Pertanika J. Sci. & Technol. 25 (S): 63 - 72 (2017)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Wind Characteristics and Outdoor Thermal Comfort Assessment in East Malaysia

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ABSTRACT

Rapid urbanisation and industrialisation have had an adverse and deep impact on the environment contributing to global warming and climate change. These thermal environmental problems can be even more challenging to people living in regions with warm and humid climatic conditions throughout the year, such as Malaysia. This paper analyses wind characteristics and outdoor thermal comfort index at the hottest temperatures based on data recorded hourly between 2012 and 2014 for two cities in East Malaysia, namely Kuching (Sarawak) and Kota Kinabalu (Sabah). Wind characteristics were analysed using only wind velocity and direction, while the level of outdoor thermal comfort was measured using Universal Thermal Climate Index (UTCI). The results showed that hourly average wind velocities for Kuching and Kota Kinabalu were 1.84 m/s and 2.15 m/s respectively while the highest average wind velocities was 10.1 m/s and 12.4 m/s respectively. No wind movement (i.e. 0 m/s) was recorded for both locations. The prevailing annual wind flow is generally from South-Southeast (150°) in Sarawak and from East-Southeast (110°) in Sabah. It was also found that both Kuching and Kota Kinabalu experienced strong and extreme heat stress conditions with UTCI levels of 44.8°C and 49.8°C respectively. Thus, it can be concluded that, East Malaysia faces strong and extreme heat stress conditions. This study is an original contribution on the subject of outdoor thermal environment in Malaysia, Further research to better understand outdoor thermal environmental problems is recommended.

Keywords: Outdoor thermal comfort, thermal stress, universal thermal climate index, warm and humid climate, wind direction, wind velocity

ARTICLE INFO

Article history:
Received: 29 September 2016
Accepted: 05 April 2017

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ISSN: 0128-7680

INTRODUCTION

In recent years, there have been an increasing academic interest in issues regarding urbanisation and climate change and their subsequent impact on global warming (Abd Razak et al., 2013; Ignatius et al., 2015; Jeong et al., 2016; Jihad & Tahiri, 2016; Martins et al., 2016; Sharmin et al., 2015). In Malaysia, thermal environmental problems have been extensively studied by researchers (Abdullah & Wang, 2012; Azizpour et al., 2013; Ghaffarianhoseini et al., 2015; Rajagopalan et al., 2014; Wang & Abdullah, 2011). In terms of global warming, temperatures have increased by 0.35°C per decade for the period 1969-2014 in Central Peninsular Malaysia (MetMalaysia, 2015). As a consequence, Malaysia's urban areas have become warmer which can adversely affect the internal and external thermal environment especially in urban areas. Furthermore, global warming can be harmful to human thermal comfort level. To date, only a few studies have tackled these issues focusing on the effects of urbanisation on outdoor thermal environment in Malaysia. Additionally, building arrangement parameters such as frontal area density (λ_f), packing density (λ_p), height-to-width ratio (λ_s) etc., have accentuated the problem of heat stress as they have not been considered during the design stage of urban development (Abd Razak et al., 2013; Hang, Li, & Sandberg, 2011; Hang, Li, Sandberg, Buccolieri, & Di Sabatino., 2012; Kubota et al., 2008). Thus, this study examined the current wind characteristics and extreme outdoor thermal comfort index. Despite these promising results, further research should be undertaken to scientifically investigate the relationship between building design and outdoor thermal environment in warm and humid climate in order to improve the unfavourable thermal conditions.

Study Area

The area of study is situated at coordinate of 2°30' North latitude and 112°30' East longitude. According to recent climatic data analysis, Malaysia experiences a wet and humid condition with daily temperature fluctuating between 24°C and 38°C (MetMalaysia, 2015). It is probable that wind velocity and prevailing wind in this area are influenced by three monsoon seasons, namely northeast monsoon, southwest monsoon and two short inter-monsoons.

