INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 14 NO. 4 (2023) 9-27

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Development of Vertical Shading Parameter Model for Reducing Energy Consumption in Tall Building based on Overall Thermal Transfer Value - A Case Study

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DOI: https://doi.org/10.30880/ijscet.2023.14.04.002
Received 04 November 2022; Accepted 31 May 2023; Available online 15 October 2023

Abstract: In tall building, shading design is a configuration that includes geometry, material, and the system. Currently, the design of the shade found for building's envelope is not only used to improve the thermal performance, but is also required to provide aesthetic value to the appearance of a building. The use of shading design in the form of vertical shade at certain places will provide differences in the acquisition of sunlight for interior spaces. Therefore, by shading design the appearance will certainly affect the thermal performance of the building envelope. This study aims to develop and propose a model that can be used as parameter measures of the effect of shading design variations on the thermal performance of the building envelope. This variation will include shading design concept which applies different vertical shading that covers glass material, the shading width, and the shading angle. This research design includes the calculation of the shade coefficient (SC) and overall thermal transfer value (OTTV) of each variant, followed by using multiple linear regression (MLR) analysis with manufacturer's SC glass, shading width, and shading angle as the predictor variables. The study is conducted by two parts: designing of vertical shading parameters that affect the value of the SC and determining the thermal performance of the building. The MLR analysis is carried out to obtain a linear equation showing the effect of shading design on thermal performance of the building envelope. Based on the regression analysis result, it can be seen that the manufacturer's SC of glass has the biggest impact on the OTTV value, while the shading angle has the lowest. With 95.2%-98% of the predictors data can explain the value of OTTV, the model can be used as the tool for designing vertical shading for reducing the energy consumption in the building.

Keywords: Vertical shading, thermal performance, energy consumption

1. Introduction

In its quite recent development, buildings no longer only pay attention to aspects that affect the occupants, but also aspects related to the environment. One aspect related to the environment is the energy consumption. Buildings consume about 40% of the world's energy (Berardi, 2017). Furthermore, according to the 2012 Green Building User Guide, the most energy consumption is by cooling and air conditioning systems in buildings, which is 47% to 65% respectively (Wei et al., 2018). The main energy consumers in a building are generally heating, cooling and air conditioning systems (Ghahramani et al., 2015). Meanwhile, based on the 2012 Jakarta Green Building User Guide, it is explained that the largest energy consumption in buildings is the cooling load, where 63% of the cooling load is caused by the building envelope component (Azmi & Setiawan, 2021). The cooling load is the cooling requirement in a building which is influenced by the building envelope, the use of objects in the building, and the occupants of the

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building itself (Ding et al., 2018). Meanwhile, in Indonesia's National Standard (SNI) 03-6389 of 2011 concerning Energy Conservation in Building Envelopes, one of the parameters that can be used as a benchmark for building energy consumption through building envelopes is Overall Thermal Transfer Value (OTTV). OTTV is a value that shows the amount of solar heat obtained by the building envelope area (Sheng et al., 2020). So the bigger the OTTV, the greater the energy consumption in a building. The OTTV value regulated in SNI 03-6389 of 2011 may not exceed 35 Watt/m2.

OTTV in buildings can be considered to be a reflection of the thermal performance of buildings. The determinant of the thermal performance of a building is the passive design of the building (Mukhtar et al., 2019). One of the passive design components or components that affect the passive performance of the building's thermal is the shading device. Shade as a component of the building envelope has a function to minimize the occurrence of fenestration of sunlight on the glass or any other transparent materials. The changes in the geometry of the shade by increasing the length of the vertical shade by 38 to 100 cm gave a decrease in temperature of up to "2℃ (Yi et al., 2018). Meanwhile, the addition of vertical shading to the existing horizontal shading resulted in a decrease in OTTV of 18.25% (Chan & Chow, 2014; A. Hajji & Hilmi, 2021). From some of these studies, it can be seen that the optimization of the shade can be done by changing the configuration of the shade starting from the geometry, material, to the shading system. The shading configuration which includes geometry, material, to the shading system used to maximize the shading function is called the shading design (Karim et al., 2019). The existing aspects of the shade design according to SNI 6389-2011 include glass material and shade geometry. While the geometry of the shade referred to in SNI 6389-2011 includes the direction of the shade (vertical or horizontal), the length of the shade, the width of the shade, the angle of installation of the shade, and the orientation of the shade.

Currently, the design of the shade found in many buildings is not only used to improve the thermal performance of the building envelope, it is also required to provide aesthetic value to the appearance of a building. One example of the buildings that is unique in its shade design in the State University of Malang (UM), Indonesia is the twin-towering 9-stories integrated classrooms buildings (GKB) UM. In the buildings, there are shade components arranged in such a way as to give a unique and iconic impression, especially on the northeast and southwest sides. The impression is obtained from the difference in width between the shading in certain places on each side. The difference in the width of the shade forms an icon so that it can be seen as the symbol of UM. The difference in width when viewed from the point of view of shading according to SNI 6389-2011, will affect the coefficient of effective shading (SCeff) and directly affect the OTTV. The definition of SCeff according to SNI 6389-2011 theoretically is the division between sunlight gain in real conditions and sunlight gain on clear glass with a thickness of 3 mm (Pramesti et al., 2018). The difference in the acquisition of sunlight at certain places on the northeast and southwest sides will affect the thermal performance of the building envelope at GKB UM. Meanwhile, according to the 2012 Jakarta Green Building User Guide, the shading design has the greatest energy saving potential among all building envelope components, which is 10.1% of the total 30.1% potential energy saving by the building envelope (Al-Yasiri & Szabó, 2021). Therefore, the design of the vertical shading becomes a very important aspect in saving energy.

This research aims to develop and propose a model that can be used as parameter measures as the effect of shading design variations on the thermal performance of the building envelope. This variation will include shading design concept which applies different vertical shading that covers glass material, the width of the shade, and the angle of installation of the shade. In the case of this research, where GKB UM is an existing building, it is important to evaluate the thermal performance of the building envelope in the building. On the other hand, based on the description of the importance of shading design in energy saving by building envelopes, it is also important to conduct research and to build a model explaining the effect of vertical shading design on the thermal performance of building envelopes as an option in modifying existing shading designs.

Research on the efforts of quantifying the energy consumption in tall building is part of the campaign for green and energy efficient construction. How the buildings and construction projects answer the responsibility upon energy use and environmental impacts are undertaken by plan and actions through construction's emission mitigation and its energy conservation (Aditya et al., 2017; Chwieduk, 2017; A. Hajji et al., 2019; A. M. Hajji & Ariestadi, 2018; A. M. Hajji & Lewis, 2017; Liu et al., 2019). In recent decades, many studies addressing this global issue have been conducted on various-relevant topics (Figure 1). They covered many technical and engineering aspects from tall building construction and infrastructure project, construction methodologies, productivity issues in construction, to green building rating system and regulations. In tall building construction topics, the discussions for energy efficiency touches many layers of its components: sub-structure, upper-structure, top-structure, mechanical-electrical and plumbing technologies, as well as building's comfort that covers thermal, visual, and acoustics. Concerning the state of 'being-green', many discussions offer rating and evaluation system for buildings are also studied. The systems that are mostly aimed at green certification have addressed site development, energy efficiency and conservation, water conservation, material resource and cycle, indoor health comfort, and building environmental management.

The proposed research, -vertical shading design parameter model for tall building-, is part of topics that analyse the energy and environmental impact of building components. Thermal comfort as the focus of this research is a key factor on reducing the energy for cooling and air conditioning system in the building. Quantifying solar heat gain by using OTTV method will determine the cooling load of the building's air conditioning (AC) system. The load of AC system will determine the energy consumption of the building. Since the most energy in the buildings (60-64%) consumed by the AC system (Gupta & Tiwari, 2016), the strategy in reducing solar heat gain into the buildings is very important.

