

The Effects of Low Ventilation on Thermal Condition in Cathedral Churches

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Abstract— Building designs that are being prioritized today are sustainable architecture and green architecture. The designs can reduce the energy consumption that has a positive impact on climate. Actually, the design of such buildings has started since the Dutch colonial era. Buildings from that era are very adaptive to the climate just using passive cooling system. Passive cooling became the best technology at that time to achieve thermal comfort and save energy. Church is one of the few public buildings requiring special attention to its thermal comfort. The churches built during the Dutch colonial era like every Cathedral Church succeeded in achieving thermal comfort. Some of Cathedral Churches like in Semarang and Bogor city have unique ventilation called low ventilation located at the bottom area of the wall. Research held in these two Cathedral Churches (Semarang and Bogor) in three periods of church services and some specified measurement items. Dry bulb temperature, effective temperature, relative humidity, and air velocity were measured to gain thermal condition. The purpose of this study was to examine building's thermal condition and low ventilation impacts. The results of this study showed that as the effect of low ventilations, there was a significant change on thermal condition inside the buildings. The measuring points near the low ventilation had lower effective temperature, relative humidity, and higher air velocity compared with others. This study provides insight into passive cooling system; in this case, low ventilation is essential part for sustainable architecture.

Keywords— Sustainable Architecture, Passive Cooling, Thermal Condition, Historical Building, Church

I. INTRODUCTION

A building design shall be sustainable. Energy consumed in the buildings sector is near to 20.1% of the total delivered energy in the world [1]. With deeper knowledge and more understanding of the buildings energy consumption and their cumulative effect to the environment, the building sector is in the spotlight of climate change and energy efficiency policy[2]. Therefore, reaction to the local climate is needed to make a sustainable design. Contextual respond of the local climate and people sensation structured the thermal comfort. However, nowadays building designs prefer the aesthetics rather than the climate in which the building will be built, resulting in discomfort and high energy consumption. Indonesia is a country that has a humid tropical climate. For

that reason the humid tropical design shall become the basics of designing buildings.

Tropical climate is having high amount of solar radiation, reative humidity level, and rainfall [3]. Lippsmeier (1994) noted that comfortable thermal condition in tropical area demanded the right effective temperature. The characteristics of wet tropic area, including the type of rainforest, are red soil covered by grass, the high variety of plants, the landscape on the equator line, same seasons all over year, the 60-90% cloudy weather, 850-7000Cd/m² of sky lamination, the high solar radiation, 21-32°C of the air temperature between day and night, the high precipitation in rainy season, 55-100% humidity, and the low air velocity.

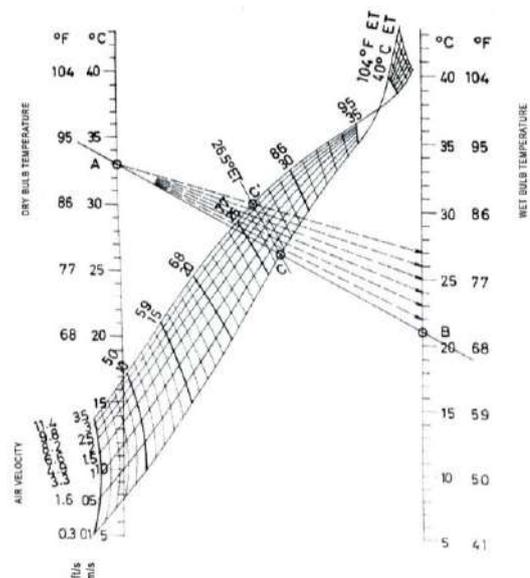


Fig. 1. Effective Temperature Diagram (Source: Lippsmeier 1994)

Thermal comfort is a state of mind that expresses one's satisfaction with its thermal environment [4]. Thermal comfort is one element of comfort that is very important, because it concerns the condition of a comfortable room

temperature. Furthermore to determine the thermal comfort, some factors such as: humidity, temperatures. air velocity shall be obtained under several different spots and periods before being related to the people sensations [5]. Thermal comfort is the condition where the effective temperature is between 23°C - 27°C, the air humidity is between 30% -60%, the metabolic rate is between 1-1.2, the clothing condition is between 0.5 - 0.6, the wind speed is more than 0.2 m/s, ET is around 23°C - 27°C [6].

Thermal comfort in environment affected people's health and work efficiency. Higher requirement of indoor thermal comfort indicates high consumption of energy in the building [7]. Historical buildings are examples of buildings that apply the local climate as a design concept so that it can be an example of a building that reaches its thermal comfort and energy efficiency [8].

Indonesia has structures and infrastructures that are being developed from the European colonialism era until present. Some of the buildings stand as witness to the history of Indonesia development phases [9]. Colonized for almost 365 years, Dutch colonialism was the biggest influence of Indonesia's building development. Dutch colonial buildings had a lot of development as well. They learned from environment, culture, and also the tropical climate of Indonesia. A lot of historical buildings from Dutch colonial era are spread across Indonesia, including in Semarang and Bogor cities. Semarang and Bogor are cities that have a lot of historical buildings from Dutch colonial era. They both have a Cathedral Church from Dutch colonial era that still stands and also functions until now. Semarang and Bogor Cathedrals still can use their passive cooling system until now and they become interesting objects to study about their thermal condition. They both have special ventilations that were installed at the bottom of the wall called low ventilations.



