SKIN LOAD PERFORMANCE OF DOUBLE-SKIN FACADE IN INDONESIA

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ABSTRACT

Models of double-skin facade with various outer and inner glass skin combinations, distances and orientations has been analyzed using numerical simulation. The results show that the thickness of the glass skin is important in reducing solar heat gain: as the thickness of the glass is increased, solar heat gain decreases. On the contrary, as the distance between the glass skins is increased, thermal transmittance becomes lower. Analysis for the condensation found that throughout the building operation time there is no condensation found at the double-skin facade. In comparison to the single-skin façade, double-skin facade is better in reducing skin load.

Keywords: *double-skin facade, single-skin facade, thermal transmittance, solar heat gain, condensation*

ABSTRAK

Model fasad ganda dengan kombinasi berbagai kaca luar dan dalam, jarak dan orientasi telah dianalisis menggunakan simulasi numerik. Hasil penelitian menunjukkan bahwa ketebalan kaca penting dalam mengurangi perolehan panas matahari: dengan peningkatan ketebalan kaca, perolehan panas matahari berkurang. Sebaliknya, bila jarak antara fasad kaca meningkat, transmitansi termal menjadi lebih rendah. Analisis kondensasi menunjukkan bahwa pada seluruh waktu saat bangunan beroperasi tidak terjadi kondensasi pada fasad ganda. Dibandingkan dengan fasad tunggal, fasad ganda lebih baik dalam mengurangi beban pemanasan.

Kata kunci: *fasad ganda, fasad tunggal, transmitansi termal, perolehan panas matahari, kondensasi.*

INTRODUCTION

Extensive research is recorded in the literature about optimization of energy consumption in buildings. Many researches have been done to reduce the energy use in buildings as well as many concepts have been proposed by some researcher to provide energy efficient in buildings. Therefore, double-skin facade is one of the building façade concepts which proposed efficient energy consumption.

Double-skin facade is one of façade system utilized in buildings to provide both improved indoor climate and reduced the usage of energy. It is mostly developed in European countries which climates are moderate. Furthermore, double-skin facade is a facade system that allows the outside conditions to influence the indoor climate and it performance is highly depends on solar radiation and outdoor temperature.

The advantages of double-skin façade concepts had been reported by many researchers and building scientists. In many cases, double-skin façades has significant role with critical responsibility in connecting the indoor environment of building to the outdoor. Buildings with large areas of glazing for instance, incur excessively high electrical demands. One way of reducing the magnitude of this demand is through double-skin façade. Hence, the effectiveness of double-skin facade to reduce heating loads in winter as well as to decrease cooling load in summer has been proven obviously along with it possibility of being applied in cold and temperate climate area.

However, the effectiveness of the application of double-skin facades in hot-humid climate condition area likes Indonesia is not known or less documented yet. For that reason, however, this study attempts to find out the skin load performance of double-skin façade in hot-humid climate area with the case study of Indonesia.

Overview of Double-Skin Facade

Double-skin facade is a façade construction of building envelope, which consist of two transparent glass covering surfaces as an exterior and interior glass wall aside by air cavity as a channel for airflow exchange, shading device, top and bottom ventilation. The cavity's function is like a thermal buffer for the indoor air temperature (Jiru and Haghighat, 2008; Zou and Chen, 2010). It is addressing the customs of natural ventilation. Fresh air from outside exchanged the air in the cavity and moved out throughout the air outlet at the top of the building.

Notwithstanding the fact that the expenses of double-skin facades are higher than those of normal facades, it advantages had been reported by many researchers and building scientist (Poirazis, 2004). Chan et al (2009) have investigated the performance of double-skin facade in comparison to a conventional single-skin facade with absorptive glazing in Hong Kong. A comparison between double-skin facade and single-skin façade have also been done by Hamza (2008) in hot arid climate area and found that a reflective glass used in double-skin facade can achieve better energy savings than a single-skin façade with reflective glazing. Research on thermal performance of double-skin facade by natural ventilation with venetian blind had been done by Xu and Yang (2008). Hien et al (2005) found that double glazed facade with natural ventilation could minimize energy consumption as well as to improve the indoor environment thermal comfort. All is discloses that double-skin facade have a significant role with critical responsibility in connecting the indoor environment of building to the outdoor environment. Buildings with large areas of glazing facade, incur excessively high electrical demands (Al-Rabghi et al, 1999). One way of decreasing the magnitude of this demand is through double-skin facade.