Shading is one of the systems in the building that plays a role in providing a balance of energy and interior comfort in the building (Kunwar et al., 2018). The most effective way to control overheating is to prevent sunlight from reaching the windows (Piotrowska & Borchert, 2017). Generally, shading is a component found on the window, whether it's the glass itself, exterior shading devices, shading outside the room, or interior shading devices. A good shading system works by reducing the heat gain from the sun and also ensuring there is sufficient and comfortable sunlight during the day (Kunwar et al., 2018). Shading systems in buildings can be a combination of glazing with exterior or interior shading devices to reduce solar heat gain. In SNI 6389:2011 concerning Energy Conservation of Building Envelopes in Buildings, the combined shading system will produce a combined shading coefficient which is one of the factors that affect the OTTV value. From the description above, it can be concluded that the importance of shading for openings of a building (glass, exterior shading devices, interior shading devices, or a combination of the three) is to reduce solar heat gain.

2. Method

2.1 Design of Vertical Shading Parameters

The dependent variable of this research is the thermal performance of tall in terms of OTTV. While the independent variable in this study is the variation of the vertical shading design. The shade design referred to in this study includes aspects that affect the value of the shading coefficient (SC), which are the type or material of the glass, the width of the shade, and the angle of installation of the shade. The variation in the width of the shade is carried out uniformly on the vertical shade, signed as 'Shading 1' and 'Shading 2' so as not to eliminate the existing pattern of building's exterior skin. Figure 1 shows the overall look of the building façade.

Fig. 1 - The use of shading design for building facade

Shading design is the arrangement of shading devices to maximize the function of the shading device on translucent walls (Kirimtat et al., 2016). The basic function of the shading device is to block or minimize sunlight entering the building. Based on this, the success of the shading design is very dependent on the shading tool used. Several configurations of shading device arrangements or shading designs are horizontal shading devices, vertical shading devices, combined shading devices (Mangkuto et al., 2019). The configuration of the shading arrangement will affect how efficient and how optimal the thermal performance of a building is. A shading device that is placed on the exterior will affect the acquisition of radiation into the interior of the building so that the transmittance of solar energy appears (Rocha et al., 2016). The heat gain due to this shading system will cause the outer fraction of the window exposed to the sun (G) which will affect the OTTV value. The G value caused by this exterior shade can be determined by using the geometry of the sun by knowing the value of the vertical shadow angle and the horizontal shadow angle. Basically, the G value is the ratio of the exposed window area to the total window area.

$$G = \frac{A_e}{A}$$

where,

G = Sun exposed fraction

A = Total area of the window

Ae = Area of the visible window

According to SNI 6389-2011, the shading coefficient is the result of the division between the gain of sunlight on each combination of glass and exterior shading with the gain of solar radiation on clear glass with a thickness of 3 mm. In OTTV calculations, interior shading effects such as curtains are not taken into account. To get the optimal OTTV value, what can be done is modification of the exterior shade only. In general, the fenestration shade coefficient can be calculated by the following equation.

$$SC = SC_K \times SC_{EFF}$$

where,

SC = fenestration shade coefficient
SCk = Shading coefficient on glass
SCeff = Effective shading coefficient due to exterior shading

A study has shown that increasing the width of the shade by 35 cm without changing the angle of the shade, effectively reduced the OTTV value up to 17.3% (Wibawa et al., 2021). Meanwhile, the addition of the shade width of 50 cm, 75 cm, and 100 cm, shows a graph of the decrease in temperature in the room (Park et al., 2021). Therefore, the variation carried out in this study was the addition of the width of the shade with several variants, namely as many as 35 cm, 75 cm, and 100 cm, followed by changes in the angle of installation. Variations in the angle of installation of the shade are based on the angles that exist in SNI 6389-2011, namely 0°, 10°, 20°, 30°, 40°, 50°. The variants of the shade design based on the physical design of the shade used in this study are shown in Table 1.

Table 1 - Variations on setting angle of vertical shading design

No.	Setting Angle					
	0°	10°	20°	30°	40°	50°
	Additional width of vertical shade (cm)					
1	0	0	0	0	0	0
2	35	35	35	35	35	35
3	75	75	75	75	75	75
4	100	100	100	100	100	100

Based on the Table 1, it can be seen that the addition of the width of the vertical shade must also be considered in terms of the angle of installation. This of course will provide more accurate results when compared to previous studies, which did not review the angle of installation of the shade. The illustration of the addition of the width of the shade and the angle of installation of the shade is shown in Figure 2.

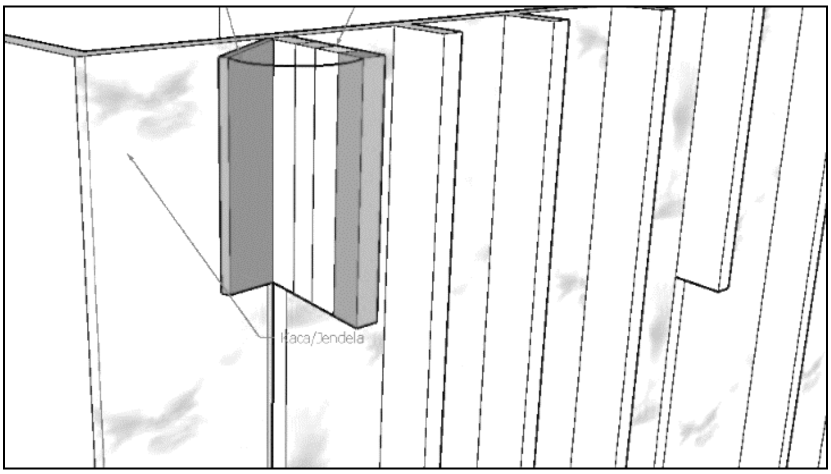

Fig. 2 - Width and angle of vertical shade design

In SNI 6389 of 2011 it is explained that the use of glass material with a certain manufacturer's SC value and the orientation or direction towards the shade will also affect the OTTV value in a building. The use of exterior glass in the GKB Building based on the Work Plan and Conditions (RKS) is glass with an SC value of ± 0.38. Meanwhile, according to the Jakarta Green Building User Guide, the SC value of single 8 mm glass which has the lowest visual transmittance value is 0.40 to 0.69. To simplify the variance without compromising the essence of describing the data to be obtained, three manufacturers' SC variants were taken: 0.38, 0.53, and 0.69.

2.2 Determining the Thermal Performance of the Building

The method used in this research is an experimental method with descriptive data analysis. Experiments were carried out on aspects that affect the value of the shading coefficient (SC), namely the use of the material or type of glass, the dimensions of the shade, and the angle of installation of the shade. As displayed on Figure 3, the OTTV calculation is carried out on each change in the shade aspect, then an analysis is carried out on the influence between the shade design variants on the OTTV, so that conclusions can be drawn about the effect of the shade design on the thermal performance of the building envelope at the GKB buildings.