Fig. 2. Semarang Cathedral (upper) Bogor Cathedral (lower)

The purpose of this study is to examine thermal conditions of both cathedrals and the impact of low ventilations installed in the buildings. Both cathedrals are equipped with air conditioners (AC) but in this study AC would be turned off to see the performance of their passive cooling system. The hypothesis of this study assumed that low ventilations have significant effects on both cathedrals and they make the cathedrals enter the comfort zone of thermal condition.

II. METHODS

The quantitative method was performed in this research. The quantitative research method is related to numbers to measure and performed in a systematic way to investigate some phenomena. The quantitative method answered questions on relationships within measured variables to explain, predict and control some phenomena [10]. Researchers use the method of quantitative to identify variables in their research work and proceed the data and variables.

For this research, data collection is separated into two stages, first was site observation to obtain floor plans, and second was thermal measurements inside both cathedrals. Data for thermal measurement inside the cathedrals consisted of relative humidity (%), air velocity (m/s), and dry bulb temperature (°C). Data was taken on specific spots inside the cathedrals. Data was measured during worship activity when the air conditioners were turned off. As shown in figure x, Semarang Cathedral had 9 (nine) spots and Bogor Cathedral had 15 (fifteen) spots. Table 1 shows that thermal measurements to collect data were held on 3 (tree) different worship times. Low ventilations of two cathedrals were conditioned as open and closed as shown in figure 2 and 3 when collecting data. To help collecting data, there were several gears used as shown in figure 4 and 5; they are hotwire anemometer and digital thermo hygrometer that had already been calibrated properly.

Measurements result would be analyzed and then discussed to draw the conclusion. They would be analyzed using charts, tables, and graphics so that all information in

this study can be presented briefly and the readers can evaluate its validity and reability.

TABLE I. TIME MEASUREMENT

Measuring Time	Period
Morning	8.45
Evening 1	16.30
Evening 2	18.15

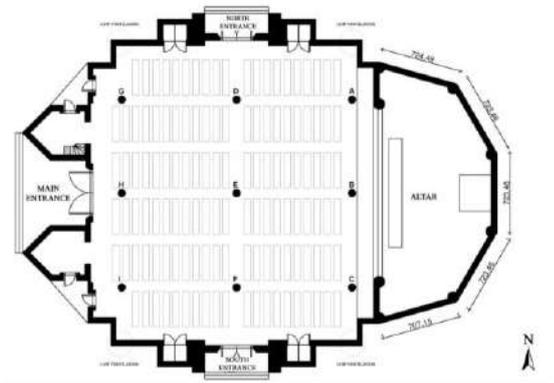


Fig. 3. Measuring Spot Plan of Semarang Cathedral

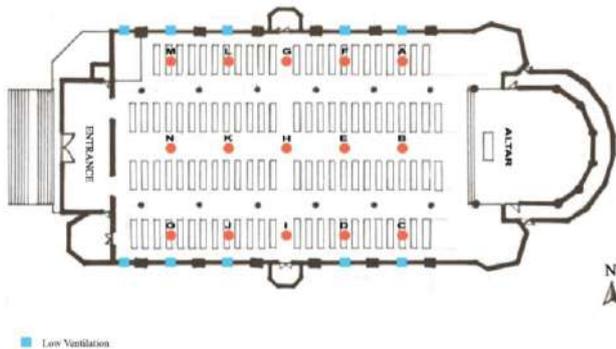


Fig. 4. Fig. 3. Measuring Spot Plan of Bogor Cathedral



Fig. 5. Hotwire Anemometer.(left), Digital Thermo Hygrometer (right)



Fig. 6. Semarang Cathedral's Low Ventilation (left) and Bogor Cathedral's Low Ventilation (right)

III. MEASUREMENT RESULTS

Figure 7 and 8 are measurement results of thermal conditions inside the cathedrals. Figure 7 shows the results of Semarang Cathedral and it shows that when low ventilation was open, air velocity was 0.09 to 0.11 m/s higher than air velocity when low ventilation was closed. But when low ventilation was open, relative humidity (RH) was 1.3 to 1.4% lower than RH when low ventilation was closed. The effective temperature (ET) when low ventilation was open ranged between 0.8 to 1.5°C lower than ET when low ventilation was closed. Figure 8 shows results of Bogor Cathedral. It shows that when low ventilation was open air velocity was 0.09 to 0.11 m/s higher, in the other side RH become 1.5% to 2.5% lower than when low ventilation was closed. ET ranged between 1.1 to 1.3°C lower when low ventilation was open. The measurement results of both cathedrals show the same results that low ventilation made air velocity became higher but RH and ET became lower. Low ventilation made significant impacts on the thermal conditions inside both cathedrals.

Conditions: Low Ventilation Opened, With Prayer Activities							
Measuring Time	Measuring Spots	Weather	MRT (°C)	Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)	Effective Temperature (°C)
8:45	A		25,2	25,6	82	0,31	23,8
	B	C	25,4	25,7	83	0,18	24,9
	C	L	25,1	25,55	83	0,26	24
	D	E	25,9	25,95	84	0,12	25,8
	E	A	25,8	25,9	85	0,11	25,7
	F	R	25,6	25,8	83	0,18	25
	G		25,3	25,65	82	0,24	24,3
	H	26	25,5	25,75	82	0,22	24,6
	I	78%	25,2	25,6	82	0,33	23,7
16:30	A		26,5	27	72	0,51	24,3
	B	C	26,6	27,05	73	0,25	25,6
	C	L	26,4	26,95	74	0,36	24,8
	D	E	26,9	27,2	76	0,33	25,4
	E	A	26,8	27,15	76	0,29	25,6
	F	R	26,6	27,05	73	0,32	25,2
	G		26,5	27	73	0,42	24,6
	H	27,5	26,6	27,05	75	0,34	25,1
	I	69%	26,3	26,9	77	0,56	24
18:15	A		27,1	28,05	72	0,61	24,9
	B	C	27,2	28,1	72	0,29	26,3
	C	L	27,1	28,05	72	0,49	25,2
	D	E	27,1	28,05	72	0,27	26,3
	E	A	27,1	28,05	73	0,25	26,5
	F	R	27,1	28,05	73	0,45	25,4
	G		27,1	28,05	73	0,97	24,1
	H	29	27,2	28,1	72	0,27	26,4
	I	70%	27,1	28,05	72	0,65	24,8

