EVALUATION OF SECONDARY SCHOOL STUDENT'S OUTDOOR THERMAL COMFORT DURING PEAK URBAN HEATING HOURS IN GREATER KUALA LUMPUR

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Abstract

Background: There are rising concerns for the deterioration of outdoor thermal comfort (OTC) level as it influences the health and well-being of sensitive and vulnerable urban communities such as school children. However, the understanding of OTC among school children in an urban setting has been poorly highlighted in existing literature.

Methods: A cross-sectional quantitative study was conducted among secondary school students in a selected area within Greater Kuala Lumpur (GKL) so as to understand their thermal perception towards the urban outdoor environment. A clustered random sampling was used to gather a total of 236 students for this study. Meteorological data were collected concurrently with the questionnaire survey which was conducted during the peak urban heating hours (0800 – 2000) from July 2018 to January 2019.

Results: The secondary school students in the selected study area felt hot (n=120, 51%) and experienced little discomfort (n=144, 61%). If given a choice, 76% (n=179) of the students preferred a cooler environment although 56% (n=132) accepted the current thermal environment. Findings based on the on-site meteorological observations revealed that the students were constantly exposed to a mean of 32.7˚C Physiological Equivalent Temperature (PET) while the expected neutral temperature was found to be 25.1˚C PET.

Conclusion: Based on these outcomes, it can be deduced that the students in this study showed traits of thermal acclimatization. Future studies should be conducted to identify the influence of other confounding factors, such as gender, ethnicity, and clothing variations among the secondary school students so as to ensure that the students are able to better adapt to the deteriorating OTC levels in urban outdoor spaces.

Keywords: *Heat Exposure, Outdoor Thermal Comfort, Tropical Climate, Urban Heat Island Urban Well-being*

Introduction

Global climate change and rapid urbanization in the tropical cities are weakening the liveability status of the urban population. Urban Heat Island (UHI), a phenomenon associated with rapid urbanization, worsens this problem by adding additional warmth in city centres (1). The increasing UHI intensity (UHII) in tropical cities have worsened the environment, the urban ecosystem, and people's well-being, which subsequently induced human thermal stress in urban spaces (2, 3). As half of the world's population is concentrated in the tropics (4), more studies (5) are focusing on identifying the strategies which can enhance the liveability of the urban communities in tropical cities The deterioration of outdoor thermal comfort (OTC) levels, as a direct impact from the UHI should be of public concern because a constant rise in temperature within tropical cities will lead to the aggravation of heat waves, heat-related illnesses (HRI), and even mortalities (6).

In general, thermal comfort refers to the condition of the mind that expresses satisfaction with the thermal environment (7). Specifically, OTC refers to the comfort level of a person with regards to an exposed outdoor environment. OTC can be evaluated using indices, such as Physiological Equivalent Temperature (PET) that was developed based on the heat exchange process between the human body, and the external environment which forms the fundamental human-thermal energy balance equation (8, 9). As PET is expressed in a widely known unit (°C), it is commonly used to establish an understanding among those who are unfamiliar with the human bio-meteorological conditions, such as urban planners and policy makers (10).

The thermoregulatory capabilities of the human body in maintaining body core temperature is important for avoiding potentially hazardous health implications (11). Vulnerable groups such as children, elderlies, pregnant women, and those with existing health complications are at a higher risk due to the deterioration of the OTC levels (12-14). A significant lack of studies on human OTC in the tropics (15-20) therefore, highlights the urgent need for more scholarly studies to be conducted on these vulnerable groups. Distinctively, children possess unique vulnerability characteristics because they are less capable in dealing with such complex environments although they have more years of life expectancy. This implies that they have more time to develop chronic illnesses that have been triggered by early exposures (21). Aiming to address this need, the current study was thus conducted so as to identify the OTC of the secondary school children based in selected urban areas in Greater Kuala Lumpur (GKL). In particular, this study aims to evaluate the OTC of the secondary school students towards the outdoor thermal environment. This study also aims to identify the neutral temperature for secondary school students at outdoor urban spaces.

This study follows the holistic approach of conducting the OTC assessment in the tropical region as proposed by Fong *et al.* (2019) (6).

Ethical considerations

The current study was approved by the University of Malaya Medical Ethics Committee (MECID NO: 2016928-4295). Informed consent was obtained from the respondents verbally. They were also informed that participation was voluntary, and any information obtained from the survey would be kept confidential and only used for this study.