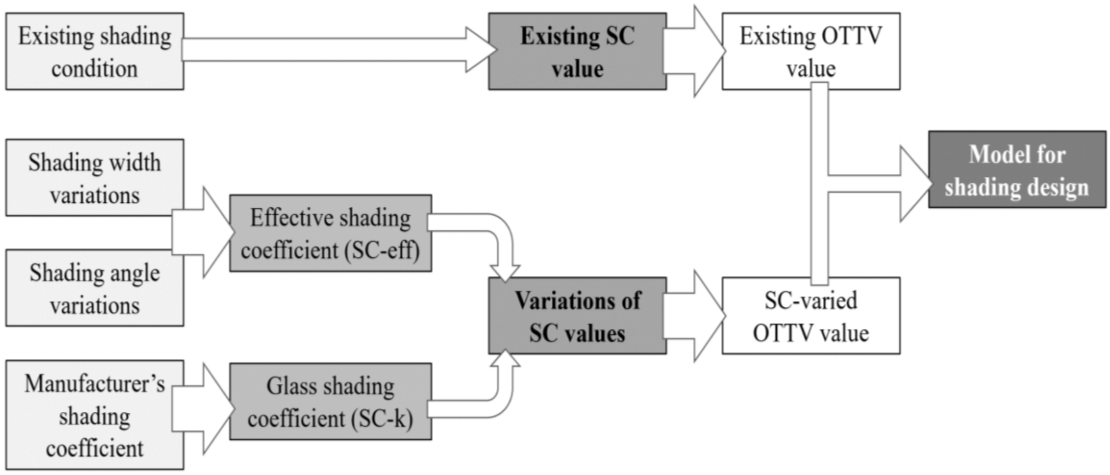

Fig. 3 - Research methodology and steps on analysing the effect of shading on OTTV value

The next step is to conduct an analysis to determine the effect of variations in shade width, shade angle, and type or glass material on the OTTV. Overall Thermal Transfer Value (OTTV) according is a value that shows the amount of solar heat obtained by the building envelope area. The calculation of OTTV is also contained in SNI 6389:2011 concerning Energy Conservation of Building Envelopes in Buildings. OTTV can be calculated simply by using the following formula.

$$OTTV = \left[\alpha_1 \left\{U_{W1} \times {}^{A_1}/_{\sum A} (1 - WWR) \times T_{DEK}\right\} + \left\{U_f \times WWR \times \Delta T\right\} + \{SC \times WWR \times SF\}\right]$$

where,

OTTV	= Overall thermal transfer value (W/m^2)
α	= Absorptance of solar radiation
Uw	= Transmittance of opaque wall (W/m^2.^{o}C)
WWR	= Ratio of window area to wall area
TDEK	= Equivalent temperature difference (^{o}C)
SF	= Solar radiation factor (W/m^2)
SC	= Shading coefficient
Uf	= Thermal transmittance of fenestration (W/m^2.^{o}C)

2.3 Formulating the Vertical Shading Design Variation Model

Multiple linear regression (MLR) modelling will be carried out to obtain a linear regression equation showing the effect of the independent/predictor variables (shade design) on the dependent/response variable (thermal performance of the building envelope). MLR analysis in this study will be carried out with the help of IBM SPSS Statistics 2.5 software. Then the linear regression equation is described in the form of a graph of the relationship between the independent and dependent variables to describe the effect of shading design on the thermal performance of the building envelope in terms of the OTTV value so that conclusions can be drawn regarding the effect of shading design variations on the thermal performance of the building envelope at the buildings.

3. Results and Analysis

Based on secondary data in as built drawing, there are two main types of materials in the building façade: transparent and opaque walls. The transparent walls are green 8 mm thick reflective glass with an SC value of 0.38. The opaque walls are made of white 4-mm thick aluminium composite panels (ACP), 100 mm-thick white light-bricks, and 1 cm-thick black andesite stones. The area of façade based on the type of materials are shown in Table 2 and Table 3.

Table 2 - Area of façade based on types of material – Building 1

No.	Material	Area (m^2)	
1	*4 mm-thick aluminium composite panel*	NE	629.61
		SW	1,066.70
		NW	290.33
		E	82.00
2	10 cm-thick white light brick	NE	73.08
		SW	89.06
		NW	263.52
		E	273.88
3	8 mm reflective glass	NE	1,864.40
		SW	1,925.45
		NW	71.58
		E	269.55
4	1 cm-thick andesite stones	NE	420.41
		SW	416.88
		NW	218.16
		E	218.16

Table 3 - Area of façade based on types of material – Building 2

No.	Material	Area (m^2)	
1	*4 mm-thick aluminium composite panel*	NE	1,066.70
		SW	629.60
		NW	290.33
		E	82.00
2	10 cm-thick white light brick	NE	89.06
		SW	73.08
		NW	263.52
		E	273.88
3	8 mm reflective glass	NE	1,925.45
		SW	1,864.40
		NW	71.58
		E	269.55
4	1 cm-thick andesite stones	NE	416.88
		SW	420.41
		NW	218.16
		E	218.16

In addition to facade components that have been described in Table, the building envelope also has vertical and horizontal shading. Building 1 has 2400 mm width of horizontal shading on the northeast and northwest sides, and 1500 mm width on the southwest and southeast sides, while in Building 2 has 2400 mm width of horizontal shading on the southwest and northwest sides, and 1500 mm width on the northeast and southeast sides. As for vertical shading, Figure 4 shows the dimension of both shading 1 and shading 2.

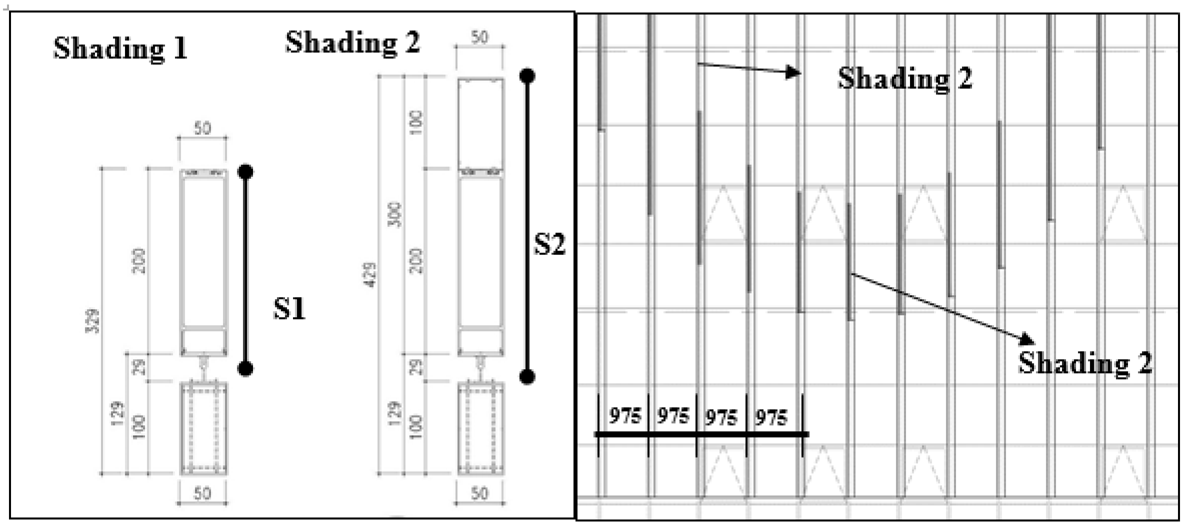

Fig. 4 - Vertical shading design

The effect of the shading design on OTTV value in this study was for vertical shading only. Therefore, only the values of S1 and S2 or the width of shading 1 and shading 2 will be generated in the linear regression model equation.

3.1 Conduction Through Opaque Walls

Calculation of conduction through opaque walls is based on Indonesia's National Standard SNI 6389-2011 concerning Energy Conservation of Building Envelopes. It is explained that the conduction of opaque walls is influenced by the thermal transmittance of opaque walls (Uw), material absorbance (α), and temperature differences equivalent (TDEq). The calculation of heat conduction on an opaque wall is as follows:

$$Q_w = \left[\alpha_1 \left\{U_{W1} \times {}^{A_1}/_{\sum A} (1 - WWR) \times T_{DEq}\right\}\right] + \left[\alpha_2 \left\{U_{W2} \times {}^{A_2}/_{\sum A} (1 - WWR) \times T_{DEq}\right\}\right] + \cdots \left[\alpha_n \left\{U_{Wn} \times {}^{A_n}/_{\sum A} (1 - WWR) \times T_{DEq}\right\}\right]$$

where,

Qw	= opaque wall heat conduction (W/m^2)
α	= material's solar radiation absorbance
Uw	= thermal transmittance of opaque wall (W/m^2.^{o}C)
WWR	= windows-to-walls area ratio
TDEq	= temperature differences equivalent

The results of calculation of opaque wall conduction in Building 1 and Building 2 are displayed on Table 4 and Table 5.

