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THERMAL COMFORT OF COLONIAL OFFICE BUILDING, SEMARANG USING ENERGYPLUS SIMULATION

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ABSTRACT

Many colonial office buildings are located in the Old City of Semarang, Central Java, Indonesia have a passive cooling system. These office buildings are characterized by high ceilings and roof angles, thick wall panel and normally used as a gallery under sun shading. The Djakarta Lloyd office room was selected to determine the correlation between the width of sun shading and percentage of wall opening toward thermal comfort parameters such as indoor air temperature and percentage difference of relative humidity. The calibration and validation graph of temperature versus time was conducted between data measured at site and computer simulation using Energy Plus program. The results showed that 3.6m width of sun shading and 40% of the wall opening is significant toward the indoor air temperature and percentage differences of relative humidity. Whereas, 0m together with 1.8m and 1.8m with 3.6m of width of sun shading and 10% together with 20% and 10% together 40% of wall opening were insignificant toward indoor air temperature and relative humidity. For design purposes, it is recommended to use the narrowest wall opening of 10% and the widest sun shading to give the lowest indoor air temperature and the highest percentage of relative humidity for the colonial Dutch office building particular in Semarang, Indonesia.

Keywords: colonial office buildings, energy plus simulation, sun shading, wall opening, thermal comfort.

1. INTRODUCTION

Semarang is the capital city of Central Java Province, Indonesia, which is located at the north Coast of Java Island. Geographically, it is located between 6°50'-7°10' South Latitude and 109°35'-110°50' East Longitude. Semarang has a humid tropical climate with high temperature and humidity and year-round rainfall. The areas with humid tropical climate are often characterized by high relative humidity (often above 90%), high rainfall, and annual average temperatures above 18˚C and typically at 23˚C which may increase to 28 ˚C and 38 ˚C. Semarang is known as a trading city during the Dutch colonial period in the early 20th century. The Old Town area was a modern trading and service area and there are many national and international offices. Most of the old offices were designed by architects from the Dutch colonial period by considering the tropical climate issue as part of their building design (Purwanto, 2004). The Dutch architects were more concerned with the application of the passive cooling system in buildings through the processing of architectural elements to achieve the thermal comfort of the buildings by using the natural ventilation system.

Principally, the passive cooling method is based on the control of the sun's heat through the media of the building such as building construction materials, openings, shading and orientation direction of the building (Idham, 2016). The architectural element which is mostly used to decrease the exposure of the sun radiation is sun shading (Harry, 2006).Sun shading can reduce the incoming sunlight to a certain level according to the type and function in each room, through the creation of shade and shadow areas. Meanwhile, the opening of a building with a window requires a proper design and precise calculation by considering the existing side of the building which becomes a windward area and does not get a shadow of the wind (leeward) with sufficient wind speed for thermal comfort. The opening location determines how air enters the building effectively allowing for cross ventilation. To optimize the natural ventilation system, exposure to sun radiation needs to be avoided and fresh air flow into the building needs to be streamlined to provide thermal comfort in the building.

A study on the effectiveness of the passive system of flats and condominiums were managed by the Housing Development Board of Singapore (Sock, 2007; Wong and Li, 2007). The investigation on the effectiveness of window shading on cooling energy consumption for the east and west windows in Singapore were between 2.62% to 3.24% of the energy cooling load can be stored by applying the sun shading with a 30cm horizontal width of the window (Wong and Li, 2007). The sun shading window with a 60cm width can save between 5.85% to 7.06% cooling load. When the width of the sun shading reaches 90cm, the cooling load of the room is reduced by 8.27% to 10.13%.However, Wong and Li's study considered only east and west orientations, but did not take into considerations of other parameters such as the width of the openings, height of the openings, horizontal shadow angle, and vertical shadow angle. The previous study by Yu (2008) on a high-rise residential building in Taiwan indicated that envelope shading is the best strategy to decrease cooling energy consumption,