Description of the study area

GKL refers to a geographical region that comprises of Kuala Lumpur (KL), and its surrounding satellite towns (1). In general, GKL experiences a tropical climate with sufficient amount of annual rainfalls, relatively constant annual net solar radiation, and a monthly mean temperature of at least 18°C and above (22). Prior to any micro-scale climate observation, the observation site (Masjid Jamek) within GKL was chosen and defined to cover 500m radius so as to ensure that the air temperature of this zone did not overlap with the neighbouring thermal climate zones (23). In particular, Masjid Jamek was chosen due to its position as the centre of an economic hub that has multifunctional roles in commerce, transportation, and education. The area embraces six public schools, two private schools comprising of an International school and a Chinese Independent school, and five tuition centres in the vicinity. The location of the selected study area is illustrated in Fig. 1.

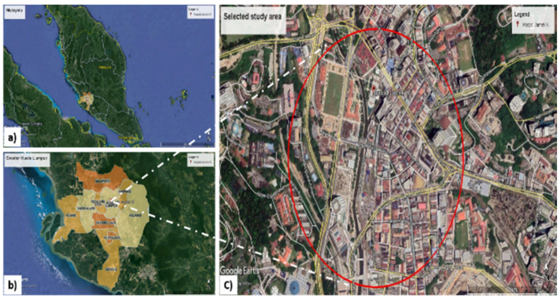

Figure 1: a) Map of Malaysia. b) Map of Greater Kuala Lumpur. c) The selected study area, Masjid Jamek (3° 8'56.15"N, 101°41'44.56"E) Source: Google Earth Pro (2019)

Sample size

The findings from a similar study by Na *et al.* (2012) (24) was utilized together with the OpenEpi software (Version 3.01) to estimate the sample size of this study. It was noted that the required sample size should be 206 respondents.

Sampling population

Data sampling was conducted around the selected study area at Masjid Jamek (MJ). The participants chosen for this study must fulfil two inclusion criteria: 1) they must be secondary school students, and 2) they must be exposed to the outdoor environment. To minimize the influence of biasness in reporting the OTC, the respondents were required to be exposed to the outdoor environment in a standing posture for at least 10 minutes. This was done to allow thermal equilibrium to set in between the individuals and the thermal environment prior to conducting the subjective assessment (11). Biasness in reporting the OTC level may occur because of the respondents being in a cooler environment prior to answering the questionnaire. Data sampling was carefully conducted so as to ensure that the proportion of males to females was equally distributed.

Data collection duration

Data collection was conducted from July 2018 to January 2019. To address the daily microclimatic variations, the collection of meteorological parameters, such as air temperature, relative humidity, wind speed, and solar radiation was conducted from 0800 to 2000 as the UHII was found to vary in between these time periods (25).

Data collection

In-situ field measurements for the collection of meteorological parameters

Variations in the surrounding thermal environment were recorded via in-situ measurements so as to collect the meteorological data, such as air temperature, relative humidity, wind speed, wind direction as well as solar radiation from the weather stations. The height of the instrument was set to be 1.5m above ground surface so as to represent the human-height level (6) for collecting data.

Subjective assessment using structured questionnaire

As thermal comfort varied subjectively from one person to another (26), on-site surveys were needed for the individual level of the OTC analysis (27). In the present study, school students who were found within the study area were invited to answer the questionnaire as it was rational to assume a consistent microclimate condition within the selected study area (28). While the subjective assessment of the OTC was on-going, the microclimate measurements were also recorded simultaneously. The questionnaire mainly consists of two sections: questions on sociodemographic information, and OTC assessments. In the sociodemographic section, information such as gender, age and ethnicity were requested from the respondents. In the OTC assessment section, respondents were required to express their thermal sensation, preference, acceptance, and comfort levels using established Likert scales based on the ISO 10551: "Ergonomics of The Thermal

Environment -- Assessment of The Influence of the Thermal Environment Using Subjective Judgment Scales" (29).

Data analysis

Variations in the meteorological and subjective assessment of the OTC

All statistical evaluations were conducted using the SPSS software (version 25). The descriptive analyses were performed so as to identify the mean and standard deviations of the urban microclimate variations in the study area. A PET value was calculated using the means of the meteorological data. This helped to express the microclimate variations in terms of the physiological equivalent heat stress. This value will be used for comparison with the neutral temperature expected by the secondary school students in the data analysis.