Table 4 - The values of heat conduction through opaque walls – Building 1

Orientation	Façade material	α	Uw (W/m^2.^{o}C)	T_{DEq} (K)	WWR	Qw (W/m^2)
NE	ACP type 1	0.40	3.47	12	0.56	3.05
	ACP type 2	0.40	2.27	10		1.28
	Light brick	0.89	2.10	12		1.35
	Andesite stone	0.95	1.71	10		2.48
						8.17
SW	ACP type 1	0.40	3.47	12	0.54	5.17
	Light brick	0.89	2.10	10		0.48
	Andesite stone	0.95	1.71	10		1.97
						7.63
NW	ACP type 1	0.40	3.47	12	0.04	3.01
	ACP type 2	0.40	2.27	10		4.31
	Light brick	0.89	2.10	12		3.68
	Andesite stone	0.95	1.71	10		2.20

						13.22
SE	ACP type 1	0.40	3.47	12	0.16	0.85
	ACP type 2	0.40	2.27	10		4.31
	Light brick	0.89	2.10	12		3.83
	Andesite stone	0.95	1.71	10		2.20
						11.20

Table 5 - The values of heat conduction through opaque walls – Building 2

Orientation	Façade material	α	Uw ($W/m^2.^oC$)	T_{DEq} (K)	WWR	Qw (W/m^2)
NE	ACP type 1	0.40	3.47	12	0.54	5.17
	Light brick	0.89	2.10	10		0.48
	Andesite stone	0.95	1.71	10		1.97
						7.63
SW	ACP type 1	0.40	3.47	12	0.56	3.05
	ACP type 2	0.40	2.27	10		1.28
	Light brick	0.89	2.10	12		1.35
	Andesite stone	0.95	1.71	10		2.48
						8.17
NW	ACP type 1	0.40	3.47	12	0.04	3.01
	ACP type 2	0.40	2.27	10		4.31
	Light brick	0.89	2.10	12		3.68
	Andesite stone	0.95	1.71	10		2.20
						13.22
SE	ACP type 1	0.40	3.47	12	0.16	0.85
	ACP type 2	0.40	2.27	10		4.31
	Light brick	0.89	2.10	12		3.83
	Andesite stone	0.95	1.71	10		2.20
						11.20

3.2 Conduction Through Transparent Walls

Conduction through transparent walls is determined by the value of thermal transmittance of fenestration, the ratio between windows and walls area, and the inside-outside temperature difference. The conduction through transparent walls is calculated by the following formula:

$$Qf = U_f \times WWR \times \Delta T$$

Where:

Qf = transparent wall conduction (W/m^2)
Uf = thermal transmittance of fenestration ($W/m^2.^oC$)
WWR = windows-to-walls area ratio
ΔT = temperature difference (^oC)

The results of calculation of transparent walls conduction in Building 1 and Building 2 are displayed on Table 6 and Table 7.

Table 6 - The values of heat conduction through transparent walls – Building 1

Orientation	Uf ($W/m^2.^oC$)	ΔT (^oC)	WWR	Qf (W/m^2)
NE	5.82	5	0.56	16.32
SW	5.82	5	0.54	15.80
NW	5.82	5	0.04	1.29
SE	5.82	5	0.16	4.89

Table 7 - The values of heat conduction through transparent walls – Building 2

Orientasi	Uf (W/m².ºC)	ΔT (ºC)	WWR	Qf (W/m²)
NE	5.82	5	0.54	15.80
SW	5.82	5	0.56	16.32
NW	5.82	5	0.04	1.29
SE	5.82	5	0.16	4.89

3.3 Radiation Through Transparent Walls

Radiation value through transparent walls is calculated by the following formula:

$$Q_{fr} = SC \times WWR \times SF$$

where:
Qfr = radiation through transparent walls (W/m^2)
SC = shading coefficient
SF = solar radiation factor (W/m^2)
WWR = windows-to-walls area ratio

According to SNI 6389-2011, the SC value is obtained from the multiplication of the glass manufacturer's SC with the shading SC-eff. In this study, there are three variants of the manufacturer's SC: 0.38, 0.53, and 0.69. SC-eff value is obtained from the value of R1 which is the result of the division between the width of the horizontal shading and the height of the window and R2, which is the result of the division between the width of the vertical shading and the width of the window (Figure 5).

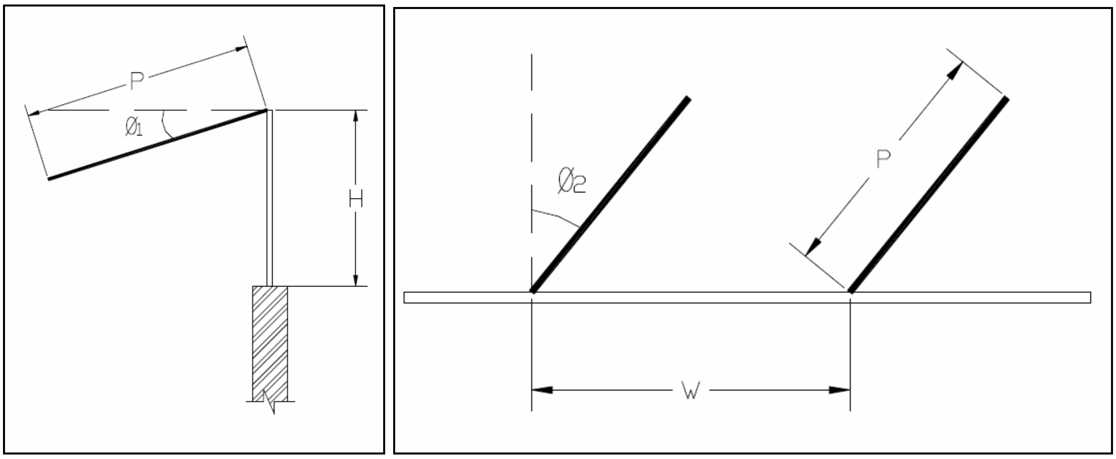

Fig. 5 -Vertical and horizontal shading component

The values of radiation through transparent walls for existing condition are shown in Table 8 and Table 9.

Table 8 - The values of heat radiation through transparent walls – Building 1

Orientation	SC	SF	WWR	Qfr
NE	0.28	113	0.56	17.81
SW	0.30	176	0.54	29.17
NW	0.24	211	0.04	2.26
SE	0.30	97	0.16	4.97

Table 9 - The values of heat radiation through transparent walls – Building 2

Orientation	SC	SF	WWR	Qfr
SW	0.28	176	0.56	27.73
NE	0.30	113	0.54	18.92
NW	0.24	211	0.04	2.26
SE	0.30	97	0.16	4.97

3.4 OTTV Calculation

Based on calculation results on conduction through opaque and transparent walls, and radiation through transparent wall, the existing OTTV values for Building 1 and 2 are shown in Table 10 and Table 11.

