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The Effect of Glass Planes on Thermal Comfort in Office Buildings

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ABSTRACT

One of the most important aspect in architecture is the selection of exterior material. This material surface faces directly with building's surrounding climate and environment, transferring the heat through its wall and roof significantly so it requires more consideration from the designers. Widely use of glasses on building's exterior impacts its heat absorbing. Thereby, it needs more power for air conditioning in order to keep the interior temperature productively workable. The objective of this research is to analyze the impact of glass planes to the room thermal environment and what is the the thermal sensations of the occupants. The heat transfers to the room by using OTTV also calculated. The analysis also correlates between thermal environment and heat transfer to the room. The research results show that the highest average air temperature in building F is at 27.5^{0}C. The transparent openings in this building reach 70%. Thus, the flow of solar heat radiation entering the room becomes large (OTTV). namely 294 W/m2. Then, the perception of the building occupants is in the range of neutral and slightly warm.

Keywords: glass planes, thermal condition, thermal comfort, sensation, office building, OTTV .,

1. Introduction

The comfort factor in a building is influenced by the architectural design of the building. such as the shape of the building, the orientation of the building, and the materials used [1][2]. The use of glass in buildings has a positive value for visual comfort, but can interfere with thermal comfort because the frequency of heat can penetrate the glass and heat up the inside of the building. [3][4].

In this case, the glass incorporates natural light and radiant heat which will affect energy use for building operations. [5]. The building envelope with a very large glass area affects the heat gain of the building, thus increasing the cooling load so that the occupants inside remain comfortable [6].

Buildings using glass windows do have advantages in terms of visuals [6][7]. However, don't let the desire to install a glass wall with the intention that people from inside can enjoy the natural beauty outside, and outsiders can see the beauty of the interior inside the room, it actually disturbs thermal comfort. [8].

The building design must be able to achieve the desire that outgoing communication can be created without reducing the sense of thermal comfort. [9]. The principle of thermal comfort itself is to create a balance between human body temperature and the surrounding body temperature. [10]. Because if the temperature of the human body and its environment has a significant temperature difference, discomfort will occur which is manifested through the heat / cold experienced by the body [11].

Research related to the use of glass in buildings has been carried out quite a lot, as was done by [12][13]. Several studies related to glass in buildings were carried out by [14][15][16] who discussed the OTTV aspect. There were also those who discussed the energy aspect as was carried out by [17][18]. Then there are those who discuss in detail about various types of glass [19][20].

However, no one related the use of glass with the comfort of room users. This study aims to determine the effect of glass walls on thermal conditions in buildings and occuppants' sensations of these conditions and to determine the comfortable temperature for building users. Apart from that, how much heat will enter the building with the OTTV method will also be sought. So that later it will be known whether the building complies with energy-efficient building standards or not

2. Material and Methods

This type of research is correlational research which aims to investigate the extent to which the variables in a factor are related to the variables in other factors. The research location is the office of PT. X which operates from 09.00 WIB to 18.00 WIB.

The variables used in this study are the Independent Variable (IV), namely glass and the Dependent Variable (temperature, thermal comfort of the respondent and energy). Data collection methods consist of primary data (direct measurement and questionnaires) and secondary data (literature study).

The measurements themselves were carried out for two days during working hours for all buildings from building A to building F. And filling in the questionnaire for 69 employees was also carried out for 2 days and by calculating the building's OTTV to get how much energy caused by the building.

3. Results and Discussions

3.1. Indoor Air Temperature

The measurement was conducted for two days, on Monday and Tuesday, from 9:00 a.m. to 6:00 p.m. The results of the air temperature measurement for each building are as follows:

a) *Measurement on building A*

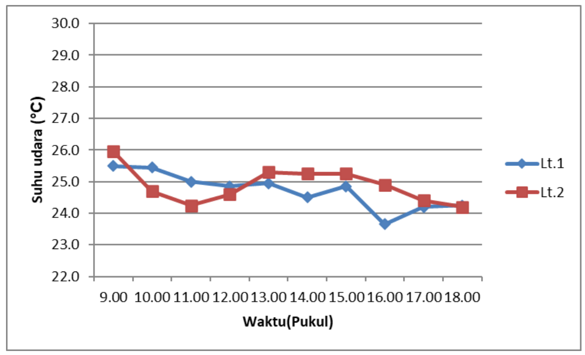

Figure 1. The thermal condition of building A
(Source: Data analysis)

