Indoor thermal environment in tropical archipelago city

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Abstract. This study aims to evaluate the indoor thermal comfort of the office building in the tropical archipelago city of Ternate, Indonesia. Survey and data collection were performed using several instruments, LSI-LASTEM Thermal Comfort Multi Logger, HOBO data logger, and HOBO data logger with the external sensor for measuring temperature, relative humidity, and wind velocity. At the time of measurement, thermal condition perceived by respondents is observed by the questionnaires of Thermal Comfort Vote (TCV) and Thermal Sensation Vote (TSV). TSV is performed by ASHRAE standard 55 and TCV from Bedford scale. The results show that indoor thermal condition is in uncomfortable level with the average temperature exceeds 29°C, RH is more than 70%, and wind velocity is lower than 0.5 m/s. More than 60% employees feel warm condition in TCV and TSV scales, but a majority of them (67%) still accept these conditions. It indicates that the employees in tropical archipelago city are quite tolerant to high temperatures. About 59% of respondents feel wind velocity is uncomfortable and 70% respondents expect to increase of wind velocity. Therefore, the new design concepts are needed to improve natural ventilation performance by combining cross ventilation with clerestory ventilation systems and planting trees around the building to reduce solar heat gain that penetrates to the building’s interior.

Keywords: micro climate, thermal comfort, natural ventilation, office building

1. Introduction
Air temperatures are increasing throughout the world due to the increase of CO\textsubscript{2} emission in the atmosphere, especially in metropolitan cities, as the consequence of exhaust gas from industry, motor vehicle, and alteration of land surface characteristics from natural elements to artificial ones such as asphalt, concrete and steel. The increase of CO\textsubscript{2} in the atmosphere causes an urban heat island effect and climate change. Increasing outdoor temperatures strongly affect indoor temperatures, making it hard to achieve thermal comfort and causing the increased use of air conditioner (AC). Utilization of AC significantly affects the increase of energy consumption in the building. The building sector consumes almost one-third of energy from global energy consumption and is an equally important source of CO\textsubscript{2} emissions [1]. Building sector contributes up to 30\% of global annual greenhouse gas emissions and consumes up to 40\% of all energy, both in developed and developing countries [2].

The ISO 7730 standard defines thermal comfort as the condition of mind, which expresses satisfaction with the thermal environment [3] (ISO, 1995). Indoor thermal comfort affects the employees’ work productivity. According to the Lawrence Berkeley National Laboratory, work productivity increases 7-13\% in buildings with the better air quality and 15 - 50 \% in buildings with the better sunlight quality [4]. Thus, improving indoor thermal comfort is very important especially by applying natural ventilation and natural lighting strategies.
Utilization of natural ventilation has been successful in many buildings in America such as school buildings, hospitals, supermarkets, offices, warehouses with the following advantages: energy efficiency, improving indoor environmental quality, lower energy equipment costs, lower maintenance costs and replacement of conditioning equipment air and electricity, enhanced thermal comfort, and integrated with natural lighting. Research results in the United States show that a naturally ventilated office building consumes less than half the energy consumed by buildings using AC [5]. Therefore, this paper will discuss indoor thermal performance on the office building in the Archipelago City of Ternate.

2. Methods
This research is focused to evaluate the indoor thermal comfort of several office buildings in Ternate City (archipelago city) by using several instruments, LSI-LASTEM Thermal Comfort Multi Logger, HOBO data logger, and HOBO data logger with external sensor for measuring temperature, relative humidity, and wind velocity. At the time of measurement, thermal condition perceived by respondents is observed by the questionnaires of Thermal Comfort Vote (TCV) and Thermal Sensation Vote (TSV). TSV is performed by ASHRAE standard 55 [6], which consist of seven scales: hot (+3), warm (+2), slightly warm (+1), neutral (0), slightly cool (-1), cool (-2), and cold (-3), and also TCV is measured by seven categories from Bedford scale [7]: much too warm (+3), too warm (+2), comfortably warm (+1), comfortable (0), comfortably cool (-1), too cool (-2), and much too cool (-3). Besides, respondents were also asked their opinions about the thermal preference and thermal acceptance whether the thermal environment was acceptable or unacceptable.

![Figure 1. Five office buildings for the research objects.](image)

3. Discussion
3.1. Climate condition of Ternate Island
Ternate is a small island in the North Maluku (Moluccas Island) and dominated by the area of volcanic mountain Gamalama with high reaches 1715 m. The population is fewer than 200,000 in the area of 111.39 km² [8-9]. Ternate City is an archipelago region characterized by a tropical climate with the annual average temperature is around 24-32°C, Humidity is around 77 – 83%, Wind speed is about 7 – 10 km/h, and precipitation is generally exceeded of 120 mm, except during August until October is very low of around 60-90 mm. The highest precipitation occurs on May (about 200 mm), and the lowest occurs in September (around 60 mm) (see Table 1). This condition portrays that based on
annual weather averages; the temperature is not too high because rain occurs every month with different frequency or there is no summer season. However, based on the daily weather distribution especially on sunny days, the weather condition is very hot with the high temperature is up to 37°C. In this case, outdoor temperature can cause the rising of indoor temperature and application natural ventilation is very difficult to reduce temperature until comfortable level. Therefore, the new design concept is needed to improve natural ventilation performance in the building.

