SPATIAL CHARACTERISTICS OF URBAN HEAT ISLAND IN JOHOR BAHRU CITY, MALAYSIA

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ABSTRACT

This study investigates the spatial characteristics of urban heat island (UHI) in the city of Johor Bahru, Malaysia. Two field measurements were carried out in March (rainy season) and September (dry season) 2008 in order to analyze the spatial distributions of nocturnal air temperature and humidity in the city. The nocturnal temperature difference between the urban and surrounding areas recorded only 2°C in the rainy day, but it reached a maximum of 4°C in the sunny day. More than one UHI were observed in the city. It was found that relatively large open spaces scattered in between the built-up areas may create low air temperature areas and divide the UHI of the city.

1. INTRODUCTION

The urban heat island (UHI) is the phenomenon that temperatures in urban area become higher than those in the surrounding areas due to urbanization. The scientific awareness of urban climate anomaly arose at least in the mid-eighteenth century. However, experimental studies had not been carried out until the development of meteorological instruments such as the thermometer in the mid-nineteenth century (Oke, 1991). Especially from the mid-twenty century, UHIs have been observed practically in most part of the world except in extreme cold climates (Emmanuel, 2005).

Most of the cities in Southeast Asia experience hot-humid climate all the year round. Thus, UHI in this region would cause considerable increase of annual cooling loads for buildings and therefore raise urban energy consumption significantly. The air temperature rise caused by UHI may also result in the expansion of tropical diseases such as dengue fever and malaria, etc. Moreover, since UHIs lead to decrease of the average wind speed and stimulate the occurrence of photochemical smog in cities, it would cause further deterioration in urban air pollution.

As before, it is evident that UHIs would cause various serious environmental problems in the tropics, but the urban climate of tropical cities has not been extensively studied (Oke, 1982). Sani (1987) has conducted comprehensive researches regarding this subject in Kuala Lumpur. The above study analyzed both air temperature distribution and air pollution levels in the city and observed the urban-rural temperature difference of 4.4-5°C. However, the above study did not deal with other major Malaysian towns such as Johor Bahru. The characteristics of UHI much depend on the geographic and climatic conditions of respective towns. Therefore, in order to identify the characteristics of UHI in the tropics profoundly, it is essential to compare them between different towns.

This study investigates the spatial characteristics of UHI in the city of Johor Bahru. Two field measurements were carried out in March (rainy season) and September (dry season) 2008 in order to analyze the spatial distributions of nocturnal air temperature and humidity in the city.

2. METHODS

The city of Johor Bahru is located in the southernmost part of the Peninsular Malaysia (Fig. 1). It is the second largest city after Kuala Lumpur in terms of population size. Its population including the conurbations was nearly one million in 2000. In most of the Malaysian towns, the monthly mean air temperature and humidity are almost constant. The annual mean air temperature is about 26°C in the city of Johor Bahru and the deviation of monthly mean air temperatures is about 1°C. However, there is a seasonal climatic change, which is dominated by the monsoons, in terms of wind conditions and rainfalls. The monsoon season can be divided into two monsoon periods and the inter monsoon period; namely, the northeast monsoon period (November to March), the southwest monsoon period (May to September) and the inter monsoon periods (April and October).

Precipitation in the northeast monsoon period (November-March) is relatively higher in the city of Johor Bahru (rainy season) than that in the southwest monsoon period (May-September) (dry season). Hence, the field measurements were carried out in March and