Natural ventilation is an important part on the performance of double-skin facade which correlates to the thermal performance and solar heat gain. Some investigations had been carried out to define the correlation between natural ventilation and thermal performance of double-skin facade by the integrated and modelling process using simulation tools (Pappas and Zhai, 2008; Ding et al, 2005; Manz and Frank, 2005; Wong et al, 2008; Høseggen et al, 2007) . Most of them are using the notion of stack effect or solar chimney concept.

Research Methods

In this study, five storeys of naturally ventilated double-skin facade models with different orientation, configurations of outer and inner glass thickness, and distances combinations were used. Between outer and inner glass attached a light colour horizontal blind as a shading device (Figure 1).

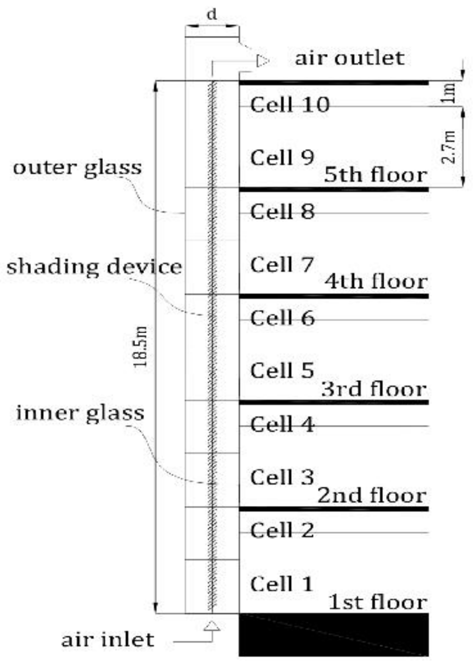

Figure 1. Model of Double-Skin Facade

To simplify the calculation, the models were divided into 10 cells and each floor consists of 2 cells. List of various glass skin combinations and distances between outer glass skin and inner glass skin configurations can be found on Table 1.

Table 1. Glass Skin Combinations, Distances and Orientations

Glass skin combination		Distance between outer & inner glass (d)				Orientation			
Outer glass [mm]	Inner glass [mm]	Alt. 1 [cm]	Alt. 2 [cm]	Alt. 3 [cm]	Alt. 4 [cm]	Group 1	Group 2	Group 3	Group 4
10	6	200	150	100	80	North	East	South	West
10	8	200	150	100	80	North	East	South	West
10	10	200	150	100	80	North	East	South	West
10	12	200	150	100	80	North	East	South	West
12	12	200	150	100	80	North	East	South	West

A numerical simulation model was used to calculate the solar heat gain and thermal transmittance of double-skin facade using FORTRAN module. A FORTRAN's source code has been developed and verified by the measured data from Izumi Campus Media Building of Meiji University located in Tokyo-Japan (Kato et al., 2008; Yoon et al, 2005).

In this numerical model, outer glass skin ($_{og}$), shading device ($_{sd}$), and inner glass skin ($_{ig}$) were assume to have a single mass point in the direction of thickness. Convective heat transfer ($_{hc}$), mutual radiation of long-wavelength radiation ($_{hr}$), and solar radiation (I) were taken into account. Multiple reflection and variation of direct solar radiation due to the incident angle were also taken into account for the solar transmittance, reflectance, and absorptance (Figure 2).

