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# Outdoor thermal performance simulation in campus area during the dry season, Yogyakarta

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**Abstract:** The outdoor thermal performance reflects the microclimate condition in any significant area. This study simulated the thermal performance with measured and modeled three meteorological parameters, air temperature (Ta), relative humidity (RH), and wind speed in the dry season tropical city. The research focused on thermal performance simulation and distribution. Here, we disregarded anthropogenic activities as the heat source. The result showed that there were different ranges between a measured and simulated value of Ta, RH, and wind speed. The highest Ta difference between measure and simulation occurred at 11 AM, which was 1.97°C. The highest difference of RH occurred at 13 PM (26.75%), and the highest difference of wind speed was at 11 AM (0.37 m/s) respectively. The heat distribution in the focus area was influenced by the solar direction which impacted on the ground and near-surface air temperature.

**Keywords:** *thermal performance; air temperature; relative humidity; wind speed; microclimate*

## 1. Introduction

Anthropogenic activities have an important role in the outdoor thermal environment. Thermal comfort is defined as an individual ability to express thermal situation called thermal environment. The thermal environment is an environment characteristic which causes individual energy loss [1]. There are two types of thermal comfort, indoor and outdoor. Each has its own characteristics based on the result impacted. Indoor thermal comfort is affected by building materials, shape, ventilation, or width [2]. Outdoor thermal comfort is a thermal sensation in the human body caused by temperature stimulation [3][4]. Outdoor thermal comfort is closely related with eco-urban planning since it has connectivity with urban climatology (air temperature, air humidity, wind speed, and solar radiation) [5][6], land coverage, evaporation and evapotranspiration, building and vegetation shading, and human activities [7].
There are various researches to evaluate outdoor thermal comfort, i.e., the Predicted Mean Vote (PMV), Physiological Equivalent Temperature (PET), Standard Effective Temperature (SET), Outdoor Standard Effective Temperature (OUT_SET), and Universal Thermal Climate Index (UTCI)[8][9][10]. PMV is calculated based on a large group of people thermal sensation and unsuitable for evaluating outdoor thermal comfort. PET and SET are analyzed based on the human energy balance and integrate the effects of air temperature (Ta), vapor pressure (VP) (or

relative humidity (RH), mean radiant temperature (Tmrt) and airspeed (*v*) [11][4]. In order to investigate outdoor thermal comfort, a lot of researches suggest UTCI since it has high sensitivity on ambient stimuli and temporal local temperature changes[12]. The present study aims to simulate the outdoor thermal performance of built environment located in Universitas Gadjah Mada, Yogyakarta during the dry season at daytime.

## 2. Methods

### *Model preparation*

To simulate the model, we used an ENVI-met lite with 2 m x 2 m for each grid cell based on the smallest building distance in existing areas. Totally, we had 60 grids X and 120 grids Y.