From the above figure, the air temperature movements in building A on the first and second floors are apparent. The temperature on the first floor appears to be higher than the second floor from 9:00 AM to 12:00 PM, and from 1:00 PM to 6:00 PM, the temperature on the first floor is lower than the second floor. The lowest temperature on the first floor occurred at 4:00 PM, which was 24.2 °C, and the highest temperature was 24.9 °C, which occurred at 1:00 PM. On the second floor, the lowest temperature occurred at 6:00 PM, which was 24.2 °C, and the highest temperature was at 9:00 AM, which was 26.0 °C. The average temperature for the first floor is 24.7 °C, while for the second floor it is 24.9 °C.

b) Measurement on building B

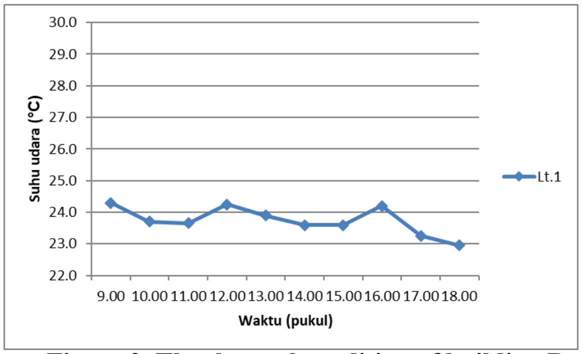

Figure 2. The thermal condition of building B
(Source: Data analysis)

From the above figure, the air temperature movements in building B are apparent. The highest temperature occurred at 12:00 PM, which was 24.3 °C, and the lowest temperature occurred at 6:00 PM, which was 23 °C. The temperature in building B is generally low, with an average temperature of 23.7 °C. This is because building B has less glass wall area compared to the brick wall area.

c) *Measurement on building C*

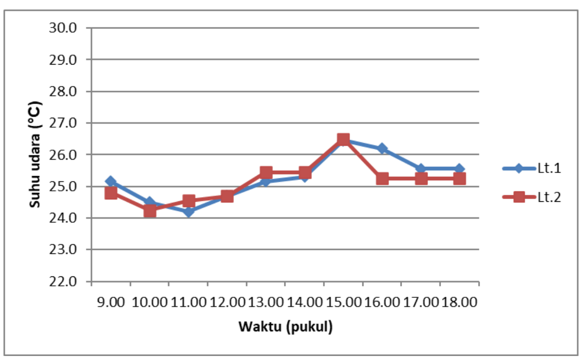

Figure 3. The thermal condition of building C
(Source: Data analysis)

From the above figure, it can be seen the air temperature movement in building C on the first and second floor. The temperature on both floors shows almost the same temperature. The highest temperature on the first floor occurred at 15.00, which was 26.5 °C and the lowest at 11.00, which was 24.2 °C. Similarly, on the second floor, the highest temperature occurred at 15.00, which was 26.5 °C and the lowest at 11.00, which was 24.6 °C. The average temperature for the first floor is 25.3 °C, while for the second floor, it is 25.1 °C.

d) *Measurement on building D*

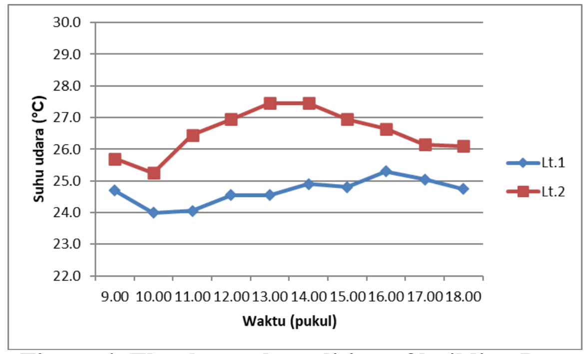

Figure 4. The thermal condition of building D
(Source: Data analysis)

