Optic performance of single and double-glazed laminated glass in tropical climate

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Abstract. Validation model was generated by WINDOW 7.6 software to simulate the temperature changes of laminated glass. This approach is used as a validation model to compare the real time temperature changes observed. The parameter in the test were clear laminated glass and coloured laminated glass with using single- and double-glazed technology to assess the impact of optic glass, including U-Value, SHGC, and additional layer application of laminated Glass (Double Glazing Technology) in building temperature changes for creating thermal comfort. The results showed that single glazed technology application on clear laminated glass adjust the room temperature between 30.2°C to 31.4°C. In comparison, single colour laminated glass technology application set the room temperature 27.7°C to 28.5°C. Interestingly, the double-glazed application reduced the indoor temperature between 27.1°C to 28.5°C. These results showed that buildings' significant thermal performance could be accomplished by applying double-glazed technology. Nevertheless, double glazed technology was not suggested to apply in all of the skin of tropical building design due to the high-cost issues.

1. Introduction

Population growth, the evolution of the construction industry, and increasingly advanced technology have led to an increase in the construction of glass-glazed high-rise buildings [1]. Glass-covered buildings have grown into an icon in various developing countries, such as Indonesia [2]. Laminated glass is one type of glass that is easily found in Indonesia, especially in Jakarta, this is due to its relatively low price and low property value of laminated glass. Glass allows natural light, provides visual communication with the outdoor space and enhances the aesthetics of the building [3].

However, in tropical climates, glass allows solar radiation to enter interior spaces, causing unfavorable thermal comfort for the occupants. Thermal comfort is defined as a state of mind that expresses satisfaction toward the thermal environment [4]. Thermal comfort is influenced by two variables, notably personal variables, including metabolic rate and clothing insulation and environmental variables, including air temperature, air velocity, and humidity [5].

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Air temperature is one of the factors that influence the thermal comfort associated with solar radiation that enters the building through glass. The solar radiation that enters through the glass is influenced by the value of the Solar Heat Gain Coefficient (SHGC) and U-Value, where SHGC calculates the amount of radiation received by glass [6]. In contrast, U-Value calculates the amount of heat circulation to the glass between the outer and inner buildings [7].

Air temperature is one of the most dominant factors in determining thermal comfort. The units used for air temperature are Celsius, Fahrenheit, Reaumur, and Kelvin [8]. The results of studies conducted [9,10] that the temperature as the most crucial thing in building thermal comfort. This air temperature has close relation to the heat created by the difference in temperature, while the heat flows from high to low temperature.

Air temperature can be divided into two, precisely normal air temperature and average air temperature (MRT = Mean radiant temperature), which is the average temperature of the environment encompassing a person. MRT affects person's body by 66% [10]. Thermal comfort will be generated if the difference between MRT and normal air temperature is less than 50. Thermal comfort in humans fits at a body temperature of 37°C, and if it rises to 50 or drops to 20, then there will be discomfort or even death. While the ambient air temperature is assumed to be comfortable around 25°C, the human body sweats above 26°C [10]. Therefore, in addition to the human body's ability to maintain temperature, optimal environmental conditioning is also necessitated.

Various studies on thermal comfort conducted in tropical climates in Jakarta shows temperature within range of 24°C-30°C are still considered comfortable for humans [11]. Meanwhile, a normal indoor or room temperature based on the Minister of Health NO.261/MENKES/SK/II/1998 range between 18°C - 26°C. Table 1 shows a comfortable temperature level for Indonesians based on the standards by SNI 03-65722001.

Table 1. Thermal comfort limits according to SNI 04-6572-2001

	Temperature (TE)	**Humidity (%)**
Cold Temperature	20.5°C TE – 22.8 °C	50%
Upper limit	24 °C TE	80%
Optimum Temperature	23.8 °C TE -25.8 °C TE	70%
Upper Limit	28 °C TE	
Hot Temperature	25.8 °C TE – 27.1 °C TE	60%
Upper limit	31 °C TE	

In the glazing system, the facade's properties, such as the SHGC and U-Value values, can affect the thermal comfort of the building. The value of the Solar heat gain coefficient (SHGC) is a measurement of the solar radiation heat transmitted through the window, which is absorbed and radiated into the building [6]. The lower the SHGC value of the window, the less solar heat is transmitted [6].