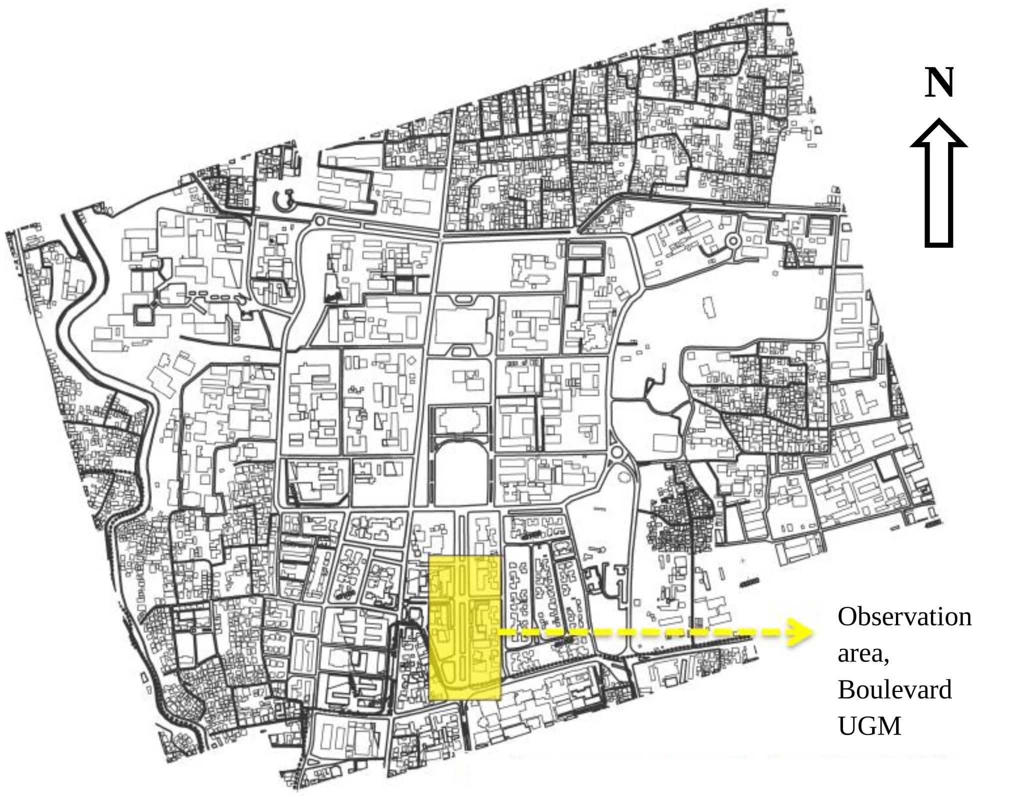


**Fig. 1**. Universitas Gadjah Mada, Yogyakarta, campus map

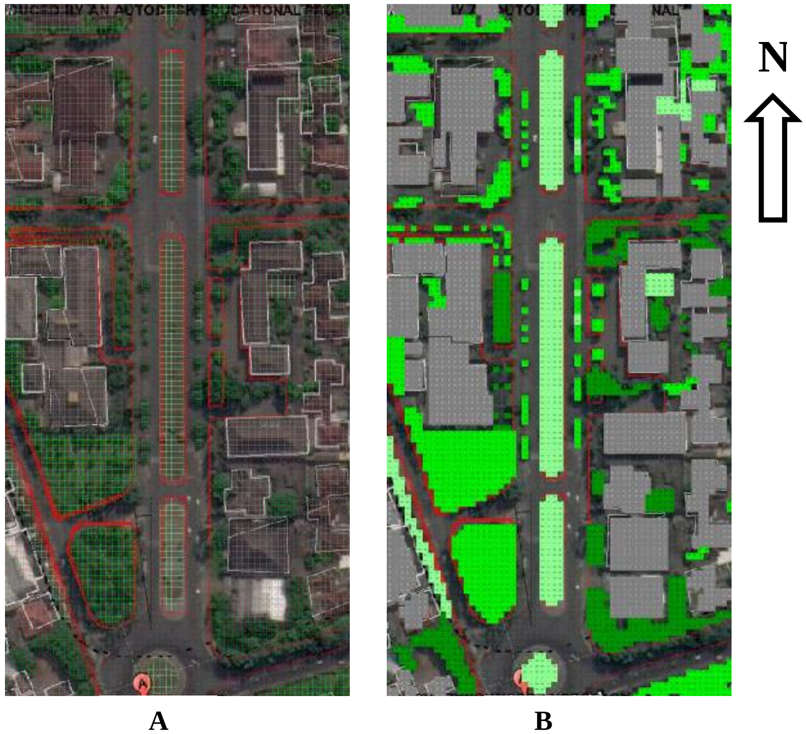


**Fig. 2.** Selected buildings and vegetations in the observation area based on google earth (A). Building and vegetation model preparation in Envi-met lite version (B).

