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Performance of passive design strategies in hot and humid regions. Case study: Tangerang, Indonesia

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ABSTRACT

The building sector is one of the largest energy consumers worldwide. Especially in the hot-humid Southeast Asian region, this sector consumes about 30% of primary energy demand. This is mainly dominated by air conditioning systems to provide space cooling and dehumidifying. In this paper, three passive design strategies to reduce cooling energy and attain a good daylight environment in an office in Tangerang, Indonesia, will be evaluated using both measurement and simulation methods. Improving thermal insulation, natural ventilation, and solar shading are the strategies studied in this paper. The measurement result shows that the excessive daylight can be reduced by solar shading and the indoor temperature can be reduced by both solar shading and natural ventilation. The result of the simulation also validates the effects of shading and natural ventilation on lowering the indoor temperature and reducing the cooling load. Besides, it is proved that the difference in the building’s airtightness can cause an obvious difference in the effect of natural ventilation. There will be a large potential to adopt passive design even in hot and humid regions if the strategies are applied appropriately and good performance of the building, including high airtightness and proper thermal insulation, is guaranteed.

1. Introduction

In recent years, Southeast Asian countries have experienced economic growth accompanied by rapid urbanization, which results in a significant increase in the urban energy consumption. For example, in Indonesia, energy subsidies have contributed to about 80% of the total budget for social programs in the last ten years. Therefore, there is a strong interest to utilize energy resources as efficiently as possible (Kwong, Adam, and Sahara 2014; Setyawan 2014). It is predicted that by 2020, the energy consumption in Southeast Asian countries will exceed that of developed countries. Figure 1 shows a typical building energy consumption in Southeast Asian countries (Katili, Boukanouf, and Wilson 2015). Due to the hot and humid climate in Southeast Asian countries, the energy consumption for cooling and dehumidifying in buildings is enormous.

Besides, the urban heat island (UHI) phenomenon has been confirmed in major cities such as Johor Bahru (Kubota and Ossen 2010), so that it is predicted that cooling energy consumption will further increase. Nam estimated the total cooling loads in all the residential buildings in Hanoi under the current condition and the future master plan condition, based on the numerical simulations. It is predicted that the total cooling load of all the residential buildings in Hanoi will increase by 32.2% after the implementation of the Hanoi Master Plan 2030 (Nam, Kubota, and Trihamdani 2015). Aside from the UHI phenomenon, global warming also leads to an increased cooling load of buildings. Lee, Trihamdania, and Kubota analyzed the contributions of land-use changes and global warming to the future increase in urban temperatures in Hanoi by the 2030s. It is shown that global warming will contribute, at most, 71% of the temperature increase in existing urban areas in the 2030s, and the temperature increase will likely offset the cooling effect from any of UHI mitigation measures (Lee et al. 2017). Doan and Kusaka provided regional climate projections for the 2050s for greater Ho Chi Minh City, a fast-growing megacity in Southeast Asia, which showed that an additional warming of 0.5 °C is expected in newly urbanized areas, corresponding to 20–30% of the global warming (Doan and Kusaka 2018). Considering the further movement of urbanization and climate change including the urban heat island phenomenon in Southeast Asian countries, it is desirable to introduce appropriate passive design strategies as much as possible, thereby lowering the indoor temperature and reducing the cooling load.

To reduce the cooling load of buildings in hot and humid regions, researchers have considered various passive design techniques. These techniques could be categorized based on their focus on different aspects of building environmental design, such as the envelope,
microclimate, ventilation, daylighting, orientation, thermal insulation, shading, construction materials, and so on. Since the current study focuses on thermal insulation, natural ventilation, and solar shading, the related researches are reviewed and presented here.

Miyazaki and Yamamoto analyzed the effects of thermal insulation, including exterior wall and window glass, on reducing cooling energy consumption of residence in Cambodia by simulation. The simulation result showed good effects of thermal insulation (Keiko et al. 2012). Surapong and Vu presented results from an experimental and simulation study on comparative energy and economic performance of walls, insulated to different thicknesses, used to enclose air-conditioned spaces. Results show that insulation can generally help improve the thermal performance of walls (Chiraratananon and Hienc 2011). Mehmet studied the influence of three different types of thermal insulation on the building cooling load for a sample office center located in Adana. Building cooling load was calculated according to the Radiant Time Series (RTS) method suggested by ASHRAE. The results showed that the design cooling load of the sample building decreased a maximum of 33% due to thermal insulation (Aktacir, Büyükalaca, and Yilmaz 2010). Yueer He examines naturally ventilated buildings in hot and humid summer zones and proposes an air enthalpy-based energy conservation rating method. The results indicate that natural ventilation is an effective way to improve thermal comfort while maintaining a low cooling energy consumption in hot-humid summer zones. Using natural ventilation could help reduce cooling energy demand by 10–30% compared to not using natural ventilation (Yueer et al. 2017). Hirano and Kato evaluated two residential building models, having a void ratio of 0% and 50% individually, using computational fluid dynamics (CFD) analysis and thermal and airflow network analysis. The result of the heat load indicates that improvements in the natural ventilation performance would significantly reduce the cooling load (Hiranoa et al. 2006). Kubota and Doris investigated the effectiveness of the night ventilation technique for residential buildings in the hot-humid climate of Malaysia, and prove that the night ventilation has a better effect than daytime ventilation and all-day ventilation (Tetsu and Doris Toe 2009). Allen and Elias investigated the potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in Malaysia. The results suggest that the use of various shading devices on Low-E double glased facades will result between 1.0% and 3.4% annual cooling energy savings (Lau et al. 2016). Waleed and Muhammad focused on the energy-saving potential and economics of incorporating external shading devices with a self-shading envelope for a multi-story hotel building in the hot and humid climate of Saudi Arabia. The results show that the proposed shading could save the annual energy consumption of the building by 20.5% compared to the base case, while improving the baseline insulation and glazing save only 5% of annual energy consumption (Alhuwayil, Mujeebu, and Algamy 2019).