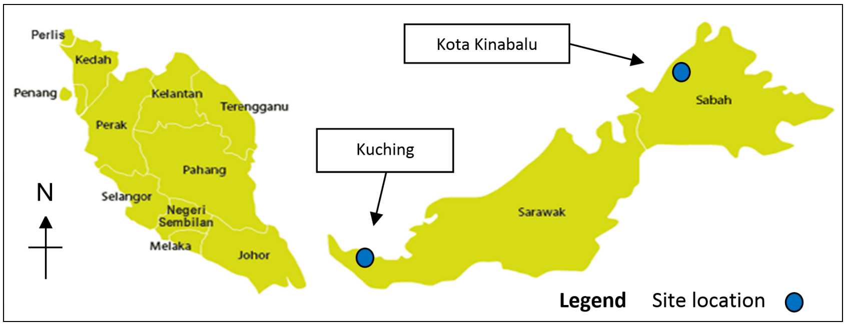


Figure 1. Map of Peninsular Malaysia showing the case study stations

During southwest monsoon season, wind velocity is below 8m/s. Meanwhile, for northeast monsoon season, the wind velocity is in the range of 5 to 10 m/s. Generally, wind velocity is light and inconsistent during inter-monsoons seasons. Annually, Malaysia experiences monthly average relative humidity between 70% to 90%. Additionally, the country has around 6 hours of solar radiation per day on average (MetMalaysia, 2015). This study was aimed at enhancing our understanding of outdoor thermal environment in two different cities in East Malaysia, namely Kuching (i.e. Northwestern part of the Borneo island) and Kota Kinabalu (i.e. West coast of Sabah), as shown in Figure 1 and outlined in Table 1. The wind characteristics and outdoor thermal comfort levels were examined using weather data that correspond with the hot and humid tropical climate of Malaysia from two principal weather stations in Kuching and Kota Kinabalu.

Table 1
Location of weather stations

Station	Latitude	Longitude	Height above sea level (m)
Kuching	1° 29' N	110° 21' E	20.90
Kota Kinabalu	5° 56' N	116° 03' E	2.10

MATERIALS AND METHODS

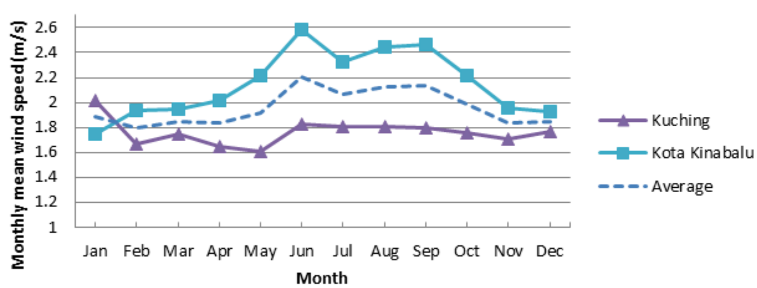
First, hourly weather data for 20 years (1994-2014) from Kuching and Kota Kinabalu weather stations were obtained and studied (MetMalaysia). The aim was to determine the hottest ambient temperature of the day throughout the 20 year period and to examine whether high heat stresses occur based on universal thermal climate index (UTCI) . Hourly wind velocity and wind direction data from 2012 to 2014 were analysed to examine wind characteristics. The wind velocity and direction at both weather stations were measured using rotating cup type anemometer and wind vane installed at the height of 10 m above the ground as suggested by Katsoulis (1993) for practical and climatological considerations. The hourly interval of wind velocity and directions were measured and stored in data logger. This study assesses the outdoor thermal comfort level using UTCI value which is calculated based on regression equation devised by International Society of Biometeorology Commission 6 by COST (European Cooperation in Science and Technology) Action 730 under the umbrella of the WMO Commission on Climatology (Jendritzky et al., 2012). Weather parameters taken into account for calculating UTCI (°C) consist of wind velocity (m/s), ambient temperature (°C), relative humidity (%) and solar radiation (W/m^2) (Kjellstrom et al., 2015). The UTCI is suitable for thermal evaluation in all climates and seasons (Jendritzky et al., 2012).

