladybug Tools simulation programs. The results showed that the combination type of external shading device could reduce OTTV to a maximum limit of 16% and maintain the intensity of natural lighting (sDA) within the threshold of 61.8% and free from glare (sGA) by 94.9%. There is a correlation between OTTV and natural lighting performance. The increase in OTTV is directly proportional to the intensity of natural lighting and glare. The highest correlation was found in the vertical type, followed by the horizontal type, and the lowest in the combination.

Keywords OTTV, Natural Daylighting, Performance, Shading Device, Gallery

1. Introduction

The problem of global warming is worsening, causing climate change that impacts thermal comfort and health conditions. Energy production and use are the primary sources of global warming, producing greenhouse gases [1]. Cities are among the main contributors to global warming [2],[3] because buildings in cities require energy to operate properly. Globally, buildings contribute about 30% of total energy consumption and produce about 26% of global emissions [4],[5]. The high energy needs of buildings aim to achieve various aspects of comfort for their users. These aspects of comfort include lighting, thermal comfort, air quality, and acoustics [6],[7],[8].

Building facades dominated by glass materials impact the building's energy needs. On the one hand, glass facades play a role in increasing lighting performance, but on the other hand, they can be a significant source of heat, resulting in an increase in building temperature [9],[10]. Another impact of rising temperatures in buildings is reduced thermal comfort, contributing to increased use of electrical energy for air conditioning. Approximately 10% of global electricity is used for air conditioning and contributes approximately 4% of greenhouse gas emissions [11]. Therefore, energy efficiency and savings are top priorities in designing buildings in areas with hot climates [12]. It is a concern for architects when designing buildings with glass facades, especially in hot climates such as Indonesia.

As a sector that plays an essential role in energy conservation, buildings have a strategic role [13]. In Indonesia, there are specific guidelines and policies for energy conservation, which are regulated in the Indonesian National Standard (SNI) 6389 of 2020 concerning "Energy conservation of building envelopes in buildings" [14]. This standard guides in calculating OTTV (Overall Thermal Transfer Value), one way to minimize energy use without sacrificing user comfort. OTTV regulates the design of building facades to meet the heat gain value limit and reduce the energy requirement for air conditioning [15]. However, the building facade and the characteristics of the local climate are the factors that influence the energy efficiency of the building [16],[17]. In addition, OTTV is also used as a measure of the thermal transfer value in building facades that use air conditioning [18]. Thus, reducing OTTV can reduce dependence on air conditioning [19].

The Standard National Indonesia (SNI) 6389-2020 on energy conservation and recommendations for building envelopes has several strategies to reduce heat gain on the building envelope. One uses external shading devices on glass windows to protect the building from solar radiation. Because in tropical areas, protection from the sun is crucial [20]. However, in addition to reducing heat gain, the use of shading devices also has the potential to affect the performance of natural lighting due to the shadowing on the windows. Although shading devices can reduce solar heat, they can also increase the need for artificial lighting [21]. An example of shading devices that can impact natural lighting performance is using combination-type shading devices, namely egg-crate type. As stated by Khanh Phuong et al. [9], combining shading devices can improve thermal performance and reduce heat gain, but they can also reduce the availability of natural lighting. So, the architect needs to choose the right external shading device [22].

It is necessary to protect windows to reduce solar heat gain and improve energy efficiency in buildings while still paying attention to the entry of sunlight through the windows [12]. Architecture must be able to provide both thermal and visual comfort for its users [23]. Balancing thermal comfort and the availability of natural lighting is critical to creating a sustainable and comfortable space [24],[25]. In facing this problem, it is necessary to evaluate various types and configurations of external shading devices in a case study of a building. Its function is to balance thermal performance (OTTV) and natural lighting. In addition, the researcher needs to identify the effect of OTTV on the facade with external shading devices on natural lighting performance. Based on these problems, this study aims to evaluate the types and configurations of shading devices that can optimize the OTTV value while considering the performance of natural lighting. In addition, this study seeks to identify the extent of its influence on both variables (OTTV and natural lighting).

1.1. External Shading Devices in Integrating Thermal Performance and Daylighting

Several studies aim to reduce energy consumption by analyzing thermal performance and daylighting, and considering the potential use of external shading devices to reduce energy consumption and ensure optimal daylighting levels. In a Seoul, South Korea study, various configurations of shading devices, such as overhangs, horizontal louvers, fins, and vertical panels, were tested to reduce energy use for space cooling and increase daylighting in residential buildings. The findings showed that overhangs and vertical panels reduced cooling requirements by 19.7% and 17.3%, respectively, with little sacrifice in visual comfort, such as Daylight Factor (DF) at 1.9% and in Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) by 2% [26].

The use of external shading devices significantly reduced energy requirements for cooling. However, the impact was a 20% decrease in UDI percentage in an office space on the island of Réunion, France [27]. In the context of reducing energy consumption through OTTV by integrating natural lighting when using external shading devices, as stated by Adi et al. [28], in addition to engineering the Window-to-Wall Ratio (WWR) and type of glass, the level of shading of the shading device against the sun can affect OTTV and natural lighting simultaneously.

1.2. External Shading Devices in Integrating Thermal and Glare Performance

The effect of shading devices on thermal performance and natural lighting also allows for glare reduction. As stated by Nguyen et al. [29], shading devices can also minimize heat through windows into the room, thereby reducing OTTV and glare due to excess light in the perimeter area. If a user cannot control the light entering the room, it will cause several risks of glare or lack of lighting intensity [8].

A case study of office space in Toronto, Canada, evaluates the benefits of light shelf shading devices considering different windows and orientations. The results showed that the optimal distribution of sunlight can improve visual comfort and reduce glare. Light shelves also increased the floor area within the UDI threshold by 11.3% [30].

1.3. Climatic Conditions on Thermal Performance and Daylighting

One approach to managing energy use and maintaining building performance is passive design [31]. However, this highly depends on future climate conditions and surrounding weather fluctuations [32]. Therefore, the impact of climate on long-term energy use patterns should be addressed [33]. In energy-saving strategies through OTTV calculations, climate plays an important role. The main significant factors in OTTV calculations are climate data and building room conditions [34]. In OTTV calculations, we use climate data to calculate solar heat gain through windows. However, calculating solar heat gain through windows requires solar factor data based on the location of the building and also data on the amount of solar radiation to calculate the shading coefficient needed for external shading devices.

Furthermore, this research uses several metrics to evaluate the performance of natural lighting, one of which is Daylight Autonomy (DA). It is based on the Climate-Based Daylight Model (CBDM), which considers realistic sun and sky conditions based on local climate data [35],[36]. Before CBDM, the daylighting evaluation used the Daylight Factor (DF) metric, which describes the amount of lighting outdoors and under CIE standard cloudy skies [37]. However, DF does not consider the influence of building orientation, which can affect the precision and accuracy of daylighting evaluation [38]. In addition, a CBDM-based index for evaluating glare potential in daylighting is Daylight Glare Probability (DGP). DGP is part of daylighting metrics used to assess daylight quality [39].

1.4. Natural Lighting According to GBCI Guidelines and Glare Index

LEED v4 sets a minimum natural lighting standard of 300 lux per year (sDA 300/50%) for at least 55% to 75% of the total floor area. Meanwhile, according to the guidelines from the Green Building Council Indonesia (GBCI), the natural lighting standard is 300 lux from 30% of the total floor area [40]. LEED and GBCI use the same method to determine their standards, but LEED applies stricter rules.

The Glare Index, when using the DGP metric, is regulated by the EN 17037 standard. The threshold value for the Glare Index used to distinguish between disturbing and non-disturbing glare is a maximum of 40% (Perceptible Glare) [41].

2. Materials and Methods

The method used in this study is an experiment using a simulation program. The simulation makes it possible to evaluate design choices and performance in the area around the environment [42]. In addition, we use number processing and statistical programs to facilitate the processing and analysis of data obtained from experimental results, such as Microsoft Excel and IBM SPSS.