Aside from researches focusing on one particular strategy, many researchers considered multiple strategies at the same time. Many pieces of related research have been done on various kinds of buildings, especially on the residence. Seyedehzahra and Mohd reviewed the effect of building envelope on the thermal comfort and energy-saving for high-rise buildings in hot–humid climate. The various aspects of the building envelop, which include insulation, natural ventilation, and external shading have a great influence on the energy consumption (Mirrahimi et al. 2016). Sugiyama and Yasufuku evaluated the effects of natural ventilation, combined with skin thermal insulation and solar shading, on attaining thermal comfort and reducing cooling load of residence in Malaysia. It is proved that the combination can lower the average operative temperature to 28.5°C (Susumu, Satoshi, and Tetsu 2015). Besides, Uno and Hokoi researched on the reduction of energy consumption by AC due to ventilation strategy as well as building airtightness of residences in hot and humid climates by computational fluid dynamics (CFD), pointing out the influence of airtightness and ventilation pattern on reducing energy consumption (Uno et al. 2012).

On the other hand, aside from reducing cooling load, a good daylight environment is also an important aim of the passive design, especially for office buildings. The research of Julia and Benjamin presents results from a large-scale study, which included field measurements and surveys of three large commercial office buildings in the U.S, evaluating three different types of shading strategy: automated blinds, electrochromic glazing, and roller shades (Day et al. 2019). Francisco and José carried out a case of study to learn the effects of louvers shading devices on visual comfort and energy demand of an office building. The research used real-time experiments and computer simulations to study how the shading devices, including vertical fins, diagonal fins, and egg crate, work in controlling air temperature and improving illuminance level (Hernández et al. 2017). Freewan investigated the effect of shading devices on the visual environment, air

Figure 1. Typical building energy consumption in tropical countries.
temperature, and users’ interaction in offices facing south-west façade. The study found that shading devices could improve the visual environment and reduce the temperature of the offices, compared to the base case (Freewan 2014).

In the literature reviewed, the experiments and measurements, which aimed at clarifying the effect of thermal insulation in hot and humid regions, are rarely done in a real used office. Besides, in hot and humid regions, although it has been proved by numerous researches that using natural ventilation in residential buildings has a good effect on the thermal environment of the building, the potential of using natural ventilation in the office is still not widely acknowledged.

This research used both measurement and simulation methods to evaluate the effects of three passive design strategies on reducing cooling load and attaining a good daylight environment in an office in Tangerang, Banten, Indonesia. The passive design strategies are improving skin thermal insulation, natural ventilation by vertical operable vents, and solar shading by operable louvers. The main purpose of this research is to show the effect of the three passive design strategies on reducing cooling energy in hot and humid regions. Besides, it is also proved that excessive daylight can be reduced by Operable louvers.

2. Case Information

The building in this study belongs to a company in Tangerang, Banten, Indonesia. In 2018, one of the company’s existing buildings was renovated and converted to a research and development facility. The location of Tangerang in Indonesia is shown in Figure 2 and the coordinates of the building are shown in Table 1. The target room in this study is the main office room located on the second floor of the building with a floor area of 271.4 m². The west side and the north side of the room face outside and have long-horizontal windows. The 3rd floor is also office rooms, and the 1st floor is the factory area (Figure 3).

At the time of the renovation, we focused on energy saving and applied various passive design strategies. Improving thermal insulation, natural ventilation, and shading are the main strategies that are used in this project.

- Improvement of thermal insulation

Before the renovation, the exterior wall had a simple construction consisting of steel plates and gypsum boards only and the windows used single-pane glass, which means the performance was extremely poor. During the renovation, 50 mm glass wool was added between the steel plates and the gypsum boards. In addition, the windows’ glass was changed to Low-E single-pane glass. (Table 2)

- Natural ventilation

Vertical operable vents were installed between windows to allow natural ventilation. In total, there are four units of operable vents at each west and north facades, respectively. (Figure 4)

- Solar shading

![Figure 2. The location of Tangerang in Indonesia.](image1)

![Figure 3. Plan and section of the target room.](image2)

Table 1. Location details of the case.

| City Name | Tangerang |
|-----------|-----------|
| Province Name | Banten |
| Coordinate point | 6°13' 03.1" S 106°34' 47.1" E |

| Name          | Location |
|---------------|----------|
| Target Room   |          |
| Meeting Room  |          |
| Dinning       |          |
| Factory Area  |          |
| Open Office   |          |
| 1F            |          |
| 2F            |          |
| 3F            |          |
Table 2. Improvement of insulation.