### Table 1. Annual weather averages in Ternate during 2005–2015 [10].

|                          | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| High Temp (°C)           | 30  | 31  | 31  | 31  | 31  | 31  | 31  | 31  | 32  | 31  | 31  | 31  |
| Low Temp (°C)            | 24  | 24  | 24  | 24  | 24  | 24  | 24  | 24  | 24  | 24  | 24  | 24  |
| Mean Temp (°C)           | 27  | 27  | 28  | 28  | 28  | 28  | 27  | 27  | 27  | 28  | 28  | 28  |
| Humidity Ave (%)         | 83  | 82  | 81  | 82  | 81  | 78  | 77  | 78  | 78  | 82  | 83  |     |
| Wind Ave (km/h)          | 10  | 10  | 10  | 8   | 7   | 7   | 8   | 8   | 8   | 7   | 8   |     |
| Precipitation (mm)       | 160 | 122 | 126 | 147 | 200 | 176 | 120 | 92  | 63  | 69  | 153 | 142 |

#### 3.2. Indoor thermal performance

In Ternate City, energy resources are insufficient. It is only produces by diesel power plant, while the demand for energy keeps increasing primarily because new buildings are constructed. Based on the field observation, a cooling system in the building is generally using air conditioning. It causes the increasing of energy consumption in the building so that the supply of energy is not enough and power outages are done every day in rotation. This condition can influence the ventilation system and thermal performance in building especially in the office building.

### Table 2. Indoor thermal condition [12].

| Thermal Condition | Basarnas | Parawisata | Balaikota | Diknas | PU |
|-------------------|----------|------------|-----------|--------|----|
| Temperature (°C)  | 29.10    | 29.24      | 29.00     | 30.86  | 30.61 |
| RH (%)            | 69.62    | 70.87      | 70.38     | 76.41  | 75.58 |
| Wind Speed (m/s)  | 0.13     | 0.23       | 0.20      | 0.26   | 0.26 |

Table 2 portrays that the average temperature exceeds 29°C, relative humidity (RH) average is around 70 – 76% and wind speed is deficient of about 0 – 0.3 m/s. It indicates that the thermal condition in the office building is uncomfortable. The standard of thermal comfort in a hot-humid tropic area is around 24-26°C, relative humidity: 40-60%, wind velocity: 0.6 -1.5 m/s with the activity of relaxed and a thin dress [11].

Table 3 shows that thermal sensations felt by employees in office buildings during daytime of about 6% cool, 13% slightly cool, 15% neutral, 37% slightly warm, 19% warm, and 11% hot. Those conditions portray that only 15% employees felt comfortable and 85% uncomfortable; about 19% under comfortable level (-3 until -1) and 67% above comfortable level (+1 until +3). This condition can cause the increasing use of air conditioning (AC), which has an impact on the increase in energy consumption, while the energy resources are insufficient. On the other hand, it produces CO₂ emissions during its combustion process. CO₂ in large amounts is the primary cause of the global warming.

### Table 3. Thermal sensation votes (TSV).

| Thermal Condition | Basarnas | Parawisata | Balaikota | Diknas | PU |
|-------------------|----------|------------|-----------|--------|----|
cold               | 0        | 0          | 0         | 0      | 0  |
cool               | 0        | 0          | 17        | 8      | 0  |
Table 4 shows the thermal comfort felt by employees in which more than 60% of employees feel warm condition in the Bedford scale (TCV). This condition is similar to the ASHRAE level (TSV). These state that employees are generally working under uncomfortable conditions. An office which is too warm makes its occupants feel tired and one that is too cold causes the occupants' attention drifted, making them restless and easily distracted. Even, a minor deviation from comfort affects the stress, performance and safety. Workers already under stress are less tolerant of uncomfortable conditions. Thus, indoor thermal conditions are necessary to decrease until the comfortable level in order to improve work productivity.

Table 4. Thermal comfort vote (TCV).

| Thermal Condition      | Basarnas | Parawisata | Balaikota | Diknas | PU |
|------------------------|----------|------------|-----------|--------|----|
| much too cool          | 0        | 0          | 0         | 0      | 0  |
| too cool               | 0        | 0          | 17        | 0      | 0  |
| comfortably cool       | 17       | 0          | 17        | 17     | 17 |
| Comfortable            | 17       | 0          | 17        | 17     | 8  |
| comfortably warm       | 33       | 67         | 25        | 33     | 50 |
| too warm               | 8        | 33         | 17        | 17     | 17 |
| much too warm          | 25       | 0          | 8         | 17     | 8  |

| Total (%)              | 100      | 100        | 100       | 100    | 100 |

Source: Analyze 2018

Figure 2 indicates that the majority of respondents (69%) expect to decrease the temperature in the office building until the comfort level, and only 31% feel comfort. Although the thermal conditions are above the comfort level, a majority of them (67%) can still accept these conditions to work in the room. Only about 31% cannot accept the condition. Differences of respondent perception indicate that everyone is different in responding the thermal conditions. It may be due to habits of life in warmer conditions.