From the above picture, it can be seen the movement of air temperature in building D on the first and second floors. The temperature on both floors shows that the temperature on the second floor is higher than on the first floor. The highest temperature on the first floor occurred at 16.00, which was 25.3°C, and the lowest at 10.00, which was 24°C. Meanwhile, on the second floor, the highest temperature was at 14.00, which was 27.5°C, and the lowest was 25.3°C at 10.00. The average temperature for the first floor is 24.7°C, while for the second floor, it is 26.5°C.

e) Measurement on building E

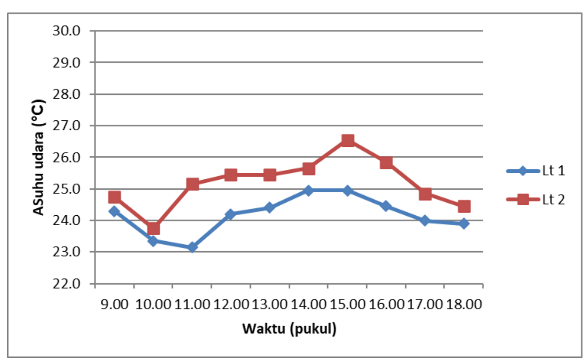

Figure 5. The thermal condition of building E
(Source: Data analysis)

From the above figure, it can be seen that the air temperature in building E on the first and second floors varies over time. The highest temperature on the first floor occurred at 2:00 PM, which was 25 °C, while the lowest was at 11:00 AM, which was 23.5 °C. Similarly, the second floor had its highest temperature at 3:00 PM, which was 26.6 °C, and the lowest at 10:00 AM, which was 23.8 °C. The average temperature for the first floor was 24.2 °C, while for the second floor, it was 25.2 °C.

Measurement on building F

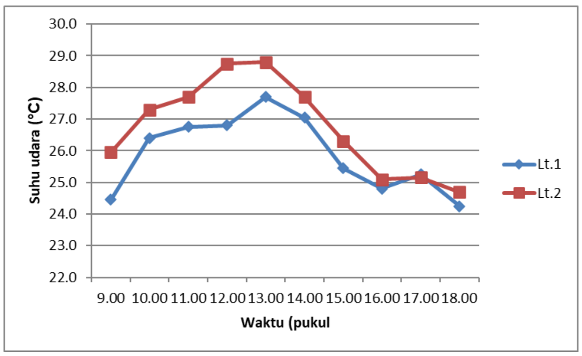

Figure 6. The thermal condition of building F
(Source: Data analysis)

From the above figure, it can be seen that there is movement of air temperature in building F on floors 1 and 2. Similar to buildings D and E, the temperature on the second floor of building F is higher than on the first floor. The highest temperature on the first floor occurred at 13:00 which was 27.7°C and the lowest was at 18:00 which was 24.3°C. Meanwhile, on the second floor the highest temperature occurred at 13:00 which was 28.8°C and the lowest was at 18:00 which was 24.7°C. The average temperature for the first floor is 25.9°C, while for the second floor it is 26.7°C.

f) The average temperature on the first floor for each building.

From the above figure, it can be seen that there is movement of air temperature on the second floor in each building. It can be observed that the temperature on the second floor is higher than on the first floor. The temperature increases from 12:00 to 14:00, while it starts to decrease from 15:00 to 18:00. The average temperature in each building differs from 1 to 1.5°C.

The building with the highest average temperature is building F, which is 26.7°C, while the building with the lowest average temperature is building A, which is 24.9°C.

g) Results of respondents' thermal sensation

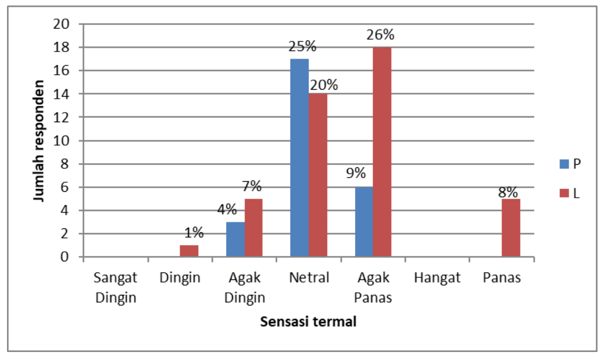

Figure 6. The perception of the occupants of the thermal condition of building F
(Source: Data analysis7