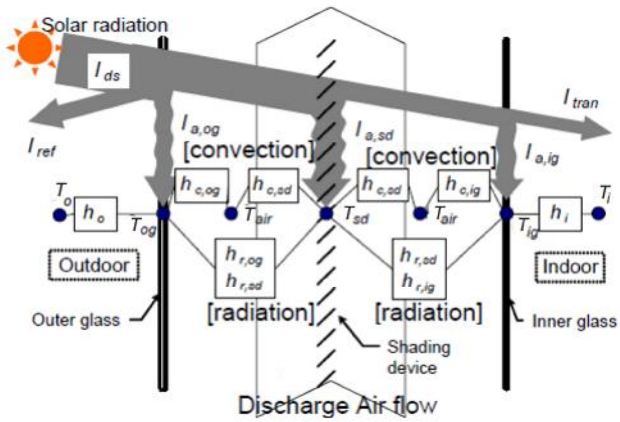

Figure 2. Outline of Numerical Model of Double-skin

Simulation runs based on the design and operational parameters (Table 2) and weather input condition from 08:00 until 17:00 during working day. Indoor temperature was set up to 25°C (Anonymous, 2005). Natural ventilation with stack effect was used with principles of heat balance to calculate the air temperature inside the double-skin facade. Both temperature distribution and ventilation volume were calculated convergence until a stationary solution is obtained at each calculation time as shown in Figure 3.