2.1. Simulation Program Used

Researchers use the Autodesk Ecotect 2011 program to obtain the SCeff (effective shading coefficient) value from the OTTV calculation. The Ecotect can simulate the percentage of the shaded area according to the location point, orientation, and shape of the building. This program has been discontinued, but it is more accurate than calculating manually, especially in buildings with more complex shapes. In addition, Ecotect is also able to calculate shading designs outside the three types set by the SNI 6389 standard [43].

In addition, researchers use Rhinoceros, and a plugin called Ladybug Tools to simulate various performances, such as energy, natural lighting, wind, and others. Ladybug tools have been built from validated engines such as EnergyPlus, Radiance, Therm/window, and OpenFoam [44]. LMN Architect uses Ladybug Tools in its design process, so proficiency in using it is required [45]. This tool is widely used in research and during the design process to evaluate the performance of a building or environment. This research uses it to analyze natural lighting performance and the potential for glare.

2.2. Research Object

The case study used for this research is Gallery Room at Q Building of Petra Christian University, Surabaya – Indonesia (Figure 1). The campus building is used for learning and teaching processes, so it requires optimal thermal comfort and lighting intensity.

Figure 1. Facade and interior of the Q Building Gallery

Criteria for selecting research objects:

a. The facade model of the Gallery Room on the north side with full glass, allows for excessive exposure to solar radiation,
b. The north side of the Q building has the highest OTTV value, as found in previous research by Gendo [46].
c. Window to Wall Ratio in the Gallery Room on the north side reaches 85%,
d. The SCeff value in the Gallery Room on the north side reaches 0.9, so it needs to be shaded with effective shading tools.

2.3. Research Parameter

a. Percentage of OTTV reduction: In this study, we researched only one spatial object, which was determined as a partial OTTV or per segment of a building facade. Thus, the optimization limit is only calculated based on the maximum percentage reduction.

b. Natural lighting according to LEED v4: To obtain optimal natural lighting, which can connect its occupants with the outdoors, strengthen circadian rhythms, and reduce electricity use for artificial lighting. LEED (Leadership in Energy and Environmental Design) sets rules for natural lighting that can be demonstrated through annual computer simulations. The metric used is spatial daylight autonomy (sDA), which is at least 55% and 75% of the total space area, getting natural lighting of 300 lux.

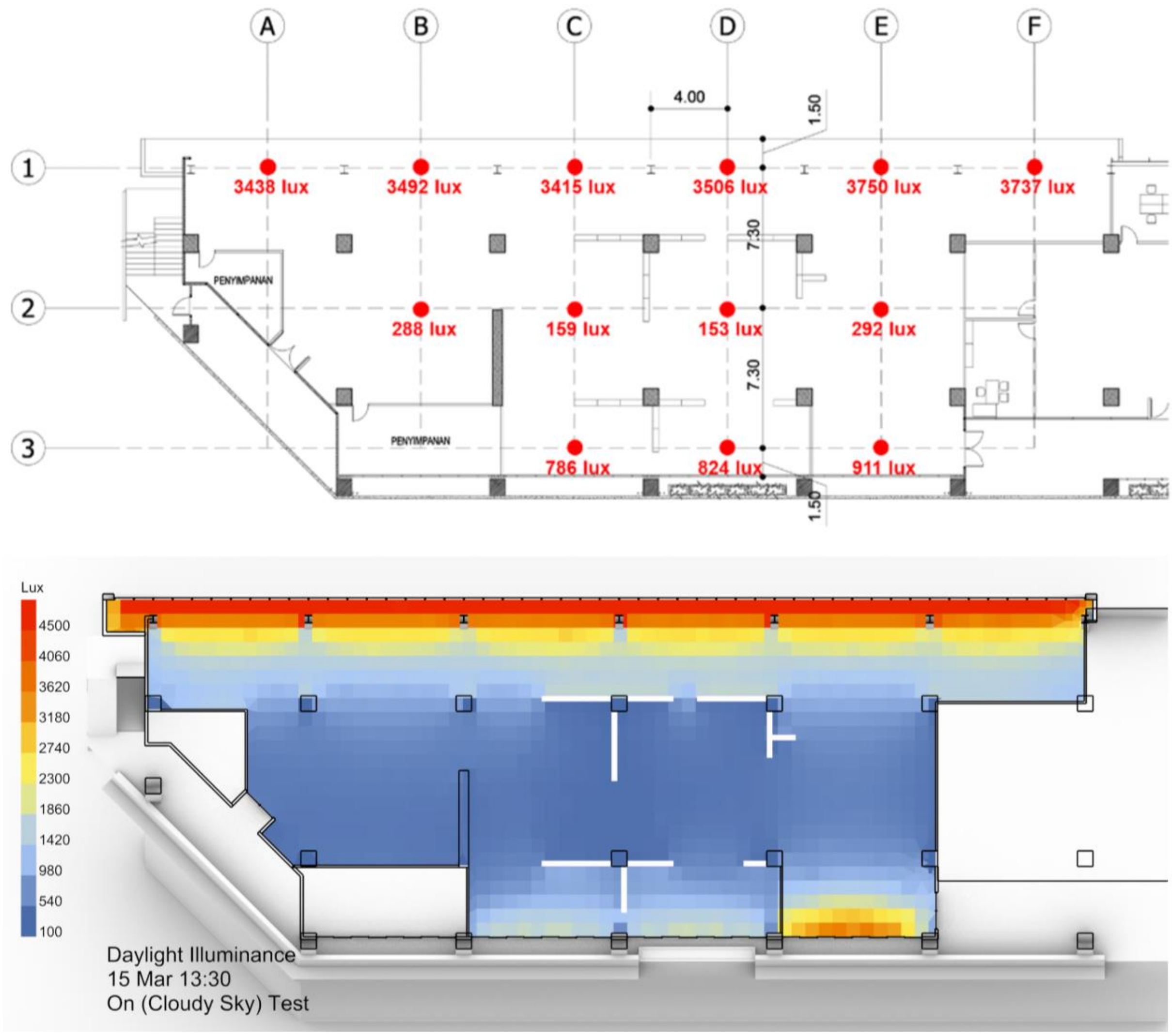
c. Percentage of glare reduction: Natural lighting is inseparable from the potential for glare that interferes with the view, especially in rooms with large openings. So, the percentage of avoiding glare will also be evaluated using Daylight Glare Probability (DGP) as its metric.

2.4. Data Collection and Analysis

The researcher calculated OTTV data using Microsoft Excel. Meanwhile, natural lighting data obtained in the field was used as a reference for calibration against data from the simulation. Furthermore, annual simulations were conducted to obtain complete natural lighting data according to the metrics used (sDA & sGA%).

The simulation data were analyzed using statistical programs to make it easier to determine results by the parameters (percentage of OTTV reduction, natural lighting intensity standards according to LEED v4, and percentage free from glare). The researcher calibrated the field data by simulating natural lighting with specific times, hours, and weather conditions. Per the previous field data, the simulation results were accurate, as shown in the R Square value of 0.973 with a reasonably good distribution graph (Figure 2).

The simulation was taken according to current field conditions. The time and conditions, when the field data was taken, were on March 15 at around 13:30 with cloudy weather conditions.