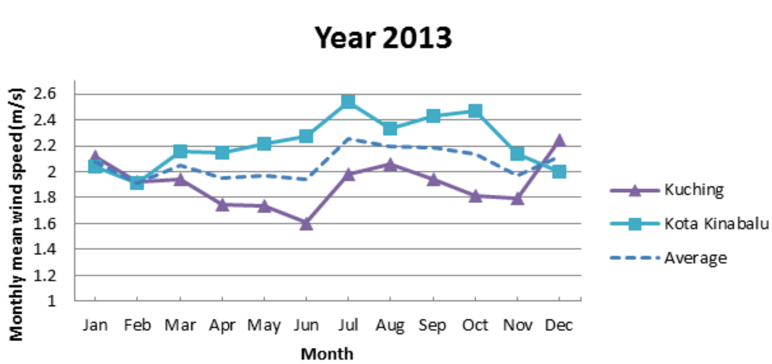
Universal Thermal Climate Index (UTCI)

The UTCI is classified into 10 different stress levels: thermal stress, 4 heat stress levels, and 5 cold stress levels (Glossary of Terms for Thermal Physiology, 2003). The UTCI is defined as the equivalent ambient temperature of a reference environment that causes the same physiological response of a reference person as well as the actual environment (Blazejczyk et al., 2012). It is based on Fiala multi-node model of human thermal regulation in combination with an adaptive clothing model (Fiala, Lomas, & Stohrer, 2008).

RESULTS AND DISCUSSION

This section discusses wind characteristics and outdoor thermal comfort by analysing weather parameters over a three-year period (2012 to 2014), which comprise relative humidity, ambient temperature, average wind velocity, min-max wind velocity, wind direction, and solar radiation. Figure 2 shows the monthly average wind velocity in Kuching and Kota Kinabalu. On average, the windiest months were from July to October which recorded between 2.02 to 2.13 m/s due to the southwest monsoon. During inter-monsoons, the minimum average wind velocity of 1.89 m/s was recorded between April and November. From November to March, the average wind velocity was in the range of 1.90 to 2.06 m/s, where it reached the peak of 2.06 m/s in January due to northeast monsoon season. Moreover, the average wind velocity for Kuching and Kota Kinabalu was 1.84 m/s and 2.15 m/s respectively. Average wind velocity at both locations indicated only slight differences. The mode of wind velocity in Kuching was 1.2 m/s, which is considered as the dominant reading with 4.76% of frequency. Meanwhile, Kota Kinabalu demonstrated 1.7 m/s as the dominant reading with 4.88% of frequency. Moreover, the maximum monthly average wind velocity for Kuching and Kota Kinabalu were 2.14 m/s and 2.37 m/s respectively. In contrast, the lowest monthly average wind velocity in Kuching was 1.68 m/s, and it was slightly higher in Kota Kinabalu at 1.92 m/s. The highest wind velocity was 12.4 m/s in Kota Kinabalu on 16th July 2013 at 4.00 p.m., while Kuching's highest wind velocity was 10.1 m/s on 25th May 2012 at 4.00 p.m. As no wind movement (i.e. 0 m/s) can be considered as the lowest hourly wind velocity for both locations, Kuching showed the highest frequency of calmness at 3.75% as compared to that of Kota Kinabalu at only 0.9%. The variations of hourly average wind velocity were displayed by standard deviation values of 1.22 and 1.04 for Kuching and Kota Kinabalu respectively.