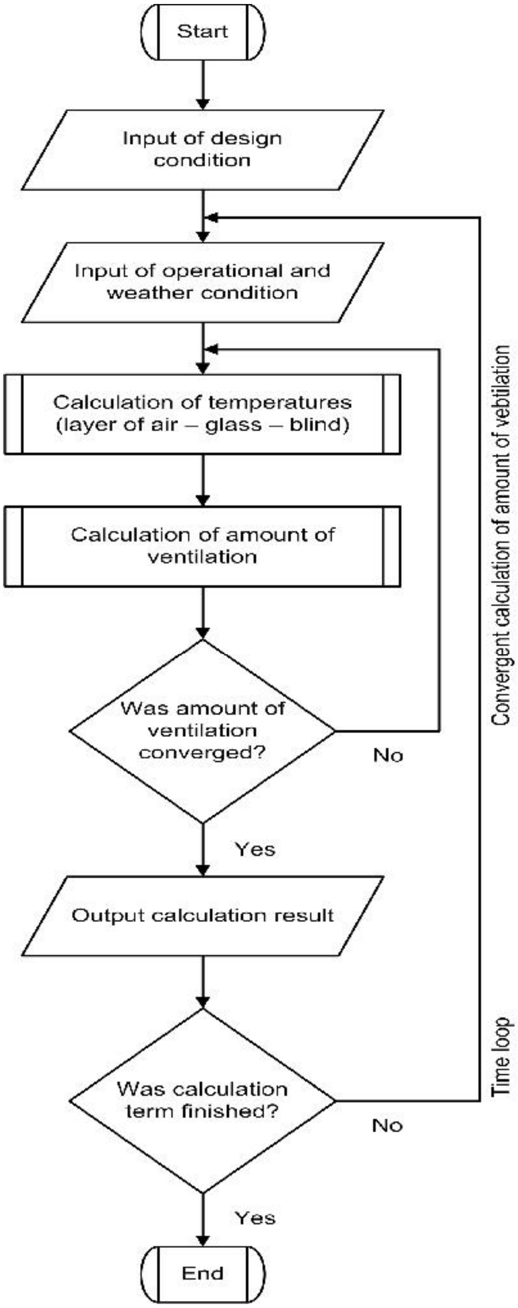

Figure 3. Calculation Flow-chart

Table 2. Design and Operational Parameters

Physical properties	Value
Azimuth angle of north oriented double-skin [°]	0
Azimuth angle of east oriented double-skin [°]	-90
Azimuth angle of west oriented double-skin [°]	90
Azimuth angle of south oriented double-skin [°]	180
Inclined angle of double-skin [°]	90
Thickness of outer glass (refers to Table 1)	
Thickness of inner glass (refers to Table 1)	
Thickness of outer layer divided by blinds for 200 cm distance [m]	1.9
Thickness of outer layer divided by blinds for 150 cm distance [m]	1.4
Thickness of outer layer divided by blinds for 100 cm distance [m]	0.9
Thickness of outer layer divided by blinds for 80 cm distance [m]	0.7
Thickness of inner layer divided by blinds [m]	0.1
Slat angle of blinds [°]	45
Solar transmittance of blinds	0.1
Solar absorptance of blinds	0.5
Emissivity of blinds	0.95
Emissivity of glass	0.837
Flow coefficient of lower and upper aperture	0.65
Area of lower and upper aperture [m^2/m]	0.30
Ground reflectance	0.14

RESULTS AND DISCUSSION

Annual Performance of Skin Load

Based on numerical simulation result, it was found that annual performance of skin load by thermal transmittance is higher than annual skin load by solar heat gain for all double skin facade simulated cases. Figure 4-5-6-7 shows the double-skin facade with 12mm outer and inner glass skin combination with the distance of 200cm as presented cases.

Annual maximum thermal transmittance of north faced double-skin facade is 115.72 W/m^2, and the annual average 48.55 W/m^2. While, the solar heat gain is 38.43 W/m^2 in annual maximum and the annual average is 10.21 W/m^2. Then, for east oriented double-skin facade, annual maximum of skin load by thermal transmittance is 102.60W/m^2 with 47.48W/m^2 in the average. Annual maximum of skin load by solar heat gain is 37.26W/m^2, and the annual average is 10.12W/m^2. South faced double skin facade has the annual thermal transmittance 77.50W/m^2 in maximum; and the annual solar heat gain performance is 19.27W/m^2. The average annual performance of thermal transmittance is 43.30W/m^2, and average annual solar heat gain is 7.96W/m^2. Annual performance skin load by thermal transmittance at west oriented double-skin facade is 109.51W/m^2 in maximum, and 47.17W/m^2 in average. Annual maximum solar heat gain is 36.99W/m^2, and the annual average solar heat gain is 9.93W/m^2.