At the same time, the frequency and percentage distribution of votes for thermal sensation, acceptance, preference and comfort levels were determined for the subjective assessment of the OTC.

Evaluating the Physiological Equivalent Temperature with RayMan model

Physiological Equivalent Temperature is defined as the air temperature where the heat balance of the human body is adjusted between two human body nodes (core and skin) under typical indoor settings, and which equals to the complex outdoor conditions being assessed (16, 30). Data on the air temperature, relative humidity, wind speed, mean radiant temperature, human clothing, and activity levels were needed for the estimation of the PET (14, 31). From the perspective of the thermal comfort, it was anticipated that individual parameters, such as metabolic heat and clothing factors would influence the thermoregulation of the human body, besides the external driving factors, such as the meteorological parameters. However, to generalize the findings in terms of the physiological equivalent heat stress, standard values were assumed for the metabolic heat, and the clothing factor. This study assumes the metabolic rate of the male and female students to be the same, which is 1.4 met for standing (1 met=58.15W/m^2). Meanwhile, the average clothing value was assumed to be 0.30 clo (1 clo= 0.155°C). This value was based on Yang *et al*. (2013) (32) who examined 2046 individuals from Singapore who were believed to share common sociodemographic attributes with the people from Malaysia.

Estimating the expected neutral temperature

A univariate linear regression was conducted so as to identify the expected neutral temperature of the secondary school students. This was performed by plotting the mean of the thermal sensation votes (TSV) against the PET through the RayMan model.

Results

Variations of the meteorological data

A descriptive statistic was performed on the meteorological data through the in-situ weather station. The mean and standard deviation of the meteorological data are summarized in Table 1.

Table 1: Microclimate conditions of the study area

Meteorological parameters	Mean*	SD*
Air temperature (°C)	28.8	2.5
Relative humidity (%)	69.1	11.4
Wind speed (m/s)	1.3	1.0
Solar radiation** (W/m^2)	309.3	290.9
Mean radiant temperature** (°C)	39.0	14.9

*based on meteorological data collected from July to December 2018

**based on solar radiation collected from 0800 to 2000

The mean PET was calculated by using the mean of the meteorological data which was 32.7 °C PET.

Sociodemographic attributes of the respondents

A total of 236 eligible responses were gathered within the data collection period. The respondents' sociodemographic attributes are summarized in Table 2.

Table 2: Sociodemographic attributes of the respondents (N=236)

	Frequency (%)
Gender	
Male	130 (55.1)
Female	106 (44.9)
Age (years)	
15	1 (0.4)
16	4 (1.6)
17	29 (12.2)
18	93 (39.6)
19	109 (46.2)
Ethnicity	
Malay	46 (19.5)
Chinese	157 (66.5)
Indian	22 (9.3)
Others	11 (4.7)

The respondents participating in this study were equally distributed in terms of gender, with males comprising 55.1% (n=130), and females comprising 44.9% (n=106). Majority of the respondents were aged between 18 (39.6%, n=93) and 19 (46.2%, n=109) years old. In terms of ethnicity, majority were Chinese students (66.5%, n=157), followed by Malays (19.5%, n=46), Indians (9.3%, n=22), and others (4.7%, n=11).

The outdoor thermal comfort level of secondary school students

The thermal sensation, acceptance, preference and comfort levels of secondary school students

In the second section of the questionnaire, the secondary school students' OTC levels were assessed. In particular, the students were asked to express their sensation towards the surrounding thermal environment. The students were also asked if the thermal environment was acceptable, and if given a choice, how would they prefer the thermal environment to be. Lastly, they were asked to express their thermal comfort levels. The responses from the questionnaire are presented in Fig. 2.

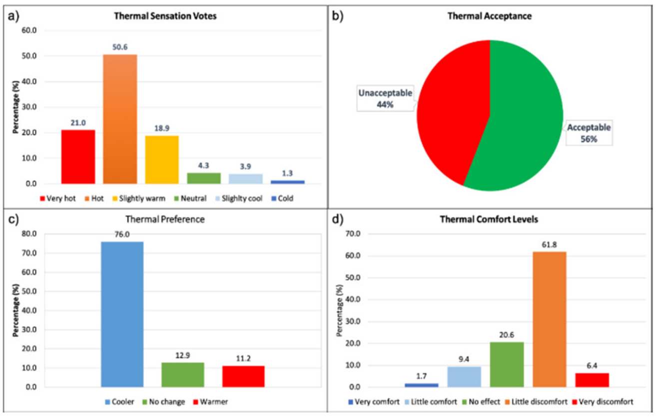

Figure 2: a) Thermal sensation votes, b) Thermal acceptance, c) Thermal preference, and d) Thermal comfort levels of secondary school students