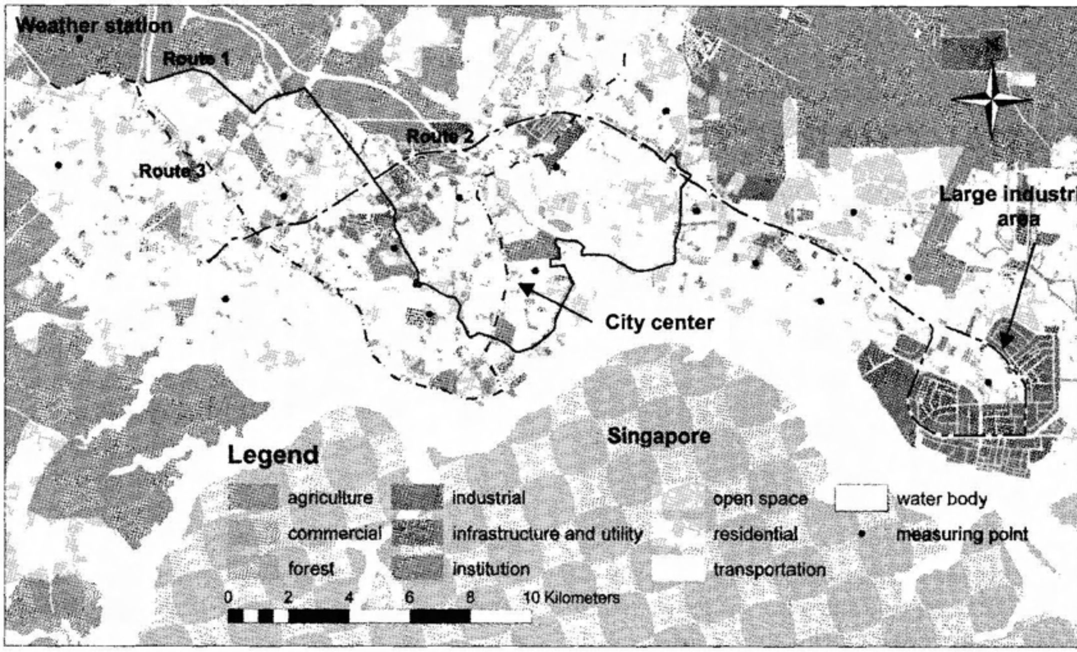
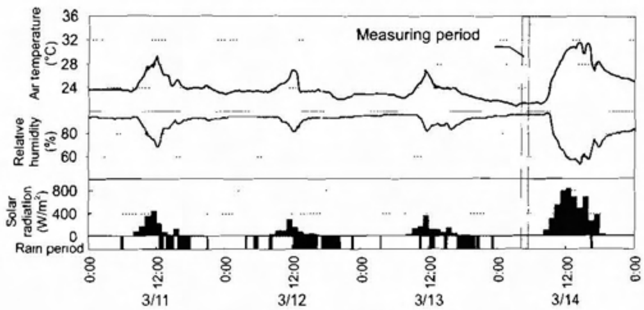
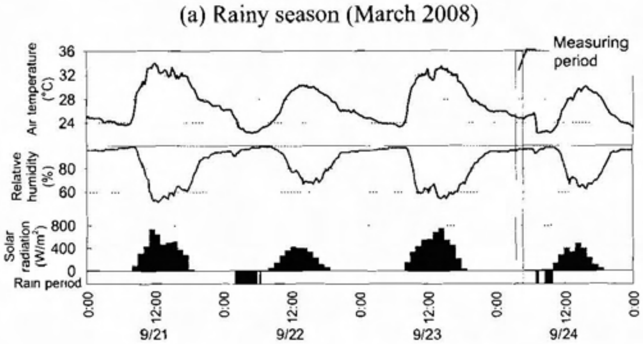


Fig. 1 Three routes for mobile survey and measuring points for stationary survey

Fig. 2 Measuring instrument for mobile survey



(a) Rainy season (March 2008)



(b) Dry season (September 2008)

Fig. 3 Weather conditions in urban surrounding area during the measuring days

September 2008 respectively, to examine the characteristics of UHI in both rainy and dry seasons.

In order to cover most part of the city, mobile surveys were conducted in different three routes simultaneously, while about 15 measuring points (stationary points) were placed at schools located in the city as shown in Fig. 1. Compact data loggers with thermometer and hygrometer (TR-72U and TR-52, T&D Corporation) were used for both measurements. In the mobile survey, the data loggers were installed in the well-insulated plastic pipes, which were fixed on the roofs of cars (Fig. 2). In the stationary survey, on the other hand, the data loggers were placed at outdoors of selected schools at 1.8m height above ground. In parallel, a weather station (EASIDATA Mark 4, Environdata) was installed in the university campus, which is situated about 20km northwest from the city center (see Fig. 1). The recorded climatic parameters at the station are air temperature, relative humidity, wind speed and direction, barometric pressure, rain fall, and horizontal global radiation.

