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In-situ Measurement of Pedestrian Outdoor Thermal Comfort in Universities Campus of Malaysia

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Abstract

The present study is intended to evaluate an outdoor thermal comfort at two universities campus in Malaysia. Field measurement and questionnaire survey were conducted simultaneously to assess the microclimatic condition and pedestrian thermal sensation. A total of 3033 samples were collected at seven different sky view factor (SVF) values that range from 0.2 to 0.9. The physiological equivalent temperature (PET) was estimated to evaluate outdoor thermal comfort. It was observed that at a highly shaded area (SVF < 0.35) the respondent's thermal sensation vote (*TSV*) are neutral (> 25%), acceptable for thermal acceptance vote (*TAV*) (> 50%) and no change (> 50%) for thermal preference vote *(TPV)*. For moderate shaded ($0.35 \leq$ SVF ≤ 0.70) *TSV* was voted as hot (> 25%), acceptable for *TAV* (40%), and prefer slightly cooler for *TPV* (>50%). For less shaded area ($0.70 <$ SVF ≤ 1), *TSV* was voted as hot and very hot (> 25%), acceptable for *TAV* (>40%) and prefer slightly cooler for *TPV* (> 40%). Moreover, the PET value increases simultaneously with the increase of SVF. Results thus suggest that at any given activities such as sitting, walking, and standing also caused effects slightly on the way people thermally perceive it during the on-campus daytime.

Keywords: thermal comfort, university campus, sky view factor

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1. Introduction

In definition outdoor thermal comfort is a complex function of atmospheric conditions with physical, physiological, psychological, and behavioral factors. Through these conditions and elements, it integrated response and thermal sensation which commonly discuss in human biometeorology studies [1-2]. Previous studies have reported, thermal sensation studies are dealing with the subjective and objective thermal assessment [3-5]. Indoor thermal comfort studies are conducted in climate-controlled condition appropriated to several standard and guidelines compared to outdoor thermal comfort studies that more challenging to access. In outdoor thermal comfort studies, several consideration is needed such as urban forms, urban geometry, surface materials, and landscapes.

In urban geometry context, sky view factor (SVF) is one of the main factors affecting local occupants' outdoor thermal sensation based on solar radiation fluxes at different shading level of the building, trees, and landscape [6-9]. Based on previous studies, the less shaded locations (high SVF) caused uncomfortable feeling than highly shaded sites (low SVF) [7-8] and the same goes for Malaysia. Since our local people are poorly hot-tolerant, thus overly shaded areas may induce comfort feeling due to low air temperatures. Therefore, Lin et al. [9] suggested multiple shading types, different levels of shading, shading devices, and planting deciduous trees that able to provide preferred thermal conditions for hot and humid climate condition. Also, trees also able to reduce wind speed and globe temperature by decreasing the radiation flux by the shading.

Moreover, in determining the outdoor human comfort satisfaction in thermal comfort it can be done by evaluating the discomfort situation by human adaption to the surrounding condition through several approaches such as interview survey or others. As past reviews of the urban climate studies, they claimed less amount of studies conducted in the tropics [10-13]. Therefore, it induces less understanding of the local urban climate in many tropical cities dealing with SVF. Thus, this paper focuses on the outdoor thermal comfort of university campus located in two city center in Malaysia to observe the substantial effect of SVF towards thermal sensation, acceptance, and preference thermal comfort at pedestrian's level under the different meteorological condition at a different city based on field measurements and questionnaire survey.

2. Method

2.1. Site descriptions

Universiti Teknologi Malaysia, Kuala Lumpur (UTMKL) is an institutional campus located in the urban area of Kuala Lumpur that experience a tropical rainforest climate or also known as hot, humid weather. The institution houses several medium rises and high rise academic blocks were connecting with different street geometry enclosing open spaces and streets for interaction. Moreover, Universiti Teknologi Mara (UiTM), Selangor is the main campus of UiTM out of 35 campuses located in city and capital state of Selangor.

This campus houses several medium and high rise academic blocks in the huge land area. The seven monitoring zones for both sites were pre-defined for evaluation in respects of urban geometry attributes (narrow streets, proximity green spaces, uniform or non-uniform streets canyons, public areas for on-campus people, pedestrian shaded and unshaded pathway). The ground surface (GS) for each location varies for different locations (concrete, interlocking brick, tiles, cement, asphalt concrete).

