Thermal condition of passive cooling system in Bogor Cathedral Church

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Abstract. Sustainable architecture recently becomes a priority design concept for all buildings in Indonesia. All designs attempt to lower the energy consumption and save more energy to achieve a sustainable building. In Dutch colonial era, passive cooling system became an effective building technology to cope with Indonesian tropical climate without wasting lot of energy. Bogor City, West Java, has a historical building named Bogor Cathedral Church that is equipped with passive cooling system. Bogor Cathedral Church has low ventilation that are adjustable (open or closed). Research was carried out three times during church services and at 15 (fifteen) measuring points where low ventilations were open and closed. Dry bulb temperature, relative humidity, air velocity, and effective temperature (ET) were measured. The purpose of this study is to investigate the thermal conditions of this passive cooling system building. The results of this study show that low ventilations made a significant change to the thermal conditions inside the building. The measuring points near the low ventilation had lower relative humidity and effective temperature, and higher air velocity compared with another points. This study can contribute to enhance understanding that passive cooling system is essential to sustainable architecture.

Keywords: sustainable architecture, passive cooling, thermal condition, historical building

1. Introduction
A building design must be sustainable with the local climate in order to achieve a sustainable design and save energy. By adjusting the local climate, thermal comfort can be achieved. But today’s building designs tend to pay attention only to aesthetics without taking into account the climate where the building is built, so that it results in high-energy consumption. Indonesia is a country that has a humid tropical climate.

Tropic or from Greece “tropikos” means turning line which covers 40% of the Earth. This line is 23°27’ South Latitude. Tropical climate has high solar radiation, very high reative humidity level, and also high rainfall [1]. Lippsmeier (1994) mentioned that to achieve a comfortable thermal condition, it must achieve the right effective temperature and the characters of wet tropic area, including the type of rainforest, the landscape on the equator line, red soil covered by grass, the high variety of plants, the same seasons all over the year, the 60-90% cloudy weather with sky lamination of 850-7000Cd/m2, the high solar radiation, the air temperature with fluctuation of 21-32°C during day and night, the high precipitation in rainy season, the humidity of 55-100%, and the low air velocity.
Thermal comfort is a state of mind that expresses one's satisfaction with its thermal environment [2]. Thermal comfort is one element of comfort that is very important, because it concerns with the condition of a comfortable room temperature. Thermal comfort can be obtained when the effective temperature is 23˚C - 27˚C, the air humidity is 30% - 60%, the metabolic rate is 1-1.2, the clothing condition is 0.5 - 0.6, and the wind speed is more than 0.2 m / s [3]. If thermal comfort can be achieved, the building can reduce energy consumption and lead to sustainable development. 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 [4].

Bogor City is a city that has many historical building in the Dutch colonial era. One historical building from Dutch colonial era that still stands firm and used until today is Bogor Cathedral Church. Bogor Cathedral Church was built on 1905 and it is still used until now. As a public historical building, Bogor Cathedral Church uses passive cooling system in its building which becomes a perfect object for finding thermal condition. It has unique ventilations installed at the bottom area of the wall called low ventilations. Low ventilation can optimize thermal comfort [5].

This study aims is to find the thermal conditions of this building with only passive cooling and to prove that low ventilations can optimize thermal comfort. All variables measured during a worship activity. The purpose of this study was to examine the thermal condition of the building in which only passive cooling system was functioned during prayer time. Bogor Cathedral Church is equipped with air conditioner (AC) too, but when the data was collected, AC would be turned off to optimize passive cooling system performance. The hypothesis of this study is that thermal conditions of Bogor Cathedral church still enter into the thermal condition’s comfort zone. The passive cooling system of this building designed at colonials era is also still capable to cope with the tropical climate and lower down the building’s effective temperature.

2. Methods
There were two stages of data collections: first was site observation and second was thermal measurement inside the cathedral. Thermal measurement data collected were dry bulb temperature (˚C), air velocity (m/s), and relative humidity (%). As shown in Table 1, there were 3 (three) periods of worship time and on 15 (fifteen) spots inside the building as shown in Figure 4. There were also
several gears calibrated properly as shown in Figure 3 and Figure 4. The measurement was performed in two different conditions: open and closed low ventilations (Figure 5).

This study employed quantitative method. Data was collected and then analyzed to communicate results and discussion. Results and discussion included tables and charts so that all information, validity and reliability could be evaluated by the readers.

### Table 1. Time Measurement

| Measuring Time | Period |
|----------------|--------|
| Morning        | 8.45   |
| Evening 1      | 16.30  |
| Evening 2      | 18.15  |

![Figure 2. Measuring Spot Plan](image)

![Figure 3. Hotwire Anemometer.](image)