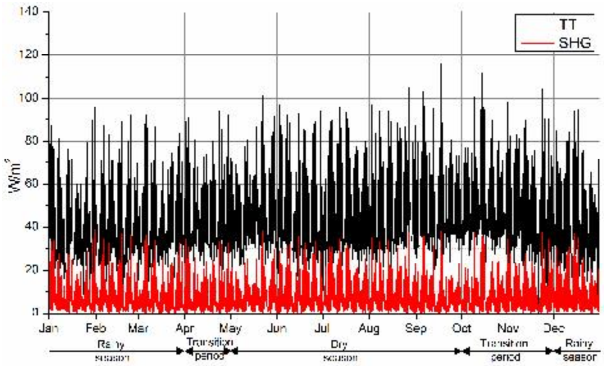

Figure 4. Annual Skin Load Performance of
North Oriented Double-skin Facade

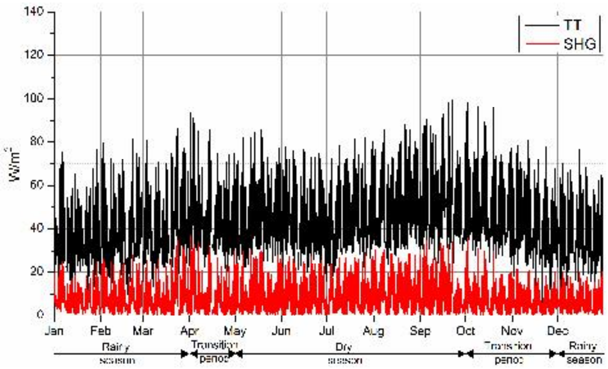

Figure 5. Annual Skin Load Performance of
East Oriented Double-skin Facade

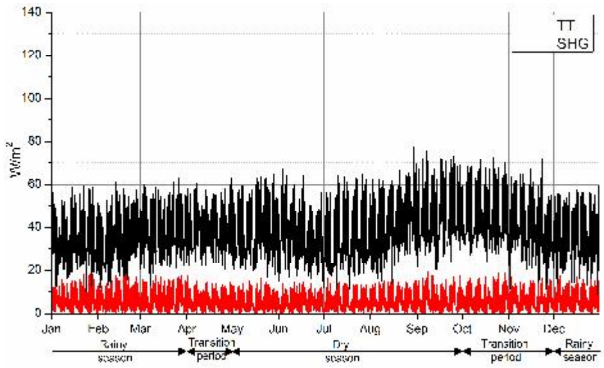

Figure 6. Annual Skin load Performance of
South Oriented Double-skin Facade

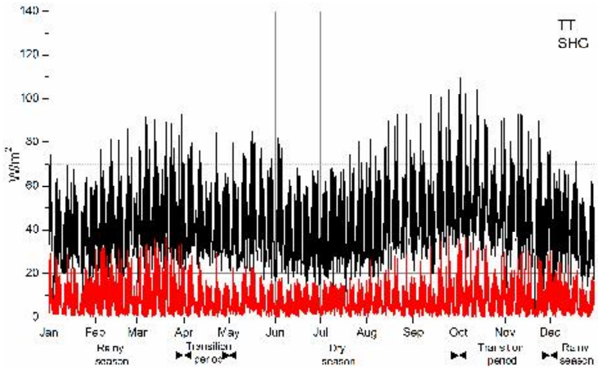

Figure 7. Annual Skin Load Performance of West Oriented Double-skin Facade

Comparing Thermal Transmittance and Solar Heat Gain Performance with Double-skin Facade Configurations

The thickness of the glass and the distance between outer and inner glass plays an important role to the performance of thermal transmittance and solar heat gain of double-skin facade. As can be seen on Figure 8, significant reduce on solar heat gain performance of double-skin facade shown on the combination 12mm outer and inner glass (DS200N.12.12), better than other glass skin combinations (DS200N.10.12, DS200N.10.10, DS200N.10.8, and DS200N.10.6).

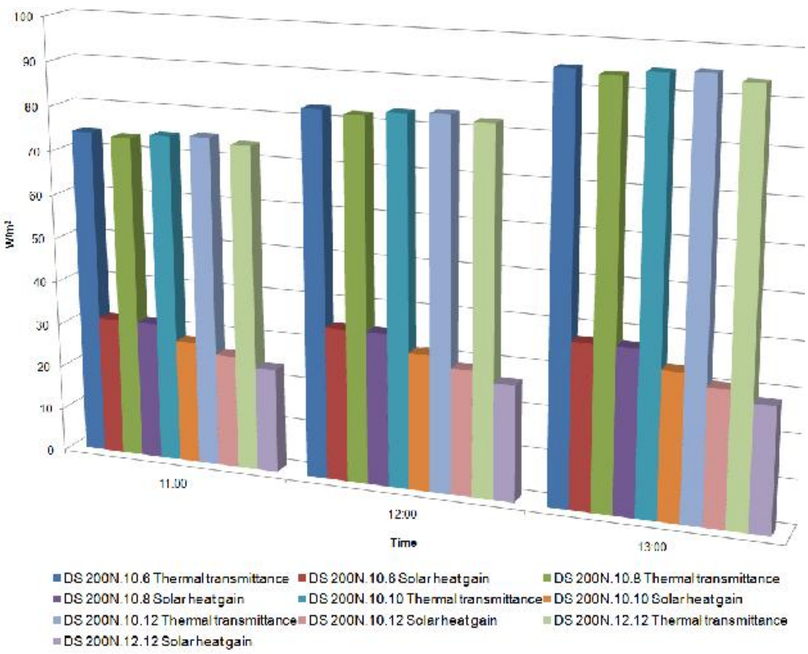

Figure 8. Solar Heat Gain and Thermal Transmittance of Double Skin Facade in Respect of Outer and Inner Glass Thicknesses