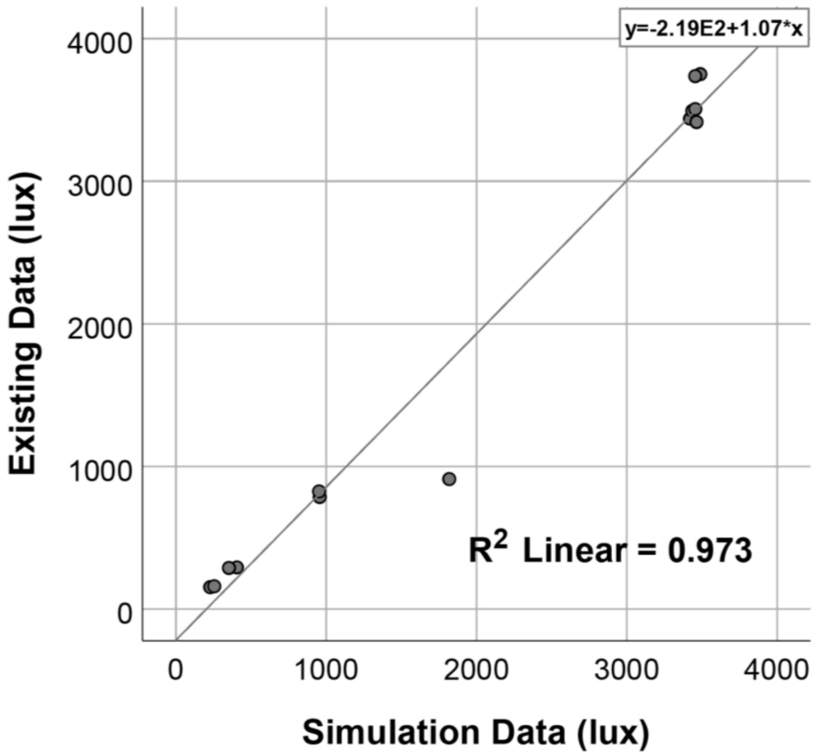


Figure 2. Calibration of existing lux intensity with simulated data

3. Results and Discussion

3.1. OTTV Calculation of the Gallery

To determine OTTV, researchers need to know the thermal transmission value (U-value), namely the heat transfer rate from a material (Table 1). The U-value can be determined by first calculating the thermal resistance value.

Table 1. U-value material at the gallery

Material Type	U-Value (W/m^{2}k)
ACP + GRC Board	0.64
ACP + Brick	0.53
ACP + Concrete Beam	0.41
ACP + Concrete Column	0.47
Concrete Column	0.99
Concrete Beam	1.59
Brick	1.73
Indoflot Clear Glass 12mm	5.94
Indoflot Clear Glass 10mm	6.20

Researchers used Autodesk Ecotect simulation to calculate the effective shading coefficient (SCeff) value on complex building shapes, such as the case study building. This software is used only to calculate the SCeff value; then, the OTTV will be recalculated manually based on SNI 6389, 2020. The calculation results show that the north direction has a reasonably high SCeff value of 0.90, which means that exposure to solar heat is higher than in the south direction, which is only 0.35 (see Table 2).

Table 2. The calculation of SCeff of the gallery façade

	SC 21st	SC 22nd	SC 23rd	SC 22nd	SC Annual
north direction	March	June	September	December	
	1	0.82	1	1	**0.9**
	SC 21st	SC 22nd	SC 23rd	SC 22nd	**SC Annual**
south direction	March	June	September	December	
	1	0.82	1	1	**0.35**

Furthermore, the OTTV of each facade in the gallery room on the 8th floor of the Q building will be calculated based on the formula in the SNI 6389, 2020 guidelines. Researchers will use the facade with the highest OTTV results to research the effect of shading devices on optimizing OTTV and their integration with natural lighting.

The total OTTV on the gallery envelope is 66.97 W/m^2, with the north facade having the highest partial OTTV value of 131.08 W/m^2 (Table 3). Therefore, the northern facade area was chosen as the research object to test the effect of shading devices on OTTV optimization and its integration with natural lighting performance. This part of the facade has the highest SCeff and OTTV values.

Table 3. The calculation result of OTTV

Orientation	Partial OTTV (W/m²)	Fa ҫade Area	Thermal Transmittance
Fa ҫade (North)	131.08	187.49	24,577.09
Facade (South)	49.67	169.72	8,430.35
Facade (West)	3.96	44.92	178.08
Facade (East)	0.96	59.65	57.39
Facade (Southwest)	6.21	38.14	237.01
Total Area of DKV Gallery Facade		499.92	33,479.93
OTTV of The Gallery Room $\frac{33,479.93 \text{ Watt}}{499.92 \text{ m}^2}$		**66.97 W/m²**	

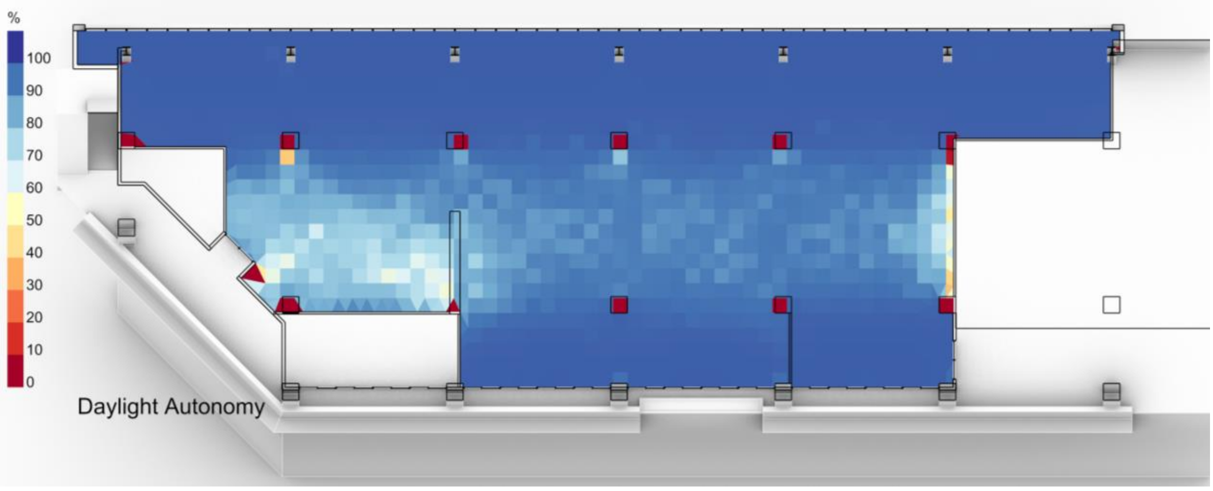


Figure 3. The sDA simulation of the gallery

3.2. Simulation of Natural Lighting and Glare in the Gallery

The simulation results of annual natural lighting obtained an excellent value. For the sDA value, the researcher got a figure of around 96% (Figure 3). Therefore, the natural lighting intensity of the gallery is a good performance. Thus, the proposed design model for shading devices must maintain the sDA value based on the LEED v4 standard so that natural lighting remains optimum.

Natural lighting of more than 3000 lux occurs in 12% of the interior gallery area (Figure 4) and is evenly distributed on the northern facade due to the large Window-to-Wall Ratio (WWR) value of 85%. The high sDA value produces high lux intensity, which has the potential to cause disturbing glare. Therefore, further simulation is needed to identify the potential for glare.

Natural lighting intensity of more than 3000 lux evenly on the north side may cause glare for gallery visitors. For this reason, researchers identified the Daylight Glare Probability (DGP) value on the north and south views and the annual glare value. DGP simulations were conducted on March 21, June 21, September 21, and December 21 at 09.00, 12.00, and 15.00. The visualization results of DGP were set using view-based simulations to analyze the potential for glare in the entire glass opening area. Figure 5 shows the measurement points.

The DGP simulation results show that the north orientation is dominated by uncomfortable glare intensity at Disturbing Glare at 40% and Intolerable Glare above 45%. Figure 6 shows a significant difference between glare intensity in the north and south directions.

Researchers re-conducted annual glare simulations to obtain data on the percentage and area affected by disturbing glare with a glare limit of 40% (Disturbing Glare) and areas free from glare. For this reason, researchers used imageless-based simulations but were able to calculate the percentage of glare at each point, orientation direction, and annual percentage.