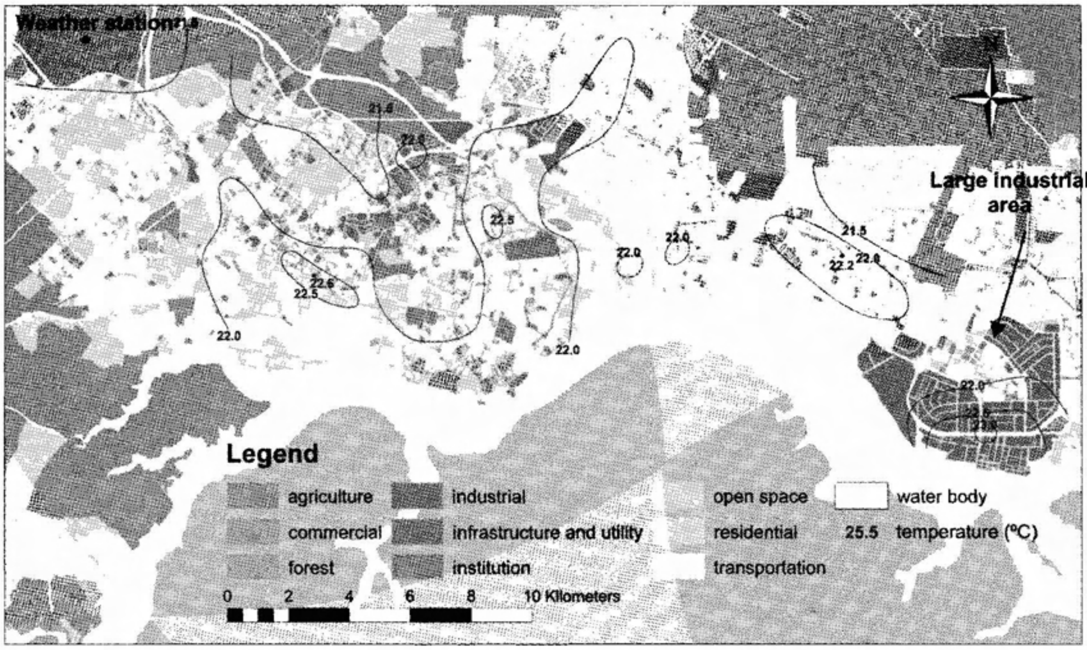
Air temperatures and relative humidity were recorded at one minute intervals in the mobile survey, while the data was taken at five minutes intervals in the stationary survey. All the data were recorded early morning of the two measuring days: 4:20a.m.-5:40a.m., 14 March and 3:45a.m.-4:45a.m., 24 September 2008. This is because it is generally believed that UHIs are particularly intense at night.