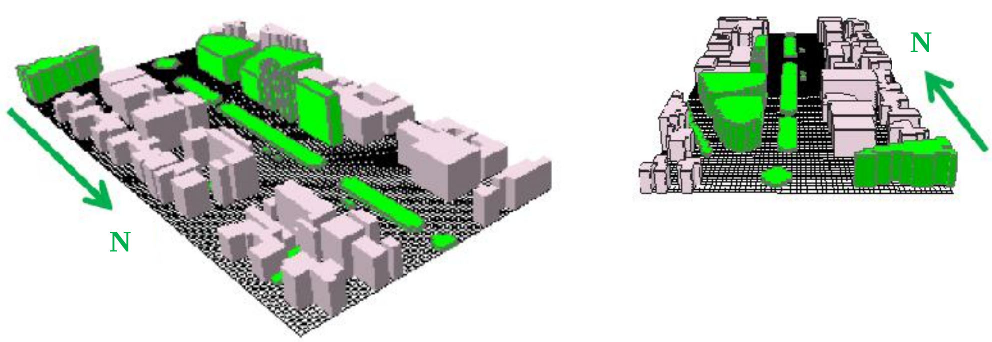


**Fig. 3**. 3D model on the observation area using Envi-met lite version.

### *Field measurement*

We measured the air temperature (Ta), air humidity (RH), and wind speed in three different times (09 AM, 12 AM, and 15 PM) during 7 – 9 October 2015. The instruments (sling psychrometer, and anemometer) were assembled on 1.5 m height outdoor tripod. The results are as follows :