| Wall                  | Before renovation | After renovation |
|-----------------------|-------------------|------------------|
| Construction layer    |                   |                  |
| Thickness (m)         |                   |                  |
| Conductivity (W/m-K)  |                   |                  |
| Heat transfer coefficient (W/m²-K) | 17.6 | 0.73 |
| Window glass          |                   |                  |
| Visible transmittance | 0.894             | 0.35             |
| Solar heat gain coefficient | 0.85 | 0.37 |
| Shading coefficient   | 0.97              | 0.43             |
| Heat transfer coefficient (W/m²-K) | 5.9 | 4.4 |

3. Measurement plan and result analysis

3.1. Measurement plan

The measurement was divided into two parts: rainy season measurement was carried out from 1/12 to 2/11, 2019 and dry season measurement was carried out from 6/27 to 8/12, 2019. The measured variables conclude outdoor temperature, indoor temperature, indoor relative humidity, indoor illuminance, heat flow through window glass and electricity current of the air conditioning units. The data were recorded at 2-minute intervals. The cooling load can be calculated from the electric current of the Air Conditioning units. The specifications of the measuring points and equipment are presented in Table 3. The layout of measuring points is shown in Figure 6 and measuring equipment is shown in Figure 7.

Four cases carried out in the rainy season, where the operable louvers were in different states by day of the week. Six cases were carried out in the dry season, where the on/off state of the operable louvers/vertical operable vents are different case by case. Detail schedules of the rainy season measurement and the dry season measurement are shown in Tables 4 and 5.

Since Tangerang is hot and humid throughout the year, the room is always cooled during working hours. The working time is from 7:00 to 17:00 on weekdays and the setpoint temperature for cooling is 24°C. Shading is controlled by the presence or absence and the angle of the operable louvers.

As shown in Figure 8, there are three states of the louvers: (1) No Louver, (2) Louver Closed, and (3) Louver Opened. Natural ventilation is controlled by the on/off state of the vertical operable vents. During the rainy season measurement, the vertical operable vents were opened from 7:00 to 8:00. During the dry season measurement, there are two following ventilation patterns:

- Pattern 1: Night ventilation only on weekdays

Open the vertical operable vents on Monday to Thursday when workers get off work (17:00). Close the vertical operable vents on Tuesday to Friday when workers begin to work (7:00).

Operable louvers (Figure 5) whose angle can be adjusted were installed outside the windows as a measure against excessive sunlight.

After the renovation, we conducted an airtightness measurement of the target office room. The results showed that the infiltration rate of the room is around 2 air changes per hour, which exceeds the common range: 1 ~ 1.5 air changes per hour.

Figure 4. Vertical vent between windows.

Figure 5. Operable louvers.
Table 3. The specifications of the measuring points and equipment.

| Type                      | Equipment                          | Point Name  | Explanation                                         |
|---------------------------|------------------------------------|-------------|-----------------------------------------------------|
| Air Temperature & Illuminance (6 Points) | Temperature/Humidity/Illuminance Logger (TR-74Ui) | TL-NW       | At the northwestern area of the room at 1.1 m height |
|                           |                                    | TL-NE       | At the northeastern area of the room at 1.1 m height |
|                           |                                    | TL-SW       | At the southwestern area of the room at 1.1 m height |
|                           |                                    | TL-SE       | At the southeastern area of the room at 1.1 m height |
|                           |                                    | TL-NWin     | Beside the north window at 1.1 m height             |
|                           |                                    | TL-WWin     | Beside the west window at 1.1 m height              |
| Air Temperature (8 Points) | Temperature/Humidity/Illuminance Logger (TR-74Ui) | T-100       | At the center of the room at 0.1 m height            |
|                           |                                    | T-600       | At the center of the room at 0.6 m height            |
|                           |                                    | T-1100      | At the center of the room at 1.1 m height            |
|                           |                                    | T-1600      | At the center of the room at 1.6 m height            |
|                           |                                    | T-2100      | At the center of the room at 2.1 m height            |
|                           |                                    | T-2600      | At the center of the room at 2.6 m height            |
|                           |                                    | T-Cor       | At the corridor at 1.1 m height                      |
| Heat Flux (2 Points)      | Voltage Logger                     | HX-N        | Heat flow through the North window                  |
|                           |                                    | HX-W        | Heat flow through the West window                   |
| Electric Current (1 Point) | Voltage Logger                     | ACWh        | Electric current of the air conditioning units      |
|                           |                                    |             |                                                     |

Table 4. Schedule of the rainy season measurement.

| 1/6 (Sun) | 7 (Mon) | 8 (Tue) | 9 (Wed) | 10 (Thu) | 11 (Fri) | 12 (Sat) |
|-----------|---------|---------|---------|----------|----------|----------|
|           | Setting and Test | [ ] | [ ] | [ ] | [ ] | [ ] |
| 13 (Sun)  | 14 (Mon) | 15 (Tue) | 16 (Wed) | 16 (Thu) | 17 (Fri) | 19 (Sat) |
| [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| No AC | No Louver | With AC | No AC | No AC | No AC | No AC |
| No Louver | Louver Opened | [ ] | [ ] | [ ] | [ ] | [ ] |
| Louver Opened | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |

20 (Sun) 21 (Mon) 22 (Tue) 23 (Wed) 24 (Thu) 25 (Fri) 26 (Sat)

| 27 (Sun) | 28 (Mon) | 29 (Tue) | 30 (Wed) | 31 (Thu) | 2/1 (Fri) | 2 (Sat) |
|----------|----------|----------|----------|----------|----------|--------|
| No AC | No Louver | With AC | No AC | No AC | No AC | No AC |
| No Louver | Louver Closed | [ ] | [ ] | [ ] | [ ] | [ ] |
| Louver Closed | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |

3 (Sun) 4 (Mon) 5 (Tue) 6 (Wed) 7 (Thu) 8 (Fri) 9 (Sat)

| 10 (Sun) | 11 (Mon) | 12 (Tue) | 13 (Wed) | 14 (Thu) | 15 (Fri) | 16 (Sat) |
|----------|----------|----------|----------|----------|----------|----------|
| No AC | No Louver | Finish | [ ] | [ ] | [ ] | [ ] |

- Pattern 2: Night ventilation on weekdays + all-day ventilation on weekends
  - Open the vertical operable vents on Monday to Friday when workers get off work (17:00). Close the
vertical operable vents on Monday to Friday when workers begin to work (7:00).

3.2. Result and analysis

3.2.1. Reducing excessive daylight by operable louvers
During both rainy season and dry season, the measurement result shows that the illuminance near the window is stable at about 1,000 lx when the operable louvers are used, regardless of whether the louvers are open or closed. It is proved that operable louvers contribute to the reduction of excessive daylight.

During the rainy season, louvers were not used on Mondays and Tuesdays, but the louvers were fully opened on Wednesday and Thursday and fully closed on Friday (Table 4). As a representative week, the results of indoor illuminance from 1/13 to 1/19 are shown in Figure 9. During the dry season, louvers are not used on 8/3 and 8/4, while the louvers are fully opened on 7/27 and 7/28 and fully closed on 8/10 and 8/11 (Table 5). The results of indoor illuminance of days noted above are shown in Figure 10.

3.2.2. Reducing indoor temperature by operable louvers
The result of rainy season measurement shows that the indoor temperature in the morning (around 7:00 am) decreased by about 1°C by using the operable louver. The results of indoor temperature from 1/13 to 1/19

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Table 5. Schedule of the dry season measurement.

|       | 6/23 (Sun) | 24 (Mon) | 25 (Tue) | 26 (Wed) | 27 (Thu) | 28 (Fri) | 29 (Sat) |
|-------|------------|----------|----------|----------|----------|----------|----------|
| No AC | No AC      | No AC    | No AC    | No AC    | No AC    | No AC    | No AC    |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| No Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents |
| Case 1 |            |          |          |          |          |          |          |
| No AC | With AC    | No AC    | No AC    | No AC    | No AC    | No AC    | No AC    |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| With Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents |
| Case 2 |            |          |          |          |          |          |          |
| No AC | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| With Vents | With Louver | With Louver | With Louver | With Louver | With Louver | With Louver | With Louver |
| Case 3 |            |          |          |          |          |          |          |
| No AC | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| With Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents |
| Case 4 |            |          |          |          |          |          |          |
| No AC | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| With Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents |
| Case 5 |            |          |          |          |          |          |          |
| No AC | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| With Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents |
| Case 6 |            |          |          |          |          |          |          |
| No AC | No AC      | No AC    | No AC    | No AC    | No AC    | No AC    | No AC    |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| With Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents |
| Case 7 |            |          |          |          |          |          |          |
| No AC | With AC    | No AC    | No AC    | No AC    | No AC    | No AC    | No AC    |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| With Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents |
| Case 8 |            |          |          |          |          |          |          |
| No AC | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| With Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents |
| Case 9 |            |          |          |          |          |          |          |
| No AC | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC    | Louver Closed | No AC |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| With Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents | With Vertical Vents |
| Case 10 |            |          |          |          |          |          |          |
| No AC | No AC      | No AC    | No AC    | No AC    | No AC    | No AC    | No AC    |
| No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver | No Louver |
| With Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents | No Vertical Vents |
| Case 11 | Finish     |          |          |          |          |          |          |
are shown in Figure 11. Besides, it was proved that the peak indoor temperature on weekends decreased by about 2°C when the louvers were used, regardless of whether the louvers were opened or closed. Louvers were not used on 1/12 and 1/13, while the louvers are fully opened on 1/19 and 1/20 and fully closed on 1/26 and 1/27 (Table 4). The results of the indoor temperature of days noted above are shown in Figure 12.

The result of dry season measurement also shows that the indoor temperature in the morning decreased by about 1°C and the peak indoor temperature on weekends decreased by about 1 to 1.5°C when the louvers were used. From 7/1 to 7/7, louvers are not used. From 7/15 to 7/21, the louvers are fully opened on weekdays and fully closed on weekends. The results of indoor temperature from 7/1 to 7/7 are shown in Figure 13 and the results of indoor temperature from 7/15 to 7/21 are shown in Figure 14. The days represented by green/purple frames are days in which the outside air temperature and the solar radiation were close.