From the above figure, it can be seen that most of the respondents chose neutral thermal sensation, with 31 people (45%), 17 females (25%), and 14 males (20%). However, there were also some respondents who chose slightly warm sensation, especially males with 18 people (26%) and females with 6 people (9%). Even some respondents chose warm sensation with 5 people (8%), 1 person (1%) chose cold sensation, and 8 people (11%) chose slightly cold sensation. The data above shows that on average, more respondents chose warm sensation than cold sensation.

h) *Results of Comfortable Temperature and Comfort Range*

Neutral temperature is defined as the temperature at which the thermal sensation (comfort vote, Y) is 0 (zero), and there is a correlation (correlation, r) between air temperature and the thermal comfort of visitors.

Meanwhile, the comfortable temperature range is defined as the range between a thermal sensation of -0.5 (between cool and comfortable) and +0.5 (between warm and comfortable).

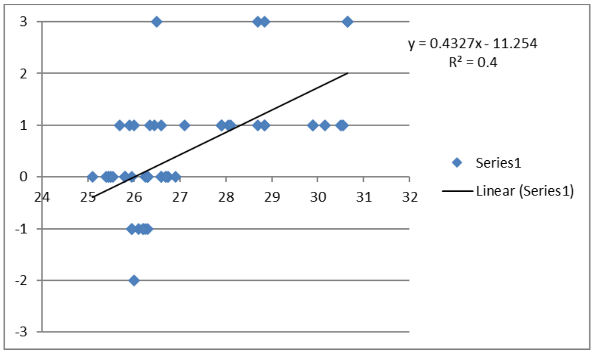

Figure 7. Regression analysis the occupants in building F. (Source: Data analysis)

The following is the calculation of comfort temperature and range of comfort

Table 1. The calculation of comfort temperature and range of comfort

Comfort Temperature	Comfort range (-0,5)	Comfort range (0,5)	Correlation
Y = 0 Y=0,432x-11.25 11.25+0=0.432x 11.25=0.432x X=11.25/0.432 X=26.04	Y = -0,5 -0,,5=0,432x-11,25 11,25-0,5=0,432x 10,75=0,432x X=10.75/0.432 X=24,88	Y = 0,5 -0,,5=0,432x+11,25 11,25+0,5=0,432x 11,75=0,432x X=11.75/0.432 X=27.20	R 2=0,4 R=0,4 R=0.632

The table above shows that overall respondents feel comfortable at a temperature of 27.10 °C, while the comfortable temperature range, where all respondents feel comfortable, is between 26.60 °C and 27.60 °C. The value of R (regression) indicates a correlation coefficient of 0.632, which means there is a fairly high correlation between the thermal sensation of the respondents and the indoor air temperature, as the value of 0.632 is close to 1, indicating a strong positive correlation.

The calculated OTTV values are for the building with the lowest average temperature, which is building B, and for the building with the highest average temperature, which is building F. Here are the results of the OTTV calculation for buildings B and F.

To calculate the U-value for glass (K-1). The following is the calculation of material resistance.

Table 2. The calculation of Resistance of the material glass K-1

Component	$\frac{b}{k}$	R
Glass 8mm	$\frac{0.008}{1.053}$	0.0075
Frame aluminium 80mm	$\frac{0.008}{211}$	0.0004
Total R		0.0079

The above table show that the calculation of window covered frame and glass. Thus the U value of the glass is:

$$U = \frac{1}{R} = \frac{1}{0.0079} = 126.58 \text{ w/m2.K}$$

SC = 0.5 for glass (K-2)

The following is the table of the calculation of resistance of the glass material:

Table 3. The calculation of resistance of the material glass K-2

Component	$\frac{b}{k}$	R
Glass 5mm	$\frac{0.005}{1.053}$	0.005
Wood	$\frac{0.15}{0.138}$	1.087
Total R		1.092

The above table indicate the calculation of window covered frame and glass. Thus the U value of the window is:

$$U = \frac{1}{R} = \frac{1}{1.092} = 10.87 \text{ w/m2.K}$$

SC = 0.5 for brick walls (D-1)

The following is the calculation table of resistance of brick material.