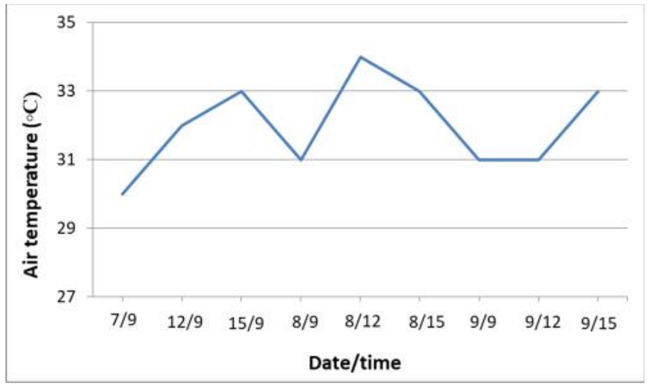


**Fig. 4**. Air temperature field measurement at observation point

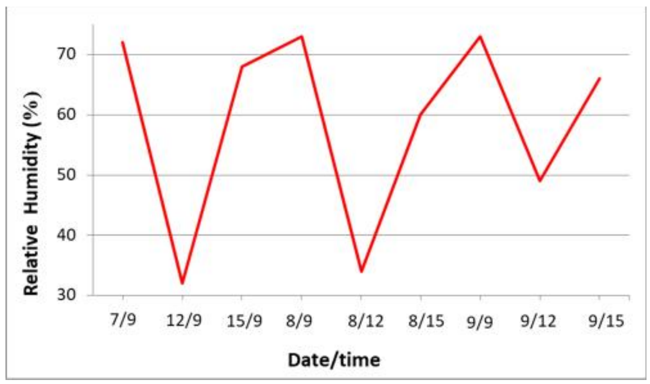


**Fig. 5**. Relative humidity field measurement at observation point

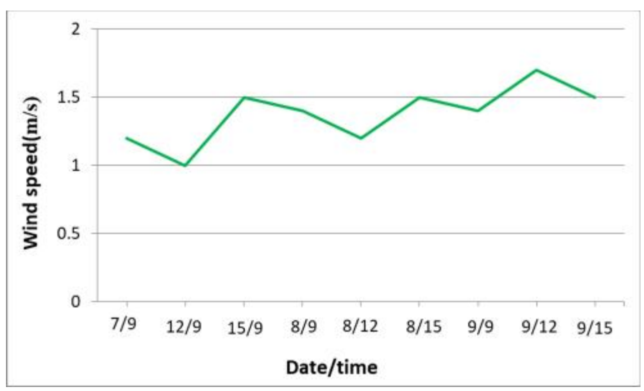


**Fig. 6**. Wind speed field measurement at observation point

## 3. Result and discussion

### *Field measurement and model validation*

In this study, we emphasized the microclimate simulation based on the existing situation without any scenario. Our research did not measure the heat storage from the anthropogenic heat release nor building façade caused by the limitation of Envi-met ability [13]. Even more, the meteorological condition was controlled by wide atmospheric activity, it was also strongly combined with the local environment. However, since the observation area was in nearly stable atmospheric condition and clear sky, the simulation tended to be accurate and illustrated real microclimate situations in the study area. We compared Ta, RH, and wind speed from 9 AM – 15 PM where people are likely to become more active in outdoor activity. The Ta seemed to be increasing from 9 AM to 12 AM then decreased at 15 PM in whole observation days (Fig. 4). The difference of Ta at 9 AM to 12 AM was +1$^o$C, while to 15 PM was -1.5$^o$C on average.

The impervious surfaces, such as asphalt and concrete are generally hotter at the daytime while natural surfaces, such as vegetation, shrubs, and soil are cooler after 15 PM to the entire nighttime [14]. Normally, the air humidity under the trees and water body will be higher in the morning than the other types of surfaces caused by evaporation and decrease in the evening (Fig. 5). The wind speed affects outdoor thermal comfort through its function as a cooling effect. The air movement in indoor that can be accepted by the human body does not exceed 0.3 m/s, and in outdoor it does not exceed 1 m/s to 8 m/s [15]. The wind speed in the observation area was 1 m/s to 1.7 m/s during measurement (Fig. 6). Throughout the observation days, Ta and relative humidity were kindly to be high in each hour, however, by cooling effect of the wind speed, the outdoor thermal comfort could be taken into account (Fig. 7)