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which can achieve the savings of 11.3% on electric consumption. In Singapore, Wong (2003) studied the effects of shading devices on temperature. His study showed that horizontal shading devices reduce indoor temperature by 0.61°C to 0.88 °C. The vertical shading device can reduce the temperature by 0.98°C in another study by Yang and Hwang (1995). They also investigated the influences of external shading on energy savings in a Taiwanese building. The direct air conditioning, power consumption readings indicate an average savings of 25% if external shading is properly installed. Contradictory, Tzempelikos (2010) and Gratia and Herde (2007) reported that shading devices can lead to big energy savings when they are applied in combination with the appropriate glass type, enabling them to modify the thermal effect of windows to a great extent.

The air temperature inside Dutch buildings with hallway around the building tends to be cooler than the buildings without hallway. Therefore, the hallway is considered effective for controlling the air temperature inside the building. Besides functioning as a barrier of sunlight, it also serves as a space between the outside and the inside of the building. Therefore, the air outside of the building does not directly affect the air inside the building (Purwanto, 2004). The results of a study by Kim *et al,* (2015) showed that the effect of sun shading on reducing the cooling load on office buildings by blocking sun radiation shows a 35.1% reduction in total cooling load.

The thermal comfort, particularly the natural air cooling of buildings relies on building design, opening design, and internal factors such as air temperature, air humidity, and wind speed in the buildings (Hendrarto *et al,* 2014). According to Hendrarto *et al,* (2014), the Indonesian thermal comfort standard is divided into three categories as follows: (1) Cool comfort between 20.5°C to 22.8°C with relative humidity of 50% - 80%; (2) optimum comfort: 22.8 °C - 25.8 °C, relative humidity: 70%-80%; and (3) nearly comfortable: 25.8°C- 27.1° C, relative humidity: 60%-70%. Thus, with regard to the gap of research for this study, there are two main purposes such as to find the influence of sun shading as architectural element and wall openings to indoor temperature in the Dutch colonial office; and to find the effect of sun shading as architectural elements and wall openings against relative humidity at the Dutch colonial office.

2. RESEARCH METHODOLOGY

The environmental simulation method was the norm in the studies involving the physical layout of the building. In order to investigate the effect of sun shading and wall openings on room temperature and relative humidity, this study employed computer modelling techniques which were an effective and reliable tool for optimizing the design process of buildings. The model was used to support building simulation with computers through accurate data collection of local building and climate data. Energy Plus program was used for the computer simulation, supported with Sketch Up program to create the modelling of the building and supported by the Open Studio program. EnergyPlus program is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumptions for heating, cooling, ventilation, lighting, plug and process loads and water use in buildings.

For simulation calibration of the model, the simulation/model program needs to compare with field measurement data at site. The research methodology was conducted in three stages, namely;

a) Field data collection, which in this case was aimed to gather data from one of the rooms in the colonial office building using sun shading and openings. These data were in the form of the dimensions of the building elements, layout of the room including sun shading and openings of the building.

b) Verification and validation of the model under sun shading and openings that were similar to the original ones used in the selected colonial office; in this research it was a Djakarta Lloyd office in the Old City of Semarang. The results from field measurement were compared with the simulation. The trend of similarity between both results of field measurements and simulation could be summarized and concluded in term of percentage difference.

c) By creating the model of colonial office building, according to the need of study and propose the stakeholder who are interested to improve the thermal comfort in any particular buildings.

The proposed building model can be used to find out the role of sun shading and wall openings to the different indoor temperature and relative humidity. The shape and dimensions of sun shading which were used for this study were as listed below:

A. A rectangle sun shading which located above the opening window with three widths distinguished dimensions of 0m denoted as without sun shading, 1.8m, and 3m, respectively.

B. A rectangle sun shading dimensions with wall openings were 10%, 20% and 40% of the entire wall area; and

C. Wall thickness, which was not varied (30 cm).

The building that used in this study was a hypothetical model which matched with the characters of the colonial office building. The dimension of the model building was 27mx12m and a 4m height of each floor. The dependent variable for thermal comfort was indoor air temperature and the relative humidity. The total number of cases (N) for this study was 1344 which is equivalent to 56 days of research data.