The window unit's capacity to withstand this heat circulation is referred to as the U-factor or U-value are expressed in the W/m²K value [7]. Jelle (2007) states that 2 U-value measurements are frequently used. The first is the Center Pane U-Value measurement, where the energy conductivity measurement is measured through the glass section. In other words, increasing the number of glass panels will affect the conductivity of the glass [7].

The addition of the number of glass panels can reduce heat loss (U-value) by 50% better than single glass. Even though the U-value decreases significantly, the double glass's SHGC value does not decrease significantly [12]. Adding a layer of glass will also reduce the VT and SHGC values. Single glass is a glass consisting of one glass panel. Glass with a single technology usually has a thickness of between 3-15 mm, yet given that there is only one layer of glass between the inside and outside of the building, it can cause a large amount of radiation that enters the building [12].

Double glass technology is constructed with two glass panels with a vacuum that separates the glass panels. In double glass technology, the radiation that enters the building is smaller than single glass [12] this is due to the presence of a vacuum that acts as an insulator, and there are more absorption and reflection of radiation and solar heat on double technology. Therefore, the use of multiple technologies is considered more efficient than a single technology [12].

Laminated glass is a glass layer consisting of two sheets of glass in which a transparent plastic coating substance called Polyvinyl Butyral (PVB) is inserted in the middle. This PVB substance can keep the glass layer bonded even when shattered; therefore, the laminated glass is frequently identified as safety glass. PVB on laminated glass can absorb UV radiation and stables in the long term [13]. In general, the types of glass used as a layer of laminated glass are clear glass and colored glass.

Clear glass is a colorless glass with a clean and flat surface whereas the colored glass is stained glass by adding metal oxides to the glass. Colored glass has filtering properties that can help reduce glare, and able to reduce energy transmission when exposed to sunlight [14]. In Indonesia, especially in Jakarta, normal glass is a type of glass that is widely used in buildings such as schools, universities and some office buildings and this is due to the quite difference of prices between clear glass and colored glass and laminated glass (Table 2).

Table 2. Price List of Glass (Source: Various Sources of Website Last accessesed: May 20th 2020)

Type of Glass	Price	Size	Source
Clear Glass	Rp. 120.000 – 350.000	m^2	Kacaku.co.id
Coloured Glass	Rp. 180.000	m^2	Kacaku.co.id
Clear Laminated Glass	Rp. 345.000 – 1.184.000	m^2	Kacaku.co.id
Coloured Laminated Glass	Rp. 400.000 – 1.250.000	m^2	Kacaku.co.id
Double Laminated Glass	Rp. 708.930 – 4.322.624	m^2	Alibaba.com

From the table above, currently it is obvious that clear glass has the lowest price compared to other types of glass, while laminated glass using double technology has a higher price.

Considering all the aspects, it is essential to create a sustainable environment with minimum cost in the upcoming construction era. Using the simulation software, this research will breakdown the final temperature changes and shows which glass that has optimum temperature and low cost.

2. Methods

2.1 Validation Model

The numerical study starts with validation phase to make sure the modelling approach could represent the actual result. Experimental study conducted by recording the temperature changes in Educational building located in Depok. The experimental setup is about the colored glass were tested to evaluate their glass temperature changes and the average temperature by using a Laser Thermometer Unit and room temperature. The colored glass was 5mm in thickness, with 5.8 of U-Value and 0.58 of SHGC. Then, it was found that the educational building has an average temperature in 30.7°C, with the coolest occurs on the 1st floor and the hottest temperature occur on the 5th floor. The temperature changes are summarized in Table 3

Table.3 Temperature Changes in Education Building by observation

Floor	Glass Surface Temperature		Room Temperature
	East	West	
1st	-	34.1°C	27.9 °C
2nd	48.4 °C	43.4 °C	30 °C
3rd	47 °C	43.4 °C	31.5 °C
4th	48.6 °C	43 °C	32 °C
5th	48 °C	42 °C	32.5 °C

Yet, for the validation we are using the same glass with the same specification by using software WINDOW 7.6 to calculate the temperature changes in the glass's surface and the average room in educational building. In this validation, the maximum temperature of Depok's City is utilized as a reference for the outside air temperature, the temperature changes by simulation is summarized in Table.4

Table.4 Temperature Changes in Education Building by Simulation

Floor	Outside Temperature	Glass Surface Temperature		Room Temperature
		Inside	Outside	
2nd	34°C	43.3 °C	43.6	30
3rd	34°C	43.4 °C	43.7	31.5
4th	34°C	43.5 °C	43.8	32.2
5th	34°C	43.5 °C	43.8	32.6

From the results of comparisons between observation and simulation, it was discovered that there were differences in room temperature and glass surface temperature in the building. In the simulation results, room temperature is directly proportional to the observation data. In contrast to room temperature, the simulated glass surface of temperature data is inversely proportional to the observed data.