Table 10 - OTTV values of each building orientation – Building 1

Orientation	Qw (W/m^2)	Qf (W/m^2)	Qfr (W/m^2)	OTTV i (W/m^2)
NE	7.94	16.32	17.81	42.0
SW	7.63	15.80	29.17	52.61
NW	1.60	1.29	2.26	16.16
SE	10.56	4.89	4.97	20.43
Total OTTV (W/m^2)		**38.09**		

Table 11 - OTTV values of each building orientation – Building 2

Orientation	Qw (W/m^2)	Qf (W/m^2)	Qfr (W/m^2)	OTTV i (W/m^2)
NE	7.63	15.0	18.92	42.36
SW	7.94	16.32	27.73	52.00
NW	12.60	1.29	2.26	16.16
SE	10.56	4.89	4.97	20.43
Total OTTV (W/m^2)		**37.98**		

3.5 Regression Analysis Result

Multiple linear regression analysis in this study was conducted to determine the effect of the independent variable or predictors, which is shading design on the dependent variable or response variable, which is the thermal performance of the building in terms of the OTTV value. The predictors are shading angle, shading width, and manufacturer's SC. The model of multiple linear regression analysis can be used as an option in modifying the existing shading design. The model is generated by using the variations of manufacturer's SC (0.38, 0.53, and 0.69), which is combined with variations of additional shading width (0 cm, 35 cm, 75 cm, and 100 cm) and shading angle (0^o, 10^o, 20^o, 30^o, 40^o, and 50^o) as predictors. The OTTV value of each building's orientation (NE, SW, NW, and SE) is the response variable. There are 144 data for both Building 1 and 2 to generate the regression model (Appendix 1).

The result of regression analysis shows how much the independent variables can explain the OTTV value. From the analysis results it can be seen that all independent variables in the model simultaneously 98.0% can explain the OTTV value of Building 1 and 95.2% for Building 2. The coefficients and regression constants of the models for both buildings are shown in Table 12 and Table 13.

Table 12 - Regression model coefficients – Building 1

Model coefficients	
Constants	25.490
Manufacturer's SC	38.383
Shading width (m)	-4.582
Shading angle	-0.031

Table 13 - Regression model coefficients – Building 2

Model coefficients	
Constants	28.432
Manufacturer's SC	33.835
Shading width (m)	-7.560
Shading angle	-0.051

Based on the values of predictor's coefficients, the regression model for both Building 1 and Building 2 are expressed as follows:

$$Y = 25{,}490 + 38{,}383X_1 - 4{,}582X_2 - 0{,}031X_3$$

$$Y = 28{,}432 + 33{,}835X_1 - 7{,}560X_2 - 0{,}051X_3$$

Where,
Y = OTTV value (Watt/m^2)
X_1 = manufacturer's SC
X_2 = shading width (m)
X_3 = shading angle (°)

4. Discussion

Based on the results, it can be seen that the OTTV values on the northeast and southwest sides of the two buildings are very high, due to the high WWR values on both sides. It proves which states that WWR has the greatest influence on OTTV (Prayudi, 2013). Both buildings have slight differences on OTTV values, which is determined by heat gain through transparent wall radiation. The value of the OTTV based on the transparent wall radiation (Qfr) in Building 1 is 17.165 Watt/m^2 and in Building 2 is 17.055 Watt/m^2. This difference occurs because there are differences in SC and SF values on the northeast and southwest sides. The This is shown more clearly in Table 14.

Table 14 - The heat gain through transparent wall radiation

Orientation	SF	Building 1			Building 2		
		SC	WWR	Q_{fr}	SC	WWR	Q_{fr}
NE	113	0,28	0,56	17,81	0,30	0,54	18,92
SW	176	0,30	0,54	29,17	0,28	0,56	27,73
NW	211	0,24	0,04	2,26	0,24	0,04	2,26
SE	97	0,30	0,16	4,97	0,30	0,16	4,97

From Table 14, it can be seen that the difference in the value of Qfr on the northeast and southwest sides is relatively small because Building 1 on the northeast side with SF of113, has a higher WWR value and smaller SC than those of Building 2. While on the northwest side with SF of 176, the WWR value in Building 1 is lower than Building 2, but with higher SC value. In short, the difference in OTTV values is relatively small on both buildings because of the opposite values of WWR and SC on the NE and NW sides.

4.1 Effects of Shading Design on OTTV Value

The acquisition of solar radiation on transparent walls is sufficient to describe how much OTTV is obtained in a building (Kusumawati, 2002). One of the components that affect the radiation gain is the shading design. Therefore, the effect of variations in shading design including the glass manufacturer's SC, shading width, and shade angle will be explained accordingly. There are three variations of SC glass manufacturers in this study: 0.38, 0.53, and 0.69. Based on the results of multiple linear regression analysis, the independent variable X1 or the glass manufacturer SC variable has a positive coefficient. This shows that by eliminating other independent variables and increasing the manufacturer's SC variable, the OTTV value will also increase. The graph of the relationship between the manufacturer's SC value and OTTV at various conditions of the installation angle of the shade is shown in Figure 6.

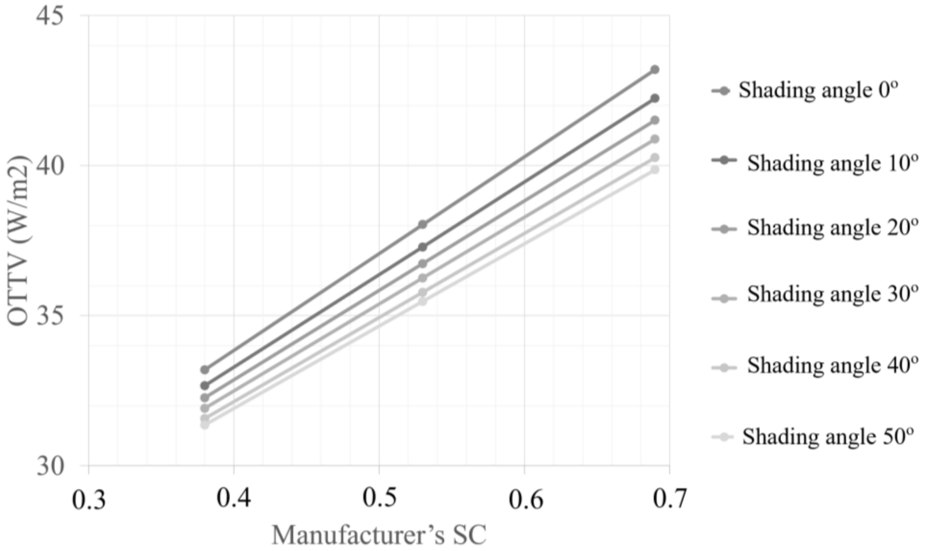

Fig. 6 - The relationship between manufacturer's SC and OTTV value

Based on the graph, it can be seen that an increase in the SC value of glass manufacturers by 0.15 will increase the OTTV value by 4.84 W/m^2 at an angle of 0^o, 4.63 W/m^2 at 10^o, 4.48 W/m^2 at 20^o, 4.34 W/m^2 at 30^o, 4.20 W/m^2 at 40^o, and 4.12 W/m^2 at 50^o shading angle. It can also be seen that the greater the angle of the shade installation, the smaller the increase in OTTV caused by the increase in the SC value of the glass manufacturer. Based on the descriptions and explanations of the graphs above, it can be seen that the higher the SC value of the glass manufacturer, the higher the OTTV value produced. However, this increase is different for each variation of the shading angle and is also different for each variation of the width of the shading. The increase in OTTV on the addition of the SC value has a tendency to get smaller when the value of the additional width of the shading and its angle are getting bigger. This happens because each variation carried out in this study is carried out simultaneously so that the OTTV value generated from the manufacturer's SC variation will have various values according to the influence of other variables. Modification of the shading design based on the glass manufacturer's SC at the building will certainly be difficult considering the building is already standing. However, the manufacturer's SC value in the existing condition is 0.38, which results in the lowest potential OTTV value. Therefore, modification of the shading design based on the glass manufacturer's SC, if necessary, should use a smaller manufacturer's SC value.