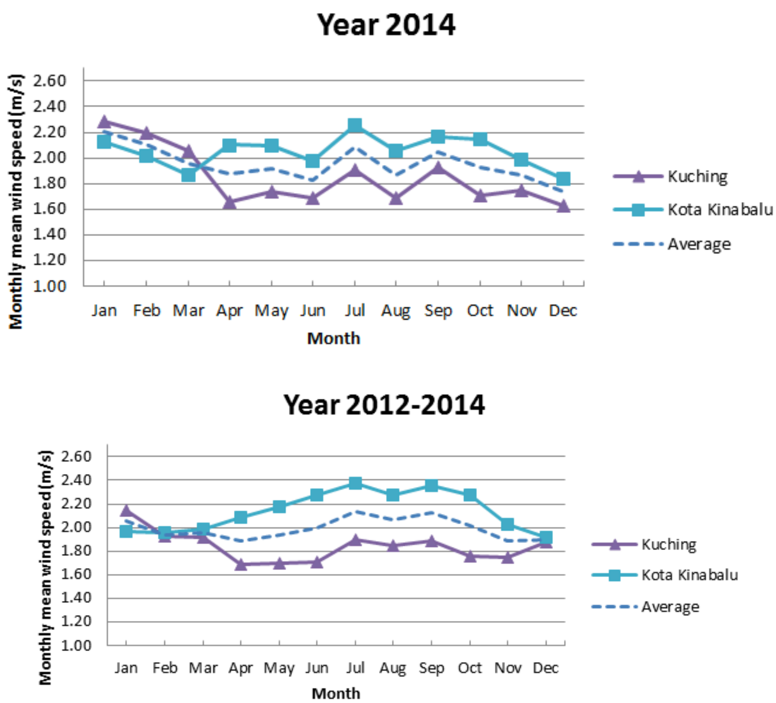
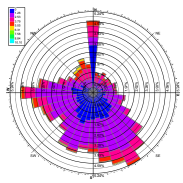
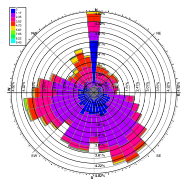
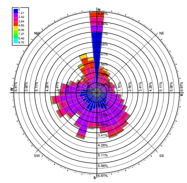
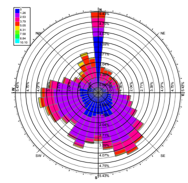
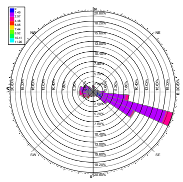
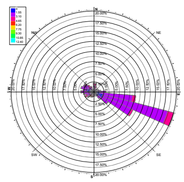
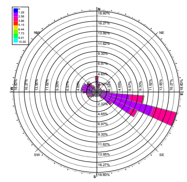
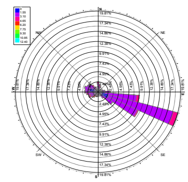


Figure 2. Monthly average wind velocities at 10 m height for the selected locations

Not only the values and trends of wind velocity, but the prevailing wind is also important in assessing the possibilities of outdoor thermal comfort conditions. The results of wind characteristic analysis can be very useful especially for design team to finalise their design of building orientation and position in relation to other surrounding buildings. This is particularly important in order to enhance building permeability for greater induction of wind that can reduce heat. Table 2 shows the trends of prevailing wind in Kuching from South-Southeast direction (150°), and from East-Southeast direction (110°) in Kota Kinabalu, with an average frequency of about 4.59% and 19.81% respectively. These results also indicated that both locations have different prevailing wind velocities throughout the years. However, their prevailing wind directions remained the same every year for each of the locations, except in 2014 where the prevailing wind direction in Kuching was from North (0°). In short, yearly weather data analysis for the three-year period show different wind directions. A more precise wind directions for both locations can be obtained if a longer study period is considered.

Table 2
Annual wind rose distribution and frequency

Location/Year	2012	2013	2014	(2012-2014)
Kuching				
Kinabalu				

Data was also analysed to determine worst heat stress scenarios. In general, as can be seen from Table 3, during the hottest temperatures, both locations experienced different levels of heat stress, where Kuching was slightly better than Kota Kinabalu. In 2012, Kota Kinabalu recorded the highest UTCI value of 49.8°C as it experienced extreme heat stress condition. In contrast, Kuching has the lowest UTCI value of 42.9°C as it experienced strong heat stress condition. In general, Kota Kinabalu experienced the most extreme heat stress condition as compared to Kuching. In short, UCTI values revealed that heat stress was a common problem in East Malaysia. It increased people's level of thermal discomfort, particularly in dense urban areas. Global warming especially in urban areas are real issues due to higher solar radiations and inadequate wind velocity to wipe out the heat entrapped in and around a building.