In addition, when the operable louvers were used, the heat flow through window glass was reduced to about half when the louvers were opened and to about 1/4 when the louvers were closed. Measurement results of Heat flow before/after the operable louvers were used are shown in Figure 15. The combination of operable louvers and thermal insulation improvement had a significant effect on reducing the cooling load of the perimeter zone.
3.2.3. Reducing indoor temperature by vertical operable vents

The measurement result shows that the night ventilation by vertical operable vents lowered the indoor temperature in the next morning (around 7:00 am) by about 1°C to 2°C and reduced the cooling startup peak, defined as the total cooling load from 7:00 am to 8:00 am, by 15% to 20%.

From 7/1 to 7/7, the vertical operable vents were closed (no ventilation) on weekdays and the vertical operable vents were opened (ventilated all days) on the weekend. From 7/29 to 8/4, the vertical operable vents were opened only during the night (ventilated at night) on weekdays and the vertical operable vents were closed (no ventilation) on weekends. Indoor temperature and cooling startup peak from 7/1 to 7/7 are
shown in Figures 16 and 18; that from 7/29 to 8/4 is shown in Figures 17 and 19.

### 3.2.4. Highlights and problems

In terms of daylight environment, the measurement result clearly shows that the shading effect of operable louvers can effectively reduce the excessive daylight, regardless of whether the louvers are open or closed. On the other hand, in terms of thermal environment, the measurement result shows that the operable louvers effectively cut the heat flow through window glass, and the night ventilation by vertical operable vents lowered the indoor temperature in the next morning and reduced the cooling startup peak.

However, the effect of night ventilation is not reflected as obvious as the shading effect of operable louvers by the measurement result, for two reasons: (1) high outdoor temperature at night, (2) low building airtightness (high infiltration rate), which results in the outdoor hot airflow into the room quickly during the daytime, reducing the effect of night ventilation. To confirm this assumption, an airtightness test simulation will be run, which is aimed to clarify the influence of building airtightness on annual cooling load. (Ch 4.4.5 The influence of building airtightness).
Figure 14. Indoor temperature from 7/15 to 7/22.

Heat flow without the operable louvers (15:00)
Heat flow with the operable louvers opened (15:00)

Figure 15. Heat flow before/after the operable louvers were used.

Figure 16. Indoor temperature from 7/1 to 7/7.

Figure 17. Indoor temperature from 7/29 to 8/4.
4. Simulation setting and result analysis

4.1. Brief introduction

This simulation is aimed to find out the effects of thermal insulation improvement, operable louvers and vertical operable vents on reducing cooling load throughout a year. The simulation was carried out by EnergyPlus V8.9.0, using revised weather data (Ch 4.2 Weather Data). The energy analytic models are built with grasshopper for rhino, using Ladybug and Honeybee plugins (Figure 20). Construction settings were done by using the data in Table 2. The infiltration rate was set to 2 air changes per hour, according to the result of the airtightness measurement in the office room. Schedules of internal heat gains, including occupancy, lighting and equipment, are shown in Figure 21. Air conditioning is on from 7:00 to 17:00 on weekdays. The cooling setpoint temperature is 24°C and the dehumidification setpoint is 50% relative humidity.

To find out the effects of thermal insulation, operable louvers and vertical operable vents separately, 8 cases were simulated. The setting of each case is shown in Table 6. The Outputs of the simulation include: (1) non-air-conditioned indoor temperature, (2) air-conditioned indoor temperature, (3) Sensitive cooling load, and (4) Latent cooling load.

4.2. Weather data

4.2.1. Measurement of weather data

The weather station for measuring the weather data around the case study building is located at 6°13’16.7”S 106°34’4.5”E (Figure 22). The weather station is equipped with the following sensors: Temperature, Dew Point and Relative Humidity sensor (S-THB-M002) with radiation shield, wind sensor set (S-WSET-B), barometric pressure sensor (S-BPB-CM50), and solar radiation sensor (S-LIB-M003), as shown in Figure 23. Sensor details are introduced in the web pages of HOBO Weather Station.

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![Figure 18](image1.png)

**Figure 18.** Cooling startup peak from 7/1 to 7/7.

![Figure 19](image2.png)

**Figure 19.** Cooling startup peak from 7/29 to 8/4.

![Figure 20](image3.png)

**Figure 20.** Energy analytic models: before renovation (Left) after renovation (Right).
Besides, because the weather station is located far from the case, an additional sensor was added to measure outdoor air temperature at the side entrance of the building (T-OUT). A temperature and humidity sensor (TR-72-nw-S) equipped with a radiation shield and fan was used, as shown in Figure 22.