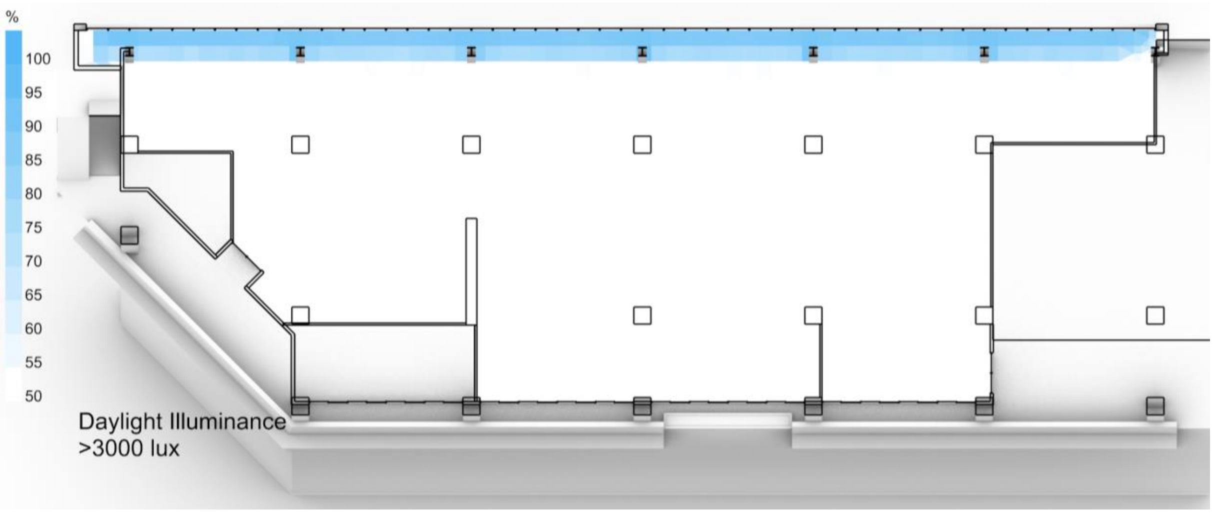


Figure 4. Area exposed to 3000 lux light in the gallery

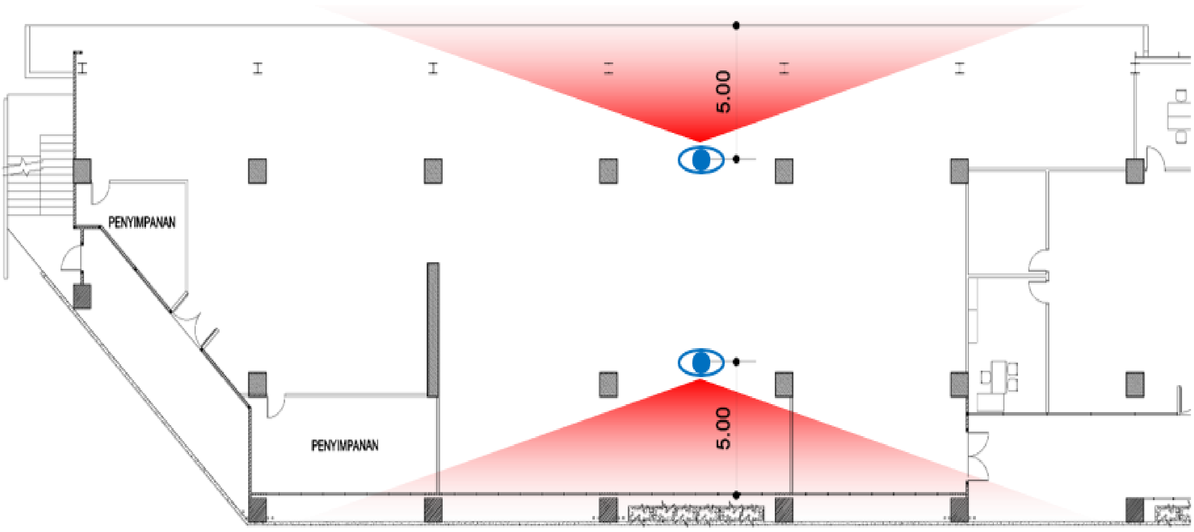
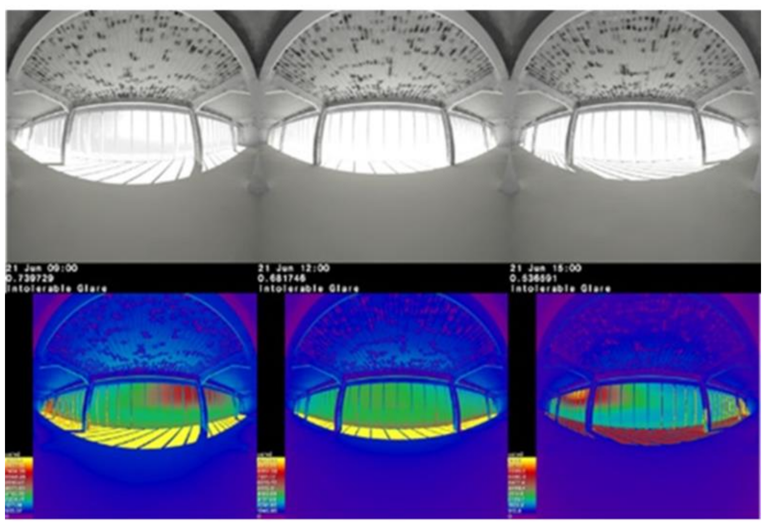
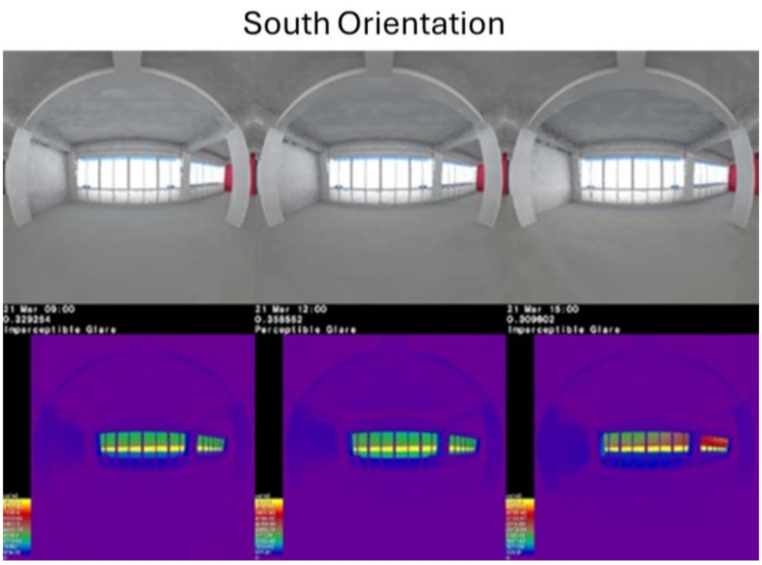


Figure 5. DGP measuring point in gallery





Orientation	Time	21st March	21st June	21st Sept	21st Dec
North	09.00	0.436	0.739	0.442	0.385
	12.00	0.472	0.681	0.454	0.416
	15.00	0.371	0.536	0.363	0.358
South	09.00	0.329	0.290	0.332	0.340
	12.00	0.358	0.320	0.349	0.369
	15.00	0.309	0.298	0.305	0.400