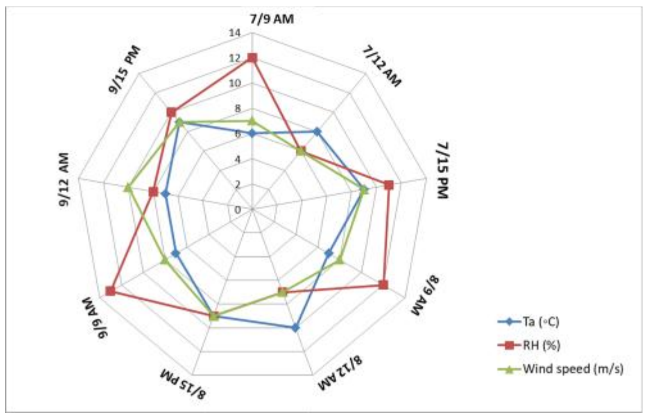


**Fig. 7**. The connectivity graph for each microclimate at observation point during 7-9 October 2015

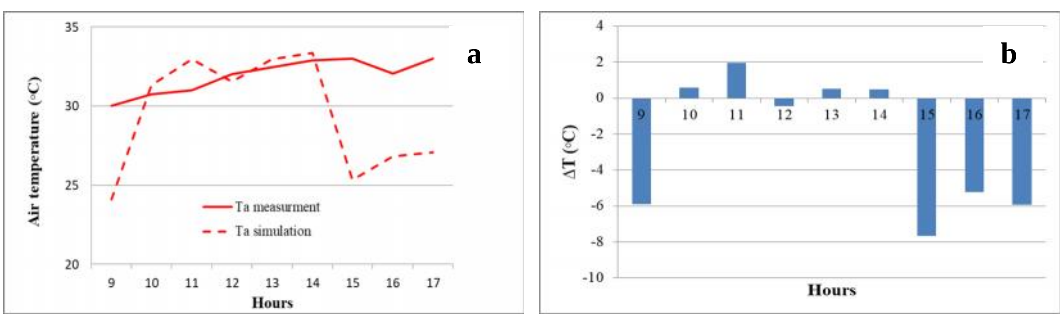


**Fig. 8**. Ta comparison (a) and Ta difference (b)between experiment and simulation

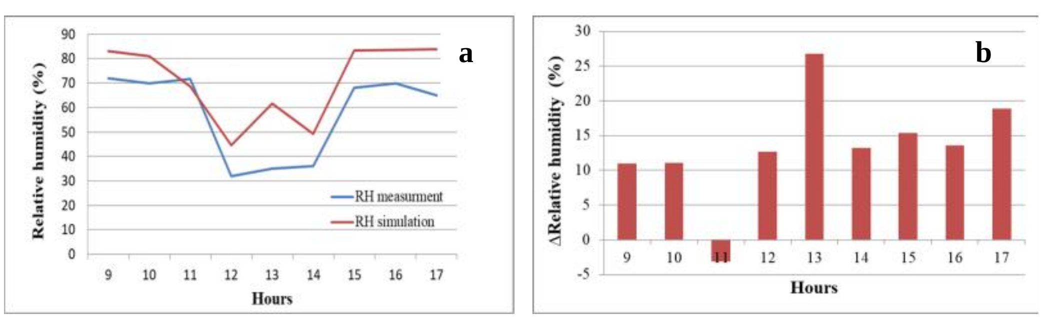


**Fig. 9**. Relative humidity (a) comparison and Relative humidity difference (b) between experiment and simulation

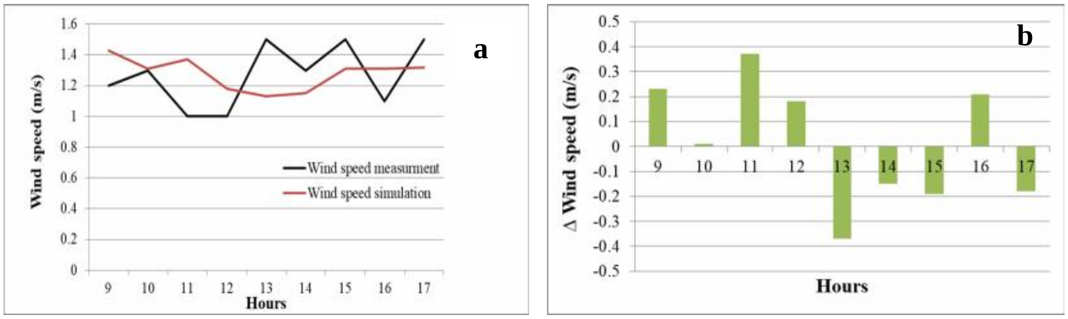


**Fig. 10**. Wind speed comparison and wind speed difference between experiment and simulation

To verify the model, the measured data were compared to the original simulation without any improvement. Figure 8 to figure 10 showed the measured and simulation result in different micro-climatic parameters at 9 AM to 17 PM. The air temperature simulation result demonstrated a quite different thermal performance between measure and model. Ta simulation had more thermal variation during observation days. The lowest Ta was started at 9 AM and gradually increased in the afternoon in both activities. The lowest difference between Ta measurement and simulation occurred at 15 PM, which was -7.66 $^oC$ (Fig. 8b). The simulation results were in an average of 29.5$^o$C for the thermal performance of outdoor air temperature. Another analysis also ran with relative humidity and wind speed that can be seen in fig. 9 and fig. 10. Compared to the RH measurement, RH simulation had higher performance, but there was no significant difference. The lowest difference was recorded at 11 AM, which was -3.09 %. A high variation of wind speed performance resulted in fig. 10a and could be proven by the wind speed difference (fig. 10b). The wind speed simulation gave a low performance in the afternoon and continued in the evening.