As seen in Fig. 2 (a), about 90% of the students voted positive thermal sensation, i.e., slightly warm (18.9%, n=45), hot (50.6%, n=119), and very hot (21.0%, n=50). Although about 90% had reported positive thermal sensation, the proportion of the thermal acceptance was quite equally distributed, i.e., acceptable (56%, n=132), and unacceptable (44%, n=104) as shown in Fig. 2 (b). Although 56% (n=132) of the respondents had reported the acceptance of the current thermal environment (Fig. 2 (b), it was noted that about 80% (n=179) of them actually preferred a cooler environment (Fig. 2 (c)). In terms of thermal comfort levels, 6.4% (n=15) of the respondents claimed that they felt a lot of discomfort whereas majority (61.8%, n=146) reported a little discomfort in the urban outdoor spaces.

The expected neutral temperature of secondary school students

A univariate regression was conducted to identify the neutral temperature of the secondary school students by analysing the linear relationship between the TSV and PET values (32). The mean of the thermal sensation votes (MTSV) according to each PET value was determined and plotted in Fig. 3.

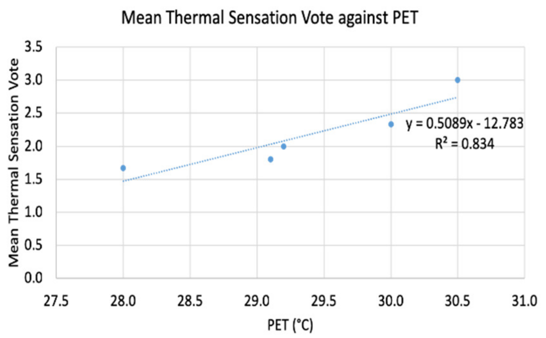

Figure 3: Mean thermal sensation votes plotted against PET

The linear regression representing the MTSV and PET for the secondary school students is shown in Eq. (1).

$$MTSV=0.5089PET - 12.783, R^2 = 0.834 \quad \textbf{Eq (1)}$$

The MTSV correlated strongly with the PET (R^2=0.834), explaining 83.4% of the variability in the TSV. Based on Eq. (1), the neutral PET was noted to be 25.1°C for the secondary school students. The finding of this study is in agreement with the findings of Yang *et al.* (2013) (32) where the preferred temperature of the Singaporeans was reported to be 25.2ºC PET.

Discussion

Urban microclimate variations in the selected study area

The population in the selected study area was expected to experience a typical hot and humid tropical climate with the combination of moderate high air temperature (μ=28.8°C, SD=2.5) with relative humidity (μ=69.1%, SD=11.4). In terms of wind speed, the selected study area with a mean wind speed of 1.3 m/s and standard deviation of 1.0 m/s was expected to experience calm to light breeze air movement, according to the Beaufort scale. In addition, the selected study area was also receiving plentiful of solar radiation with a mean of 309.3 W/m^2. The calculated mean of the PET is 32.7°C PET. This indicated that the urban communities were expected to physiologically feel slightly warm in the study area.

Outdoor thermal comfort level of secondary school students in selected study area

Results indicated that the secondary school students in the selected study area felt hot (n=120, 51%) and a little discomfort (n=144, 61%). If given a choice, 76% (n=179) of the students preferred a cooler environment although 56% (n=132) of them accepted the current thermal environment. One of the possible reasons for the students to feel hot and a little discomfort may be the lack of green lungs in the urban area. To overcome this, urban greening is essentially needed so as to improve the current OTC levels in the urban outdoor spaces (33). Besides that, providing more shades in the selected study area could also improve the local OTC level. Future studies should also explore other urban heat adaptation measures, such as the student's clothing materials to see if this may help.

Traits of adaptive thermal comfort

The secondary school students in this study exhibited traits of adaptive thermal comfort.