Figure 6. View-based DGP simulation of gallery

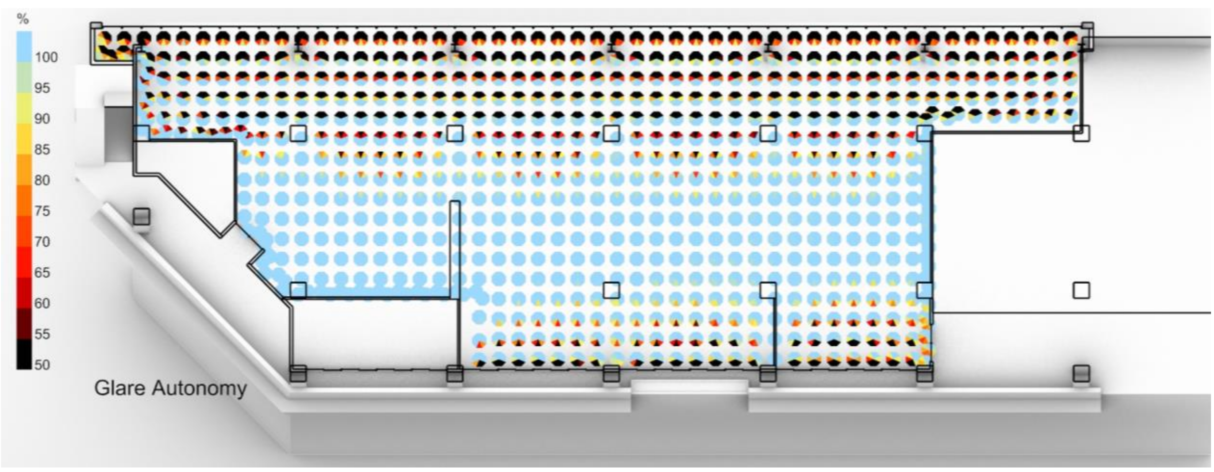


Figure 7. Simulation of sGA in gallery

3.3. OTTV Data Recap and Natural Lighting Performance of the Gallery

The existing condition of the gallery for its OTTV value is 66.97 W/m^2 and the annual natural lighting value is 96.26%, with a glare-free 64.97% (Figure 8). This research will improve the existing OTTV with the annual natural lighting limit within the parameter threshold of LEED v4. The optimization is done to keep the performance of natural lighting optimal, both in maintaining the intensity of light and the intensity of incoming glare.

The simulation results showed a yearly glare-free (sGA) of 65% and a Disturbing Glare of 35% with high and even glare intensity in the north orientation. Figure 7 shows the simulation result of sGA in the galley space.

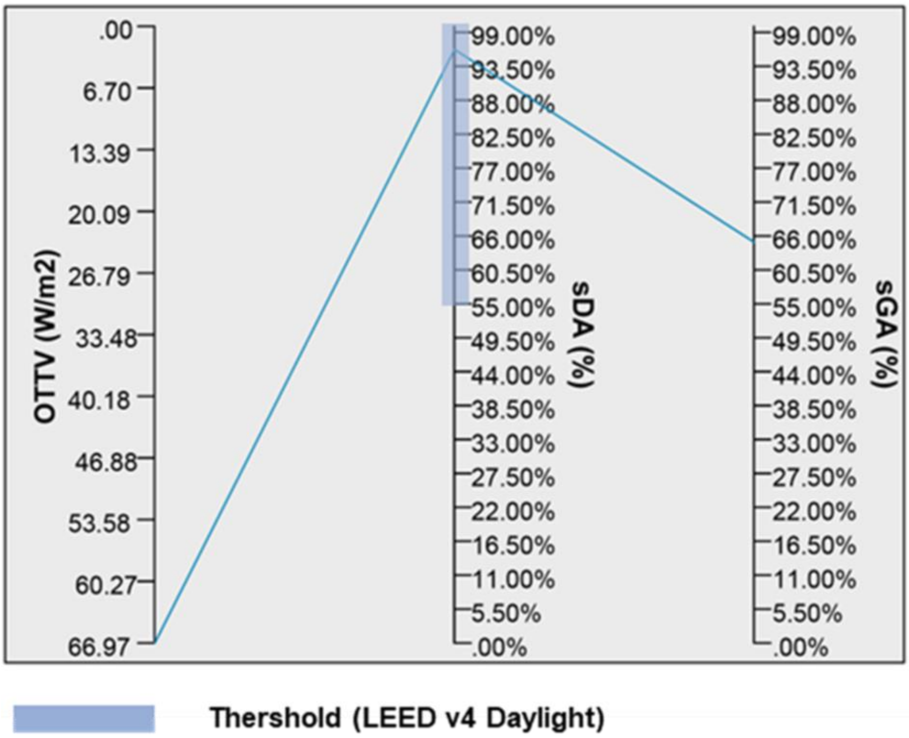


Figure 8. OTTV data recap and natural lighting performance of the gallery

3.4. External Shading Device Analysis

The researchers used the basic types of shading devices for analysis: vertical, horizontal, and combination. The three types were analyzed using various distances between the shading device elements, length, and inclination angle configurations. The researchers conducted further analysis of the external shading device data to obtain the best results for OTTV performance and natural lighting in the gallery space.

3.4.1. Vertical Shading Device Analysis

The distance configuration for the vertical shading devices is 50 cm, 100 cm, and 150 cm, with the various lengths of the shading devices 50 cm, 100 cm, and 150 cm. The researcher determines the maximum length of 150 cm due to the significance of the OTTV value reduction factor and the construction load factor for the shading device. In addition, the researcher determined the multiple of the slope angle per 10 degrees due to the significance of the OTTV value reduction, which was not significant. For vertical shading devices, the best result is type 1 with a configuration of the distance between the shading devices of 50 cm, a length of 150 cm, and a slope angle of -10 º (Figure 9A). The decrease in the OTTV value is 13.66%, natural lighting is at 61.2%, and the percentage of avoiding glare has increased by 25%.

3.4.2. Horizontal Shading Device Analysis

For horizontal shading devices, the configuration is the same as the vertical type: the length is 50cm, 100cm, and ends with a maximum of 150cm. However, the angle of the horizontal shading device does not have a negative value because there will be an ineffective design of the shading device, where the shading device will face upwards, which has the potential to catch rainwater and allow for additional heat gain and an insignificant decrease in OTTV. The second model of type 2, with a configuration of density between shading devices of 100cm, a length of 100cm, and a slope angle of 50 º, is the best result of the horizontal shading device (Figure 9B). The decrease in OTTV value was 15.71%, natural lighting was at 56.1%, and the percentage of avoiding glare increased by 30.96%.

3.4.3. Combination Shading Device Analysis

The combination of shading devices starts with a density configuration and a length of 50, 75, 100, and 125. It ends with a maximum of 150cm due to the insignificant OTTV value reduction factor and the construction load factor for the shading device if the length is more than 150cm. For the combination of shading devices, there is no angle slope because this shading device will provide a significant change in the decrease in natural lighting intensity if it has an angle slope, so it is not practical. For the combination of shading devices, the first model of type 1, with a density configuration between shading devices of 50cm, a vertical length of 50cm, and a horizontal length of 75cm, has the best results (Figure 9C). With this configuration, the OTTV value decreases by 16% and cannot be reduced any lower because the SCeff value in the north direction has reached its maximum threshold of 0.659. Furthermore, natural lighting is at 61.8%, and the percentage of glare avoidance increases by 31.54%.