Based on the results of multiple linear regression analysis, it was found that the shading width (X_2) variable has a negative coefficient, which means that if all independent variables are eliminated and the X_2 variable is increased, the OTTV value will decrease. The graph of the relationship between the addition of the shading width to the OTTV in various angles of shading with the manufacturer's SC value of 0.53 is displayed in Figure 7.

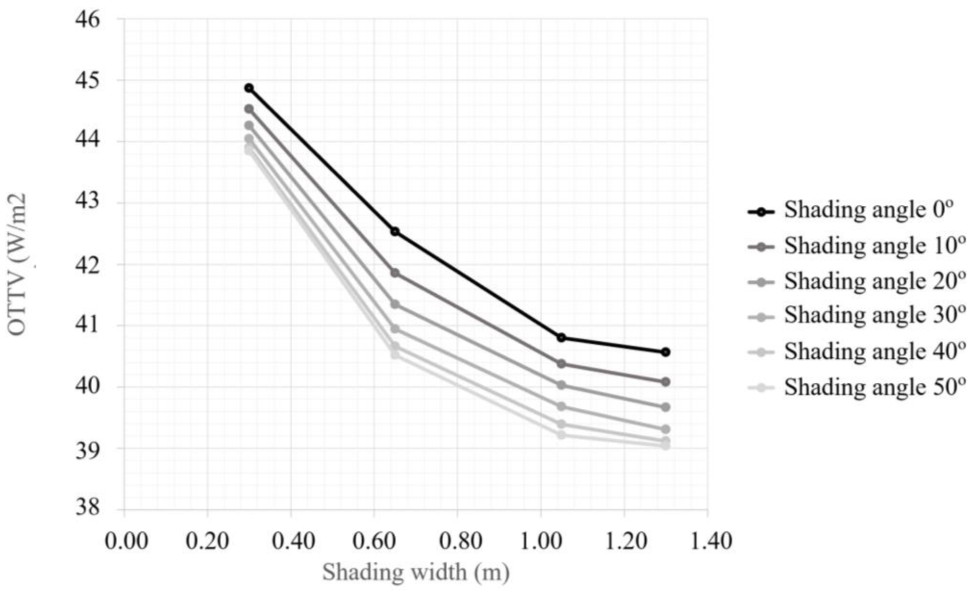

Fig. 7 - The relationship between shading width and OTTV value

Based on Figure 7, it can be seen that the addition of shading width of 0.35 m with a factory SC of 0.53 resulted in a decrease in OTTV value by 2.34 W/m^2 at shading angle of 0^o, 2.67 W/m^2 at 10^o, 2,91 W/m^2 at 20^o, 3.10 W/m^2 at 30^o, 3.23 W/m^2 at 40^o, and 3.33 W/m^2 at 50^o. While the addition of the shading width of 1 m resulted in a decrease in OTTV value by 4.31 W/m^2 at shade angle of 0^o, 4.45 W/m^2 at 10^o, 4.59 W/m^2 at 20^o, 4.74 W/m^2 at 30^o, 4.78 W/m^2 at 40^o, and 4.81 W/m^2 at 50^o. The results showed that the addition of the shading width will result in a decrease in the OTTV value (Wibawa & Hutama, 2019). The lowest OTTV value was produced by the addition of the shading width of 100 cm. The addition of the width of the existing shading design on the building to improve the thermal performance will clash with other aspects, especially those related to natural lighting. According to Sanati (2013), the use of external shading in the absence of interior shading or indoor shading will result in reduced use of lights in buildings, however, wide vertical shading will narrow the point of view of building users outside the window. Therefore, based on the relationship between the shading width and the OTTV, the recommendations are given if a modification of the shade design is to be made with the addition of a shading width of 75 cm in Building 1 and 35 cm in Building 2 because the OTTV value below 35 Watt/m2 has been achieved.

In this study, there were six variations of the shading angle: 0^o, 10^o, 20^o, 30^o, 40^o, and 50^o. Based on the results of multiple linear regression analysis, the coefficient for the shading angle (X_3) is negative. This shows that by eliminating independent variables other than the shading angle and increasing the value of this variable, the OTTV will decrease. The graph showing relationship between the shading angle to the OTTV in each variation of the manufacture's SC glass with existing shading width is displayed in Figure 8.

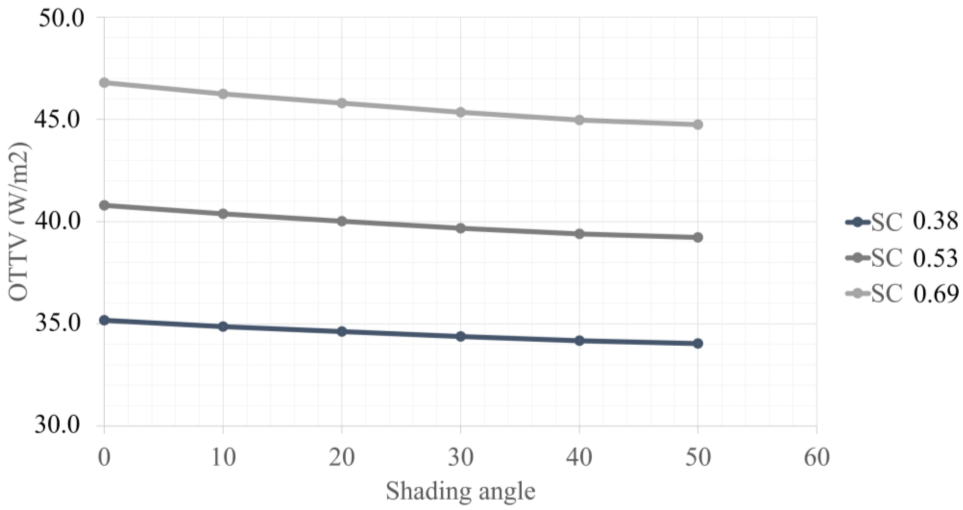

Fig. 8 - The relationship between shading angle and OTTV value

Based on Figure 8, it can be seen that an increase in the inclination of shading angle of 10o resulted in a decrease in OTTV of 0.31 W/m^2 on the manufacturer's SC of 0.38, 0.55 W/m^2 at 20^o, 0.81 W/m^2 at 30^o, 1.01 W/m^2 at 40^o, and 1.14 at 50^o. While using manufacturer's SC of 0.69, the decrease of OTTV value is 0.56 W/m^2 at 10^o, 1.01 W/m^2 at 20^o, 1.46 W/m^2 at 30^o, 1.83 W/m^2 at 40^o, and 2.01 W/m^2 at 50^o of shading angle variations. It can be concluded that an increase in the slope value of the shading angle will result in a decrease in the OTTV value. The magnitude of the decrease in the OTTV value caused by the increase in shading angle is not constant because it is influenced by the solar factor (SF) due to the orientation of the building sides (Kusumawati, 2021). The decrease in the OTTV value has a constant average value ranging from the shading angle of 0^o to 30^o. At the angle of higher than 30^o to 50^o the decrease of OTTV value became smaller. According to Pramitasari, (2016) the ideal angle of shading in the city of Malang is 30^o because the angle of inclination of the sun is 29^o. In the building as a case, the application of a 30^o shading angle will not change the iconic impression look on the southwest and northeast sides, because the impression can be seen at a certain angle. The application of 30^o shading angle actually allows a unique and iconic impression on the building.