Conditions: Low Ventilation Closed, With Prayer Activities

Measuring Time	Measuring Spots	Weather	MRT (°C)	Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)	Effective Temperature (°C)
8:45	A		25,4	25,7	84	0,23	24,5
	B	C	25,6	25,8	85	0,11	25,5
	C	L	25,3	25,65	84	0,19	24,7
	D	E	26	26	84	0,1	25,9
	E	A	26	26	85	0,09	26
	F	R	25,9	25,95	85	0,09	25,8
	G		25,5	25,75	83	0,14	25,4
	H	26	25,6	25,8	84	0,12	25,5
	I	78%	25,8	25,9	84	0,13	25,6
16:30	A		26,7	27,1	73	0,2	26,1
	B	C	26,8	27,15	75	0,13	27,2
	C	L	26,9	27,2	75	0,19	26,5
	D	E	27,1	27,3	77	0,16	27,2
	E	A	27,3	27,4	78	0,21	26,8
	F	R	27,1	27,3	75	0,25	26,1
	G		26,9	27,2	76	0,21	26,3
	H	27,5	27	27,25	75	0,22	26,3
	I	69%	26,4	26,95	78	0,23	25,6
18:15	A		27,2	28,1	74	0,24	26,7
	B	C	27,2	28,1	73	0,22	26,9
	C	L	27,2	28,1	72	0,26	26,5
	D	E	27,2	28,1	75	0,37	25,9
	E	A	27,2	28,1	74	0,35	25,9
	F	R	27,3	28,15	72	0,38	25,8
	G		27,2	28,1	75	0,25	26,7
	H	29	27,2	28,1	76	0,23	26,9
	I	70%	27,4	28,2	73	0,21	27,2

Fig. 7. Measurement Results of Semarang Cathedral (Source: Sekatia 2017)

Conditions: Low Ventilation Closed, With Prayer Activities

Measuring Time	Measuring Spots	Weather	MRT (°C)	Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)	Effective Temperature (°C)
8:45	A		26,65	27,3	89	0,24	27,3
	B		26,8	27,6	90	0,19	28,4
	C	S	26,25	26,5	86	0,26	25,9
	D	U	25,8	25,6	86	0,27	24,7
	E	N	25,85	25,7	88	0,17	26,1
	F	N	25,5	25	87	0,28	24
	G	Y	25,65	25,3	86	0,12	26,1
	H		25,75	25,5	87	0,1	25,3
	I		25,85	25,7	90	0,13	26,8
	J		25,3	24,6	85	0,33	23,2
	K		25,6	25,2	89	0,2	25,1
	L	26	25,15	24,3	86	0,35	22,9
	M	75%	25,25	24,5	84	0,36	22,9
	N		25,25	24,5	85	0,13	25,1
	O		25,15	24,3	83	0,21	23,8
16:30	A		26,35	26,4	84	0,25	25,8
	B		26,45	26,6	86	0,14	27,7
	C	C	26,15	26	85	0,27	25,2
	D	L	25,75	25,2	85	0,31	24
	E	E	26	25,7	87	0,19	25,8
	F	A	25,25	24,2	86	0,29	23,2
	G	R	25	23,7	84	0,18	23,7
	H		25,1	23,9	87	0,13	24,7
	I		24,95	23,6	83	0,2	23,3
	J		25,05	23,8	80	0,32	22,6
	K		25,05	23,8	81	0,23	23,2
	L	26,3	24,9	23,5	81	0,33	22,3
	M	78%	24,9	23,5	80	0,37	22
	N		24,9	23,5	82	0,11	24,1
	O		24,85	23,4	81	0,32	22,3
18:15	A		25,65	26,3	87	0,3	25
	B		25,75	26,5	89	0,19	26,5
	C	C	25,4	25,8	86	0,2	25,3
	D	L	25,1	25,2	86	0,22	24,4
	E	E	25,25	25,5	87	0,16	25,6
	F	A	24,85	24,7	87	0,28	23,4
	G	R	25	25	87	0,19	24,6
	H		25,3	25,6	89	0,17	25,6
	I		25,1	25,2	88	0,17	25,1
	J		24,3	23,6	88	0,28	22,4
	K		24,4	23,8	89	0,23	23
	L	25	24,2	23,4	87	0,29	22,2
	M	83%	23,75	22,5	86	0,31	21,3
	N		23,9	22,8	87	0,26	21,9
	O		23,65	22,3	86	0,34	20,9

Fig. 8. Measurement Results of Bogor Cathedral (Source: Sekatia 2018)

To more easily understand the measurement results, then here is graphics of the measurement results.