The statistical analysis which had been used in this study were as follows;

a) Two-way ANOVA,

The equation for sum squares total (SST) is;

$$(SST) = \sum_{i=1}^{r}\sum_{j=1}^{c}\sum_{k=1}^{n} T_{ijk}^2 - \frac{T^2}{rcn} \quad (1)$$

The sum squares of row (SSR) is;

$$(SSR) = \frac{\sum_{i=1}^{r} {T_i}^2}{rn} - \frac{T^2}{rcn} \quad (2)$$

The sum squares of column (SSC) is;

$$(SSC) = \frac{\sum_{j=1}^{c} {T_j}^2}{cn} - \frac{T^2}{rcn} \quad (3)$$

The sum squares interaction of row and column (SSRC) is;

$$(SSRC) = \frac{\sum_{i=1}^{r}\sum_{j=1}^{c} T_{ij}^2}{n} - \frac{\sum_{i=1}^{r} T_i^2}{cn} - \frac{\sum_{j=1}^{c} T_{j=1}^2}{} + \frac{T^2}{rcn} \quad (4)$$

The sum squares of error (SSE) is;

$$(SSE) = SST - SSR - SSC - SSRC \quad (5)$$

The degree of freedom of row (df_r) is;

$$(df_r) = r - 1 \quad (6)$$

The degree of freedom of column (df_c) is;

$$(df_c) = c - 1 \quad (7)$$

The degree of freedom interaction of row and column (df_{rxc}) is;

$$(df_{rxc}) = (r-1)(c-1) \quad (8)$$

The degree of freedom of error (df_e) is;

$$(df_e) = rc(n-1) \quad (9)$$

The mean squares of row (MSR) is;

$$(MSR) = \frac{SSR}{df_r} \quad (10)$$

The mean squares of column (MSC) is;

$$(MSC) = \frac{SSC}{df_c} \quad (11)$$

The mean squares interaction of row and column (MSRC) is;

$$(MSRC) = \frac{SSRC}{df_{rxc}} \quad (12)$$

The mean squares of error (MSE) is;

$$(MSE) = \frac{SSE}{df_e} \quad (13)$$

There are two Fisher distribution empirical equations denote as F_1 and F_2as follows;

$$(F_1) = \frac{MSR}{MSE} \quad (14)$$

$$(F_2) = \frac{MSRC}{MSE} \quad (15)$$

where:

r : row
c : column
n : number of cases
T_i : total per row
T_j : total per column
T : total

b) Further testing using Tukey equation need to be carried out in order to determine whether there is a difference in the indoor temperature and relative humidity caused by the width of the sun shading;

c) Further testing using Tukey equation was used to determine whether there was a difference in the indoor temperature and relative humidity caused by the width of the wall openings;

d) Interaction test between the width of the sun shading and the opening of the wall to the indoor temperature simultaneously;

D. Interaction test between the width of the sun shading and the wall opening to the relative humidity. The statistical software used for data analysis was SPSS.

After completing all the five steps in running the statistical analysis using two-way Anova, Equation 16 is used to determine the percentage error between the simulation results using Energy Plus program and field data measured at site which can be obtained from Equation 15.

$$error = \left|\frac{C_S - C_P}{C_P}\right| x100\% \quad (16)$$

where:

Cs : calculation results
Cp : criteria

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3. RESULTS AND DISCUSSIONS

3.1 Building model using energy plus simulation

The colonial office building was designed according to the architectural characteristics of the Dutch colonial office in Semarang which emphasized on the shape and size of sun shading in the hallways of buildings and wide window openings. In order to optimize the function of natural ventilation in the buildings and achieve the thermal comfort, the building was modelled without sun shading with 10% wall opening, 1.8m sun shading and 20% wall opening and 3.6m sun shading and 40% wall opening. These dimensions of sun shading and percentage of wall opening based on the research carried out by Wong and Li (2007) and Sara (2018). Figure-1 shows two-storey colonial office building which designed and modelled using Energy Plus without any sun shading (0m) and 10% wall opening only. The overall dimensions of this building are 27mx12mx8m.