4.2 Sensitivity Analysis

From the multiple linear regression model, it can be seen that when all variables are zero, the OTTV in Building 1 is 25.49 Watt/m^2 and in Building 2 is 28.43 Watt/m^2. This difference of OTTV values is obtained since the two buildings have the opposite WWR and SC values in the northeast and southwest orientations. The opposite WWR and SC values in these orientations also result in differences in the increase or decrease in OTTV values for each variation of the existing shading design. To determine the difference in the increase or decrease in OTTV in each variation of the shading design, the sensitivity analysis was carried out by changing one of the independent variables and setting the fixed values for the others. The first analysis was conducted by setting up the fixed value of shading width at 0.30 m with 0^o shading angle. This analysis will see the effect of manufacturer's SC values on the increase of OTTV value. Table 15 shows the relationship between SC and OTTV values.

Table 15 - Changes of manufacture's SC on the increase of OTTV value

Y	X_1	X_2	X_3	OTTV Increased (%)
26.16	0	0.30	0	0.00
27.17	0.03	0.30	0	3.88
28.19	0.06	0.30	0	7.75
29.20	0.09	0.30	0	1.69
30.22	0.12	0.30	0	1.58
31.23	0.15	0.30	0	1.38
32.25	0.18	0.30	0	2.27
33.26	0.21	0.30	0	2.17
34.28	0.24	0.30	0	3.07
35.29	0.27	0.30	0	3.96
36.31	0.30	0.30	0	3.76
37.33	0.33	0.30	0	4.65
38.34	0.36	0.30	0	4.55
39.36	0.39	0.30	0	5.44
40.37	0.42	0.30	0	5.34
41.39	0.45	0.30	0	5.14
42.40	0.48	0.30	0	6.03
43.42	0.51	0.30	0	6.93
44.43	0.54	0.30	0	6.82
45.45	0.57	0.30	0	73.72
46.46	0.60	0.30	0	77.51
47.48	0.63	0.30	0	81.41
48.49	0.66	0.30	0	85.30
49.51	0.69	0.30	0	89.20

Table 15 revealed that every increase in the manufacturer's SC value of 0.03 will increase the OTTV by 1.151 W/m^2 and an increase in the SC value from the range of 0.00 to 0.69 will increase OTTV from 24.12 W/m^2 to 50.60 W/m^2 or 109.82%. The increase in OTTV caused by variations in the SC value is quite dramatic. These results support the statement put forward by Yao., et al, (2008) that the shading design component that has the greatest impact is the glass material itself. The OTTV value in the case buildings will reach the requirements of SNI 6389-2011, which is below 35 Watt/m^2 when the SC value of glass manufacturers is reduced to 0.27 in Building 1 and 0.24 in Building 2.

The next analysis was conducted by setting up the fixed values of manufacturer' SC at 0.38 (existing) and shading angle at 0o to see the effect of shading width on OTTV value. Table 16 and Figure 10 display the results of the analysis.

Table 16 - Changes of shading width on the decrease of OTTV value

Y	X_1	X_2	X_3	OTTV decreased (%)
40.07	0.38	0	0	0.00
39.61	0.38	010	0	1.14
39.15	0.38	0.20	0	2.28
38.70	0.38	0.30	0	3.43
38.24	0.38	0.40	0	4.57
37.78	0.38	0.50	0	5.71
37.32	0.38	0.60	0	6.86
36.86	0.38	0.70	0	8.00
36.41	0.38	0.80	0	9.14
35.95	0.38	0.90	0	10.20
35.49	0.38	1.00	0	11.43
35.03	0.38	1.10	0	12.57
34.57	0.38	1.20	0	13.70
34.11	0.38	1.30	0	14.83

Table 16 shows that in the linear regression model, every increase in the value of shading width by 0.1 m will decrease the OTTV by 0.46 W/m^2 and an increase in the value of shading width at the range of 0.0 m to1.3 m will reduce OTTV from 40.08 W/m^2 to 34.12 W/m^2 or 14.86 %. The decrease in the OTTV value caused by the addition of the shading width supports the results of research conducted by Wibawa & Hutama, (2019). It is very possible to increase the width of the shading for both buildings, considering that the decrease in the OTTV value given is quite low. The OTTV value in the buildings will meet the requirements of SNI 6389-2011 which is less than 35 Watt/m^2 when the width of the shading is 0.9 -1.2 m.

To see the effect of shading angle variation to the decrease OTTV values, the next analysis was conducted by setting up the fixed values of manufacturer's SC at 0.38 and shading width at 0.30 m (Table 17). The results show that in the linear regression model, every 5^o increase of shading angle will decrease the OTTV by 0.16 W/m^2. The increase in the value of shading angle at the range of 0^o to 50^o will decrease the OTTV from 38.70 W/m^2 to 37.15 W/m^2 or 4.01 %. The small decrease in OTTV value is due to the small addition the angle of the shading is relatively small when compared to its width. To meet the requirements of SNI 6389-2011, modification of the shading angle is not recommended.

Table 17 - Changes of shading angle on the decrease of OTTV value

Y	X_1	X_2	X_3	OTTV decreased (%)
38.70	0.38	0.30	0.00	-
38.54	0.38	0.30	5.00	0.40
38.39	0.38	0.30	10.00	0.80
38.23	0.38	0.30	15.00	1.20
38.08	0.38	0.30	20.00	1.60
37.92	0.38	0.30	25.00	2.00
37.77	0.38	0.30	30.00	2.40
37.61	0.38	0.30	35.00	2.80
37.46	0.38	0.30	40.00	3.20
37.30	0.38	0.30	45.00	3.60
37.15	0.38	0.30	50.00	4.00

5. Conclusion

The study has shown that the vertical shading design is one of key factors in decreasing the OTTV value of the building. Since the value of OTTV will affects the use of energy in air conditioning system, which is the biggest portion of building's energy consumption, therefore shading design will have an important impact on energy efficiency. The regression model concerning the effect of shading width, shading angle, and manufacturer's SC value on the OTTV can be used as the tool for designing and optimizing vertical shading design for reducing the use of energy. Based on 144 data set used in generating the model, it can be seen that all independent variables simultaneously 98.0% can explain the OTTV value of Building 1 and 95.2% for Building 2. The value of manufacturer's SC of glass has the biggest impact on the change on OTTV, while the shading angle has the lowest. In term of fulfilling the national standard (SNI 6389-2011) for building's energy conservation, it is important to meet the minimum requirement of OTTV value (35 W/m^2) without having excessive shading design that could affect the overall architectural façade design.

Acknowledgement

The authors are very grateful and gives a great appreciation to the Institute of Research and Community Services (LP2M) Universitas Negeri Malang (UM), Indonesia for providing fund support and administrative assistance for the research.