Conditions: Low Ventilation Opened, With Prayer Activities

Measuring Time	Measuring Spots	Weather	MRT (°C)	Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)	Effective Temperature (°C)
8:45	A		26,7	27	85	0,33	25,9
	B		26,7	27,4	88	0,25	27,2
	C	S	25,95	25,9	84	0,39	24,2
	D	U	25,7	25,4	84	0,34	23,9
	E	N	26,3	26,6	85	0,22	26,3
	F	N	25,35	24,7	85	0,39	23
	G	Y	25,3	24,6	84	0,2	24,3
	H		25,35	24,7	85	0,2	24,4
	I		25,35	24,7	92	0,17	25,1
	J		25,3	24,6	84	0,48	22,5
	K		25,2	24,4	87	0,2	24,1
	L	26	24,95	23,9	83	0,49	21,8
	M	75%	25	24	81	0,53	21,8
	N		25	24	82	0,18	23,9
	O		25	24	78	0,32	22,6
16:30	A		26,25	26,2	83	0,36	24,7
	B		26,35	26,4	82	0,22	26
	C	C	26	25,7	82	0,43	23,8
	D	L	25,55	24,8	83	0,47	22,8
	E	E	25,75	25,2	83	0,28	24,2
	F	A	25	23,7	82	0,49	21,7
	G	R	24,8	23,3	81	0,24	22,7
	H		24,8	23,3	84	0,28	22,5
	I		24,85	23,4	80	0,31	22,3
	J		24,8	23,3	79	0,46	21,4
	K		24,9	23,5	80	0,26	22,7
	L	26,3	24,85	23,4	79	0,43	21,7
	M	78%	24,8	23,3	78	0,47	21,4
	N		24,9	23,5	79	0,19	23,3
	O		24,8	23,3	79	0,43	21,6
18:15	A		25,5	26	86	0,49	23,6
	B		25,5	26	87	0,23	25,3
	C	C	25,2	25,4	85	0,36	23,5
	D	L	24,8	24,6	87	0,38	22,7
	E	E	24,95	24,9	85	0,3	23,4
	F	A	24,65	24,3	85	0,43	22,2
	G	R	24,85	24,7	87	0,25	23,6
	H		24,9	24,8	88	0,23	23,9
	I		24,8	24,6	87	0,27	23,2
	J		24,15	23,3	87	0,4	21,5
	K		24,2	23,4	86	0,32	22
	L	25	24,1	23,2	84	0,39	21,4
	M	83%	23,65	22,3	84	0,44	20,4
	N		23,8	22,6	84	0,31	21,3
	O		23,5	22	85	0,46	20

