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Observation of Diurnal Variation of Urban Microclimate in Kuala Lumpur, Malaysia

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To realise sustainable urban architecture and design in tropical climate conditions, a quantitative understanding of the urban microclimate of a real tropical city through long-term measurements is crucial. The target city of this work, which is Kuala Lumpur, Malaysia, is classified to be within the tropical rainforest climate zone. Data were collected for a full-year study (March 2014 – February 2015) using a weather station installed in a university campus located in Kuala Lumpur. Parameters such as air temperature, relative humidity, solar radiation, wind speed and direction, and rainfall were recorded and analysed at hourly, daily, and monthly time scales. The results showed that the ranges of the urban microclimate parameters were large: the average wind speed ranged between 0 – 2 m/s, solar radiation was 100 – 200 W/m² and relative humidity 60 – 90 %. The results suggest that the urban microclimatic parameters were influenced by both monsoon seasons and the urban surface.

1. Introduction

Growing urbanisation and industrialisation have caused the deterioration of the urban environment. Oke et al. (1991) discovered that, due to land cover conversion, air temperature in densely built urban areas is significantly higher than in rural areas. This phenomenon is known as the urban heat island (UHI), instigated by the construction of buildings made from low-thermal capacity material, prevalence of heat-storing street canyon geometries, and increased greenhouse gas emissions. In urban areas, if the supply of mass or energy is greater than the physical capability of the local atmospheric system to remove it, the system's mass or energy content will increase, altering the climate system of the area (Roth, 2007) hence, creating the urban microclimate.
Most studies on the microclimate have been conducted in western mid-latitude regions and rarely in tropical and equatorial developing countries such as South East Asian countries (Yusup and Lim, 2014). The atmosphere above urban areas experiences unstable or convective conditions because of heat radiation from roads, buildings, and other man-made structures, which intensify mass and energy exchanges within the rough urban sub-layer. This phenomenon is known to keep the urban boundary layer well mixed diurnally (Yusup and Anis, 2016).
Climate change and air pollution have attracted widespread attention in many developed nations, such as Japan, the United States, and countries within the European Union. Roth (2007) comprehensively summarised research on anthropogenic climate modification and reported that the majority of work in the literature has primarily been performed in mid-latitude and developed countries. The Basel UrBan Boundary Layer Experiment (BUBBLE) project in the city of Basel, Switzerland (Rotach et al., 2005) and the Tokyo Kugahara observation (Moriwaki and Kanda, 2004) were large-scale projects of atmospheric measurements undertaken in cities of mid-latitude countries, which greatly contributed to the understanding of the modification mechanism of the

urban microclimate. Other studies were performed in arid regions, such as Mexico City (Doran et al., 1998), Savannah, Miami (Newton et al., 2007), and the subtropical, but dry city of Ouagadougou (Offerle et al., 2005). In recent years, scientists from developing countries, have returned to their home countries to conduct research on their urban microclimates. However due to limited resources, the majority of current research is conducted as isolated studies of small-scale urban phenomena. For example, Syahidah et al. (2015) took field measurements of temperature distribution using Geographical Information Systems (GIS) to understand the effect of green coverage and building morphology on the microclimate of an urban campus in Kuala Lumpur. However, data on energy fluxes (latent and sensible heat) measurements and other microclimate measurements, valid and crucial aspects of urban microclimate research, remains limited.

Populations of tropical developing countries are likely to grow exponentially and thus, are expected to worsen the urban microclimate and exacerbate existing environmental issues such as air pollution. In order to understand sustainable urban design and architecture that suit the tropical climate, an in-depth understanding of the urban physical mechanisms through long-term measurements is highly warranted. Thus, this work reports preliminary microclimate measurements in a tropical city carried out for a full year, from March 2014 to February 2015, which allows us to better understanding the tropical urban microclimate.

2. Methodology

Kuala Lumpur, the capital of Malaysia, encompasses an area of 243 km². It is one of the fastest-growing metropolitan regions in Southeast Asia. Kuala Lumpur consists of the city centre and the surrounding urban areas. In 2015, the Malaysian Department of Statistics estimated its population to be 1.73 million. Based on the Köppen classification system, Kuala Lumpur lies within the tropical rainforest climate. Universiti Teknologi Malaysia (UTM) at Jalan Sultan Yahya Petra, Kuala Lumpur (UTM KL; N 3°10'22.8", E 101°43'14.88") was chosen as our study area because it is located in the heart of Kuala Lumpur.