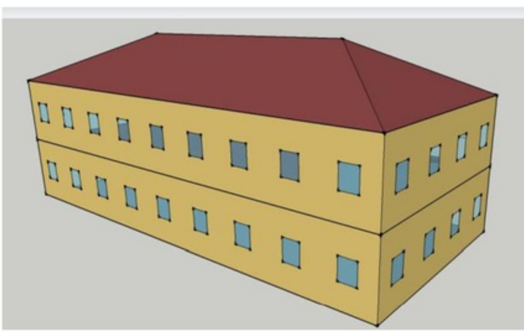

Figure-1. Colonial office building model without sun shading (0 m) and wall openings of 10%.

Figure-2 shows the colonial office building model which designed for 1.80m sun shading around the first and second floor of the building with wall openings of 20%. Meanwhile, Figure-3 shows the colonial office building which modelled and designed using Energy Plus program for wall opening 40% and 3.6m sun shading around the first and second floor of the building.

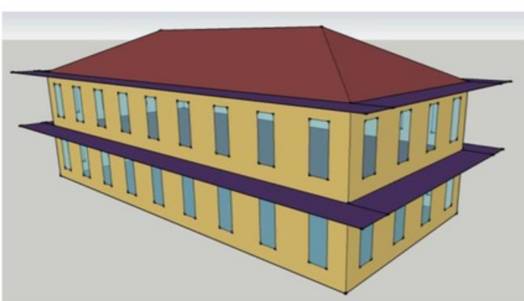

Figure-2. Colonial Office model with width of 1.80m sun shading and wall openings of 20%.

The climate data from the Agency for Meteorology, Climatology and Geophysics of Semarang City were used to simulate the Energy Plus Program. The Semarang climate data were obtained from WXA Global for simulation purpose during the hottest season in October and the coolest season in January 2014.

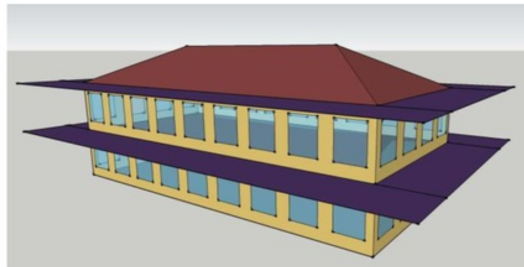

Figure-3. Colonial office building model with width of 3.6m sun shading and wall openings of 40%.

The output parameters of the Energy Plus simulation was in the form of outside temperature, indoor temperature and relative humidity. The simulation was assumed to be the hottest and the coldest day of the month in 2014 which were on 12th of October 2014 and 12th of January 2014. The simulation results were in the form of raw data which used for the two-way *ANOVA* statistical analysis. The raw data were then analyzed to look at the difference of indoor temperature and relative humidity which caused by three variations in width of sun shading and percentage of wall openings.

3.2 Calibration curves between measurement and energy plus simulation program

The calibration of Energy plus program simulation was conducted by comparing the data for temperature measurement results obtained from an inner room inthe colonial office of two-story building at Djakarta Lloyd with the simulation results of the Djakarta Lloyd office building using Energy Plus program. The model building was drawn using Sketch Up program, simulated using Energy Plus program and Open Studio program. The indoor air temperature measurement data were conducted in the office room on the second floor of the colonial office building.

Figure-4 shows the graph of temperature versus time for two-storey colonial Djakarta Lloyd office building using simulation and measurement on site. There is a similar pattern between simulation and measurement with simulation was a little bit higher than the measurement. However, they have a similar value of temperature and time at the peak of the graph. The highest measurement value of temperature was 34.01°C which occurred at 15.00 hours (3.00 pm in the evening). The highest percentage difference between the simulation and average measured temperature at the second floor of Djakarta Lloyd's colonial office was 1.34°C which occurred at 1.00 a.m. hour early in the morning. Figure-4 can be used as the valid simulation results and calibration

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of measurement data of temperature versus time which can be used as research data.