3. RESULTS AND DISCUSSION

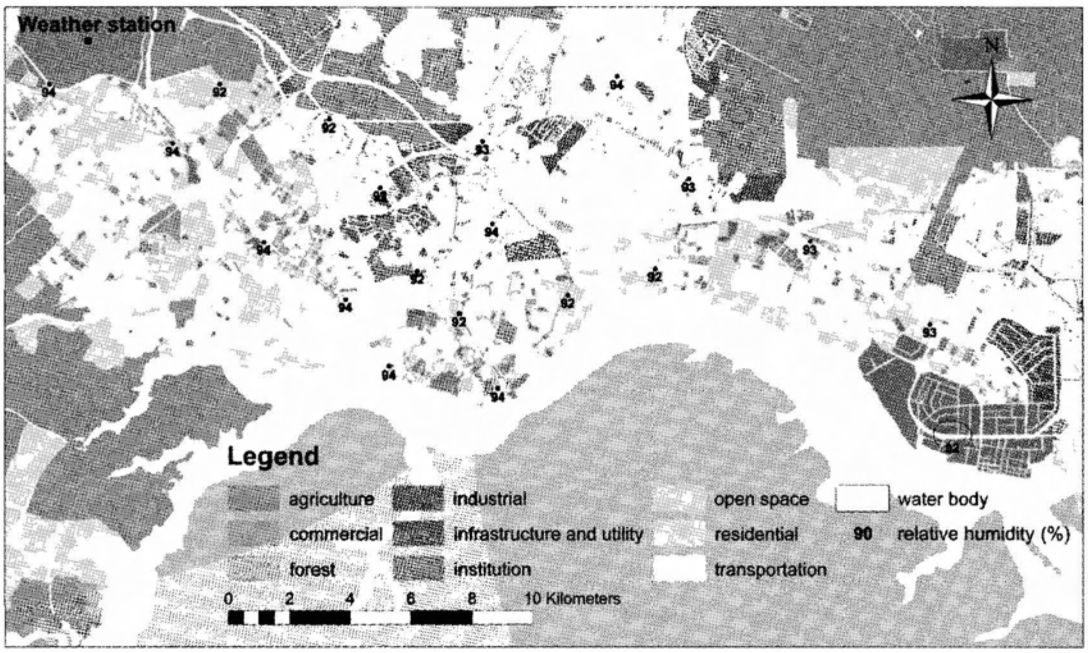
3.1 Spatial distribution

(a) Rainy season (March 2008)

The weather conditions in the two measuring periods at the weather station are summarized in Fig. 3. As before,



(a) Air temperature



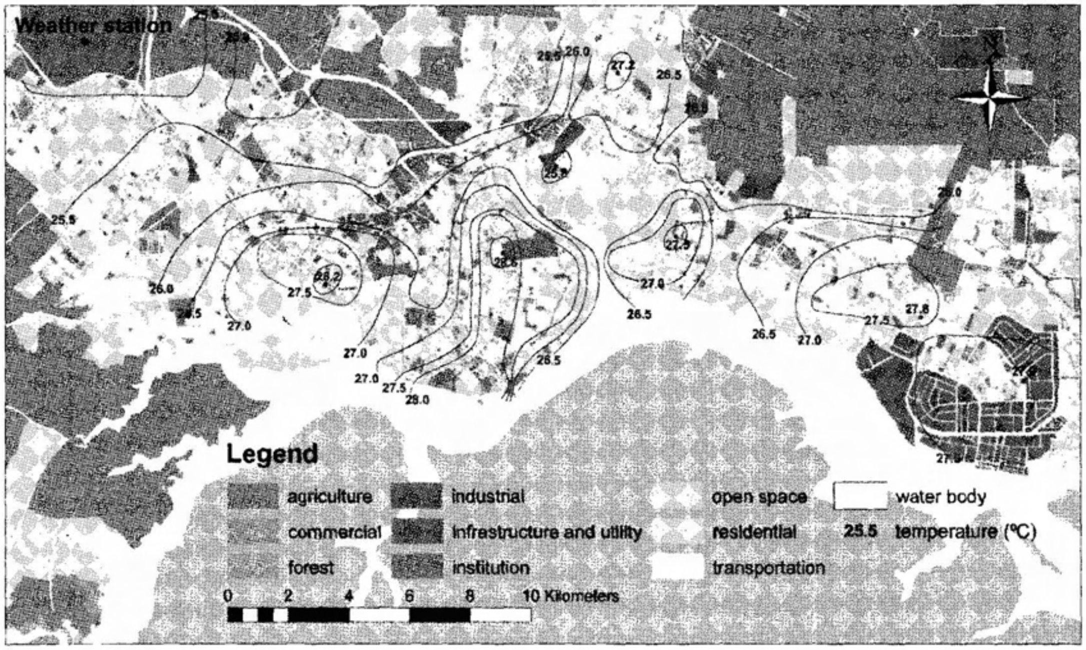
(b) Relative humidity

Fig. 4 Spatial distribution of air temperature and relative humidity in the rainy day (4.20-5:40a.m., 14 March 2008)