**Figure 21.** Schedules of internal heat gains.

**Table 6.** Case setting.

| Case  | Thermal insulation improvement | Operable louvers | Vertical operable vents |
|-------|--------------------------------|-----------------|------------------------|
| Case 1 | (Before renovation)            |                 |                        |
| Case 2 | √                              |                 |                        |
| Case 3 | √                              | Always opened   |                        |
| Case 3_a| √                              | Always opened   | Pattern 1 a\(^1\) ACH-v = 1 \(^2\) \(\text{ACH-v} = 5\) |
| Case 3_b| √                              | Always opened   | Pattern 1 ACH-v        |
| Case 4 | √                              | Weekday opened  | Pattern 2 ACH-v        |
| Case 4_a| √                              | Weekday opened  | Pattern 2 ACH-v        |
| Case 4_b| √                              | Weekday opened  | Pattern 2 ACH-v        |

\(a^1\) Pattern 1 & Pattern 2 refer to natural ventilation patterns introduced in Ch 3.1 Measurement Plan.

\(a^2\) ACH-v refers to air changes per hour by ventilation.
The data were recorded at 2-minute intervals. The measurement results of dry bulb temperature (T-OUT), dew point temperature, relative humidity and global solar radiation are referenced for revising the weather data used in the simulation.

4.2.2. Revised weather data

The revised weather data used for this simulation was based on annual weather data in Tangerang in 2005. To take weather changes and the urban heat island phenomenon into account, temperature, relative humidity and solar radiation were modified according to the result of site measurements in 2019.

- Modification of dry bulb temperature

While maintaining the dew point temperature (absolute humidity), the dry bulb temperature was raised overall by 3°C. The data in measurement periods (from 1/12 to 2/11 and 6/27 to 8/12) was rewritten by T-out, the measurement result of outdoor temperature. (Figure 25)

- Modification of relative humidity

Relative humidity decreased with modification of dry-bulb temperature. The data in measurement periods (from 1/12 to 2/11 and 6/27 to 8/12) was rewritten by RH-out, the measurement result of relative humidity. (Figure 26)

- Modification of solar radiation

In the dry season (from May to October), the total solar radiation was modified to 0.725 times of original data. In the rainy season (from November to April), the total solar radiation was modified to 0.47 times of original data. The data in measurement periods (from 1/12 to 2/11 and 6/27 to 8/12) was rewritten by GSR-out, the measurement result of global solar radiation. (Figure 27)

The revised weather data has higher outdoor temperature, lower relative humidity and lower solar radiation throughout the year than the original annual weather data in Tangerang in 2005. It reflects the effects of the location of the site, weather changes the urban heat island phenomenon. It is expected that the modification of weather data would reduce the effects of natural ventilation and shading and would reduce the latent heat load of air conditioning.
4.3. Comparison with measurement data

To confirm that the simulation can evaluate the performance of passive design strategies accurately, the results of the simulation were compared with the measured data under the same conditions.

- Condition 1: Without operable louvers and vertical operable vents (Figure 28).
- Condition 2: The operable louvers are fully open on weekdays and fully closed on weekends. The natural ventilation is controlled following Pattern 2 (Ch 3.1 Measurement Plan) (Figure 29).

Since the error is generally within 1°C, it is acknowledged that the simulation can evaluate the performance of passive design strategies accurately.

4.4. Result analysis

4.4.1. The effect of thermal insulation improvement

In this chapter, the results of Case 1 and Case 2 will be compared to show the effect of thermal insulation improvement. The result of non-air-conditioned indoor temperature shows that the thermal insulation improvement of the skin can reduce daily fluctuations.
of the temperature (Figure 30). The result of air-conditioned indoor temperature shows that the indoor temperature peaks after air conditioning is stopped are reduced on weekdays and the indoor temperature peaks at noon are reduced on weekends (Figure 31). Besides, the annual cooling load is also reduced by 7.4% (sensible cooling load is reduced by 13.8%) due to the improvement of skin thermal insulation (Figure 36). The obvious reduction in annual cooling load makes it clear that it is important to ensure good thermal insulation not only in cold regions but also in hot and humid regions.

4.4.2. The effect of operable louvers

In this chapter, the results of Case 2, Case 3 and Case 4 will be compared to show the effect of operable louvers. The result of non-air-conditioned indoor temperature shows that operable louvers can reduce the indoor temperature peaks (Figure 32). The result of air-conditioned indoor temperature shows that the indoor temperature peaks are reduced on weekends (Figure 33). Keeping louvers closed is more effective than keeping louvers open to reduce the indoor temperature peaks. Besides, combined with thermal insulation improvement, operable louvers can reduce the annual cooling load by a maximum of
8.1% (sensible cooling load is reduced by 15.0%) (Figure 36).

However, while focusing on the effect of operable louvers alone, the reduction in annual cooling load is not much obvious. The low solar radiation in Indonesia, which is shown by the measurement data (Figure 27), leads to little cooling effect from shading.
4.4.3. The effect of vertical operable vents

In this chapter, the results of Case 4, Case 4_a, and Case 4_b will be compared to show the effect of vertical operable vents. The result of non-air-conditioned indoor temperature shows that natural ventilation by vertical operable vents can reduce the indoor temperature during the night, which slightly reduces daytime peak temperature (Figure 34). The result of air-conditioned indoor temperature also shows that natural ventilation by vertical operable vents can reduce the indoor temperature during the night and the indoor temperature in the morning (around 7:00 am) decreases (Figure 35). Raising the air change rate can improve the effectiveness of natural ventilation on reducing indoor temperature. Besides, combined with thermal insulation improvement and operable louvers, natural ventilation by vertical operable vents can reduce the annual cooling load by a maximum of 8.4% (sensible cooling load is reduced by 15.5%) (Figure 36).