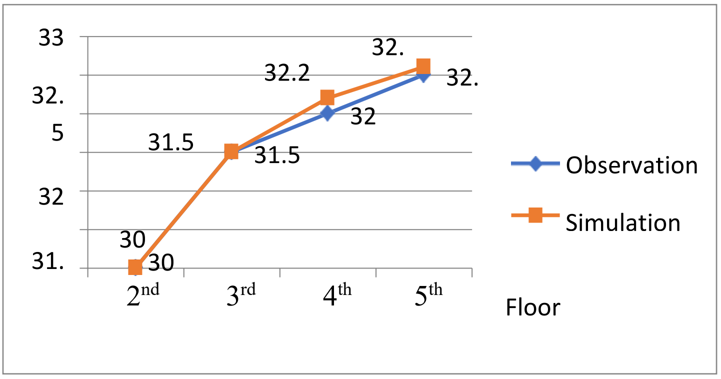

Figure.1. Graph of the room temperature difference for observation and simulation
Source: Data results of the authors

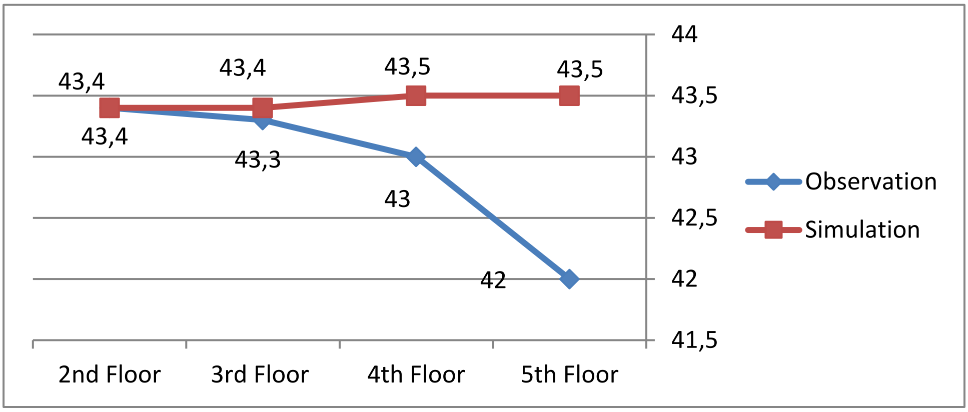

Figure.2. Graph of the room temperature difference for observation and simulation
Source: Data results of the authors

The difference in these results (Figure 1 and Figure 2) can be prompted by errors made by the authors in the observation process. This error can occur due to the lack of time taken when measuring the temperature of the glass. It can also be prompted by the distance between the tool and the glass surface, that was when the temperature measurement was accomplished. Through the obtained results, the simulation results are considered more valid than the observation results and several theories.

Emuwa (2016) shows there are directly proportional results to the glass surface temperature and room temperature, where the glass surface temperature has a higher temperature than room temperature. From this theory, it can be said that if there is an increase in the glass's surface temperature, there will also be an increase in room temperature; this is prompted by the glass material, which acts as a heat circulation medium that is directly exposed to sunlight.

Meanwhile, according to ASHRAE Standard, changes in air temperature in the room are generated by several factors, one of which is the height of a place, the higher the building, the closer the sun rays are which can cause an increase in indoor temperature. Also, the results discovered by Schiavon (2010) indicate that the influence of building height can cause an increase in average temperature [16].