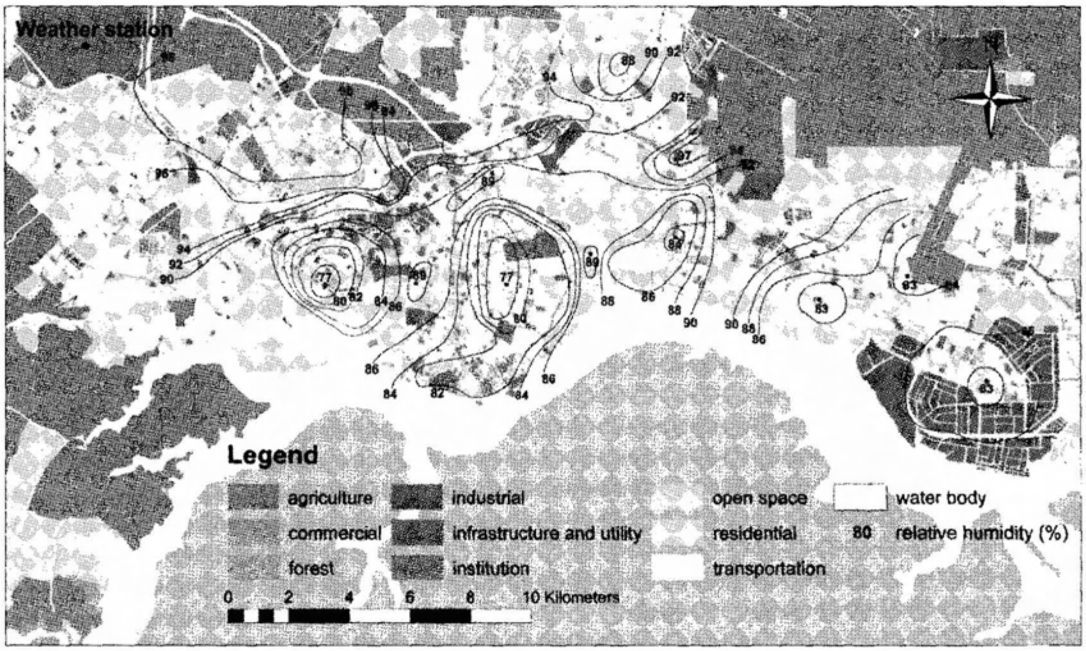
the weather station was placed in the university campus, which is located on the outskirt of the city (see Fig. 1). The campus comprises abundant green areas. Thus, the weather conditions at the station are considered to represent those of the surrounding rural areas.

As shown in Fig. 3a, the three days before the measuring day were continuous rainy days. Relatively heavy rain was observed during the afternoon and light rain was recorded in the night. Weak solar radiation was prevailed throughout the three days and therefore maintains low air temperatures especially during the daytime. The maximum air temperatures of the previous three days are 29.3°C (3/11), 27.0°C (3/12) and 26.9°C (3/13), while the average nocturnal air temperatures are 23.4°C (3/11), 22.6°C (3/12) and 21.5°C (3/13), respectively.

The range of measured air temperatures at the weather station in the measuring period was found to be only 0.1°C. Thus, it can be assumed that the data obtained through the mobile survey were observed under the constant air temperature conditions. The measured distributions of air temperatures and relative humidity are illustrated in contour lines in Fig. 4. The temperature contour lines are indicated in every 0.5°C (Fig. 4a), while the humidity contour lines are expressed in every 2%RH (Fig. 4b).



(a) Air temperature



(b) Relative humidity

Fig. 5 Spatial distribution of air temperature and relative humidity in the sunny day (3:45-4:45a.m., 24 September 2008)

As shown in Fig. 4a, although the temperature differences are not large due to the rainy conditions, there are several UHIs, where the relatively higher temperature is observed. The UHIs can be seen in relatively densely built-up areas, such as the city center, large housing estates and industrial areas. The maximum air temperature is observed at the center of large industrial area, which is 23.1°C, while the minimum temperature is seen at the weather station, which is 21.2°C. The nocturnal temperature difference between the above two points is, therefore, about 2°C.