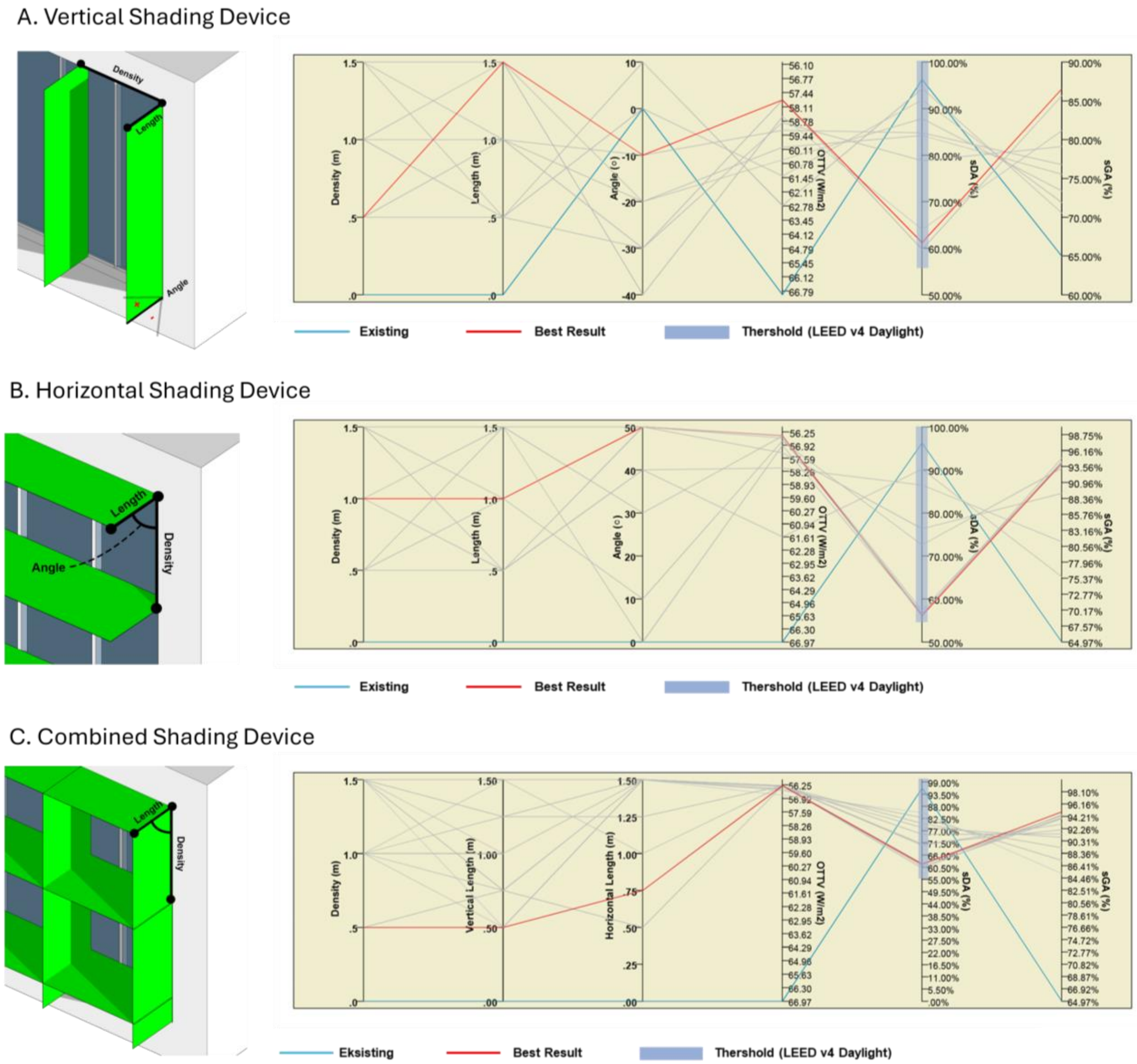


Figure 9. The analysis results of vertical shading devices (A), horizontal shading devices (B), and combined shading devices (C) in the gallery

3.4.4. Best Results for External Shading Devices

All the best results for each shading device will be re-selected through Table 4 to determine the best type to optimize OTTV and natural lighting performance and glare. From the results of the comparison table, the best results were obtained for the combination shading device type (egg-crate) with a density configuration of 50cm, vertical length of 50cm, and horizontal length of 75cm (see Table 3 and Figure 10):

a. Has the most optimal OTTV (100% shaded with SCeff reaching the threshold for the north side of 0.65) with a decrease to the maximum limit of 16%,
b. The highest annual daylight (sDA) percentage of other shading device types (61.8%),
c. Able to be free from glare (sGA) with the highest percentage of other shading device types (94.9%).

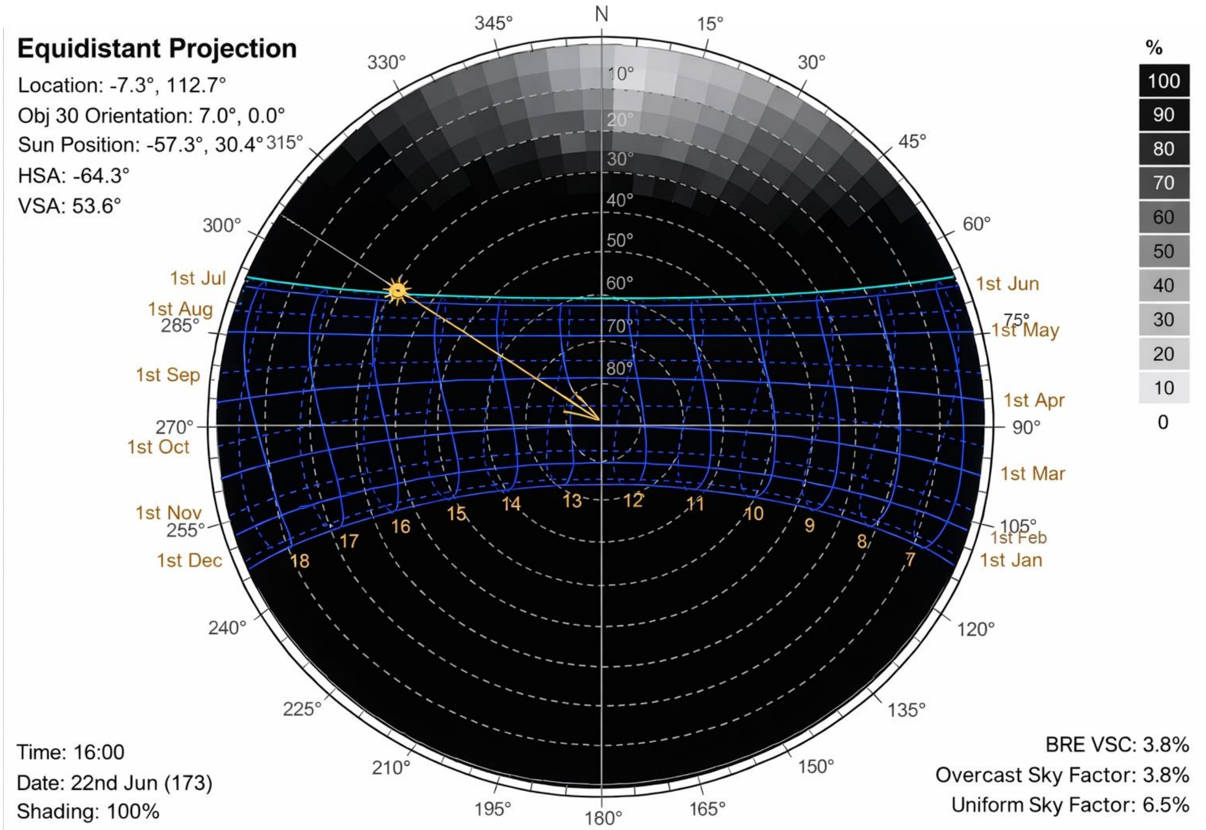
The combination type shaded the entire glass area on the gallery's facade so that it is not exposed to direct sunlight (Figure 12). Therefore, it can reduce OTTV to the maximum limit. The natural lighting produced is also better than the vertical and horizontal types. In addition, it can also minimize incoming glare well compared to the vertical and horizontal types.

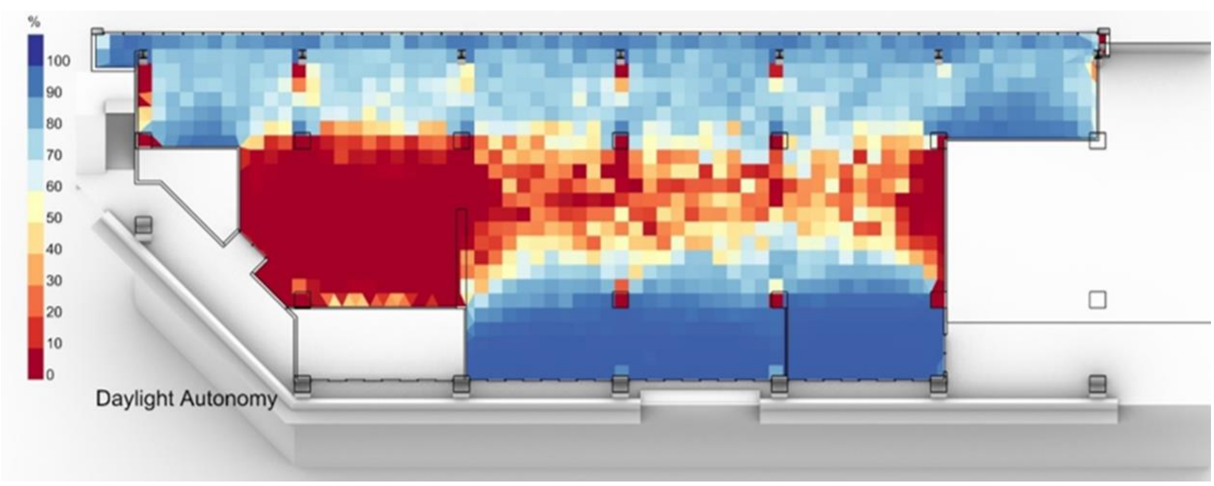
3.5. Regression Test on External Shading Devices

After obtaining data from the results of the OTTV analysis, natural lighting, and glare-free on each type of shading device, the researcher conducted a regression test to determine the extent of the influence between variables on each type of shading device used (vertical, horizontal, and combination). In addition, to determine how much impact there is between variables, namely by looking at the value of the coefficient correlation (r).