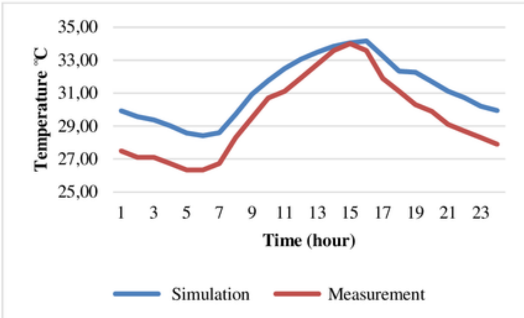

Figure-4. Comparison between measurement and simulation results on the 2nd floor of the Djakarta Lloyd's office.

The qualitative description as mentioned above can be corroborated through the error calculated using Equation 16. The percentage error was calculated using the mean and standard deviation of the data. At the 95 % confidence level or until $\overline{X}+2xS_d$, the percentage error was accurate or precise calculated (Christina and Maria, 2006). The statistical analysis for this study showed that the average percentage error was 5.54% by value of standard deviation was 2.64 and the average percentage error varies between 0.26% to 20.82%.

3.3 Correlation of width sun shading and wall opening toward indoor air temperature

Table-1 shows that the width of sun shading and wall opening affect the inner air temperature inside the room of Djakarta Lloyd's colonial office. The narrower width of sun shading would result in higher indoor air temperature or the wider the width of sun shading would result cooler indoor air temperature. The results of this study were supported by Wong and Li (2007) where 2.62% to 3.24% of the cooling load energy can be saved if a 30 cm width of sun shading were applied to the horizontal of the window. When the 60 cm width sun shading was applied, the cooling load energy can be saved between 5.85% to 7.06%. Moreover, if the width of the sun shading are increased up to 90cm, the cooling load of the room can be reduced between 8.27% to10. 13%.

From Table-1, the solely wall openings itself did not affect the indoor air temperature inside the office room. Thus, the paired sample t-test of variations in term of percentage wall openings was insignificant to the indoor air temperature. If $p \geq 0.05$, the dependent variable is significant and become insignificant if $p \leq 0.05$ (Sander et. al, 2016). The value of p is 0.058 for the effect of wall opening on the inner room temperature and it becomes insignificant variables in this study. Similarly goes into the effects of interaction between the width of sun shading and wall opening towards the indoor room air temperature with a p value of 0.956 and it also becomes insignificant variables. Both of these values p is bigger than 0.05. On the hand, the value of p for a width of sun shading is 0.008 becomes significant variable. Likewise, the effective width of sun shading and wall opening becomes significant with value of p equal to 0.043 and less than 0.05. It can be concluded that the width of the sun shading and the wall openings simultaneously influenced the indoor air temperature. The wider width of sun shading and higher percentage of wall opening lead to the decrease of indoor air temperature.

Table-2 shows the analysis of paired sample t-test for width variations of sun shading and wall opening to an indoor air temperature of the colonial office room. The statistical analysis showed that there is an insignificant result for 0m and 1.8m width sun shading with p-values of 0.099 and 0.16, respectively to the indoor air temperature of the room. There is a difference in the air temperature as a result of different width of sun shading. Contradictory, the width sun shading of 3.6m is significant toward indoor air temperature of 0.40°C with p-value of 0.007. Furthermore, when 1.8 m and 3.6 m width sun shading became an insignificant to the indoor air temperature with p-value of 0.16. Likewise, 40% wall opening become significant toward indoor air temperature of -0.34°Cwith p-value of 0.031. However, the combination of 10% and 20% together with 20% and 40% wall opening to indoor air temperature became insignificant with p-values of 0.623 and 0.254, respectively.