Through the linear regression, it was found that their expected neutral temperature iwa 25.1°C PET. Despite being constantly exposed to an urban environment with a mean of 32.7°C PET, 56% (n=132) of the respondents reported acceptance of the thermal environment. In this study, the possible reason for the acclimatization could be the students' physiological and psychological adaptation of the climate. The students in this study had been exposed to the hot-humid environment for more than 10 years. Throughout the years, their body and mind may have accepted the condition, and this may have changed their expectations about the thermal environment, hence their higher tolerance towards the thermal environment.

The strength and limitations of the study

There are several strengths to this study. Firstly, this study had provided an insight to the heat perception of school children at urban outdoor spaces within a tropical city. This study explored the OTC in terms of thermal sensation, acceptance, preference, and comfort level as well as the school children's expected neutral temperature within the city centre. The findings of this study contributed to the scientific literature in terms of understanding the impact from urban heat towards the general health and well-being within a tropical city. In addition, this study also identified that the school children had acclimatized to the thermal sensation of the study area. Future studies should explore other factors that could have influenced the school children's adaptation of the urban warming phenomenon.

The current study is also confined to some limitations. The first limitation lies in the subjective assessment of the OTC. As the interaction between the environment, built-environment and human bio-meteorology is deemed complex, it is possible that the findings derived from the OTC assessment may have experienced some bias and inconsistency due to the thermal adaptation. This was addressed, however, by using protocols to minimize the influence of such adaptive behaviours in order to improve the reliability of the findings.

The second limitation is that the metabolic rate and the clothing factors for both the male and female respondents, across the different ethnicity were assumed to be the same for the estimation of the PET in this study. It is possible that in reality, the metabolic heat and clothing preference could have varied among the individuals. For example, the clothing for a Malay school girl would be different as compared to school girls of a different ethnicity. Future studies should address some of these gaps so as to validate the current findings.

Conclusion

This study has attempted to identify the OTC of secondary school students within the city centre of GKL. Generally, the secondary school students had felt hot (n=120, 51%), and a little discomfort (n=144, 61%) in the selected study area. Although 76% (n=179) of the secondary school students preferred a cooler environment, half of the students had accepted the current thermal environment. It was found that the secondary school students were constantly exposed to the outdoor environment with a mean temperature of 32.7°C PET. Through the univariate linear regression of the MTSV and PET, it was found that the secondary school students had expected a neutral temperature of 25.1°C PET. Additionally, the students in this study showed traits of thermal acclimatization when 56% (n=132) of them registered their acceptance of the thermal environment, despite being constantly exposed to an environment that was hotter than their expected neutral temperature. It is noted that an in-depth knowledge regarding thermal adaptation and its influencing factors within the tropical context of SEA is yet to be understood. Future studies could be conducted so as to explore how other confounding factors such as gender, ethnicity and clothing variations could affect the school students' OTC level within a tropical city. These findings would be beneficial to the government for devising any effective urban heat adaptation measures that can be used to ensure the well-being of these school children when exposed to urban outdoor spaces.

Acknowledgment

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Declaration of interest

None.

References

1. Ramakreshnan L, et al. A critical review of urban heat island phenomenon in the context of greater Kuala Lumpur, Malaysia. Sustain Cities Soc. 2018 May;39:99–113.
2. Yang W, Wong NH & Lin YL. Thermal comfort in high-rise urban environments in Singapore. In: Sun Y & Pei J Ed. In Proceedings of the 9th International Symposium on Heating, Ventilation and Air Conditioning. Amsterdam: Elsevier Science Bv. 2015;121:2125–2131.