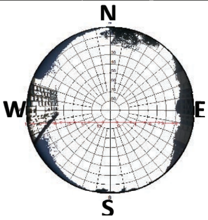
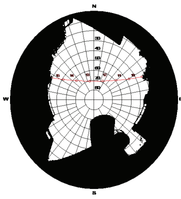
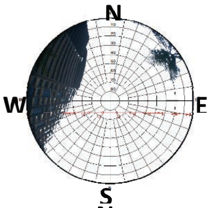
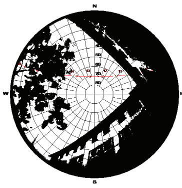
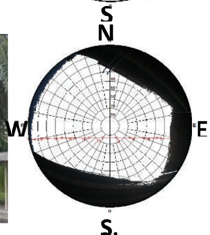
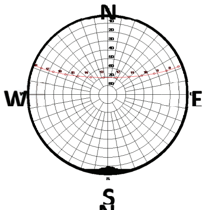
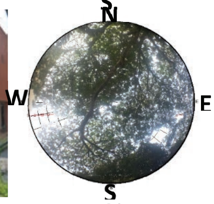
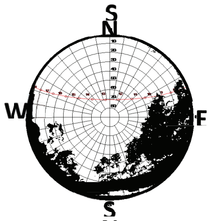
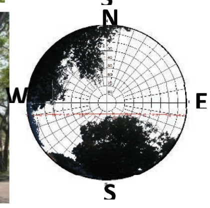
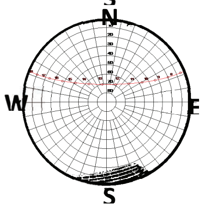
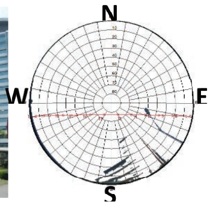
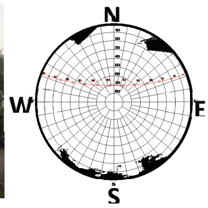
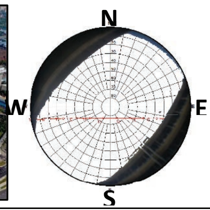
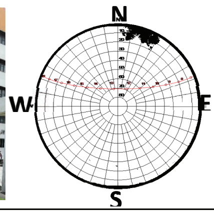
The definition of each monitoring zone was based on the photographic survey of the area by determining the visible sky from the upper hemisphere. The photographs were taken using a fisheye lens is imported to RayMan software [14]. Among 14 observation zones in UTMKL and UITM, the SVF range from 0.26-0.95. In this present study, the SVF are being categories into highly shaded ($0 < SVF < 0.35$), moderate shaded ($0.35 \leq SVF \leq 0.70$) and less shaded ($0.70 < SVF \leq 1$). The characteristic of those 14 measurement zones is sky view factor for UTMKL (A1-A7) and UiTM (B1-B7) as illustrated in Table 1.

2.2. Data collection

The on-site measurement and questionnaire survey were conducted simultaneously in each selected site in the year 2017 from the end of February to early of May in UTMKL, whereas from September to December 2017 in UiTM. The measurement spinning up to seven hours (9:00 am to 4:00 pm). A total number of 1512 questionnaires was completed within seven zones for three physical activities at UTMKL. In total, 81.2% of the respondents were males, and 18.8% was a female at the age of 18-22 years old. Whereas, 1521 questionnaire was completed at UiTM as same procedure as UTMKL with total 39.1% males and 60.9% females at 18-23 years old as shown in Table 2.

A portable weather station was utilized to measure the basic meteorological parameters, i.e., air temperature (T_a), relative humidity (*RH*), wind speed (*WS*) and direction (*WD*), globe temperature (T_g) and solar radiation (*SR*). During the field measurement, the measuring devices are placed at a 1.1 m height above ground level, and its distance from the respondent is one meter within each of measuring zone. The temperature and wind speed for thermal comfort evaluation measured at 1.1 m, respectively for seated, walking and standing people [15]. The mobile station is equipped with HOBO U series data logger and thermistor thermo recorder (TnD5i) sensor to measure the air temperature (T_a), globe temperature (T_g), and relative humidity (*RH*). The globe temperature is measured with an external temperature sensor (TMC1-HD) within a black painted table tennis ball of 40 mm diameter to obtained mean radiant temperature. The wind speed (*WS*) and wind direction (*WD*) are recorded using 2D Ultrasonic Anemometer (RM

Table 1: Characteristics of the seven measurement locations at UTMKL and UITM.

Zone (SVF) (GS)	UTMKL	Fisheye Photo	Zone (SVF) (GS)	UiTM	Fisheye Photo
A1 (0.84) (g_2, g_3)			B1 (0.48) (g_2, g_3)		
A2 (0.77) (g_2, g_3)			B2 (0.70) (g_3)		
A3 (0.66) (g_1)			B3 (0.94) (g_3)		
A4 (0.26) (g_2, g_4)			B4 (0.33) (g_2, g_3, g_4)		
A5 (0.32) (g_3, g_4)			B5 (0.91) (g_2, g_3)		
A6 (0.95) (g_2, g_3, g_4)			B6 (0.87) (g_1)		
A7 (0.83) (g_3)			B7 (0.93) (g_1)		

SVF: Sky view factor; GS: Ground surface; g1: Asphalt; g2: Interlocking Brick; g3: Granite concrete; g4: Grass

Table 2: Detail characteristics of measurement activities.