Table 1. Measured and simulation difference in microclimatic parameters performance

| **ΔTa ($^o$C)** | **Δ Relative humidity (%)** | **Δ Wind speed (m/s)** | **Hours** |
|---|---|---|---|
| -5.90 | 11.02 | 0.23 | 9 |
| 0.58 | 11.05 | 0.01 | 10 |
| 1.97 | -3.09 | 0.37 | 11 |
| -0.44 | 12.68 | 0.18 | 12 |
| 0.51 | 26.75 | -0.37 | 13 |
| 0.48 | 13.21 | -0.15 | 14 |
| -7.66 | 15.35 | -0.19 | 15 |
| -5.24 | 13.63 | 0.21 | 16 |
| -5.94 | 18.85 | -0.18 | 17 |

*Spatial distribution thermal performance*

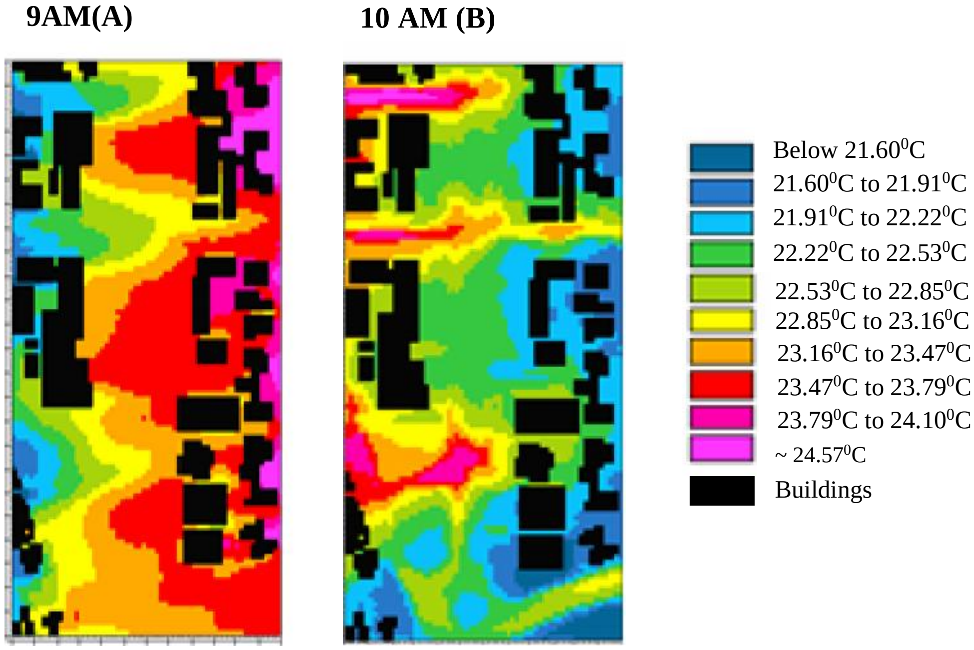


**Fig. 11**. Air temperature spatial distribution at 9 AM (A) and 10 AM (B)

The air temperature at 9 AM and 10 AM showed that the temperature was in the range of 21.60$^o$C to 24.10$^o$C. The blacks were buildings and others were non-buildings (vegetation and impervious surfaces) (Fig. 2). The morning heat distribution simulation followed solar radiation reflection in surfaces proven by the high heat intensity in the eastern side (Fig. 11a) [16]. By the time, the heat intensity in the eastern side was moving to the western side and became cooler (Fig. 11b)