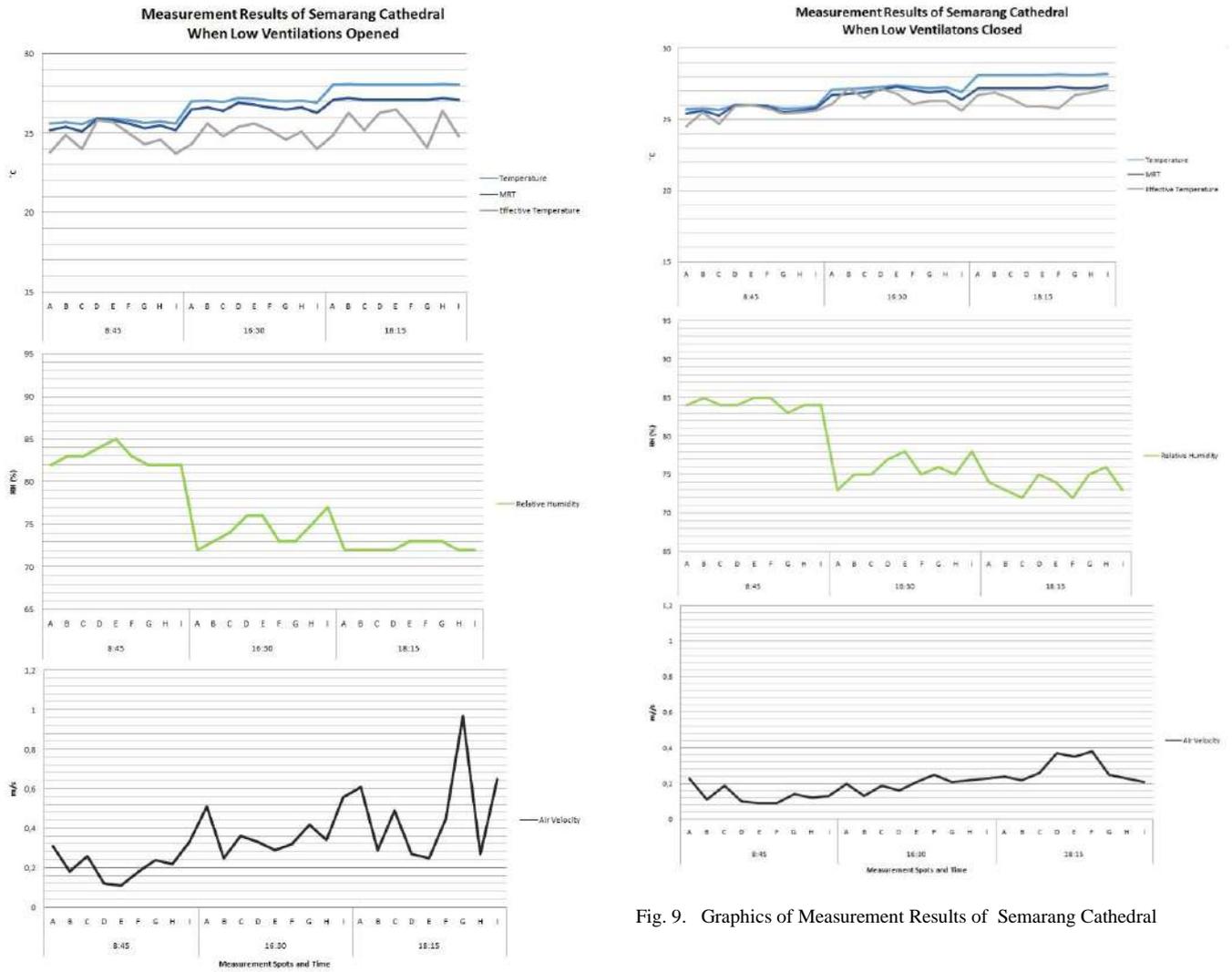


Fig. 9. Graphics of Measurement Results of Semarang Cathedral

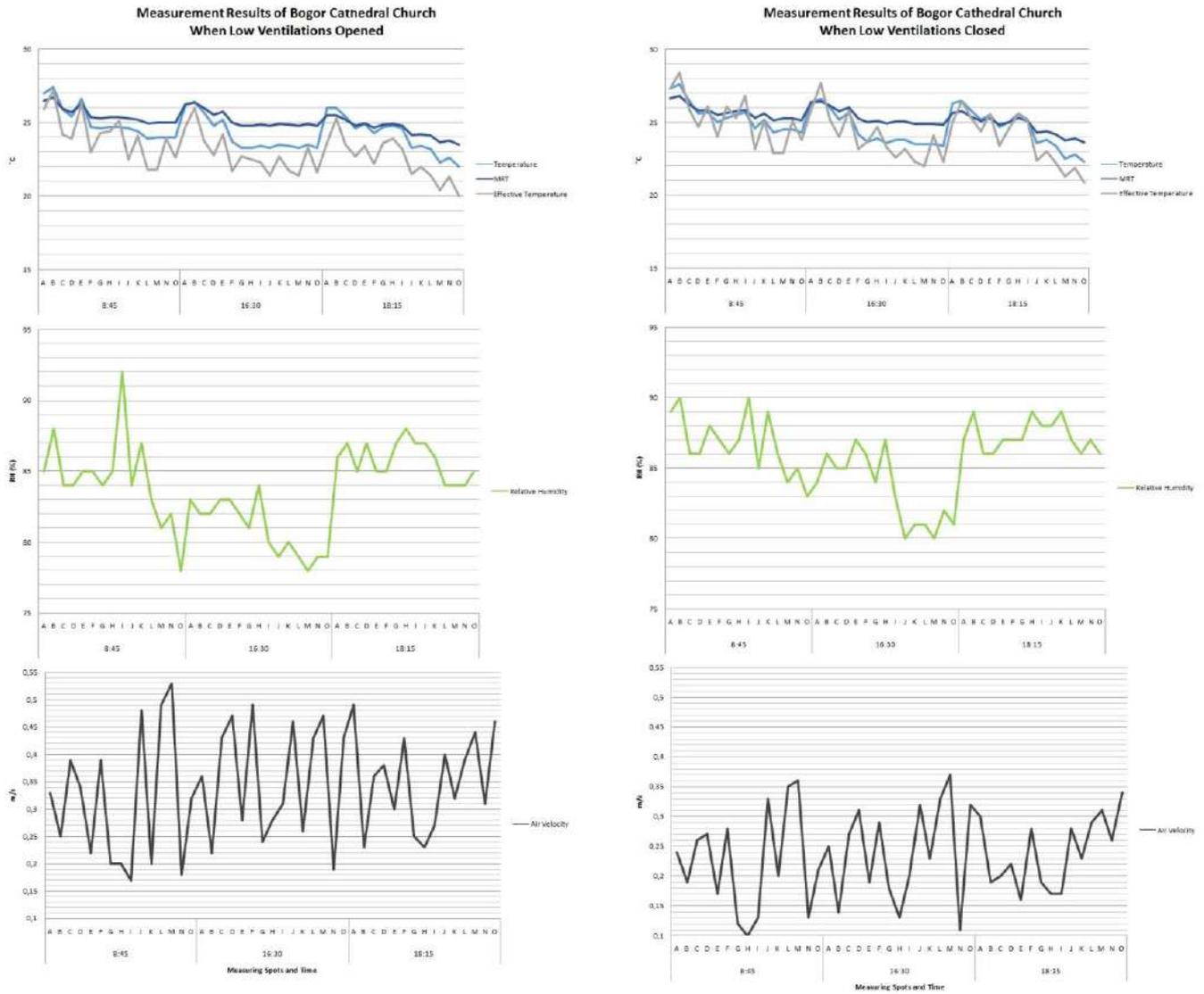


Fig. 10. Graphics of Measurement Results of Bogor Cathedral

IV. DISCUSSION AND ANALYSIS

Air velocity is one of thermal comfort factors. It will assist in evaporation process which can lower down the temperature [11]. The comfortable zone of air velocity is around 0.2 m/s – 0.8 m/s [4]. Figure 11 shows air velocity charts of Semarang Cathedral that when the low ventilation was closed, lack of air came into the Semarang Cathedral. There were only few spots at 16:30 and all spots at 18:15 included in comfort zone of air velocity. Otherwise, when low ventilation was open, all measuring times and all spots were included to air velocity’s comfort zone. The highest air velocity entered Semarang Cathedral was at 18:15. The A, C, G, and I spots located near low ventilations had higher air velocity compared with the other spots.