Table 4. The calculation of resistance of the material brick wall D-1

Component	$\frac{b}{k}$	R
Brick walls 110mm	$\frac{0.110}{0.807}$	0.136
Cement plaster 20mm	$\frac{0.040}{0.533}$	0.075
Total R		0.211

The above table shows the calculation of brick wall . Thus the U value of the wall is:

$U = \frac{1}{R} = \frac{1}{0.211} = 4.74$ w/m2.K

The weight = (1760 x 0.110) + (1568 x 0.040) = 256.32 kg/m2. Then the Temperature Difference is, TD Eq = 10

The calculation of Concrete beam (D-2) is as follows:

Table 5. The calculation of Resistance of the concrete beam D-1

Component	$\frac{b}{k}$	R
Concrete beam	$\frac{0.110}{1.442}$	0.076
Cement plaster 20mm	$\frac{0.040}{0.533}$	0.075
Total R		0.151

Then the U value is

$U = \frac{1}{R} = \frac{1}{0.151} = 6.62$ w/m2.K

Weight = (2400 x 0.110) + (1568 x 0.040) = 326 kg/m2

TD Ek = 10

Calculation of Building D's area:

- North-facing wall = South
  Brick wall (D-1) = 3.6 m2
  Glass (K-1) = 50.4 m2
- West-facing wall = East
  Brick wall (D-1) = 27.45 m2
  Concrete = 1.8 m2
  Glass = 25.2 m2

Calculation of building area for building B:

- North-facing wall
  Brick wall (D-1) = 37.7 m2
  Glass (K-1) = 3 m2
- East-facing wall
  Brick wall (D-1) = 16.45 m2
  Glass (K-1) = 6 m2
- South-facing wall
  Brick wall (D-1) = 12 m2
- Southeast-facing wall
  Brick wall (D-1) = 26.5 m2
  Glass (K-1) = 6 m2
- Southwest-facing wall
  Brick wall (D-1) = 34.5 m2
  Glass (K-2) = 6.25 m2
- Northwest-facing wall
  Brick wall (D-1) = 16.5 m2
  Glass (K-2) = 10 m2

The OTTV of the building B

The following is the table of Wall Solar Heat Gain, Glass Heat Gain and Glass Transmission Heat Gain of the building B

Table 6. The calculation of Wall Solar Heat Gain (WSHG)

Cardinal direction	Material	Area	Temp. Diff (Equivalent)	U value	Absorptivity a	Sub total
North	D-1	37.7	10	4.74	0.89	1590.41
East	D-1	16.45	10	4.74	0.89	693.96

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South	D-1	12	10	4.74	0.89	506.23
South East	D-1	26.5	10	4.74	0.89	1117.93
North West	D-1	34.5	10	4.74	0.89	1455.42
North East	D-1	17	10	4.74	0.89	717.16
West	D-1	16.5	10	4.74	0.89	696.07
Total		160.65				6777.18

Table 7. The calculation of Glass Heat Gain (GHG)

Cardinal direction	Material	Area	Solar Factor SF	Shading Co efficient SC	Factor	Sub total
North	K-1	3	0.5	130	0.72	140.4
East	K-1	6	0.5	112	1.25	420
South East	K-1	6	0.5	97	0.74	215.34
North West	K-2	6.25	0.5	176	1.25	687.5
South West	K-2	10	0.5	211	1.25	1318.75
Total		31.25				2781.99

Table 8. The calculation of Glass Transmission Heat Gain (GTHG)

Cardinal direction	Material	Area	Temp. Difference	U	Factor	Sub total
North	K-1	3	5	10.87	1	163.05
East	K-1	6	5	10.87	1	326.1
South East	K-1	6	5	10.87	1	326.1
North West	K-2	6.25	5	126.58	1	3955.625
South West	K-2	10	5	126.58	1	6329
Total		31.25				4770.875
Total seluruh		**223.15**				**14330.05**