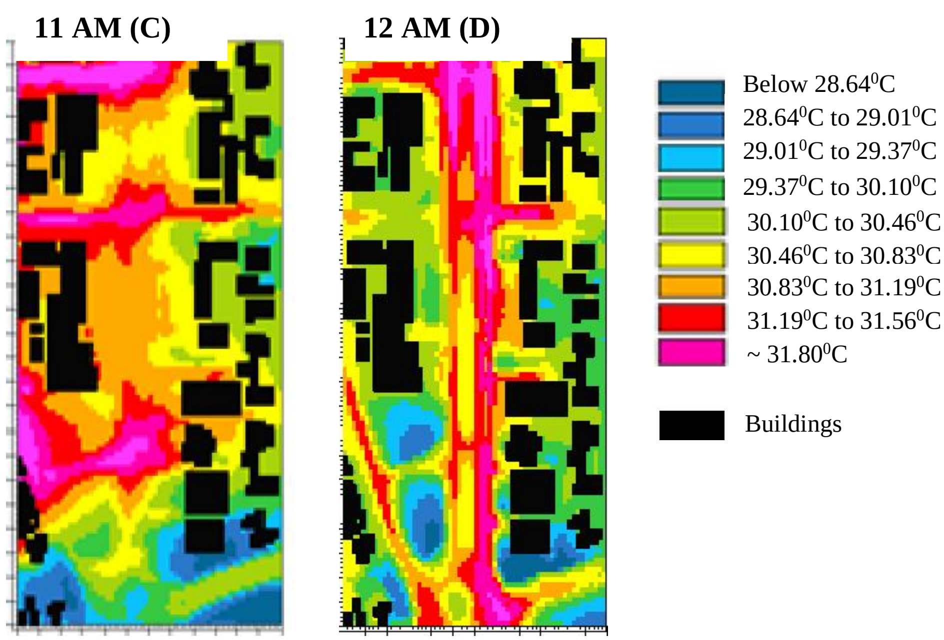


**Fig. 12**. Air temperature spatial distribution at 11 AM (C) and 12 AM (D)

Similar analysis result is presented in Fig. 12. The heat intensity at 11 – 12 AM was higher than at 9 – 10 AM and dominated by high air temperature. In this period, air temperature reached the maximum intensity which could be seen from the variation value of the heat. Compared to the previous hour, mid daytime solar radiation became higher, where the difference of the air temperature was approximately +5 $^{o}$C hotter. Unshaded impervious urban ground surfaces had increased the albedo which impacted on microclimate activities, while the vegetated could be reduced [17]. The red color in each air temperature simulation indicated hot sensation in human skin and influenced the thermal comfort.