As shown in Fig. 3a, the solar radiation had been very low during a few days before the measuring day. Therefore, the above temperature difference of 2°C is likely not due to the heat gain by the solar radiation but due to the anthropogenic heat released from the factories in the industrial area. It should be noted that the nocturnal urban-rural temperature difference can reach 2°C due to the effects of anthropogenic heat alone even in a rainy day.

As shown in Fig. 4b, the distribution of relative humidity, on the other hand, is very small simply because of the rainy conditions.

(b) Dry season (September 2008)

As indicated in Fig. 3b, although rain was observed in the early morning of 22 September, the three days before the measuring day were sunny days at large. The previous day (9/23) observed the maximum air temperature of 33.4°C and the average nocturnal air temperature of 25.8°C, respectively.

The range of measured air temperatures at the weather station in the measuring period was again found to be very small, which is 0.2°C. Thus, also in this case, it can be assumed that the data obtained through the mobile survey were observed under the constant air temperature conditions. The distributions of air temperature and relative humidity are illustrated in Fig. 5. As shown, the temperature differences in the city are much larger than those of the rainy day (see Fig. 4a). However, interestingly, the locations of UHI have some similarities between the two observations. Like shown in Fig. 4a, several UHIs can be seen in relatively densely built-up areas in Fig. 5a. Nevertheless, though the highest air temperature was observed in the industrial area in the rainy day as in Fig. 4a, the maximum air temperature in Fig. 5a is observed at the city center, which is 28.6°C. This is because the heat gain was increased further due to the solar radiation in addition to the anthropogenic heat. The minimum air temperature is seen near the weather station like in Fig. 4a, which is 24.6°C. The nocturnal urban-rural temperature difference is, therefore, 4°C.

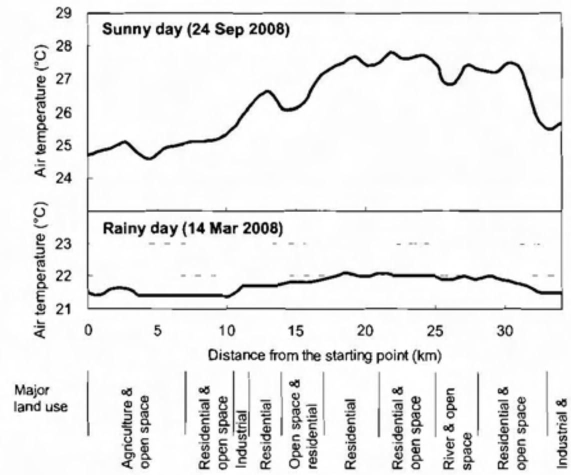
As shown in Fig. 5a, many open spaces (green areas) and rivers are scattered in between the built-up areas in the city. These open spaces may create low air temperature areas and divide the UHI of the city. It is worth to note that the temperature drop of 2-3°C can be created within a short distance such as 4km by placing relatively large open spaces in the city.

The distribution of relative humidity is the opposite conditions of that of air temperature (Fig. 5b). Basically, the areas with higher air temperatures have lower relative humidity.

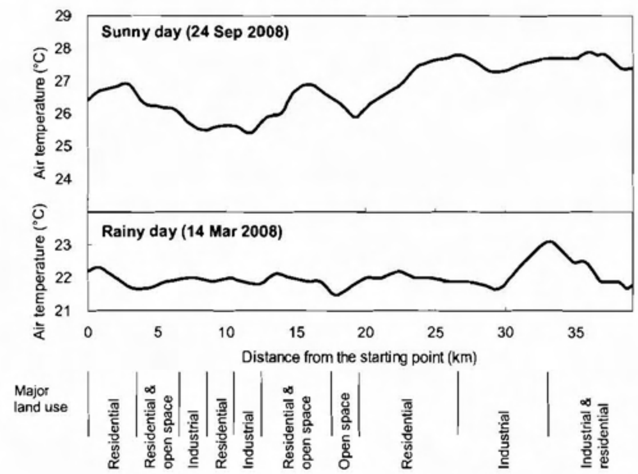
3.2 Land use and UHI intensity

Fig. 6 illustrates the air temperature distributions measured through the mobile survey. Measured air temperatures in both sunny and rainy days for different three routes (see Fig. 1) are shown, respectively. Major land use along the respective routes is also indicated at the bottom of the figures.