From the table above it can be calculated : OTTV = 14330.05 : 223.15 = **64.2171** W/m2

The OTTV of the building F

The following is the calculation of solar heat gain of the wall, glass and transmission heat gain of the building F

Table 9. The calculation of wall Solar Heat Gain (SHG) of the building F

Cardinal direction	Material	Area	Temp. Diff (Equivalent)	U value	Absorptivity a	Sub total
North	D-1	3.6	10	4.74	0.89	151.87
South	D-1	3.6	10	4.74	0.89	151.87
East	D-1	27.45	10	4.74	0.89	1158.01
	D-2	1.8	10	6.6	0.86	102.17
West	D-1	27.45	10	4.74	0.89	1158.01
	D-2	1.8	10	6.6	0.86	102.17
Total		65.7				2824.09

Table 10. The calculation of Glass Solar Heat Gain (GSHG) of the building F

Cardinal direction	Material	Area	Solar Factor SF	Shading Co efficient SC	Factor	Sub total
North	K-1	50.4	0.5	130	0.72	2358.72
South	K-1	50.4	0.5	97	0.74	1808.856
East	K-1	25.2	0.5	112	1.25	1764
West	K-1	25.2	0.5	243	1.25	3827.25
Total		151.2				9758.83

Table 11. The calculation of Glass Transmission Heat Gain (GTHG)

Cardinal direction	Material	Area	Temp. Difference	U	Factor	Sub total
North	K-1	50.4	5	126.58	1	31898.16
South	K-1	50.4	5	126.58	1	31898.16
East	K-1	25.2	5	126.58	1	15949.08
West	K-1	25.2	5	126.58	1	15949.08
Total		151.2				95694.48
Total overall		368.1				108277.39

OTTV = 18277.9 : 368.1 = 294.15 W/m2 > 45 w/m2

Legend :
U : thermal transmittance (W/m2.K)
R : thermal resistance (m2.K/W)
SC : shading coefficient from fenestration system
SF : solar radiation factor
α : solar radiation absorbtance
TDEK: Temperature difference equivalent (K)
ΔT : Temperature difference design between indoor and outdoor (taken 5K)

4. Conclusion

From the results of the research described above, the researchers obtained the following conclusions:

- The temperature in the building that has the highest average is building F, which is 27.5°C. Building F has a glass proportion of 70%. And the one with the lowest temperature is building B, which is 23.7 with a area of glass in the building of 30%.
- As many as twenty-four respondents stated their choice of a neutral sensation (slightly hot, warm, hot), thirty respondents chose neutral. Meanwhile, nine respondents stated that they preferred a neutral sensation (slightly cold, cold, very cold).
- All respondents felt comfortable at 26.04°C, with a comfortable temperature range of 24.88°C to 27.20°C. and had a correlation value of R=0.632, which means the correlation is positive.
- The OTTV (Overall Thermal Transfer Value) calculation results show a value that does not meet the SNI standard, namely > 45 W/m2.
- 4.2. Suggestion
- From the results of the research described above, the researcher draws several conclusions, namely:
- Even though the respondents felt comfortable, to achieve this comfortable temperature required a great deal of effort, namely by using air conditioners (AC), thereby increasing the burden of electrical energy.
- The solution to maintain building aesthetics and visual thermal comfort, without sacrificing thermal comfort and wastage of energy, is to replace the glass with glass that has little heat-absorbing properties.
- Reducing the use of glass areas to reduce building heat gain. with a proportion of glass in the building of 30%.
- As many as twenty-four respondents stated their choice of a neutral sensation (slightly hot, warm, hot), thirty respondents chose neutral. Meanwhile, nine respondents stated that they preferred a neutral sensation (slightly cold, cold, very cold).
- All respondents felt comfortable at 26.04°C, with a comfortable temperature range of 24.88°C to 27.20°C. and had a correlation value of R=0.632, which means the correlation is positive.
- The OTTV (Overall Thermal Transfer Value) calculation results show a value that does not meet the SNI standard, namely > 45 W/m2.

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