UTMKL (Measurement periods)	Activities (N = 1512)			UiTM (Measurement periods)	Activities (N = 1521)		
	S	W	St		S	W	St
A1 (29/2 -3/3/2017)	*n*= 75	*n*= 75	*n*= 75	B1 (3/10 -5/10/2017)	*n*= 75	*n*=75	*n*= 75
A2 (7/3 -9/3/2017)	*n*= 67	*n*= 67	*n*= 67	B2 (6/11 -8/11/2017)	*n*= 75	*n*= 75	*n*= 75
A3 (14/3-16/3/2017)	*n*= 75	*n*= 75	*n*= 75	B3 (9/10 -11/10/2017)	*n*= 75	*n*= 75	*n*= 75
A4 (21/3 -23/3/2017)	*n*= 71	*n*= 71	*n*= 71	B4 (31/10 -3/11/2017)	*n*= 70	*n*= 70	*n*= 70
A5 (28/3 -30/3/2017)	*n*= 71	*n*= 71	*n*= 71	B5 (14/11 -16/11/2017)	*n*= 71	*n*= 71	*n*= 71
A6 (2/5 -5/5/2017)	*n*= 71	*n*= 71	*n*= 71	B6 (21/11 -23/11/2017)	*n*= 71	*n*= 71	*n*= 71
A7 (18/4 -20/4/2017)	*n*= 74	*n*= 74	*n*= 74	B7 (23/10 -25/10/2017)	*n*= 70	*n*= 70	*n*= 70

S: sitting; W: walking; St: standing; *N*: total number of sample for all zones; *n*: number of sample for each zone

Young 86000) data logger attached with pyranometer (Kipp and Zenon) to measured solar radiation. All devices and sensors complied with the standard ISO 7726 [16]. All parameters were measured at one minute time intervals as instrument set-up shown in Figure 1.

2.3. Questionnaire survey

The sample size for each measurement zone is in the range of 60-75 respondents. The survey subjects were recruited through volunteer respondents. A typical method for measurement, the subjects are given 15 minutes of exposure time for adaptation and five minutes for completing time of the survey in turn for different three physical activities (sitting, walking and standing). In total, it takes two hours for each of the subjects to complete the surveys.

In this present study, the pedestrian thermal sensation is based on thermal sensation, thermal preference and thermal acceptance percentage vote evaluated through a questionnaire that consists of three sections. The first section was based on socio-demographic of pedestrian's personal information including genders, age, health condition, weight, and height. The second section consists of respondent's subjective variables (sensation, acceptance, and preferences of thermal comfort), past 15 minutes activities and personal primary countermeasure while the third section is on clothing insulation (filled in according to the ensembles present). The thermal sensation is based on 9-point scales (-4 to +4) [14, 17] while the thermal acceptance and preference are

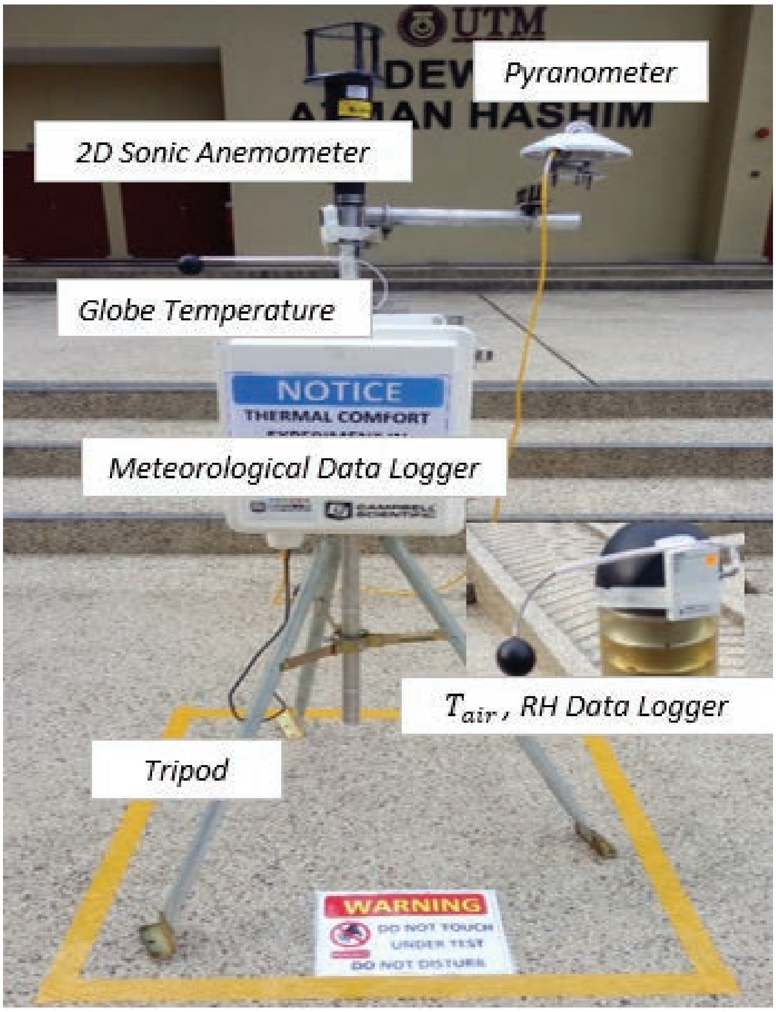


Figure 1: Measurement instrument setup for the unshaded condition during field measurement.

based on 5-point scales (-2 to +2) [18]. The detail thermal sensation, thermal recognition, and thermal preference comfort scales are illustrated in Table 3.