Table-1. Summary on effect of sun shading width and wall opening toward the indoor air temperature.

No.	Independent Variable	Dependent variable	Effect	F	P	Information
1.	The width of the Sun shading (X_1)	Inner air Temperature (Y_1)	The width of the sun shadingon the inner air temperature	4,828	0.008	Significant
2.	Wall openings (X_2)		The wall openings on the inner air temperature	2.853	0.058	Not significant
3.	The width of the sun shading (X_1) and wall openings (X_2) simultaneously		Sun shading width (X_1) and wall openings (X_2) simultaneously to the inner air temperature	2,003	0.043	Significant
4.	Interaction between the width of thesun shading (X_1) with the wall openings (X_2)		The interaction between the width of the sun shading (X_1) with wall openings (X_2)to the inner air temperature	0.166	0, 956	Not significant

Source: data analysis results (2017)

Table-2. Analysis of paired t-tests between sun shading width and wall openings to indoor air temperature.

No.	The width of sun shading	The width ofthe sun shading	The difference of the average in air temperature	p	Information
1.	0 m	1.8 m	0.27	0,099	Not significant
		3.6 m	0.40	0.007	Significant
	1.8	3.6 m	0.14	0.16	Not signifikan
	The wallopening	The wallopening	The difference of the average in inner air temperature	p	Information
2.	10%	20%	-0.13	0.623	Not significant
		40%	-0.34	0.031	Significant
	20%	40%	-0.21	0.254	Not s ignifikan

Source: data analysis results (2017)

Figure-5 shows the inverse relationship between estimated marginal means and widths variations sun shading to indoor air temperature at 10%, 20% and 40% wall opening. It can be observed that the narrower wall opening and wider sun shading could lead to the reduction of indoor air temperature. Therefore, it can be concluded that the interaction between the width of the sun shading and wall openings to the indoor air temperature did not occur at all. It means that there was no occurrence indoor air temperature when the wall opening area was 40% and width of the sun shading was greater, the inner air temperature was decreased, and b) when the wall opening was 10% and the width of sun shading became greater, the inner air temperature would increase tremendously. Further study by Nedhal *et al,* (2011) indicated that egg-crate shading has a significant impact on decreasing discomfort hours as compared with other shading types.

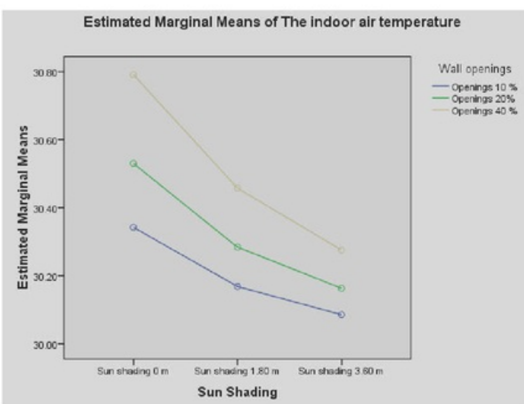

Figure-5. Interaction between width sun shading and wall openings to the indoor air temperature.

3.4 Correlation between width sun shading and wall opening towards relative humidity

Table-3 shows the correlations between the width of the sun shading and wall opening towards relative humidity in term of percentage p-values. It is evident that the wider the width sun shading, the higher values of relative humidity or vice versa. The independent variable such as width of sun shading, wall opening and width of sun shading together with wall opening have a significant effect toward the relative humidity with p-values of 0.003, 0.038 and 0.015, respectively. Nevertheless, the interaction between the width of sun shading and wall opening has an insignificant towards relative humidity with p-value of 0.950.