Urban microclimate data were collected from a weather station located in the campus of UTM KL on the rooftop of the Malaysia-Japan International Institute of Technology (MJIIT) building (Figure 1). The station was installed at a height of 68 m and consisted of a cup anemometer (Wind Sentry Anemometer, Campbell Scientific), rainfall gauge (RIMCO8000, Campbell Scientific), temperature and relative humidity probe (CSL Temp/RH Probe SDI, Campbell Scientific), and a pyranometer (Apogee Silicon, Campbell Scientific). Data were collected continuously at 10 min interval and stored in a data logger (CR1000, Campbell Scientific) from 1 March 2014 to 28 February 2015. The data also consist of hourly wind records over this one-year period.

(a) (b) (c)

Figure 1: (a) Location of the weather station on the rooftop of (MJIIT); (b) the weather station on the MJIIT rooftop; (c) the campus area, black circle indicates the location of the weather station.

3. Results and Discussion

3.1 Data Seasonal Description and Frequency Distribution of Urban Microclimate Parameters

The general Malaysian weather is influenced by monsoon seasons. Three distinct monsoon seasons were observed at this location: the Northeast Monsoon (from November to March), the Southwest Monsoon (from May to September), and the transition monsoons in the months of April and October. This observation is consistent with that in literature (Nik et al., 2011). According to Toggweiler and Key (2001), monsoon will alter cloudiness, wind speed and wind direction, producing distinct seasonal patterns. For example, during the Northeast Monsoon, wind speed will be the highest from November to February while wind speed will be lower in November but more consistent between December and March.

Figure 2 displays the frequency distribution of the urban microclimate parameters for one year (March 2014 to February 2015), namely air temperature, wind speed, wind direction, relative humidity, and solar radiation. The wind speed ranged between 1 – 2 m/s (Figure 2(c)), which is common in an urban area due to increased surface roughness. The wind was channelled, whereby the wind direction was mostly southerly (200°) (Figure 2(e)) due to obstructions on the urban surface. Interestingly, air temperature was generally low, which ranged between 26 °C and 30 °C and a peak at 28 °C. However, the distribution of air temperature exhibited a bi-modal distribution, which highlights increased temperature in the right-tail of the distribution and a second peak at approximately 30 °C (refer to Figure 2(a)) possibly due to UHI. Overall lowered temperature was due to high total rainfall, which was from 300 – 400 mm (see Figure 4(a)). This high total rainfall decreased the air temperature and solar radiation but increased relative humidity. Since the highest rainfall was recorded in 2014, the relative humidity was also the highest in this period (in the range 60 – 90 %; Figure 2(b)) with decreased solar radiation of 100 – 200 W/m² due to increased rain clouds (Figure 2(d)).