Table 3: Thermal comfort scales of thermal sensation, thermal acceptance, and thermal preference.

Scales	Thermal Sensation	Scales	Thermal Acceptance	Scales	Thermal Preference
-4	Very cold	-2	Very uncomfortable	-2	Warmer considerably
-3	Cold	-1	Uncomfortable	-1	Slightly warmer
-2	Cool	0	Acceptable	0	No change
-1	Slightly cool	1	Comfortable	1	Slightly cooler
0	Neutral	2	Very comfortable	2	Cool considerably
1	Slightly warm				
2	Warm				
3	Hot				
4	Very hot				

3. Results

3.1. Outdoor climatic parameters

Table 4 displays the comparison of meteorological parameters from seven measurement zones in UTMKL and UiTM. Specifically, the mean value range of T_a, T_g, *RH* and *SR* for UTMKL is 30-36˚C, 32-36˚C, 54-61% and 300-800 W/m^2. The averaged wind speed for UTMKL is 0.4-1.7m/s which corresponds to light air (0.3-1.5 m/s) and light breeze (1.6-3.3 m/s) according to Beaufort scale [19]. For UiTM, mean value range of T_a, T_g, *RH,* and *SR* are 31-36˚C, 32-38˚C, 53-64% and 300-700 W/m^2. The wind speed is in the range of 0.4-1.9m/s.

Table 4: Mean value of measured meteorological data during on-site measurement at UTMKL and UiTM.

Location	Zone	SVF	T_a (˚C)	RH (%)	WS (m/s)	SR (W/m^2)	T_g (˚C)
UTMKL	A1	0.84	30.4 (1.7)	60 (6.0)	1.7 (1.3)	330.6 (22.2)	32.0 (2.3)
	A2	0.77	33.3 (3.3)	58 (7.4)	0.9 (0.5)	614.8 (21.8)	36.5 (4.3)
	A3	0.66	35.9 (3.6)	52 (10.2)	0.9 (0.4)	641.9 (18.9)	38.7 (5.0)
	A4	0.26	31.0 (1.3)	59 (4.7)	0.4 (0.3)	573.5(13.3)	32.9 (1.5)
	A5	0.32	33.1 (2.1)	57 (7.6)	1.1 (0.6)	625.6(14.3)	35.8 (3.2)
	A6	0.95	35.5 (3.1)	54 (10.4)	0.6 (0.3)	481.6(15.1)	35.9 (3.2)
	A7	0.83	34.7 (3.7)	61 (15.8)	0.7 (0.3)	799.7 (15.3)	34.9 (5.8)
UiTM	B1	0.48	31.5 (3.1)	61(11.0)	1.2 (0.8)	303 (28.7)	32.8 (4.0)
	B2	0.70	32.3 (2.9)	63 (11.0)	0.4 (0.2)	356 (13.7)	33.3 (3.4)
	B3	0.94	36.0 (2.1)	535.4)	1.5 (0.5)	671(13.8)	38.0 (2.7)
	B4	0.33	32.2 (2.0)	61 (7.5)	0.7 (0.4)	297 (11.6)	33.7 (3.2)
	B5	0.91	32.7 (5.6)	64 (18.6)	0.9 (1.0)	328 (16.2)	34.1 (6.4)
	B6	0.87	33.2 (2.5)	61(7.5)	1.9 (1.3)	474 (12.8)	34.5(2.8)
	B7	0.93	35.1 (2.8)	56 (12.9)	1.1 (0.5)	517 (12.5)	37.5 (3.5)

T_a: air temperature; T_g: globe temperature; *RH*: relative humidity; *WS*: wind speed; *SR*: solar radiation; standard deviation (in bracket)

3.2. Effects of SVF on T_a, T_{mrt}, and PET

The influence of urban morphology on thermal comfort condition is determined through calculation of physiologically equivalent temperature (PET) thermal index for 15 minutes of exposure time. In this study, PET was calculated with the aid of free access Ray-Man Software [12]. This calculation required time of the day and year, meteorological parameters (T_a, T_g, *RH, WS, SR*), mean radiant temperature (T_{mrt}), surface morphological conditions (sky view factor, SVF) and personal data (age, weight, clothing, activity level) are taken into consideration. Apart from that, in biometeorology and thermal comfort

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study, mean radiant temperature is one of the main parameter concern. Mean radiant temperature (T_{mrt}), calculated from globe temperature (T_g), and wind speed (*WS*) as per given equation 1.

$$T_{mrt} = \left[(T_g + 273.15)^4 + \frac{1.10 \times 10^8 \times V_a^{0.6} \times (T_a - T_g)}{\varepsilon D^{0.4}} \right]^{1/4} - 273.15 \qquad (1)$$