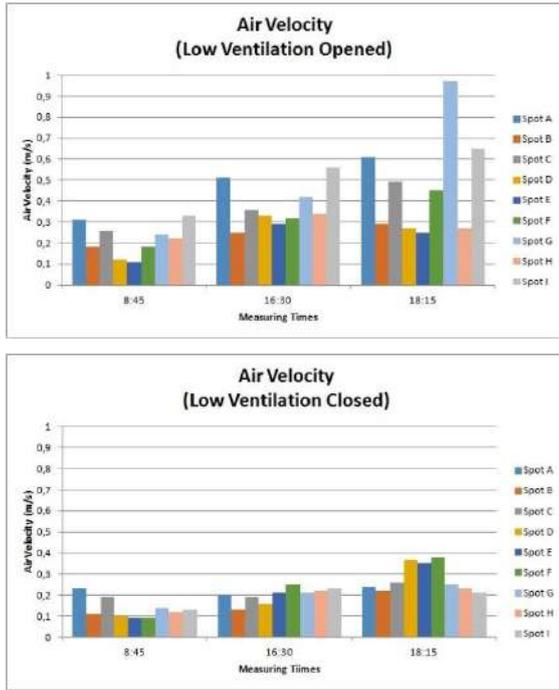


Fig. 11. Air Velocity in Semarang Cathedral

comfort zone. Like what happened at Semarang Cathedral, spots near low ventilations (A,C,D,F,J,L,M,O) of Bogor Cathedral had higher air velocity compared to the other spots.

To make it easier, figure 13 shows the average of air velocity of both cathedrals. Both Semarang Cathedral and Bogor Cathedral had the same tendency that when low ventilation was open, air velocity became higher and made thermal conditions categorized as comfort zone. Semarang Cathedral had more significant increase in air velocity than Bogor Cathedral.

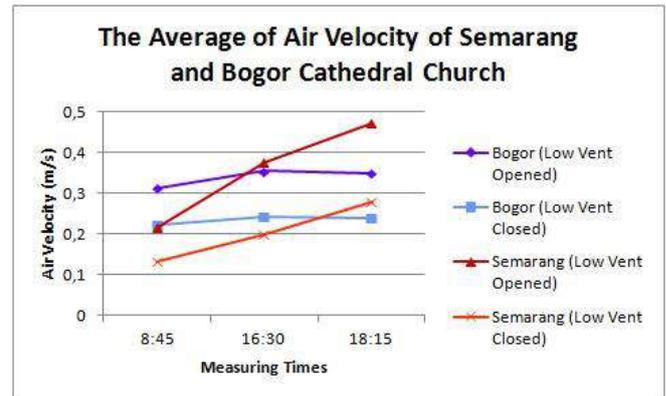


Fig. 13. Average of Air Velocity between Semarang and Bogor Cathedrals

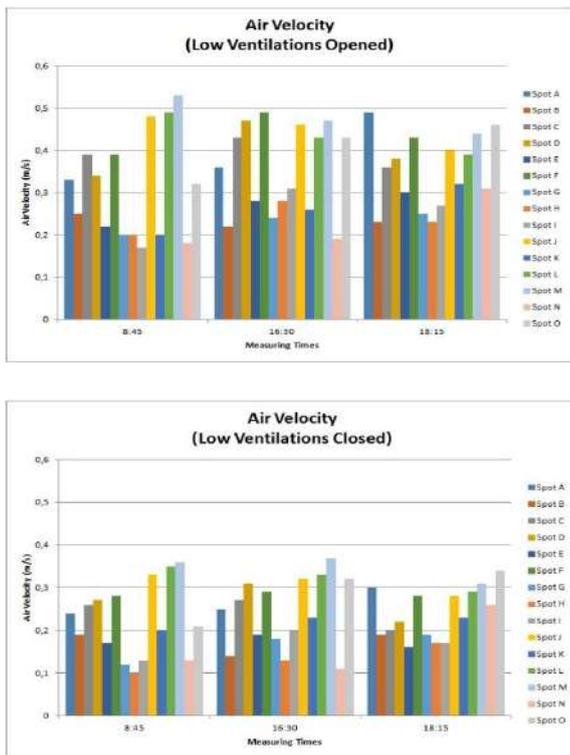


Fig. 12. Air Velocity in Bogor Cathedral (Source: Sekatia 2018)

Figure 12 shows air velocity charts of Bogor Cathedral. It shows that both conditions, air velocity at most of measuring times and spots were included to air velocity's comfort zone. Significant difference happened when low ventilation was open. When low ventilation of Bogor Cathedral was open, air velocity became higher compared to when low ventilation was closed. When low ventilation was closed, there were several spots at each measuring times not included in the