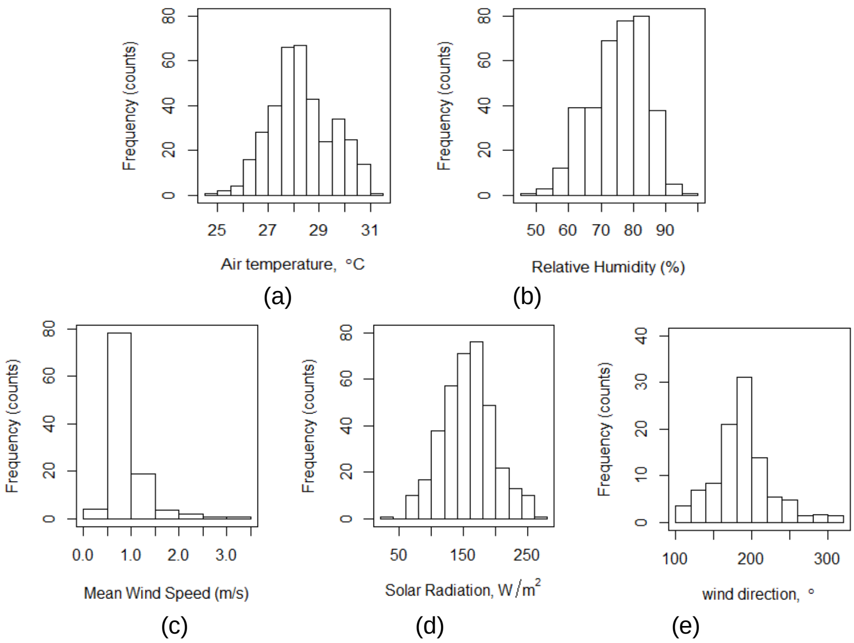
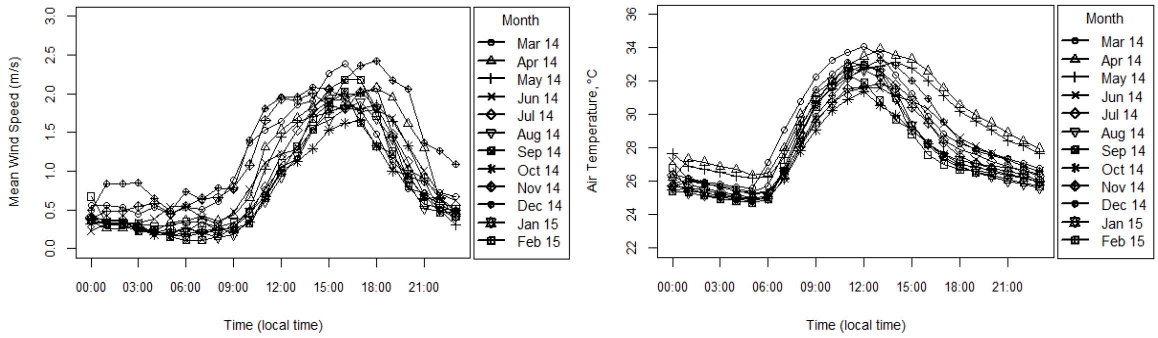


Figure *2: Frequency distribution of (a) air temperature (°C), (b) relative humidity (%), (c) mean wind speed (m/s), (d) solar radiation (W/m²), and (e) wind direction (°) for a one-year period from March 2014 to February 2015.*

3.2 Trends of Hourly-averaged Urban Microclimate Parameters

Wind speed is an important parameter in urban areas, which influence the outdoor and indoor comfort, air quality and energy consumption of buildings. During our study, the hourly wind speed was relatively high (1.5 – 2.5 m/s) between 8:00 AM and 5:00 PM (local time) but only started to decline after 4:00 PM (Figure 3(a)). During the day, as the sun heats the air, air particles become more active as differently heated parcels of air rise, fall, and move about in relation to each other to achieve an equilibrium state. As a result, it is generally windier during daytime compared to night-time. According to Oke (1987), UHI occurs during both day and night however, the maximum effect of UHI only occurs 3 – 5 h after sunset. This is because the urban area conserve much of its heat in roads, buildings and other structures that prevent it from cooling at night. Therefore, coupled with generally low wind speed, the night-time urban air temperature can be higher than it would be in rural areas, as observed in this study.

Figure 3(b) shows the hourly average air temperature. Air temperature increased from 6:00 AM to 1:00 PM and declined at 2:00 PM. The declination of air temperature was caused by the increase of wind speed at 2:00 PM. This is because wind has a cooling effect, which helps to mitigate the adverse effect of UHI on the urban microclimate and human thermal comfort. In Singapore, wind speed ranged between 1 and 1.5 m/s, which created a cooling effect equivalent to a 2 °C drop in temperature (Erell et al., 2010).



(a) (b)

Figure 3: Diurnal (a) mean wind speed (m/s) and (b) air temperature (°C) for every month from March 2014 to February 2015.

3.3 Trends of Monthly-averaged Urban Microclimate Parameters

The recorded total rainfall were analysed monthly and plotted with air temperature, to determine if any possible variation of air temperature with rainfall exists (see Figure 4(a)). The highest mean temperature (30 °C) was recorded in June 2014, which coincided with the lowest total rainfall of 120 mm whilst the highest total rainfall (380 mm), which led to the lowest mean air temperature of 27 °C, occurred in April 2014. The variation of temperature and rainfall change due to the anthropogenic heat factor, which is heat released from transportation and residential buildings. According to Ichinose et al. (1999), this heat can greatly affect the urban environment by directly changing the surface air temperature and modify the urban boundary layer structure as well as rainfall. Since there is a relationship between rainfall and air temperature thus, the urban environment is dependent on rainfall to lower its overall temperature.