From the above equation, the mean radiant temperature calculated together with the value of PET corresponding to SVF was then subsequent analysis. Figure 3 illustrates the correlation of SVF with T_a, T_{mrt}, and PET for each zone at UTMKL and UiTM. It shows that the T_a increases with the increase of SVF, but there are discrepancies found at SVF 0.84 and 0.77 where the temperature decrease when the SVF increase. It might be influenced due to topography; shading and vegetation effects. Moreover, at UiTM the T_a simultaneously increases when the SVF increase. For UTMKL, the temperature differences are approximately less than ±5°C for T_a and PET, less than ±7°C between T_a and T_{mrt} and less than ±5°C for T_{mrt} and PET. Whereas, for UiTM, less than ±5°C temperature difference were observed between T_a and PET, less than ±9°C for T_a and T_{mrt} and less than ±6°C for T_{mrt} and PET as shown in Figure 2.

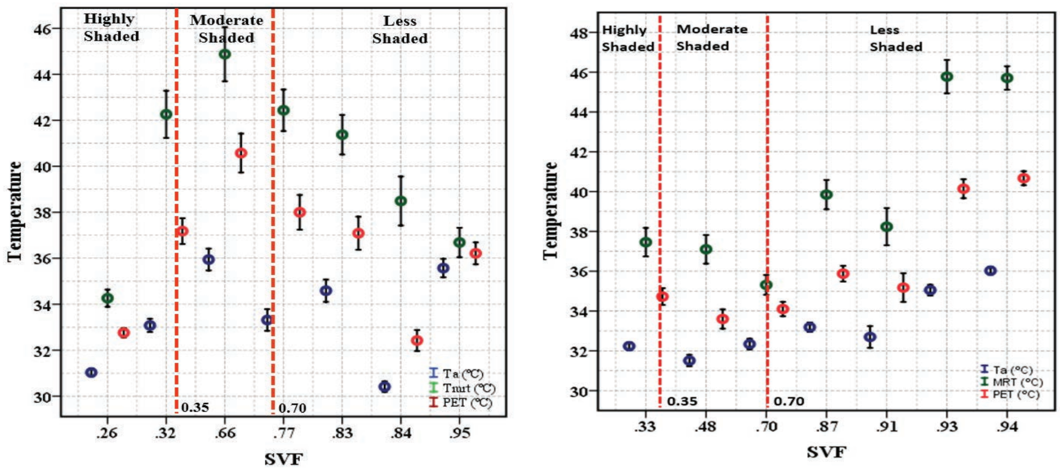

Figure 2: The relationship between SVF and T_a, T_{mrt} and PET (a) UTMKL, (b) UiTM; error bars denote standard deviation from the mean.

3.3. Thermal sensation votes (TSV)

Figure 3 expressing the percentages of *TSV* for UTMKL. At highly shaded (0 < SVF < 0.35), most of the respondent's votes for warm (24%) and hot (31%) for sitting, slightly warm (31%) and hot (30%) for walking and neutral (25%) and hot (32%) for standing. For moderate shaded (0.35 ≤ SVF ≤ 0.70) conditions, they vote for hot (31%) for sitting, hot

(33%) for walking and hot (35%) for standing. While for less shaded (0.70 < SVF ≤ 1), the respondents vote for neutral (27%), warm (21%), hot (24%) and very hot (39%) for sitting, slightly warm (21-24%), warm (21-23%), hot (21%) and very hot (33%) for walking and warm (27%), hot (20-34%) for standing.

For UiTM, at the highly shaded condition the most frequent vote is hot (27%) for sitting, neutral (23%) for walking and neutral (23%) for standing. For moderately shaded conditions, they vote for neutral (29%), warm and hot (27%) for sitting, neutral (34%) and warm (24%) for walking and neutral (33%) and warm (24%) for standing. For less shaded, respondents vote for hot (35%) and very hot (27%-37%) for sitting, hot (28-37%) and very hot (23-37%) for walking and hot (32%) and very hot (25-39%) for standing.