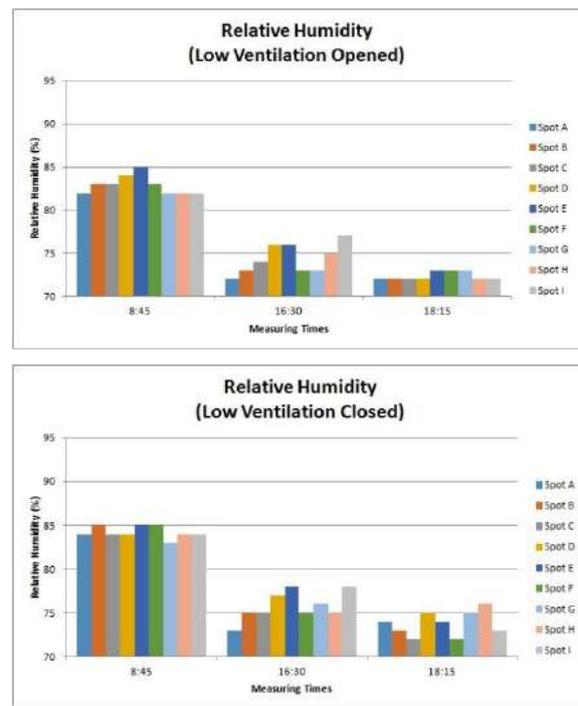


Fig. 14. Relative Humidity in Semarang Cathedral

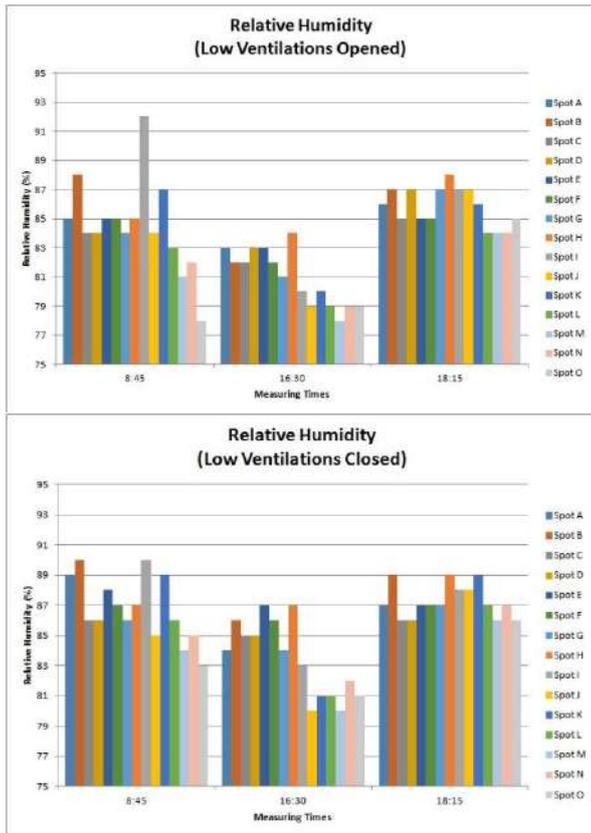


Fig. 15. Relative Humidity in Bogor Cathedral (Source: Sekatia 2018)

Comfort zone of RH is around 30% - 90% [12]. Figure 14 shown RH charts of Semarang Cathedral. RH at both conditions (when low ventilation was open and closed) included into comfort zone. The difference was when low ventilation was closed, RH became higher. It was because when low ventilation was closed, only minimum air velocity entered Semarang Cathedral. The lowest RH was at 18:15. Again, measuring spots located near low ventilation (A,C,G,I) had lower RH than other spots. Figure 15 shows RH charts of Bogor Cathedral. Similar to Semarang Cathedral, that most measuring spots and measuring times at Bogor Cathedral were included into comfortable relative humidity. It was only I spot at 8:45 that had higher than 90% RH which was not included into comfort zone. At 8:45 and 18:15 had higher RH. The spots located near low ventilations (A,C,D,F,J,L,M,O) had lowest RH.

Figure 16 shows the average of RH of both cathedrals. Semarang Cathedral had lower RH than Semarang Cathedral. It was caused by the geographical location of both cathedrals. Semarang Cathedral is located at lowland, otherwise Bogor Cathedral is located at highland. The tendency was same. RH became lower when low ventilation was closed. The difference was the time when RH reached the lowest point. Semarang Cathedral reached the lowest RH at 18:15 and Bogor Cathedral at 16:30.

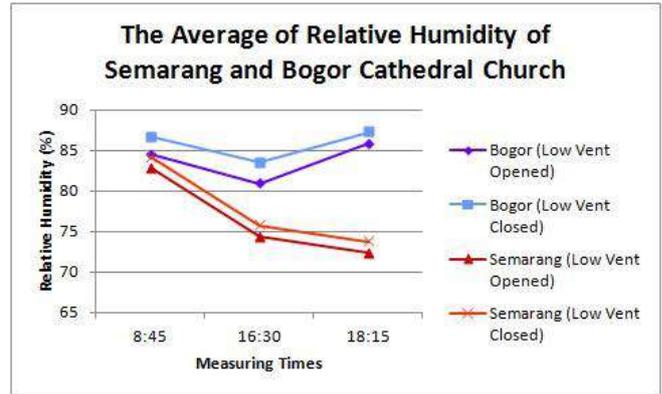


Fig. 16. Average of Relative Humidity between Semarang and Bogor Cathedrals

Temperature of not moving conditions (± 0.1 m/s) of saturated air is called effective temperature [13]. The comfort zone of ET is around 23°C - 27°C [6]. Figure 17 shows the effective temperature charts of Semarang Cathedral. It shows that ET at most of the spots in all measuring times and all conditions of low ventilations were included into comfortable zone. It shows that basically, Semarang Cathedral had a comfortable temperature. Shown at Figure 17, ET became the lowest when low ventilation was open. When the low ventilation was opened, the average of effective temperature was 0.8°C at 8:45, 1.5°C at 16:30, and 0.9°C at 18:15. A, C, G, and I spots located near low ventilations had lower effective temperature than the others.