Meanwhile, Table-4 shows summary of paired t-test of statistical analysis width sun shading and wall opening toward relative humidity. It can be seen that the width of sun shading of0m together with1.8m and 1.8m together with 3.6m have insignificant impacts toward relative humidity of p-values 0.063 and 0.543, respectively. Conversely, 3.8m width of sun shading has significant impact toward difference percentage relative humidity of -1.7723% with p-value of 0.003. In addition, 10% together 20%and 10% together 40% of the wall opening area were insignificant toward the effect of relative humidity with p-values of 0.565 and 0.89. However, 40% wall opening area has a significant effect toward the percentage difference relative humidity of 1.4454% with p-value of 0.018.It can be concluded that the wider wall openings will lead to lower relative humidity (75%) which is an indication of the comfort level, in the cool condition and comfortable category (Departemen Pekerjaan Umum, 1993).

Table-3. Correlation between width sun shading and wall openings toward relative humidity.

No.	Variable free	Dependent variable	Effect	F	p	Information
1.	Sun shading width (X_1)	Relative humidity (Y_2)	Sun shading width on the relative humidity	5.855	0,003	Significant
2.	Wall openings (X_2)		Wall openings on relative humidity	3.281	0,038	Significant
3.	Sun shading width (X_1) and wall openings (X_2)simultaneously		Sun shading width (X_1) and wall openings (X_2)simultaneously on relative humidity	2, 37	0.015	Significant
4.	Interaction between sun shading width (X_1) with wall openings (X_2)		Interaction between sun shading width (X_1) and the wall openings (X_2)on relative humidity	0.178	0.950	Not significant

Source: data analysis results (2017)

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Table-4. Summary of paired t-test analysis between width sun shading and wall opening variation to relative humidity.

No.	Sun shading width	Sun shading width	The differenceon the relative humidity average	p	Information
1.	0 m	1.8 m	-1.1978	0.063	Not significant
		3.6 m	-1.7723	0.003	Significant
	1.8 m	3.6 m	-0.57	0.543	Not significant
	Wall opening	Wall opening	The differenceon the relative humidity average	p	Information
2.	10%	20%	0.5553	0.565	Not significant
		40%	1.4464	0.018	Significant
	10%	40%	0.89	0.214	Not significant

Source: data analysis results (2017)

Figure-6 shows the direct relationship between estimated marginal means and width of sun shading at percentage wall opening of 10%, 20% and 40%. The wall opening of 10% has the highest impact between marginal means and width of sun shading. It is evident that as a low percentage of wall opening and the wider sun shading will increase the percentage difference of relative humidity for the colonial office building particularly in Semarang City, Indonesia. Conversely, as the percentage of wall opening increase and the narrower the width of sun shading will reduce the percentage of difference in term of relative humidity.

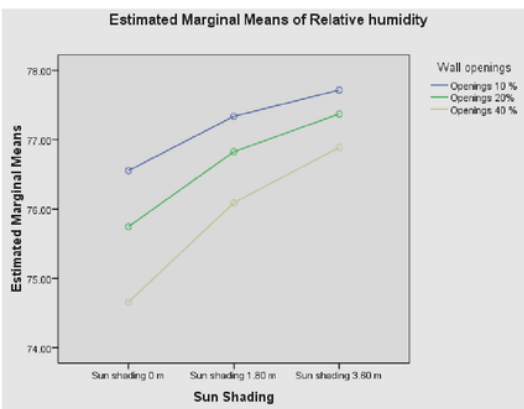

Figure-6. Interaction between the width of the sun shading and a wall opening to the relative humidity.

4. CONCLUSIONS

The conclusions based on the results of the study and previous discussion about the effect of width of the sun shading and wall openings to indoor air temperature and relative humidity of the colonial office building in Semarang are as follows:

a) The width of the sun shading and the percentage of wall openings simultaneously affect the thermal comfort of the colonial office room in that it has different indoor air temperature and relative humidity.

b) At the narrowest wall opening which was 10% and the widest width of the sun shading which was 3.60 m, the indoor air temperature reached the lowest, which means the most convenient.

c) At the widest sun shading which was 3.60 m and the narrowest wall opening which was 10%, the relative humidity reached the highest.

d) The decrease in the indoor air temperature was determined by the width of the sun shading and the increase of relative humidity was determined by the width of wall opening of the colonial office.

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