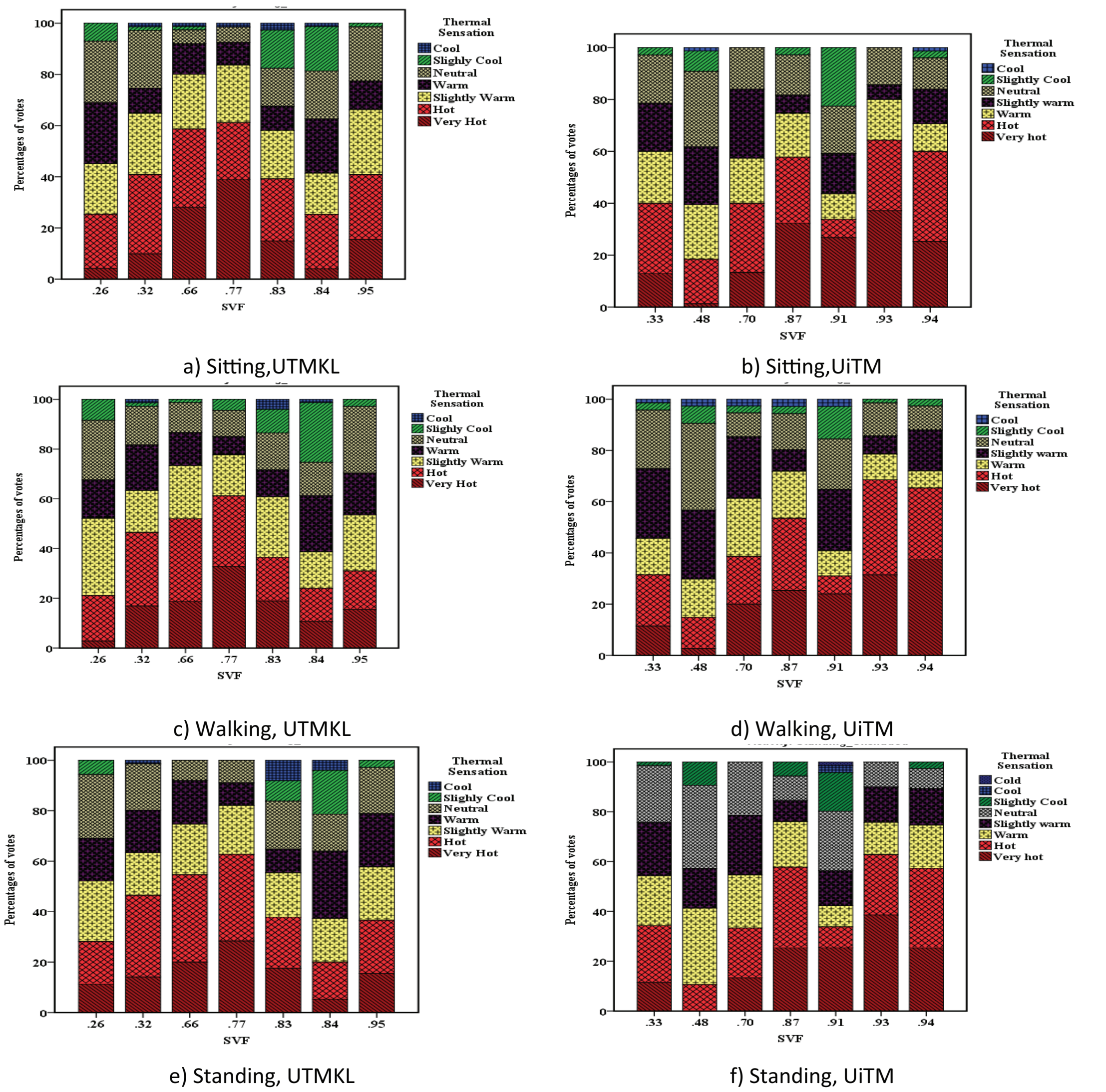

Figure 3: Percentages distribution of thermal perception in UTMKL and UiTM for sitting, walking and standing.

3.4. Thermal acceptance votes (TAV)

Figure 4 illustrated percentages of *TAV* for UTMKL and UiTM during sitting, walking and standing. Based on observation, most of the respondents voted acceptable for sitting (44-58%), walking (45%) and standing (48%) at highly shaded ($0 < SVF < 0.35$) conditions. For moderate shaded ($0.35 \leq SVF \leq 0.70$) conditions, the respondents voted for uncomfortable (44%) for sitting, acceptable for walking (36%) and standing (37%). For less shaded ($0.70 < SVF \leq 1$) the respondents vote for acceptable and uncomfortable for sitting (41-43%, 48%), walking (39-42%, 42%) and standing (37-43%, 47%).

Whereas for UiTM, at highly shaded conditions respondents voted for acceptable for sitting (40%), walking (45.7%) and standing (50%). For moderately shaded conditions, respondents voted for acceptable (41-54%) for sitting, acceptable (36-5%) for walking and acceptable (47-59%) for standing. For less shaded condition, the respondent voted acceptable and uncomfortable for sitting (44-47%, 35-40%), walking (41-52%, 37%) and standing (37-44%, 34%). The scales based on the five-point scale shown in Table 3.

3.5. Thermal preferences votes (TPV)

For *TPV* in UTMKL, respondents prefer slightly cooler for sitting (47-54%), walking (48-49%) and standing (48%) at the high shaded condition. For moderate shaded, respondents slightly cooler for sitting (47%) walking (43%) and standing (44%). While for shaded, respondents prefer slightly cooler for sitting (48-51%), walking (40-49%) and standing (41-47%) and prefer cool considerably for sitting (46%) walking (43%). While for UiTM, respondents prefer slightly cooler for sitting (47%), walking (63%) and standing (60%) at a highly shaded area. For moderate shaded condition, respondents prefer no change and slightly cooler for sitting (49%, 57%), walking (49%, 69%) and standing (47%, 61%). For less shaded, respondents prefer no change for walking (40%) and standing (34%). Also, there are respondents that voted for slightly cooler and cold considerably for sitting (41-54%, 49%), walking (41-51%, 49%) and standing (49-55%, 49%) as shown in Figure 5.