Table 3
Annual UTCI in the study at hottest temperature in 2012-2014 (3 years)

Location	Year	Time	Temperature (°C)	Relative Humidity (%)	Wind Velocity (m/s)	Solar Radiation (W/m^2)	UTCI (°C)	Stress Category
Kuching	29.9.2012	1600	35.8	39	3.6	611.11	42.9	Very strong heat stress
	23.6.2013	1500	36.1	30	2.7	736.11	44.7	Very strong heat stress
	26.7.2014	1600	37.0	33	2.1	611.11	44.8	Very strong heat stress
Kota Kinabalu	19.5.2012	1400	34.9	68	2.1	916.67	49.8	Extreme heat stress
	23.9.2013	1400	35.2	54	1.3	936.11	49.0	Extreme heat stress
	7.5.2014	1500	36.1	53	1.4	797.22	48.4	Extreme heat stress

Table 4 shows extreme heat stress condition was recorded in Kota Kinabalu and Kuching. Kota Kinabalu recorded not only the highest UTCI value of 49.8°C but also the highest solar radiation intensity of 797.22 W/m^2. Even though solar radiation in Kota Kinabalu was around 30% greater than that of Kuching, its UTCI values differed slightly around 8%. This is because wind velocity value of 2.1 m/s in Kuching was about 50% greater than that of Kota Kinabalu. It is almost certain that higher wind velocity would contribute to a positive effect on heat stress performance.

Table 4
UTCI index of the hottest temperature in 1994 to 2014 (20 years)

Location	Year	Time	Temperature (°C)	Relative Humidity (%)	Wind Velocity (m/s)	Solar Radiation (W/m^2)	UTCI (°C)	Stress Category
Kuching	26.7.2014	1600	37.0	33	2.1	611.11	44.8	Very strong heat stress
Kota Kinabalu	7.5.2014	1500	36.1	53	1.4	797.22	48.4	Extreme heat stress

CONCLUSION

An analysis of weather data in Kuching and Kota Kinabalu over a 20-year period (2012-2014) showed that the average monthly mean wind velocities were 1.84 m/s and 2.15 m/s respectively; while the highest wind velocity for Kuching and Kota Kinabalu were 10.1 m/s and 12.4 m/s respectively. The results indicate that Kota Kinabalu experienced windier conditions compared with Kuching which showed the lowest frequency of calmness at 0.9%. In addition, the annual trend of prevailing winds in Kuching and Kota Kinabalu demonstrated a slight difference. The prevailing wind direction in Kuching was from South-Southeast (150°), and Kota Kinabalu was from East-Southeast (110°) with their average frequencies of about 4.59% and 19.81% respectively. Additionally, Kota Kinabalu recorded the most extreme heat stress condition as compared to Kuching. The UTCI values also pointed to extreme heat stress conditions in Kota Kinabalu, and very strong heat stress in Kuching. The present study was a preliminary investigation in evaluating the wind velocity and prevailing wind direction characteristics as a reason to have an inclusive wind data base. These findings have significant implication, particularly to researchers in evaluating a better prediction of outdoor thermal comfort in future work. Despite its exploratory nature, this study offers some insight and awareness on the current heat stress problem in East Malaysia. These findings would be useful for researchers, state authorities and country's policy makers. This should help improve predictions of current environmental issues as well as encourage a proper and well-planned strategies by incorporating suitable design parameters such as building geometry, building orientation, and building permeability; which can reduce heat in urban areas and thereby increase the level of outdoor thermal comfort, especially in warm and humid climate of Malaysia.

ACKNOWLEDGEMENT

The authors are grateful to the financial support from the Ministry of Education Malaysia, Universiti Tun Hussein Onn Malaysia Malaysian (UTHM), Meteorological Department and Research Grant STG Vot No. U339.

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