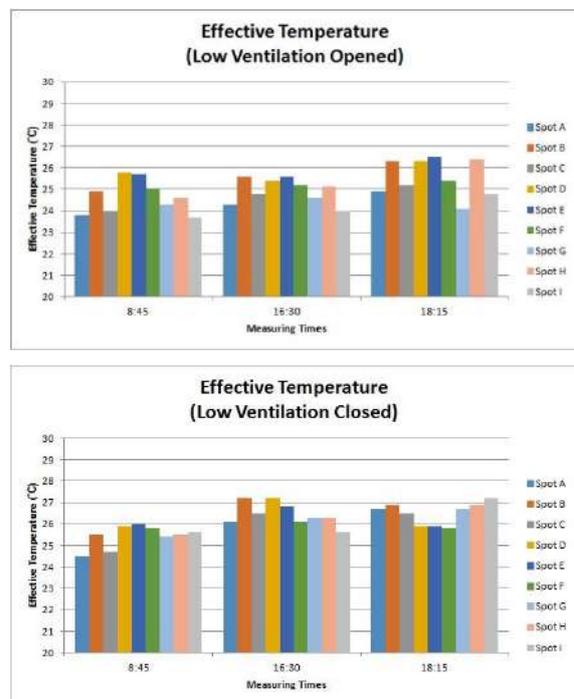


Fig. 17. Effective Temperature in Semarang Cathedral

Figure 18 shows the effective temperature charts of Bogor Cathedral. In Bogor Cathedral, ET charts show various dynamics because there were some spots in each measuring time that had lowest temperature than comfort zone. It shows that basically, Bogor Cathedral church had comfort to cool effective temperature. Similar to Semarang

Cathedral, ET became lower when low ventilation was open. The lowest ET occurred at 18:15. It can be seen in figure 18 that 8 from 15 spots had lower ET than 23°C. Spots near the low ventilations (spots A, C, D, F, J, L, M, O) had lower ET from other spots.

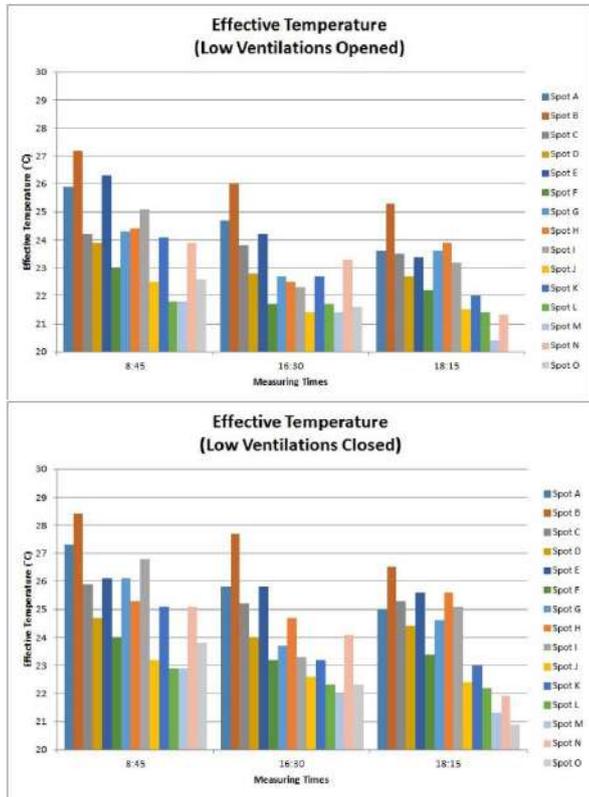


Fig. 18. Effective Temperature in Bogor Cathedral (Source: Sekatia 2018)

Figure 19 shows the average of effective temperature of both cathedrals. Both Semarang Cathedral and Bogor Cathedral had the same tendency that when low ventilation was open, effective temperature became lower and made thermal conditions achieve the comfort zone. The difference was at Semarang Cathedral the ET was increasing from 8:45 to 18:15 and achieved the highest ET at 18:15. But at Bogor Cathedral, ET was decreasing from 8:45 to 18:15 and achieved the lowest ET at 18:15.

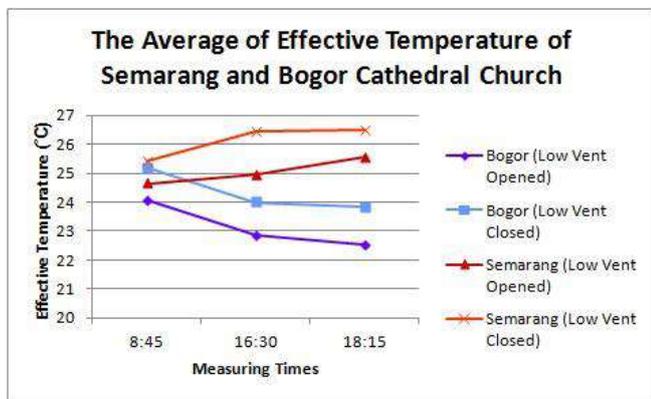


Fig. 19. Average of Effective Temperature between Semarang and Bogor Cathedrals

V. CONCLUSION

The conclusion from discussion and analysis above is Semarang and Bogor Cathedral churches are categorized as thermal comfortable buildings. All measurement data and analysis were included in comfort zone. The achievement of thermal comfort zone of these buildings could not be separated from the existence of low ventilations. Low ventilations made significant effects on thermal comfort inside both buildings. Low ventilations successfully lower down the ET so that the temperature of those buildings became cooler. The air humidity which has comfort zone from 30% - 90% also achieved. Spots near the low ventilations had lower value of ET and air humidity than other spots. The air velocity also achieved its comfort zone (0.2m/s - 0.8m/s) while low ventilations made more air velocity entered the building. Low ventilations installed at these Cathedral churches are proven to achieve thermal comfort, and low ventilations are also proven to optimize the thermal conditions to enter the comfort zone. The tendency of air velocity, relative humidity, and effective temperature from both cathedrals toward low ventilations was exactly the same. The difference was only the value of each measurements. That was because the different geographic locations.

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