4. Conclusions

In this paper, field measurements of urban microclimatic parameters (i.e., air temperature, relative humidity, wind speed, wind direction, solar radiation) in Kuala Lumpur

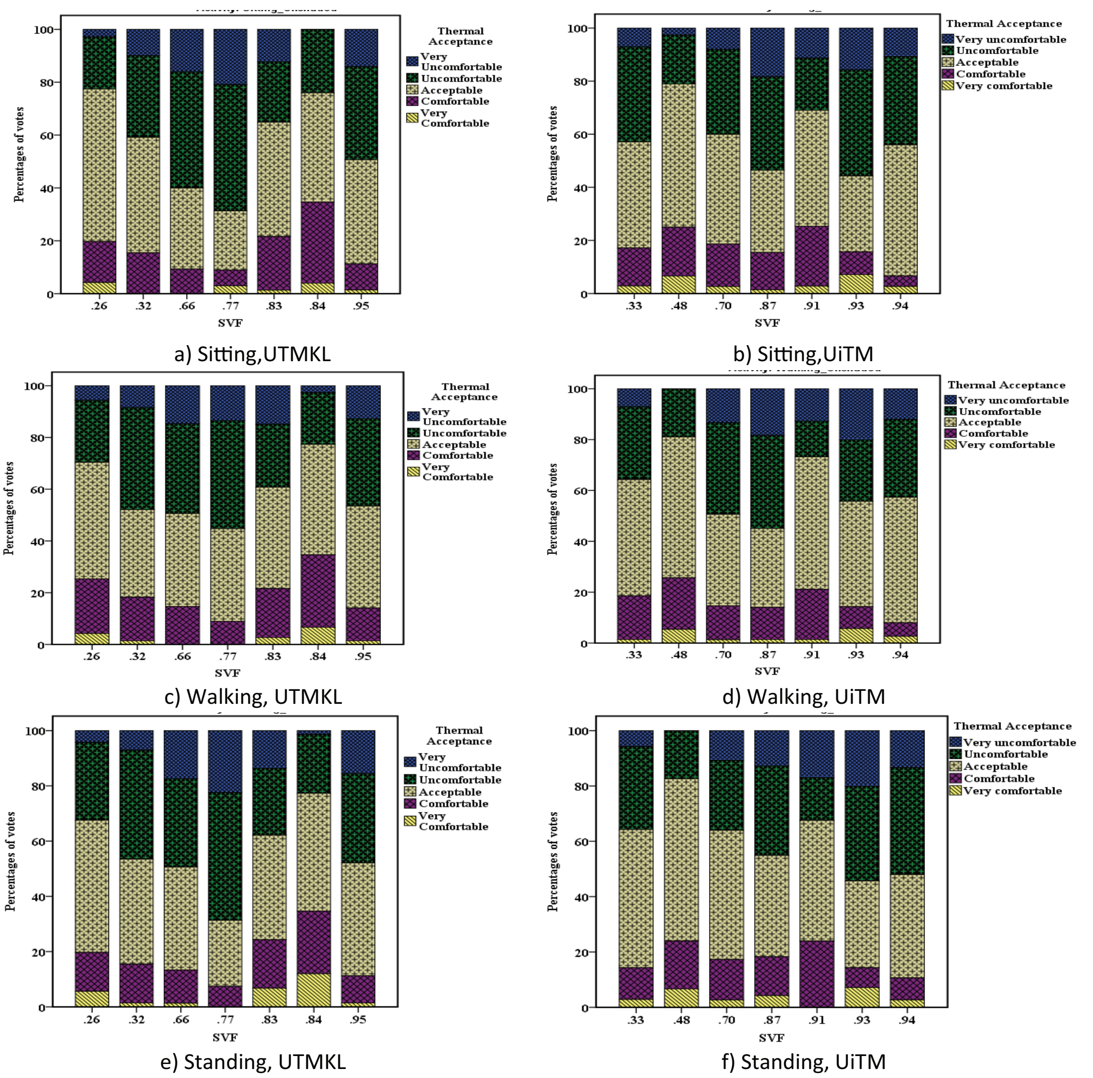

Figure 4: Percentages distribution of thermal adaptation in UTMKL and UiTM for sitting, walking and standing.

and Selangor were measured simultaneously with questionnaires. The summary of the findings as follows:

1. Based on observation, the SVF factors are influencing the observed air temperature and PET values. The increasing of SVF values will indirectly increase the air temperature and indirectly increase PET values.

2. For thermal sensation, at a highly shaded area (0 < SVF < 0.35) respondents vote for neutral, slightly warm and warm. While for moderate (0.35 ≤ SVF ≤ 0.70) and less shaded area (0.70 < SVF ≤ 1), high percentages vote was observed for warm, hot and very hot.