Therefore, it can be concluded that from the results of the room temperature comparison data between the observation data and the simulation data are quite the same. Although there are differences, it has been unearthed that the simulation results have more valid results than the observation results; this is supported by several theories that have been described previously. The simulation is able to see changes in temperature and surface temperature on laminated glass

2.2 Studied Glass Types

The Study objective is to observe the temperature changes of 2 type of laminated glass which is Clear glass and colored glass with single and double-glazed technology. The properties of the glass will be used to be simulated following Table.5

Table.5 Glass Properties of Laminated Glass

	Coloured	Clear	Colored	Clear	Colored

	Glss	Laminated (Single Technology)	Laminated (Single Technology)	Laminated (Double Technology)	Laminated (Double Technology)
U-Value	5.8	5.5	5.1	3.2	3.1
SHGC	0.58	0.59	0.56	0.44	0.40

3. Result and Discussion

The U-value measures the transmission of heat circulated through the window, while the SHGC measures the transmission of solar radiation through the glass. The simulation results show the temperature changes that occur in the laminated glass using single and double-glazed technology. It was found that colored laminated glass has a lower temperature change, compared to clear laminated glass; this is due to the optical values (U-Value and SHGC) of each glass type are different.

Table 6 shows that the U-value and SHGC on the clear laminated glass are higher than those of colored laminated glass; this is due to the colored laminated glass adds vanadium metal oxide which can help reduce energy transmission when exposed to sunlight, which causes the SHGC value in this glass to decrease. From the simulation of 2 types of laminated glass and the use of their technology, it can be concluded that clear laminated glass with a single technology possesses the highest room temperature value, which is then followed by the colored laminated glass with a single technology, clear laminated glass with dual technology, and the lowest room temperature values are in the type of colored laminated glass with double technology.

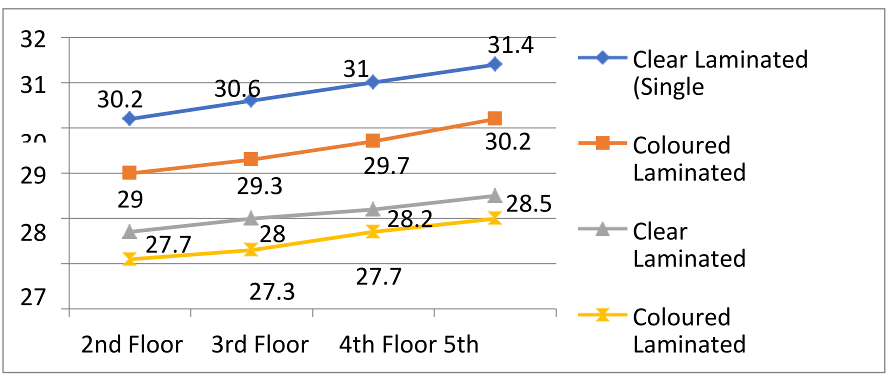

Figure. 3. Graph of Temperature comparison of 3 types of glass and glass technology
Source: Authors' diagram

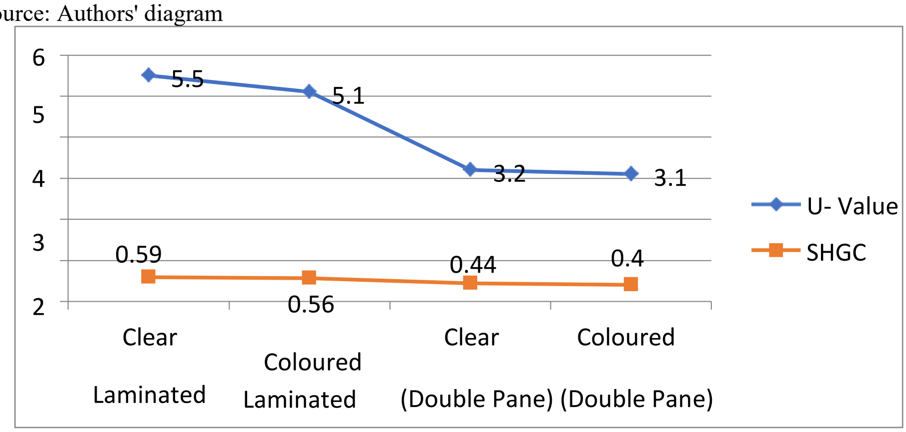

Figure. 4. Graph of optical values comparison of 3 types of glass and glass technology
Source: Authors' diagram

Figure 3 and 4 exhibits the correlation between the increase and decrease in temperature, which is influenced by the U-value factor and the SHGC value on the glass. From the graph, it can be noticed that there is a result between the temperature gain. It is directly proportional towards the optical value of the glass. The lower the U-value and the SHGC value, results the lower the temperature changes that occur on the glass surface which have an impact on decreasing the temperature in the room.