Table 4. The best results of the shading device analysis in the gallery

Type	Density (m)	Length (m)	Angle (◦)	SCeff	OTTV (W/m^2)	Spatial Daylight Autonomy (sDA%)	Spatial Glare Autonomy (sGA%)
Vertical	50	150	-10	0.693	57.79	61.2%	86.6%
Horizontal	100	100	50	0.662	56.45	56.1%	94.1%
Type	**Density (cm)**	**Vertical Length (cm)**	**Horizontal Length (cm)**	**SCeff**	**OTTV (W/m^2)**	**Spatial Daylight Autonomy (sDA%)**	**Spatial Glare Autonomy (sGA%)**
Combination (Eggcrate)	50	50	75	0.659	56.30	61.8%	94.9%





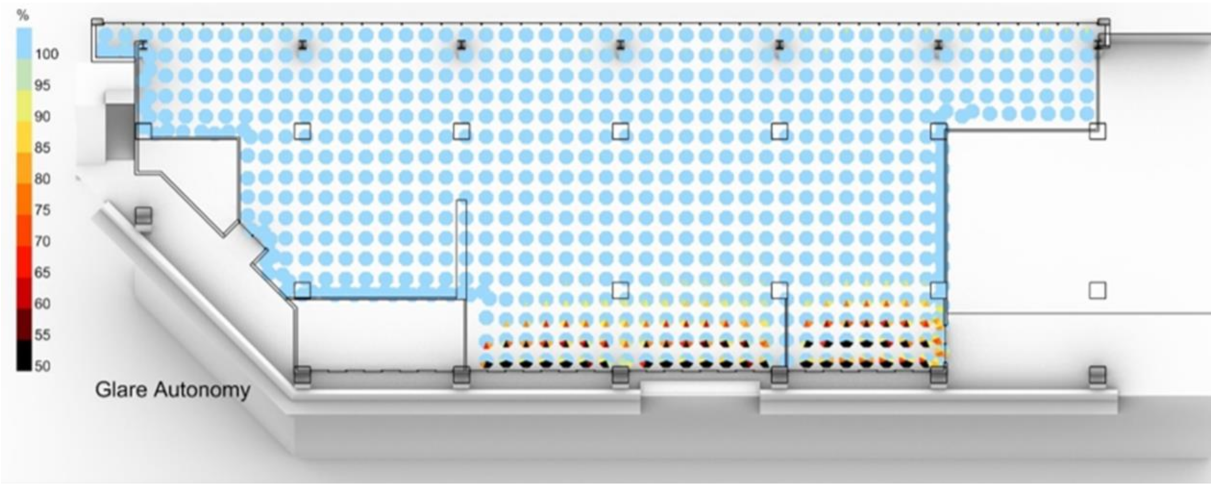


Figure 10. Simulation visualization for combined shading devices in the gallery space

3.5.1. Vertical Shading Device

For a significant value (Sig.) of 0.000. This value is smaller than the probability of 0.01, so the OTTV variable influences the performance variables of natural lighting and glare-free (Figures 11 and 12). In the vertical shading device, the determination coefficient (R Square):

a. OTTV against natural lighting (sDA) is 0.599

b. OTTV against glare-free (sGA) is 0.816

OTTV & sDA

		OTTV	sDA
OTTV	Pearson Correlation	1	.774**
	Sig. (2-tailed)		.000
	N	99	99
sDA	Pearson Correlation	.774**	1
	Sig. (2-tailed)	.000	
	N	99	99

**. Correlation is significant at the 0.01 level (2-tailed).

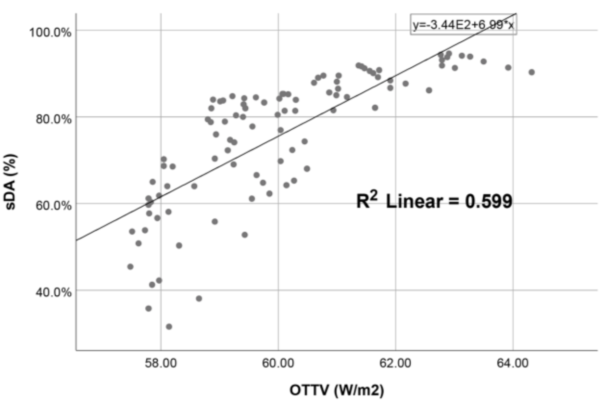


Figure 11. Correlation and regression tests of OTTV & sDA on vertical shading devices

OTTV & sGA

		OTTV	sGA
OTTV	Pearson Correlation	1	-.903**
	Sig. (2-tailed)		.000
	N	99	99
sGA	Pearson Correlation	-.903**	1
	Sig. (2-tailed)	.000	
	N	99	99

**. Correlation is significant at the 0.01 level (2-tailed).

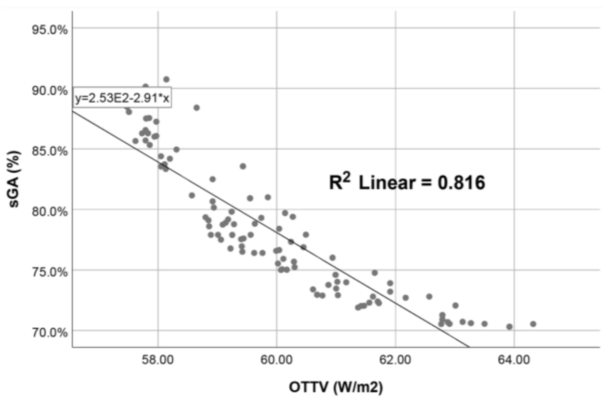


Figure 12. Correlation and regression tests of OTTV & sGA on vertical shading devices

3.5.2. Horizontal Shading Device

For a significant value (Sig.) of 0.000. This value is smaller than the probability of 0.01 so the OTTV variable influences the performance variables of natural lighting and glare-free (Figures 13 and 14). In the horizontal shading device, the determination coefficient (R Square):

a. OTTV against natural lighting (sDA) is 0.599

b. OTTV against glare-free (sGA) is 0.816

OTTV & sDA

		OTTV	sDA
OTTV	Pearson Correlation	1	.568**
	Sig. (2-tailed)		.000
	N	54	54
sDA	Pearson Correlation	.568**	1
	Sig. (2-tailed)	.000	
	N	54	54

**. Correlation is significant at the 0.01 level (2-tailed).

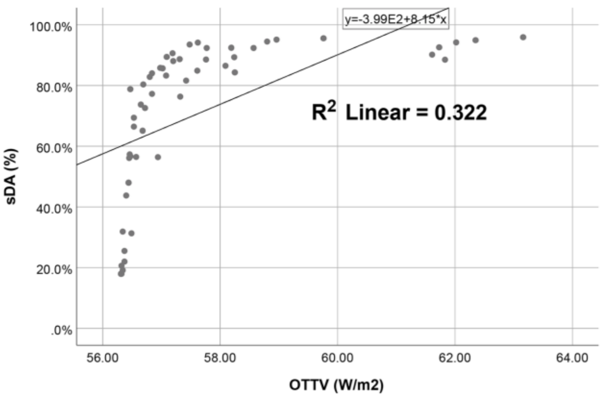


Figure 13. Correlation and regression tests of OTTV & sDA on horizontal shading devices