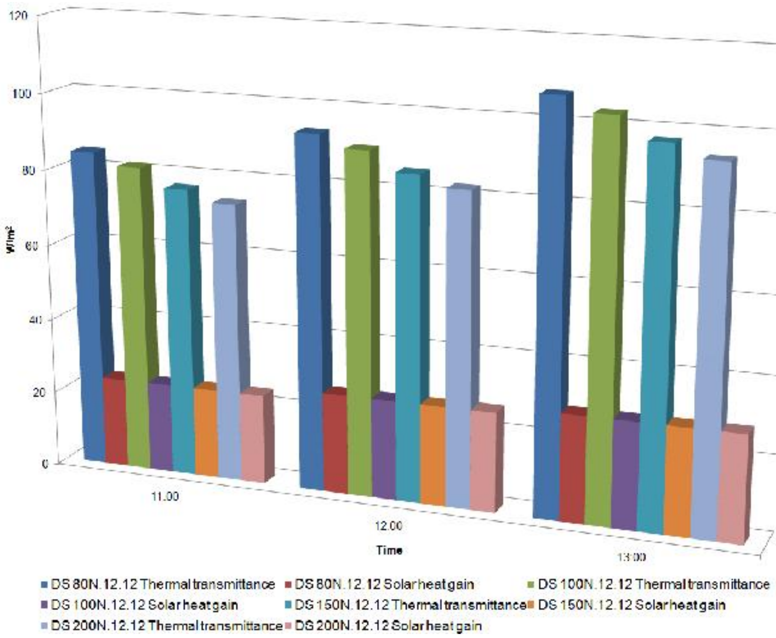

Figure 9. Solar Heat Gain and Thermal Transmittance of DoubleSkin Facade in Respect of Outer and Inner Glass Thicknesses Outer and Inner Glass Distances

On the contrary, the distance between outer and inner glass of double-skin facade is greatly influencing the performance of thermal transmittance and solar heat gain of double-skin facade. As shown on Figure 9, significant reduce on thermal transmittance value is by the distance of 200cm of outer and inner glass. While, the solar heat gain value is nearly constant. All of above shows that the application of double-skin facade in Indonesia is available in any orientation (for north, east, south, and west orientation cases). However, looks like the thermal transmittance influencing the skin loads; higher than solar heat gain. Thermal transmittance in double-skin facade is mostly influenced by the distance of outer and inner glass skin, while solar heat gain value is influenced mostly by the thickness of the glass.

Possibility of Condensation

It is important to analyze the possibility of condensation at the outer surface of inner glass of double-skin facade since during the rainy season the humidity is increase. A calculation had been performed during operation time of building from 08:00 to 17:00 with indoor setup temperature was 25°C. The result found that there is no possibility of condensation to occur during building operation time.