However, the effect of natural ventilation by vertical operable vents on reducing annual cooling load is not much obvious, for two reasons: (1) high outdoor temperature at night, (2) low building airtightness (high infiltration rate). It is consistent with the earlier measurement results (Ch 3.2.4 Highlights and problems).

4.4.4. The influence of operation pattern

Comparing the annual cooling load results of the last six cases, it is shown that the operating pattern of louvers and vertical operable vents, which is related

![Figure 34. Non-air-conditioned indoor temperature (case 4, case 4_a, case 4_b, T-out).](image)

![Figure 35. Air-conditioned indoor temperature (case 4, case 4_a, case 4_b, T-out).](image)

![Figure 36. Annual cooling load of each case.](image)
4.4.5. The influence of building airtightness

Low building airtightness is considered to be one of the reasons for the low effect of night ventilation by vertical operable vents, mentioned in chapter above (Ch 3.2.4 Highlights and problems & Ch 4.4.3 The effect of vertical operable vents). Therefore, an airtightness test will be introduced in this chapter to show the influence of building airtightness on annual cooling load. The setting of each case is shown in Table 7. Case A is the same as the Case4 in the simulation above, and Case C is the same as the Case4_b, which means Case A and Case C have the same airtightness level as the actual office room, too. Case B and Case D have higher airtightness levels, whose infiltration rates are 1/4 of that of the actual office room.

The result of the airtightness test is shown in Figure 37. Comparing Case A and Case B, the annual cooling load is reduced by 47.5%, which clarifies that improving the airtightness of the air-conditioned room has a great effect on reducing the cooling load. Besides, a higher airtightness level can also lead to better effect of natural ventilation. Under the same ventilation conditions, the annual cooling load of the high airtightness room is reduced by 5.4%, while that of low airtightness room is only 0.2%.

5. Conclusion

In this paper, the effect of improving thermal insulation, natural ventilation and solar shading on reducing cooling load, lowering the indoor temperature and attaining a good daylight environment are evaluated using both measurement and simulation methods in an office in Tangerang, Indonesia.

In terms of daylight environment, the measurement result clearly shows that the shading effect of operable louvers can effectively reduce the excessive daylight caused by direct light, regardless of whether the louvers are open or closed.

In terms of thermal environment, the measurement result shows that the indoor temperature can be reduced by both shading and natural ventilation. The indoor temperature in the morning decreased obviously by the night ventilation and the peak indoor temperature on weekends decreased by the shading effect of operable louvers particularly. The result of the simulation, including indoor temperature and cooling load, also validates the same effect of shading and natural ventilation on lowering the indoor temperature and reducing the cooling load. Besides, thermal insulation improvement obviously reduced the annual cooling load, which shows that it is important to ensure good thermal insulation in hot and humid regions, too.

Due to the hot and humid climate in Southeast Asian countries, it is common to cool a building throughout a year, so the reduction of cooling load should be the main aim of passive design. However, according to the simulation result, the effect of shading by operable louvers and natural ventilation by vertical operable vents on reducing annual cooling load is small when the building airtightness is low. To achieve better effect of shading

| Table 7. Case setting (airtightness test). |
|------------------------------------------|
| Case | Thermal insulation improvement | Operable louvers | Vertical operable vents | Airtightness Level |
| A    | ✓                             | Weekday opened  | Low (ACH-i = 2 a^-3)   |
| B    | ✓                             | Weekday opened  | High (ACH-i = 0.5)     |
| C    | ✓                             | Weekday opened  | Pattern 2 ACH-v = 5    |
| D    | ✓                             | Weekday opened  | Pattern 2 ACH-v = 5    |

\(a^-3\) ACH-i refers to air changes per hour by infiltration.

![Figure 37. Annual cooling load of each case (airtightness test).](image-url)
and natural ventilation, it is necessary to improve thermal insulation and reduce the unintentional introduction of outside air, which can reduce daily fluctuations of indoor temperature and prevent outdoor hot air flow into the room during the daytime.

This case study shows that, in hot and humid regions, there would also be a large potential if passive design strategies are applied appropriately and good performance of the building, including high airtightness and proper thermal insulation, is guaranteed.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**References**

Aktacir, M. A., O. Büyükalaca, and T. Yilmaz. 2010. "A Case Study for Influence of Building Thermal Insulation on Cooling Load and Air-conditioning System in the Hot and Humid Regions." *Applied Energy* 87: 599–607.

Alhuwayl, W. K., M. A. Mugeebu, and A. M. M. Algaryn. 2019. "Impact of External Shading Strategy on Energy Performance of Multi-Story Hotel Building in Hot-humid Climate." *Energy* 169: 1166–1174.

Chiararatananon, S., and V. D. Hienc. 2011. "Thermal Performance and Cost Effectiveness of Massive Walls under Thai Climate." *Energy and Buildings* 43: 1655–1662.

Day, J. K., B. Futrell, S. N. Robert Cox, A. A. Ruiz, A. H. Zarrabi, and M. Azarbayjani. 2019. “Blinded by the Light: Occupant Perceptions and Visual Comfort Assessments of Three Dynamic Daylight Control Systems and Shading Strategies.” *Building and Environment* 154: 107–121.