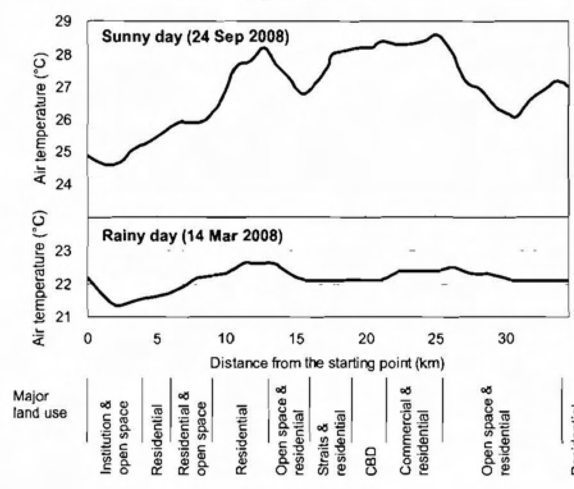
Route 1 starts from the vicinity of the weather station and heads to the city center. After reaching the city center, the car went to the northeast of the city (see Fig. 1). In this route, the minimum air temperature is recorded around the starting point, which is 24.6°C in the sunny day and 21.4°C in the rainy day. After that, the air temperatures increase towards the city center in both days as in Fig. 6a. Although the peak air temperatures are recorded at almost same locations between the two observations, the intensity of UHIs is significantly different. The maximum air temperature reaches 27.8°C in the sunny day, while the corresponding air temperature for the rainy day is only 22.1°C. The fluctuation of air temperature distribution is large in the sunny conditions, thus up to 1-2°C temperature drops can be seen. This is



(a) Route 1



(b) Route 2



(c) Route 3

Fig. 6 Relationship between major land use and temperature distribution

likely due to the existence of open spaces (green areas) as shown in Fig. 6a.

Route 2 runs across the city from west to east (see Fig. 1). As shown, a large industrial area is situated at the end of the route. In this route, the profile of air temperature distribution is considerably different between the two observations especially at the large industrial area (Fig.

6b). As discussed before, the UHI intensity in the industrial area is very high compared with that in the surrounding areas especially in the rainy day. In the rainy day, the maximum air temperature of the city is observed in this industrial area.

Route 3 starts from the vicinity of the weather station and heads to the city center. After reaching the city center, the car went to the north through the commercial areas (see Fig. 1). As shown in Fig. 6c, the minimum air temperatures are recorded near the starting point in both observations. In the sunny day, the maximum UHI intensity is observed in this route, which is 4°C. The highest points are seen in densely built-up areas in both observations. Considerable temperature drops by 1-2°C are observed in the sunny day. As discussed before, this is also likely due to the existence of open spaces (green areas) as shown in Fig. 6c.

4. CONCLUSIONS

(1) The nocturnal temperature difference between the urban and surrounding areas in the city of Johor Bahru recorded only 2°C in the rainy day, but it reached a maximum of 4°C in the sunny day.
(2) It was found that there are several UHIs in both rainy and sunny days in the city. The maximum nocturnal air temperature was observed in the large industrial area in the rainy day. This indicated that the urban-rural temperature difference can reach 2°C due to the effects of anthropogenic heat alone even in a rainy day.
(3) The maximum nocturnal air temperatures in the sunny day were recorded in relatively densely built-up areas, such as the city center, large housing estates and industrial areas. It was found that relatively large open spaces (green areas) scattered in between the built-up areas may create low air temperature areas and divide the UHI of the city.

Further study is needed to examine the possible mitigation measures for the effects of UHI in the tropics, focusing especially on the temperature reduction effects caused by the green areas.

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