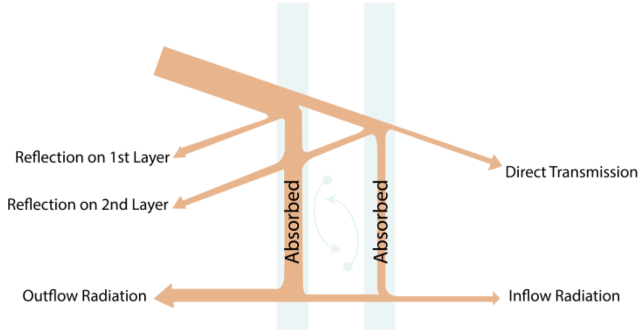

Figure. 5. Heat circulation scheme through double laminated glass
Sources: https:\\www.glazingguru.org/technology/what-is-the-g-factor/

From the simulation results, the double technology shows a significant change in the glass's surface temperature. This is due to the first panel of glass being directly exposed to solar radiation (Figure 5). The radiation will then be transmitted into the room through the air chamber and the second panel of glass. In the air space, a convection process occurs, which can reduce heat. Therefore, in the second panel of glass, the energy transmission received is reduced, prompting less solar energy to enter the room and reduce excess heat in the room.

Table 6. The table of comfort limit corresponds to the glass type. (Source: Authors)

Type of Glass	Temperature	Comfort Limit SNI 04-62572-2001	Average Temperature
Single clear laminated glass 5mm	30.2 - 31.4	Upper Threshold of Warm Comfort - Not Comfortable	22°C - 30 °C
Single-coloured laminated glass 5mm	29 -30.2	Upper Threshold of Warm Comfort - Not Comfortable	
Double clear laminated glass 15mm	27.7 - 28.5	Upper Threshold of Optimal Comfort - Warm Comfort	
Double coloured laminated glass 15mm	27.1 - 28	Upper Threshold of Optimal Comfort	

Table 6 displays that of 2 types of laminated glass with a single technology or double technology. It is discovered that clear laminated glass with a single technology is at an uncomfortable temperature for residents. Lippsmeier (1997) based the conditions at that temperature are no longer possible, whereas in the coloured laminated glass with singular technology are still in a comfortable temperature range.

In contrast to applying glass addition technology, clear laminated glass with double-technology is at a temperature of upper threshold optimal comfort and warm comfortable. Additionally, the laminated glass with a single technology is at the upper threshold optimal comfort. Therefore, using coloured laminated glass with double-glazed technology can optimize the room temperature in keeping it cold. Moreover, it provides thermal comfort to the residents.

4. Conclusion

It was discovered that the temperature on clear laminated glass adopting single-glazed technology has the highest temperature ranging from 30.2°C - 31.4°C. According to SNI standards, that temperature was at an uncomfortable temperature. It was then followed by the coloured laminated glass with a single technology whose temperature is still in under the comfortable category, at 29°C - 30.2°C. The last is clear and coloured laminated glass with dual technology, which can reduce the temperature to 27.1°C - 28.5°C, where the temperature range is at the optimal comfortable temperature.

These results indicate that adding the number of glass panels can reduce the glass's surface temperature and the room temperature in buildings. It shows that by increasing the number of glass panels, the optical value (U-values and SHGC values) on the glass will get lower.

A low U-value retains heat and provides more excellent insulation. It helps maintain the right temperature. Meanwhile, a low SHGC value can reduce heat circulation that transpires through the glass. Thus, the lower the U-Value and SHGC Value, the lower the glass surface temperature and room temperature. Therefore, it can be stated that the change in room temperature goes directly proportional to the optical value of the glass.

Thermal comfort in buildings is a paramount. Therefore, determining the type and optical value of the glass must be optimal with the consideration of thermal performance and low cost. Coloured laminated glass with dual technology can reduce the temperature optimally in buildings and impact the thermal comfort of residents in tropical climates. However, due to the high cost consideration, this technology is not recommended for their use in high-rise building construction.

Thus, the use of single-coloured laminated glass can be recommended for high buildings in tropical climates. It maintains optimal thermal performance with less expensive construction cost.

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