3. Yang W, Wong NH & Li CQ. Effect of street design on outdoor thermal comfort in an urban street in Singapore. J Urban Plan Dev. 2016 Mar; 142(1):05015003.
4. Siemens A. Asian green city index assessing the environmental performance of Asia’s major cities. German: Siemens AG. 2011;1–123.
5. Ignatius M, Wong NH & Jusuf SK. Urban microclimate analysis with consideration of local ambient temperature, external heat gain, urban ventilation, and outdoor thermal comfort in the tropics. Sustain Cities Soc. 2015 Dec;19:121–135.
6. Fong CS, Aghamohammadi N, Ramakreshnan L, Sulaiman NM & Mohammadi P. Holistic recommendations for future outdoor thermal comfort assessment in tropical Southeast Asia: a critical appraisal. Sustain Cities Soc. 2019 Jan;46:101428.
7. ASHRAE Standard 55: Thermal environmental conditions for human occupancy. ASHRAE. 2013;ASHRAE Sta:58.
8. Parson K. Human thermal environments the effects of hot, moderate, and cold. 2003;3–4.
9. Mayer H & Hoppe P. Thermal comfort of man in different urban environments. Theor Appl Climatol. 1987;38(1):43–49.
10. Lin TP & Matzarakis A. Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. Int J Biometeorol. 2008 Mar; 52(4):281–290.
11. Kurazumi Y, Ishii J, Fukagawa K, Kondo E & Aruninta A. Ethnic differences in thermal responses between Thai and Japanese females in tropical urban climate. 2016 March;52–68. Available from: file.scirp.org.
12. Acero JA, Arrizabalaga J, Kupski S & Katzschner L. Urban heat island in a coastal urban area in northern Spain. Theor Appl Climatol. 2013 Jul;113(1–2):137–154.
13. Nakano A. Urban weather generator user interface development: towards a usable tool for integrating urban heat island effect within urban design process. 2015;125-131. Available from: https://dspace.mit. edu/handle/1721.1/99251.
14. Wilby R. A review of climate change impacts on the built environment. Built Environ. 2007 Mar;33(1):31–45.
15. Ahmed KS. Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments. Energy Build. 2003;35(1):103–110.
16. Chow WTL, Akbar SNABA, Heng SL & Roth M. Assessment of measured and perceived microclimates within a tropical urban forest. Urban For Urban Green. 2016;16:62–75.
17. Johansson E & Emmanuel R. The influence of urban design on outdoor thermal comfort in the hot, humid city of Colombo, Sri Lanka. Int J Biometeorol. 2006 Oct;51(2):119–133.
18. Lin TP, Matzarakis A & Hwang RLL. Shading effect on long-term outdoor thermal comfort. Build Environ. 2010 Jan;45(1):213–221.
19. Lin TP. Thermal perception, adaptation and attendance in a public square in hot and humid regions. Build Environ. 2009 Oct;44(10);2017–2026.
20. Morris KI et al. Impact of urbanization level on the interactions of urban area, the urban climate, and human thermal comfort. Appl Geogr. 2017 Feb;79:50–72.
21. Landrigan PJ. Children as a vulnerable population. Hum Ecol Risk Assess: An Int J. 2007;11(1):235–238.
22. Peel MC, Finlayson BL & McMahon TA. Updated world map of the Köppen-Geiger climate classification. Hydrol Earth Syst Sci. 2007;4(2):439–473.
23. Oke TR & Stewart ID. Local climate zone for urban temperature studies. Bull Am Meteorol Soc. 2012;93:1879–1900.
24. Na W et al. The effects of temperature on heat-related illness according to the characteristics of patients during the summer of 2012 in the Republic of Korea. J Prev Med Public Heal. 2013 Jan;46(1):19–27.

25. Ramakreshnan L, Aghamohammadi N, Fong CS, Ghaffarianhoseini A, Wong LP & Sulaiman NM. Empirical study on temporal variations of canopy-level urban heat island effect in the tropical city of greater Kuala Lumpur. Sustain Cities Soc. 2019 Jan;44:748–762.
26. Epstein Y & Moran DS. Thermal comfort and the heat stress indices. Ind Health. 2006;44(3):388–398.
27. Hwang RL & Lin TP. Thermal comfort requirements for occupants of semi-outdoor and outdoor environments in hot-humid regions. Archit Sci Rev. 2007 Dec;50(4):357–364.
28. Spagnolo J & de Dear R. A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney, Australia. Build Environ. 2003;38(5):721–738.
29. Din MFM et al. Thermal comfort of various building layouts with a proposed Discomfort Index range for tropical climate. J Therm Biol. 2014 Apr;41(1):6–15.
30. Höppe P. The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment. Int J Biometeorol. 1999 Oct;43(2):71–75.
31. Matzarakis A, Rutz F & Mayer H. Modelling radiation fluxes in simple and complex environments: basics of the rayman model. Int J Biometeorol. 2010 Feb;54(2):131–139.
32. Yang W, Wong NH & Jusuf SK. Thermal comfort in outdoor urban spaces in Singapore. Build Environ. 2013 Jan;59:426–435.
33. Ramakreshnan L, et al. A qualitative exploration on the awareness and knowledge of stakeholders towards urban heat island phenomenon in greater Kuala Lumpur: critical insights for urban policy implications. Habitat Int. 2019 Apr;86:28–37.