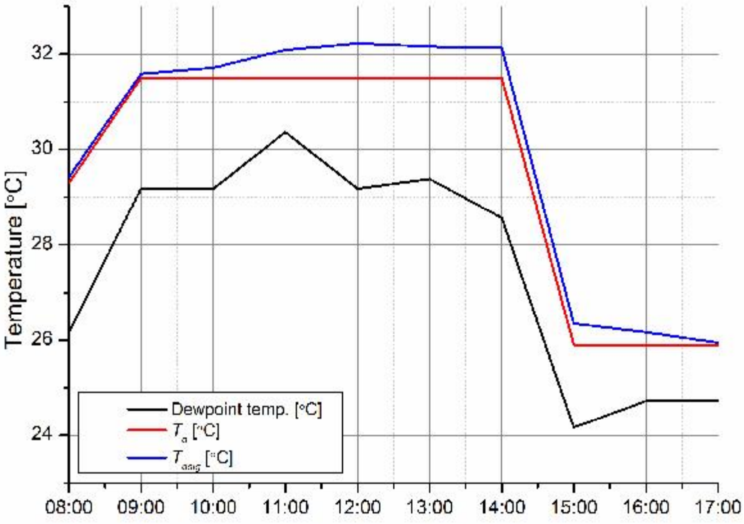

Figure 10. Possibility of Condensation at Rainy Season

Figure 10 shows the condition of south faced double-skin facade during the rainy season at January 3. Temperature of outer surface of inner glass of double-skin facade was nearly the same with outdoor temperature in the morning and afternoon. Moreover, at that time, temperature of outer surface of inner glass of double-skin facade was not reach saturated point, since there was approximately more than 1°C difference to dew point temperature. Condensation occurs when the temperature of air is lower than its dew point temperature. However, since simulation time was limited to the building operation time, and also there is a tendency of the temperature of outer surface of inner glass to become decrease during the time, there is a possibility of condensation to occur at night time. This matter should be investigated in the future.

Skin Load Comparison between Single-skin Facade and Double-skin Facade

In order to define the effectiveness of double-skin facade in reducing skin load, the result of simulated skin load double-skin facade model was compared with skin load of single-skin facade window system listed at the Table 3.

Table 3. Specification of Single-skin Facade Window System

Windows system		U value	SC
FL+BD	Float glass + light-colored inner blinds.	4.8 [W/m^2.K]	0.55
ML+BD	Double-glazed glass (layer of air: 6mm) + light-colored inner blinds.	3.0 [W/m^2.K]	0.54
HF+BD	Highly-insulated double-glazed glass (layer of air: 6mm) + light colored inner blinds.	2.2 [W/m^2.K]	0.34

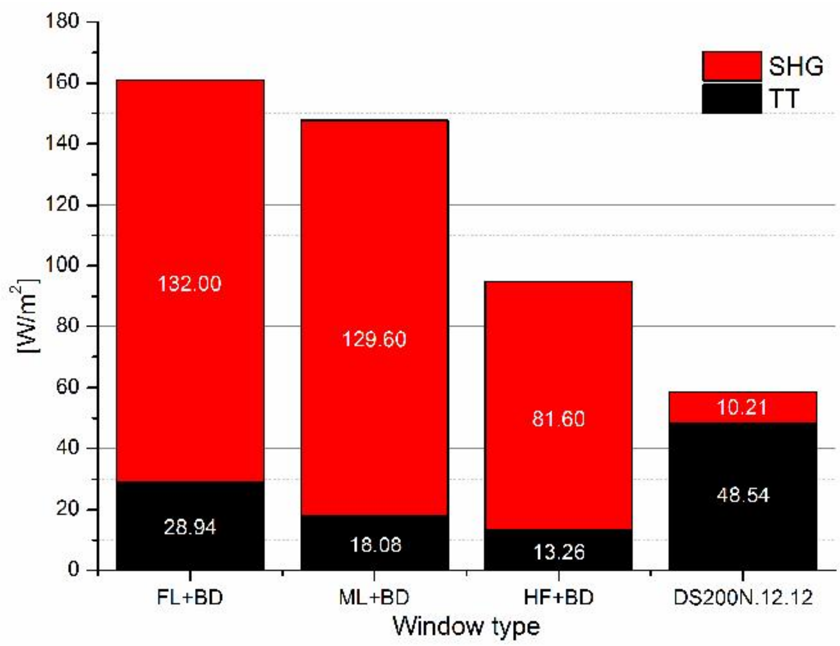

Figure 11. Skin Load of Double-skin Facade
Compared to Skin Load of Single-skin Facade

As can be seen on Figure 11, double-skin facade is characterized by higher in thermal transmittance value but lower in solar heat gain value. On the other side, single-skin facade is characterized by higher solar heat gain but lower in thermal transmittance value. In this case, more than 50% of skin load can be reduced by double-skin facade compared to single-skin facade. In single-skin, approximately 80% of skin load is by solar radiation and 20% by thermal transmittance. This is different to skin load value in double-skin facade. In double-skin façade, solar heat gain value due to its orientation is approximately 80% caused by thermal transmittance and about 20% is caused by solar heat gain. But overall, total skin load in double-skin facade is lower than single-skin window system. This phenomenon is indicating that double-skin facade is applicable and could be more beneficial for equator area wherein solar radiation is abundant like Indonesia in reducing facade skin load.