Monthly mean wind speed in December 2014 was slightly higher than in other months (from 0.7 m/s to 1.5 m/s) but still fell within the average range of wind speed in Kuala Lumpur (see Figure 4(b)). The mean monthly wind direction in Kuala Lumpur was less than 200° (from the southeast), except for March 2014, January 2015, and February 2015 with southwest winds (Figure 4(e)). These variations are likely due to Monsoon seasonal changes. At the monthly time scale, these results do not indicate that wind speed affected air temperature as apparently as rainfall.

Since relative humidity is inversely related to air temperature, it conversely follows the same trend as air temperature. Figure 4(c) shows the monthly relative humidity (%) from March 2014 until February 2015. The lowest relative humidity (less than 80 %) was noted in March 2014, June 2014, July 2014, August 2014, September 2014, January 2015, and February 2015, while in other months, it was greater than 80 %. Monthly solar radiation was related to relative humidity (and rainfall), where the lower the solar radiation, the higher the relative humidity (and rainfall) but lower the air temperature. In March 2014 the highest solar radiation (190 W/m²) was observed (Figure 4(c)) while the relative humidity was 68 % (see Figure 4(d)) and the air temperature was 28 °C (see Figure 4(a)). This corresponded with low total rainfall of 250 mm (see Figure 4(a)).

3.4 Trends of Daily-averaged Urban Microclimate Parameters

The measured urban microclimate parameters were also analysed at the daily time scale to understand the short-term responses of the parameters throughout one year. Among the parameters, wind speed exhibited some variation with day of year. Maximum mean wind speed was greater than 4 m/s while the highest mean wind speed was 12 m/s, which occurred in February 2015 (see Figure 5(a)). During this month, the mean wind speed was 3.5 m/s (Figure 5(e)) but the air temperature was higher than 30 °C (see Figure 5(c)) while the relative humidity was low at 78 % (Figure 5(d)). This indicates that, during this month, the weather was hot but windy. The wind was blowing from the northwest (see Figure 5(b)), which was during the Northeast Monsoon.

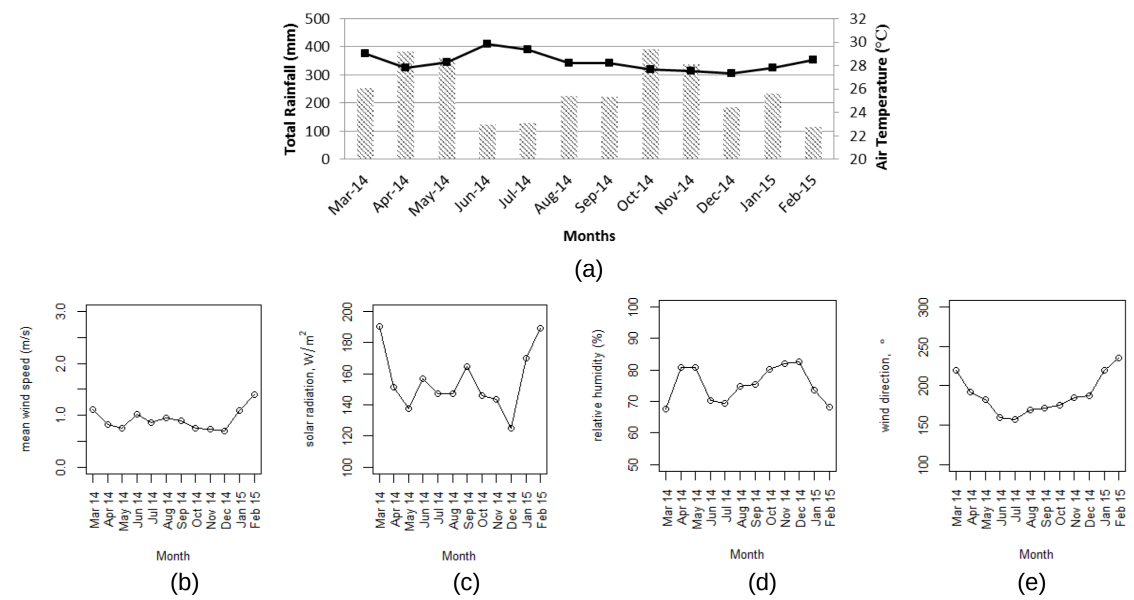


Figure 4: Monthly (a) total rainfall (mm) and air temperature (°C), (b) mean wind speed (m/s), (c) solar radiation (W/m²), (d) relative humidity (%), and (e) wind direction (°) observed from March 2014 to February 2015.