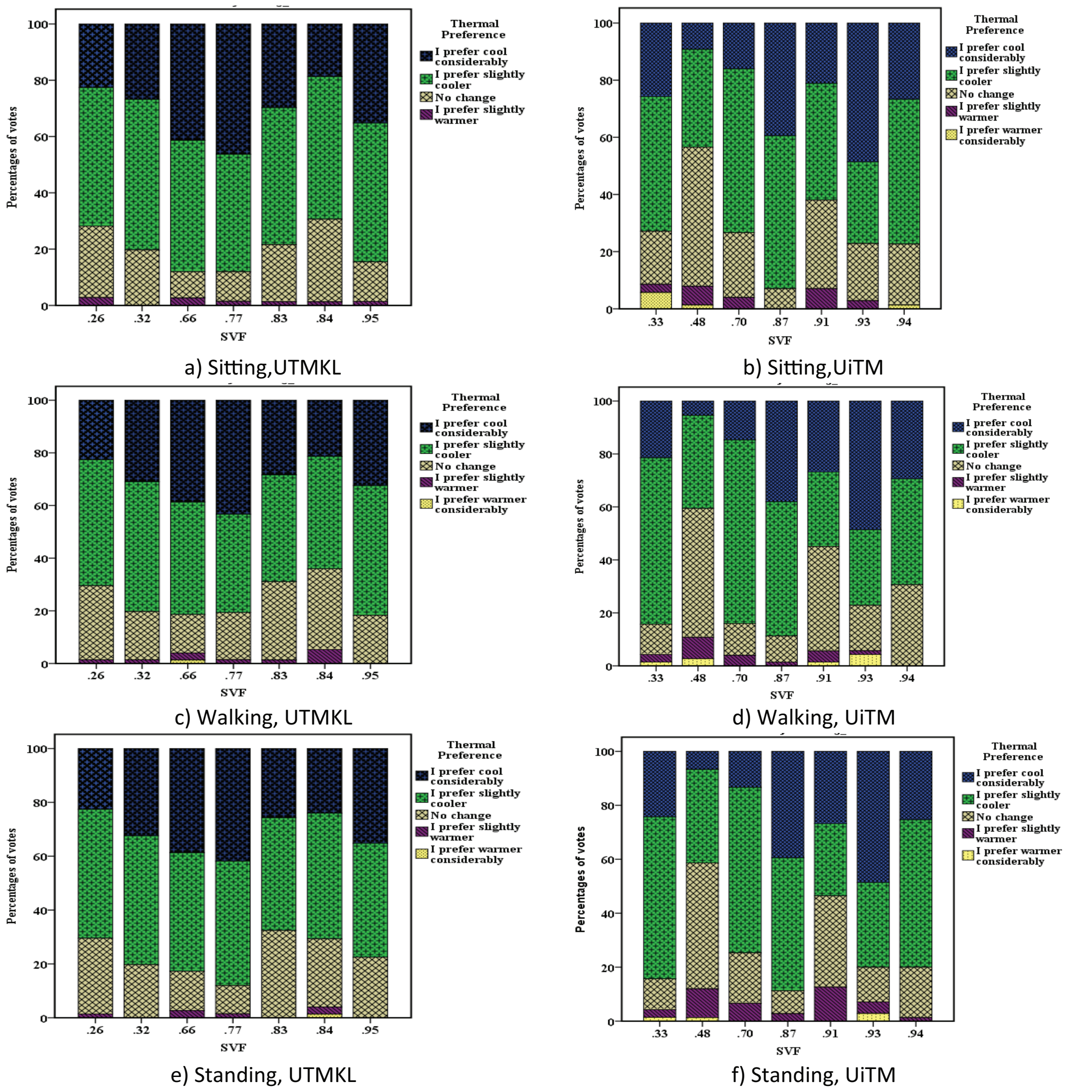

Figure 5: Percentages distribution of thermal preferences in UTMKL and UiTM for sitting, walking and standing.

3. For thermal acceptance, at a highly shaded area (0 < SVF < 0.35) most of the respondents feel acceptable while at moderate (0.35 ≤ SVF ≤ 0.70) and less shaded area (0.70 < SVF ≤ 1), respondents feel acceptable and uncomfortable.

4. For thermal preference, at a highly shaded area (0 < SVF < 0.35) respondents prefer no change while at moderate (0.35 ≤ SVF ≤ 0.70) and less shaded area (0.70 < SVF ≤ 1), majority respondents prefer slightly cooler and cool considerably.

In conclusion, the research shows well distributed thermal environment of Malaysia different combination and configurations proportions of environmental factors such as climate, environment, and vegetation that influences thermal perception, acceptance, and preferences among different people. For a hot-humid region like Malaysia, lower SVF (highly shaded) value may provide cooler environment than higher SVF (less shaded) value. This study helps to understand further the thermal comfort in creating a better outdoor condition for future enhancement. The results of the simultaneous measurement and surveys have demonstrated a significant difference in thermal perception, acceptance and preference voting exist at different SVF values.

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