Doan, V. Q., and H. Kusaka. 2018. "Projections of Urban Climate in the 2050s in a Fast-growing City in Southeast Asia: The Greater Ho Chi Minh City Metropolitan Area, Vietnam." *International Journal of Climatology* 38 (11): 4155–4171.

Freewan, A. A. Y. 2014. "Impact of External Shading Devices on Thermal and Daylighting Performance of Offices in Hot Climate Regions." *Solar Energy* 102: P.14–30.

Hernández, F. F., J. M. C. López, J. M. P. Suárez, M. Carmen González Muriano, and S. C. Rueda. 2017. "Effects of Louvers Shading Devices on Visual Comfort and Energy Demand of an Office Building. A Case of Study." *Energy Procedia* 140: 207–216.

Hirano, T., S. Kato, S. Murakami, T. Ikaga, and Y. Shiraiishi. 2006. "A study on a porous residential building model in hot and humid regions: Part 1—the natural ventilation performance and the cooling load reduction effect of the building model." *Building and Environment* 41: 21–32.

Introduction page of HOBO Weather Station Kits. [https://www.onsetcomp.com/support/application_solutions/weather-station-kits](https://www.onsetcomp.com/support/application_solutions/weather-station-kits)

Katili, A., R. Boukhanouf, and R. Wilson. 2015. “Space Cooling in Buildings in Hot and Humid Climates – A Review of the Effect of Humidity on the Applicability of Existing Cooling Techniques.” 14th International Conference on Sustainable Energy Technologies – SET 2015 25th - 27th of August 2015, Nottingham, UK.

Keiko, M., Y. Yuki, W. Satoshi, and T. Hiroto. 2012. “Research On Mitigation Methods Of Energy Consumption Increase Of Cambodian Houses: Proposal OF ENERGY Conservation Model Houses .” *Journal of Environmental Engineering, Architectural Institute of Japan* 77 (673): 193–202.

Kubota, T., and D. R. Ossen. 2010. “A Field Measurement of Temperature Distribution in Johor Bahr, Malaysia: A Preliminary Study of Mitigation Measures for Urban Heat Island in the Tropics, Summaries of Technical Papers of Annual Meeting." *Architectural Institute of Japan* D1: 919–920.

Kwong, Q. J., N. M. Adam, and B. B. Sahani. 2014. "Thermal Comfort Assessment and Potential for Energy Efficiency Enhancement in Modern Tropical Buildings: A Review." *Energy and Buildings* 68: 547–557.

Lau, A. K. K., E. Salleh, C. H. Lim, and M. Y. Sulaiman. 2016. “Potential of Shading Devices and Glazing Configurations on Cooling Energy Savings for High-rise Office Buildings in Hot-humid Climates: The Case of Malaysia.” *International Journal of Sustainable Built Environment* 5 (2): 387–399.

Lee, H. S., A. R. Trihamdani, T. Kubota, S. Iizuka, and T. T. T. Phuong. 2017. "Impacts of Land Use Changes from the Hanoi Master Plan 2030 on Urban Heat Islands: Part 2. Influence of Global Warming." *Sustainable Cities and Society* 31: 95–108.

Minahimi, S., M. F. Mohamed, L. C. Haw, N. L. N. Ibrahim, W. F. M. Yusoff, and A. Afkai. 2016. "The Effect of Building Envelope on the Thermal Comfort and Energy Saving for High-rise Buildings in Hot-humid Climate." *Renewable and Sustainable Energy Reviews* 53: 1508–1519.

Nam, T. H. H., T. Kubota, and A. R. Trihamdani. 2015. “Impact of Urban Heat Island under the Hanoi Master Plan 2030 on Cooling Loads in Residential Buildings.” *International Journal of Built Environment and Sustainability, IJUBES* 2 (1): 48–61.

Setyawon, D. 2014. “Formulating Revolving Fund Scheme to Support Energy Efficiency Projects in Indonesia.” *Energy Procedia* 47: 37–46.

Susumu, S., Y. Satoshi, and K. Tetsu; Doris Hooi Chyeen TOE. 2015. “Effectiveness Of Energy-Saving Renovation Techniques Through Passive Cooling For Urban Houses In Hot-Humid Climate Of Malaysia.” *Journal of Environmental Engineering* 80 (714): 673–683.

Tetsu, K., and H. Doris Toe. 2009. “The Effectiveness Of Night Ventilation Technique For Residential Buildings In Hot-Humid Climate Of Malaysia.” *Journal of Environmental Engineering* 74 (635): 89–95.

Uno, T., S. Hokoi, S. N. N. Eksawi, and N. H. A. Majid. 2012. “Reduction of Energy Consumption by AC Due to Air Tightness and Ventilation Strategy in Residences in Hot and Humid Climates.” *Journal of Asian Architecture and Building Engineering* 11 (2): 407–414.

Yueer, H., M. Liu, T. Kvan, and S. Peng. 2017. “An Enthalpy-based Energy Savings Estimation Method Targeting Thermal Comfort Level in Naturally Ventilated Buildings in Hot-humid Summer Zones.” *Applied Energy* 187: 717–731.