Appendix A: OTTV Values as Obtained from Variations of Shading Design

Building 1

Manufacturer's SC	Additional width	Shading angle	OTTV value				OTTV Total (Watt/m^2)
			NE	SW	NW	SE	
0,38	+0 cm	0	42.08	52.62	16.17	20.43	38.10
		10	41.36	52.62	16.17	20.43	37.85
		20	40.79	52.62	16.17	20.43	37.66
		30	40.34	52.62	16.17	20.43	37.50
		40	40.03	52.62	16.17	20.43	37.40
		50	39.93	52.62	16.17	20.43	37.36
	+35 cm	0	37.15	52.62	16.17	20.43	36.42
		10	35.74	52.62	16.17	20.43	35.94
		20	34.66	52.62	16.17	20.43	35.57
		30	33.81	52.62	16.17	20.43	35.28
		40	33.23	52.62	16.17	20.43	35.08
		50	32.92	52.62	16.17	20.43	34.98
	+75 cm	0	33.51	52.62	16.17	20.43	35.18
		10	32.61	52.62	16.17	20.43	34.87
		20	31.88	52.62	16.17	20.43	34.62
		30	31.15	52.62	16.17	20.43	34.37
		40	30.55	52.62	16.17	20.43	34.17
		50	30.18	52.62	16.17	20.43	34.04
	+100 cm	0	33.02	52.62	16.17	20.43	35.01
		10	32.00	52.62	16.17	20.43	34.66
		20	31.13	52.62	16.17	20.43	34.37
		30	30.37	52.62	16.17	20.43	34.11
		40	29.97	52.62	16.17	20.43	33.97
		50	29.81	52.62	16.17	20.43	33.92
0,53	+0 cm	0	49.11	64.13	17.06	22.40	44.87
		10	48.10	64.13	17.06	22.40	44.53
		20	47.32	64.13	17.06	22.40	44.26
		30	46.68	64.13	17.06	22.40	44.05
		40	46.25	64.13	17.06	22.40	43.90
		50	46.11	64.13	17.06	22.40	43.85
	+35 cm	0	42.23	64.13	17.06	22.40	42.53
		10	40.27	64.13	17.06	22.40	41.86
		20	38.77	64.13	17.06	22.40	41.35
		30	37.58	64.13	17.06	22.40	40.94
		40	36.77	64.13	17.06	22.40	40.67
		50	36.33	64.13	17.06	22.40	40.52
	+75 cm	0	37.16	64.13	17.06	22.40	40.80
		10	35.91	64.13	17.06	22.40	40.37
		20	34.89	64.13	17.06	22.40	40.03
		30	33.87	64.13	17.06	22.40	39.68
		40	33.03	64.13	17.06	22.40	39.40
		50	32.52	64.13	17.06	22.40	39.22
	+100 cm	0	36.47	64.13	17.06	22.40	40.57
		10	35.05	64.13	17.06	22.40	40.08
		20	33.84	64.13	17.06	22.40	39.67
		30	32.78	64.13	17.06	22.40	39.31
		40	32.22	64.13	17.06	22.40	39.12
		50	32.00	64.13	17.06	22.40	39.04
0,69	+0 cm	0	56.61	76.42	18.01	24.49	52.10
		10	55.30	76.42	18.01	24.49	51.65
		20	54.27	76.42	18.01	24.49	51.30
		30	53.45	76.42	18.01	24.49	51.02
		40	52.89	76.42	18.01	24.49	50.83
		50	52.71	76.42	18.01	24.49	50.77
	+35 cm	0	47.66	76.42	18.01	24.49	49.05
		10	45.09	76.42	18.01	24.49	48.18
		20	43.14	76.42	18.01	24.49	47.51
		30	41.60	76.42	18.01	24.49	46.99
		40	40.54	76.42	18.01	24.49	46.62

		50	39.97	76.42	18.01	24.49	46.43
	+75 cm	0	41.05	76.42	18.01	24.49	46.80
		10	39.42	76.42	18.01	24.49	46.24
		20	38.10	76.42	18.01	24.49	45.79
		30	36.77	76.42	18.01	24.49	45.34
		40	35.68	76.42	18.01	24.49	44.97
		50	35.01	76.42	18.01	24.49	44.74
	+100 cm	0	40.16	76.42	18.01	24.49	46.49
		10	38.30	76.42	18.01	24.49	45.86
		20	36.72	76.42	18.01	24.49	45.32
		30	35.35	76.42	18.01	24.49	44.85
		40	34.62	76.42	18.01	24.49	44.61
		50	34.33	76.42	18.01	24.49	44.51

Building 2

Manufacturer's SC	Additional width	Shading angle	OTTV value				OTTV Total (Watt/m^2)
			NE	SW	NW	SE	
0,38	+0 cm	0	42.36	52.01	16.17	20.43	37.99
		10	42.36	50.87	16.17	20.43	37.60
		20	42.36	49.90	16.17	20.43	37.27
		30	42.36	49.19	16.17	20.43	37.02
		40	42.36	48.64	16.17	20.43	36.84
		50	42.36	48.39	16.17	20.43	36.75
	+35 cm	0	42.36	44.31	16.17	20.43	35.36
		10	42.36	42.11	16.17	20.43	34.61
		20	42.36	40.28	16.17	20.43	33.99
		30	42.36	38.90	16.17	20.43	33.52
		40	42.36	37.79	16.17	20.43	33.14
		50	42.36	37.18	16.17	20.43	32.93
	+75 cm	0	42.36	37.95	16.17	20.43	33.20
		10	42.36	36.40	16.17	20.43	32.67
		20	42.36	35.23	16.17	20.43	32.27
		30	42.36	34.21	16.17	20.43	31.92
		40	42.36	33.21	16.17	20.43	31.58
		50	42.36	32.56	16.17	20.43	31.36
	+100 cm	0	42.36	36.75	16.17	20.43	32.79
		10	42.36	35.47	16.17	20.43	32.35
		20	42.36	34.11	16.17	20.43	31.89
		30	42.36	33.04	16.17	20.43	31.52
		40	42.36	32.24	16.17	20.43	31.26
		50	42.36	31.90	16.17	20.43	31.13
0,53	+0 cm	0	49.83	62.95	17.06	22.40	44.72
		10	49.83	61.37	17.06	22.40	44.18
		20	49.83	60.02	17.06	22.40	43.72
		30	49.83	59.02	17.06	22.40	43.38
		40	49.83	58.26	17.06	22.40	43.12
		50	49.83	57.91	17.06	22.40	43.00
	+35 cm	0	49.83	52.21	17.06	22.40	41.06
		10	49.83	49.16	17.06	22.40	40.02
		20	49.83	46.59	17.06	22.40	39.14
		30	49.83	44.67	17.06	22.40	38.49
		40	49.83	43.13	17.06	22.40	37.96
		50	49.83	42.28	17.06	22.40	37.67
	+75 cm	0	49.83	43.35	17.06	22.40	38.04
		10	49.83	41.18	17.06	22.40	37.30
		20	49.83	39.56	17.06	22.40	36.74
		30	49.83	38.13	17.06	22.40	36.26
		40	49.83	36.74	17.06	22.40	35.78
		50	49.83	35.83	17.06	22.40	35.47
	+100 cm	0	49.83	41.68	17.06	22.40	37.47
		10	49.83	39.88	17.06	22.40	36.86
		20	49.83	38.00	17.06	22.40	36.21

		30	49.83	36.51	17.06	22.40	35.70
		40	49.83	35.38	17.06	22.40	35.33
		50	49.83	34.91	17.06	22.40	35.16
0,69	+0 cm	0	57.80	74.63	18.01	24.49	51.90
		10	57.80	72.57	18.01	24.49	51.19
		20	57.80	70.82	18.01	24.49	50.60
		30	57.80	69.51	18.01	24.49	50.15
		40	57.80	68.52	18.01	24.49	49.81
		50	57.80	68.07	18.01	24.49	49.66
	+35 cm	0	57.80	60.65	18.01	24.49	47.13
		10	57.80	56.67	18.01	24.49	45.78
		20	57.80	53.33	18.01	24.49	44.64
		30	57.80	50.83	18.01	24.49	43.79
		40	57.80	48.82	18.01	24.49	43.10
		50	57.80	47.71	18.01	24.49	42.72
	+75 cm	0	57.80	49.11	18.01	24.49	43.20
		10	57.80	46.29	18.01	24.49	42.24
		20	57.80	44.17	18.01	24.49	41.52
		30	57.80	42.31	18.01	24.49	40.88
		40	57.80	40.51	18.01	24.49	40.27
		50	57.80	39.32	18.01	24.49	39.86
	+100 cm	0	57.80	46.94	18.01	24.49	42.46
		10	57.80	44.60	18.01	24.49	41.66
		20	57.80	42.14	18.01	24.49	40.82
		30	57.80	40.20	18.01	24.49	40.16
		40	57.80	38.74	18.01	24.49	39.68
		50	57.80	38.13	18.01	24.49	39.46

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