Furthermore, Table 4 shows daily average the performance of all double-skin facade cases analyzed in this research for the comparison of skin load performance of double-skin facade to the single-skin facade window system.

Table 4. Daily Average Performance of All Double-skin Facade Cases

Orientation	Outer Inner glass distance [cm]	Glass thickness [mm]		Daily average		Orientation	Outer Inner glass distance [cm]	Glass thickness [mm]		Daily average	
		Outer glass	Inner glass	Solar heat gain [W/m^2]	Thermal transmit. [W/m^2]			Outer glass	Inner glass	Solar heat gain [W/m^2]	Thermal transmit. [W/m^2]
	80	10	6	49.05	13.50	East	80	10	6	47.64	13.09
North		10	8	48.63	13.50			10	8	47.23	13.09
		10	10	48.98	12.00			10	10	47.56	11.66
		10	12	49.03	11.07			10	12	47.62	10.76
	100	10	6	50.18	13.50		100	10	6	48.67	13.09
		10	8	49.76	13.50			10	8	48.26	13.09
		10	10	50.11	12.00			10	10	48.60	11.66
		10	12	50.17	11.07			10	12	48.65	10.76
		12	12	49.72	10.21			12	12	48.23	9.93
	150	10	6	51.97	13.50		150	10	6	50.27	13.09
		10	8	51.54	13.50			10	8	49.86	13.09
		10	10	51.90	12.00			10	10	50.20	11.66
		10	12	51.96	11.07			10	12	50.26	10.76
		12	12	51.56	10.21			12	12	49.89	9.93
	200	10	6	53.05	13.50		200	10	6	51.23	13.09
		10	8	52.62	13.50			10	8	50.81	13.09
		10	10	52.98	12.00			10	10	51.16	11.66
		10	12	53.04	11.07			10	12	51.22	10.76
		12	12	52.68	10.21			12	12	50.88	9.93
South	80	10	6	47.64	13.09	West	80	10	6	47.95	13.34
		10	8	47.23	13.09			10	8	47.54	13.34
		10	10	47.56	11.66			10	10	47.88	11.88
		10	12	47.62	10.76			10	12	47.94	10.97
		12	12	43.30	7.96			12	12	47.48	10.12
	100	10	6	48.67	13.09		100	10	6	49.00	13.34
		10	8	48.26	13.09			10	8	48.59	13.34
		10	10	48.60	11.66			10	10	48.93	11.88
		10	12	48.65	10.76			10	12	48.99	10.97
		12	12	48.23	9.93			12	12	48.56	10.12
	150	10	6	50.27	13.09		150	10	6	50.63	13.34
		10	8	49.86	13.09			10	8	50.22	13.34
		10	10	50.20	11.66			10	10	50.57	11.88
		10	12	50.26	10.76			10	12	50.63	10.97
		12	12	49.89	9.93			12	12	50.26	10.12
	200	10	6	51.23	13.09		200	10	6	51.61	13.34
		10	8	50.81	13.09			10	8	51.19	13.34
		10	10	51.16	11.66			10	10	51.55	11.88
		10	12	51.22	10.76			10	12	51.62	10.97
		12	12	50.88	9.93			12	12	51.27	10.12

CONCLUSIONS

Skin load performance of double-skin facade models has been simulated and the cases have been compared to single-skin facade window system. It was found that thermal transmittance value of double-skin facade is always higher than solar heat gain value during the year. Double-skin facade is also found effective to minimize skin load by solar heat gain. Combination of glass thicknesses of outer and inner glass is useful to reduce skin load by solar heat gain as well as configuration of outer and inner glass distances is beneficial to reduce skin load by thermal transmittance on double-skin facade. Moreover, double-skin facade has also shown the best performance in reducing the solar heat gain if compared to single-skin facade. Furthermore, double-skin facade has satisfied for reducing the skin load with no condensation occurred at the surface of the inner glass during building operation time even at rainy season.

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