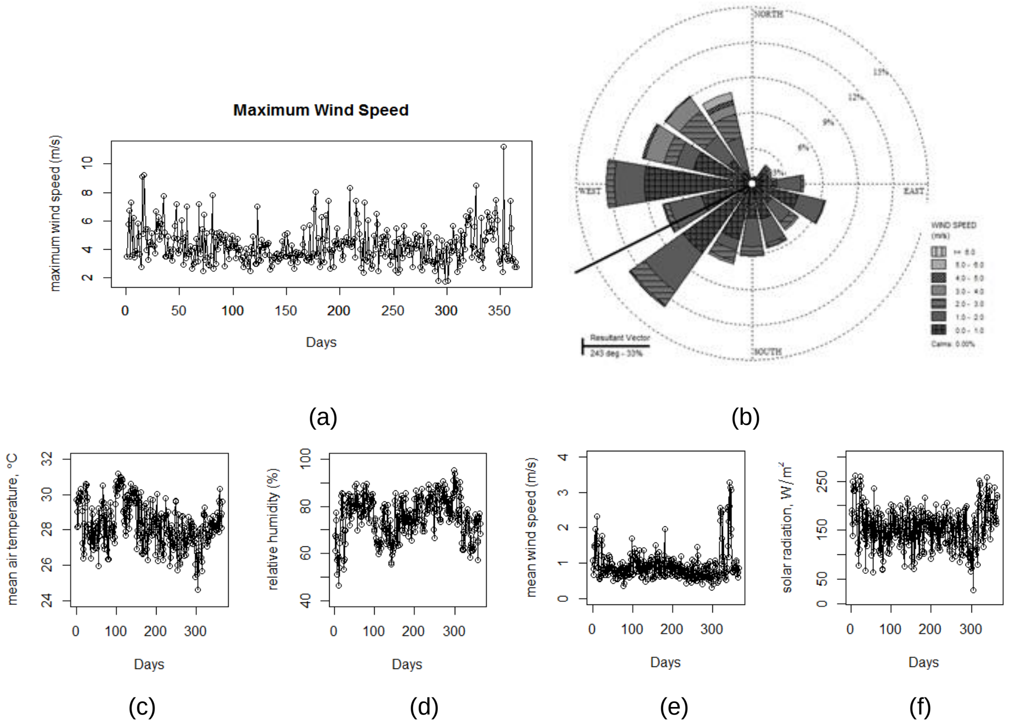


Figure 5: Daily (a) maximum wind speed (m/s), (b) Wind rose plot, daily-averaged (c) mean air temperature (°C), (d) relative humidity (%), (e) mean wind speed (m/s), (f) solar radiation (W/m²) observed from March 2014 to February 2015.

4. Conclusions

In this paper, field measurements of urban microclimatic parameters (i.e., air temperature, relative humidity, wind speed, wind direction, solar radiation, and rainfall) in Kuala Lumpur were analysed (at hourly, daily and monthly time scales) and presented. The results show that the ranges of microclimatic parameters were large:

average wind speed was in the range of 0 – 2 m/s, while solar radiation was between 100 to 200 W/m² and relative humidity 60 – 90 %. This indicates that the urban microclimatic parameters were influenced by monsoon seasons and the urban surface, which contributed to the anthropogenic heat release into the overlying atmosphere and gave rise to the UHI phenomenon. UHI increases the risk of overheating in buildings and consequently, energy demand for cooling. To address this issue, effective urban planning and sustainable architecture are needed to reduce the negative impacts of UHI while simultaneously reducing energy demand. This dataset has important applications to outline new strategies for tropical urban areas for low carbon societies in the region.

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