The average of relative humidity is generally above 70% (see Table 1). It means that the relative humidity is high and less comfortable. Relative humidity comfort is around 30-60%. Humidity vote portrays that around 60% of respondents felt dry conditions, only 32% felt comfort and 8% for slightly
humid (see Figure 3). This condition can influence work productivity; high humidity can lead to a feeling of discomfort because high humidity disrupts one of the main ways our body regulates its temperature: sweat. In case the condition is too hot, the body secretes water on the skin’s surface. The water cools in the breeze and lowers the temperature of the skin, but when the humidity level is close enough to the condensation point, sweating loses its cooling effect. Moreover, high humidity levels can lead to health effects.

Figure 3. Employees’ response to the air humidity.

3.3. Wind velocity and natural ventilation performance

Wind velocity in archipelago region such as Ternate is sufficient for the application of natural ventilation. Several previous studies suggest that natural ventilation is effective to reduce the building’s temperature. For example, in Sultan Ternate Mosque, natural ventilation is used by combining clerestory ventilation and cross ventilation systems. The indoor thermal conditions can reach a comfortable level [13]. It indicates that the application of natural ventilation in the archipelago city of Ternate is effective to achieve comfort thermal level and minimize the energy consumption in offices building.

However, measurement results suggest that the wind velocity in the office building is very low. It is lower than 0.5 m/s. Based on the velocity vote, only 11% of respondents feel comfortable, 32% for slight breeze, and around 59% feel wind velocity is very low (slightly still until much too still scale). Thus, wind velocity it is necessary to increase. About 70% of respondents expect the increase of wind velocity. Moreover, only 26% feel comfortable (see Figure 4). The distribution of air flow causes air velocity into the room not covered the entire room, so that employee sitting near the window feels comfortable. It indicates that cross ventilation system is not enough to circulate air fresh into the room due to the dimension or orientation of ventilation is not suitable to the standard. On the other hand, office buildings in Ternate City are generally designed for the usage of air conditioner, so that the natural ventilation strategy is not adopt effectively. In the application of natural ventilation, the sufficient wind speed is needed to increase air circulation in the building. Cross ventilation and stack effect can increase it.

Figure 4. Wind velocity preference and acceptance of employees.

For increasing wind velocity, it is necessary to maximise the cross ventilation system, but keep in mind that Ternate Island is covered by an active volcano of Gamalama, which may emit hot dust and
have a negative impact to the application of natural ventilation due to the dust pollution. Therefore, the strategy of the ventilation system in Ternate Island is should use a combination of natural ventilation and with a mechanical system. Natural ventilation is operated by the combination system between cross ventilation with open-closed ventilation systems. In normal condition, cross ventilation or open ventilation system is used, and if the eruption occurs, the natural ventilation is closed, and air conditioner can be used for preventing dust pollution into the room.

Furthermore, Outdoor temperatures are determined by land surface condition. Land surface characteristics, building materials, vegetation, water, and human activities have important effects on microclimate changes. Vegetation and water are useful means for improving microclimatic conditions [14-15]. Effect of climate change can be reduced by improving land cover, reducing anthropogenic heat, and increasing local wind circulation [16]. The proper placement of trees decreases hot temperature and then reducing air conditioning loads by 30% [17]. Vegetation is effective to decrease temperatures in the urban area so that buildings near from vegetation have lower surface temperature than those of buildings are distant from plants. Therefore, in addition to improving the natural ventilation system, mitigation of land cover or landscape arrangement around buildings is very useful to improve thermal comfort in the building.

4. Conclusion
The indoor thermal condition is uncomfortable level with the average temperature exceeds 29°C; Relative Humidity is over 70%; where more than 60% of employees feel warm condition in TCV and TSV scales. However, the majority of them (67%) still accept these conditions to work in the room. It indicates that the employees in a tropical archipelago city are quite tolerant to high temperatures due to their habits of life in warmer conditions.

Wind velocity is lower than 0.5 m/s. About 59% of respondents feel wind velocity uncomfortable and 70% respondents expect to increase of wind velocity, portrays that cross ventilation system is not enough to circulate air fresh into the room because their orientation and dimension are minimal or not suitable standard, so that natural ventilation is necessary to improve by combining cross ventilation (open-closed systems) with clerestory ventilation systems, and planting trees around the building to reduce solar heat gain that penetrates to the interior of the building.

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