![Figure 4. Digital Thermo Hygrometer](image)
3. Measurement Results

| Conditions: Low Ventilation Opened, With Proper Activities | Measuring Time | Measuring Spot | Temperature (°C) | Relative Humidity (%) | Air Velocity (m/s) | Effective Temperature (°C) |
|----------------------------------------------------------|--------------|---------------|-----------------|----------------------|--------------------|--------------------------|
| 28.02.19 A                                               | 8:40         | A             | 26.9            | 56                    | 0.02               | 26.7                     |
| B                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| C                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| D                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| E                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| F                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| G                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| H                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| I                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| J                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| K                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| L                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| M                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| N                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| O                                                        | 26.7         | 56            | 0.02            | 26.7                 |

| Conditions: Low Ventilation Closed, With Proper Activities | Measuring Time | Measuring Spot | Temperature (°C) | Relative Humidity (%) | Air Velocity (m/s) | Effective Temperature (°C) |
|----------------------------------------------------------|--------------|---------------|-----------------|----------------------|--------------------|--------------------------|
| 28.02.19 A                                               | 8:40         | A             | 26.9            | 56                    | 0.02               | 26.7                     |
| B                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| C                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| D                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| E                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| F                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| G                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| H                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| I                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| J                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| K                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| L                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| M                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| N                                                        | 26.7         | 56            | 0.02            | 26.7                 |
| O                                                        | 26.7         | 56            | 0.02            | 26.7                 |

The measurement results revealed that when low ventilations were open, ET and RH became lower, but the air velocity became higher. There were significant differences.

4. Discussion

Effective Temperature (ET) is a thermal comfort’s function of radiant heat, temperature, RH and air movement or air velocity [6]. ET is defined as the temperature of saturated air in near or not moving...
conditions (± 0.1 m/s) [7]. Effective temperature is categorized as comfortable when its temperature is around 23°C - 27°C [3]. As shown in Figure 7, the charts of effective temperatures have various dynamics. Some spots in all measuring time and in all conditions (low ventilations open/closed) were included into comfortable effective temperature (23°C - 27°C), but some other spots had lower ET. It shows that basically, Bogor Cathedral church has ET included into comfort to cool temperature. B spot was the only spot that entered not comfortable ET because its ET was higher than 27 °C. Two graphics in Figure 7 had a difference. ET became lower when low ventilations were open than when low ventilations were closed. Lowest ET was located at 6:15 pm, it can be seen at figure 7 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.

![Effective Temperature During Activities](image1)

**Figure 7.** Effective Temperature during activities.

Relative humidity shows the comparison between the existing steam pressure to the maximum possible steam pressure (degree of saturation) under certain air temperature [1]. RH between 30 – 90% is included into comfort zone of relative humidity [8]. Figure 8 shows that most measuring spots and measuring times were included into comfortable relative humidity. It was only 1 spot at 8:45 am that had higher than 90% RH. As seen in Figure 8, relative humidity became higher when low ventilations were closed. It was caused by the lack of air velocity that entered the building so that relative humidity became higher and higher. At 8:45 am and 6:15 pm had higher relative humidity than at 4:30 pm.

![Relative Humidity During Activities](image2)

**Figure 8.** Relative humidity during activities.

Air movement or air velocity assists in the evaporation process which can lower the air temperature [6]. Air velocity between 0.2m/s - 0.8m/s is included into comfortable zone of air velocity [2]. As shown in figure 9, almost all spots, measuring times, and conditions were categorized as comfort zone.
When low ventilations were closed, almost half of all measuring spots had air velocity lower than 0.2 m/s. It means that when low ventilations were closed, almost half of measuring spots were categorized into not comfortable air velocity. As shown in Figure 9, spots A, C, D, F, J, L, M, and O near the low ventilations had higher air velocity in compared to the other spots.

![Figure 9. Air velocity during activities.](image)

5. Conclusion
From the discussion above, we can conclude that Bogor Cathedral church is categorized as a thermal comfortable building. All measurement data and analysis were included in the comfort zone. The achievement of thermal comfort zone of this building could not be separated from the existance of low ventilations. Findings of this study revealed that low ventilations successfully lowered down the ET so that the temperature of this building became cooler. The air humidity having comfort zone from 30% - 90% was also achieved. Spots near the low ventilations (A, C, D, F, J, L, M, O) had lower value of ET while low ventilations resulted in more air velocity entering the building. Passive cooling system of this Bogor Cathedral church was proven to achieve thermal comfort, and low ventilations were also proven to optimize the thermal conditions to entered the comfort zone.

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7. References
[1] Lippsmeier, Georg 1994 Tropical Building. 2nd edition. Syahmir Nasution, translator. Jakarta: Erlangga
[2] Szokolay 1973 Manual of Tropical Housing And Building. India: Orient Longman
[3] ASHRAE 1989 Handbook of Fundamental Chapter 8 Physiological Principles, Comfort, and Health. USA: ASHRAE
[4] Martinez-Molina, A., Tort-Ausina, I., Cho, S. and Vivancos, J. L 2016 ‘Energy efficiency and thermal comfort in historic buildings: A review’, Renewable and Sustainable Energy Reviews. 61 70–85
[5] Sekatia,Augi, Hasrthritis, Bangun I.R, Setyowati, Erni and Hardiman, Gagoek 2017 Thermal Condition in Semarang Cathedral’s Passive Cooling System. Proceedings of International Conference on Engineering, Technology, and Industrial Application
[6] Frick, Heinz and FX. Bambang Suskiyatno 2007 Dasar dasar Arsitektur Ekologis. Yogyakarta: Kanisius

[7] Houghten, F.C. and C.P. Yagloglou. 1923. Determining Lines of Equal Comfort. Transactions of the American Society of Heating and Ventilating Engineers. 29 163

[8] ASHRAE STANDARD 55 2004 Thermal Environmental Conditions For Human Occupancy. USA: ASHRAE