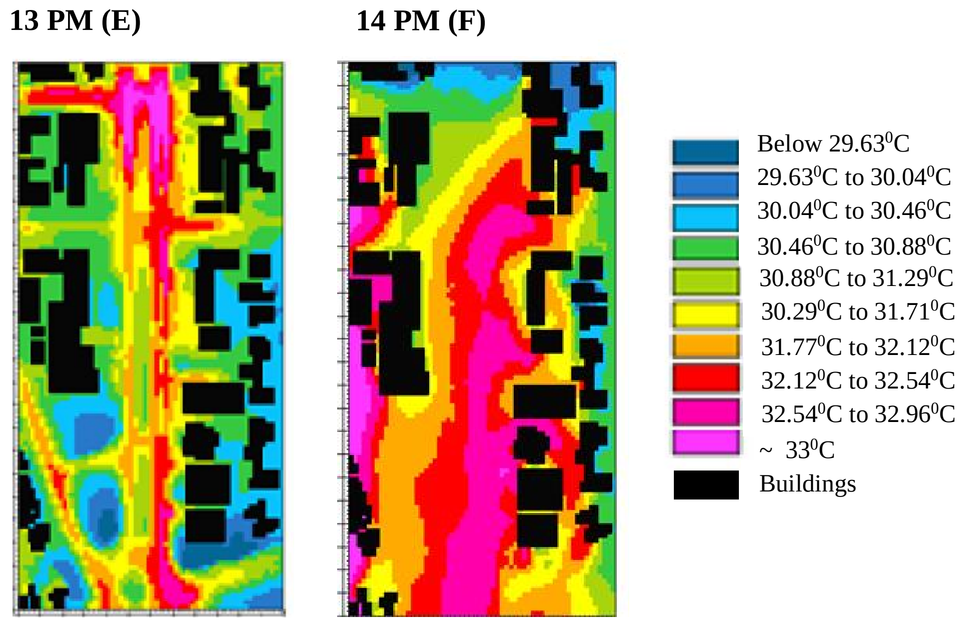


**Fig. 13**. Air temperature spatial distribution at 13 PM (E) and 14 PM (F)

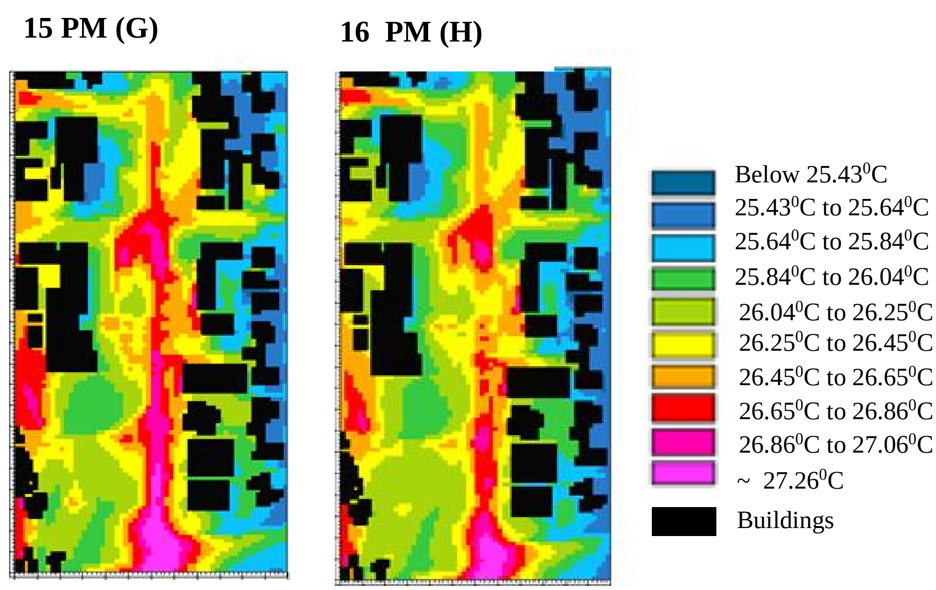


**Fig. 14**. Air temperature spatial distribution at 15 PM (G) and 16 PM (H)

Fig. 13 and 14 are the last simulation of air temperature in the focus area. An almost similar result in fig.12 is simulated in fig.13, where both figures show the peak hours of solar albedo and high near-surface air temperature in the urban ground feature. The degree of albedo had slowly reduced at 15 PM and 16 PM (minimum air temperature was 25.43$^o$C, maximum 27.26$^o$C). The coolest period was estimated near the vegetation and shaded surfaces. In all simulation results, vegetation and shading were the main points of the cooling effect of solar radiation even though the relative humidity was high and wind speed was slow [18][19][20].

## 4. Conclusion

This paper focused on outdoor thermal performance in high-intensity anthropogenic activities university campus area. A numerical model was run in order to simulate the microclimatic condition in a dry season day time. The result showed that generally, heat activity was spread out to the entire location with different temperature intensities on each time period. We used air temperature, relative humidity, and wind speed as the microclimate parameters to simulate the thermal performance during the day.

The spatial heat activity followed solar radiation where it impacted on the air temperature, and relative humidity degree. In the morning, the air temperature and relative humidity were relatively low where it caused a warm sensation in the human skin. In the mid-afternoon, the air temperature and relative humidity reached the peak point, naturally, urban surfaces released the maximum heat into the atmosphere in the afternoon and decreased in the evening. The observation area was laying in the stable meteorological condition, where the wind speed average was 1.2 m/s in the whole area. The vegetated and impervious urban ground surfaces influenced the outdoor thermal performance and local climate.

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