OTTV & sGA

		OTTV	sGA
OTTV	Pearson Correlation	1	-.854**
	Sig. (2-tailed)		.000
	N	54	54
sGA	Pearson Correlation	-.854**	1
	Sig. (2-tailed)	.000	
	N	54	54

**. Correlation is significant at the 0.01 level (2-tailed).

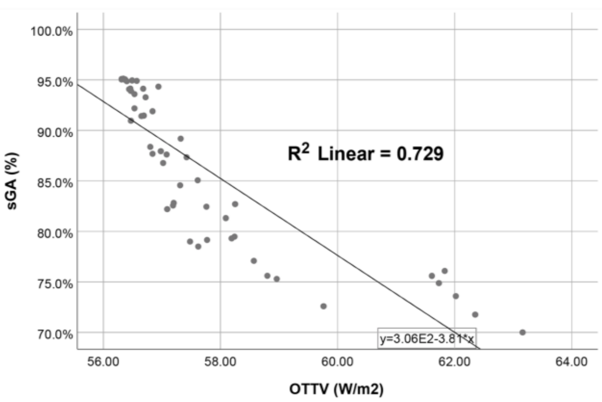


Figure 14. Correlation and regression tests of OTTV & sGA on horizontal shading devices

3.5.3. Combination Shading Device (Egg-Crate)

For a significant value (Sig.) of 0.000. This value is smaller than the probability of 0.01, so the OTTV variable influences the performance variables of natural lighting and glare-free (Figures 15 and 16). In the combination shading device, the determination coefficient (R Square):

a. OTTV against natural lighting (sDA) is 0.216
b. OTTV against glare-free (sGA) is 0.690

OTTV & sDA

		OTTV	sDA
OTTV	Pearson Correlation	1	.465**
	Sig. (2-tailed)		.000
	N	65	65
sDA	Pearson Correlation	.465**	1
	Sig. (2-tailed)	.000	
	N	65	65

**. Correlation is significant at the 0.01 level (2-tailed).

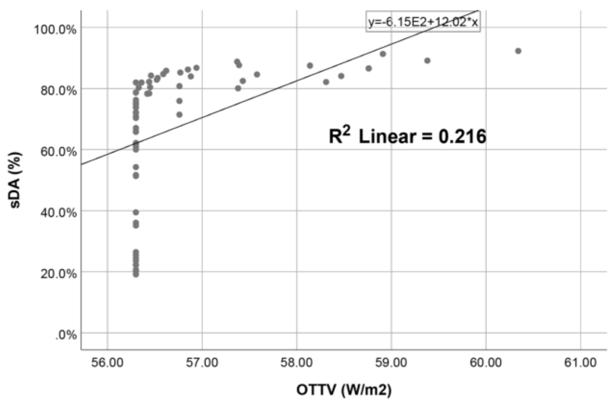


Figure 15. Correlation and regression tests of OTTV & sDA on combined shading devices

OTTV & sGA

		OTTV	sGA
OTTV	Pearson Correlation	1	-.831**
	Sig. (2-tailed)		.000
	N	65	65
sGA	Pearson Correlation	-.831**	1
	Sig. (2-tailed)	.000	
	N	65	65

**. Correlation is significant at the 0.01 level (2-tailed).

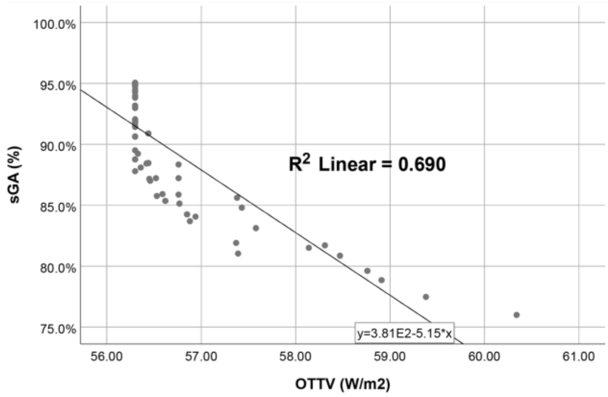


Figure 16. Correlation and regression tests of OTTV & sGA on combined shading devices

The results of the regression test between OTTV and natural lighting (sDA) and glare-free (sGA) are different influences for each type of shading device used. The downward sloping line (negative) indicates that the lower the OTTV, the higher the percentage of glare-free (sGA). The upward-sloping line (positive) indicates that the higher the OTTV, the higher the natural lighting (sDA).

This study revealed that external shading devices on openings significantly reduce OTTV and the intensity of natural lighting. The external shading device can block incoming heat and light, so optimization is needed for both variables. In addition, this study also shows that modifying openings with the use of external shading devices can control the intensity of glare entering the building.

Similar research conducted by Adi et al. [28] also revealed that window orientation, size, and external factors affect OTTV and natural lighting. In their study, they tried to modify the Window-to-Wall Ratio (WWR) to achieve optimal levels of natural lighting while keeping OTTV within standard limits. In addition, research conducted by Li et al. [47] tried to correlate OTTV and natural lighting openings using three types of glass, the results of which showed different effects on annual additional electricity use. Therefore, the opening on the building facade is one of the most influential factors in increasing or decreasing OTTV and the intensity of natural lighting.

4. Conclusions

In tall buildings, the facade element is one of the parts that significantly influences thermal comfort and the availability of natural lighting. Therefore, it is necessary to optimize the facade area so as not to increase energy use for air conditioning and artificial lighting. One way is through the use of external shading devices. However, this energy conservation strategy sometimes also has an impact on the performance of natural lighting, especially for the availability of light entering the building. The findings in this study, in general, are that using external shading devices with the correct configuration can optimize OTTV and natural lighting performance and reduce glare significantly. Specifically, the results of this study are as follows:

The main factors influencing the optimization of OTTV and natural lighting performance using external shading devices are the type and configuration used. Experiments with the vertical type provide better natural lighting intensity than with the horizontal type, but the OTTV and glare percentage are higher. Meanwhile, after conducting experiments with the combination type (egg-crate), the most optimal OTTV can be achieved with the highest natural lighting intensity and the lowest glare percentage compared to the vertical and horizontal types. Of the three types, the combination shader (egg-crate) is the best type with the most optimal OTTV reduction of 16% because SCeff has reached the maximum threshold for its reduction of 0.659. Furthermore, natural lighting is at 61.8%, and the percentage of glare avoidance has increased by 31.54%.

The study's results indicate a causal relationship between OTTV and natural lighting and glare, with different results depending on the type of shader used. If the OTTV is higher, the intensity of natural lighting and glare will also be higher, and vice versa. The highest relationship figure occurs in the vertical type, followed by the horizontal type, and the lowest is the combination type. The results of the regression test to find the relationship between OTTV, natural lighting and glare are as follows:

a. Significance value (Sig.) Of 0.000, the OTTV variable influences the performance variables of natural lighting and glare (sDA & sGA).
b. The R and (R-Square) values of the OTTV variable against the natural lighting variable (sDA) have the lowest values because the decrease in OTTV occurs slowly, and the maximum threshold for the shading coefficient (SC) is only 0.65. On the contrary, in natural lighting, the decrease occurs drastically.
c. The R and (R-Square) values of the OTTV variable against the glare-free variable (sGA) have the highest values because the decrease in OTTV and glare occurs slowly.

The combination type of shading device (egg crate) provides the best results compared to other types in reducing heat transfer while maintaining natural lighting and glare to remain within standard limits, with the following value differences:

a. The combination type has an OTTV value of 2.58% lower, the intensity of natural lighting is 0.97% better, and the glare gain is 5.1% lower than the vertical type.
b. The combination type has an OTTV value of 0.27% lower, the intensity of natural lighting is 9.26% better, and the glare gain is 0.84% lower than the horizontal type.

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