REGULAR ARTICLE

INFLUENCE OF LANDSCAPE ENVIRONMENTAL SETTINGS ON OUTDOOR PEDESTRIAN THERMAL COMFORT IN TROPICAL CLIMATE

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ABSTRACT

A suitable microclimate can increase pedestrian comfort and encourage walkability and support sustainability. This study aimed at measuring the effectiveness of selected types of Landscape Environmental Settings for Pedestrian (LESP) in influencing the thermal comfort in tropical campus environments. Field measurement data was collected under 5 different types of LESP in a university campus. The types are; No shade (T1), Metal deck (T2), One row of trees (T3), Combined deck and trees (T4), and Two rows of trees (T5). Pedestrian thermal comfort is assessed by measuring i) Air temperature (Ta), ii) Globe temperature (Tg), iii) Wind velocity (v), iv) Surface temperature (Ts), and v) Relative humidity (Rh). Data were analysed and ranked according to the comfort level of the pedestrians. Results indicate the importance of natural and man-made shading and pavement materials on pedestrians' comfort. Shading can reduce the temperature of pavements even from low albedo materials such as dark grey asphalts and contribute to pedestrian thermal comfort. The findings can be helpful for landscape architects and urban planners in specifying appropriate microclimatic interventions to improve pedestrian comfort in the tropical environment.

Keywords: *: Landscape settings; urban microclimate; outdoor thermal comfort; tropical campus; landscape design.*

1. INTRODUCTION

Understanding urban microclimate is essential in urban designing and campus planning (Brown, 2011). Microclimate is an important element in providing comfortable walking ambience. Pedestrian's thermal comfort is totally dependent on the microclimate of pedestrian walkways and their landscape settings in a tropical climate (Hwang et al., 2015). Brown and Gillespie (1995), defined microclimate as the condition of solar and terrestrial radiation, wind, air temperature, humidity, and precipitation in a small outdoor space. They highlighted that an understanding of microclimate can provide the tools for creating thermally comfortable habitats for people and provide energy-efficient landscapes for buildings. Toner (2015) defined microclimate as the climate within or surrounding a city block or development. He demonstrated that a microclimate can be designed through changing the forms of buildings, landscaping, and shading to allow or block wind or solar radiation at pedestrian level.

Microclimate can also be defined as the weather in a particular small area, especially when it is different from the surrounding area (Hornby, 2005). Microclimate is influenced by the characters of the landscape (Takács et al., 2016). On the other hand, landscape characters can influence the parameters of microclimate. These microclimatic parameters determine the weather of any microclimate. Therefore, local microclimate greatly affects people's sensations of thermal comfort and also influences decisions on whether to use the space. For example, in their study Watanabe and Ishii (2016) analysed the effects of microclimatic conditions on pedestrians' behaviour in selecting shaded places when waiting at traffic lights in Nagoya, Japan. They used on-site microclimatic measurements and unobtrusive observations in the study. The study found that half of the pedestrians' selected shaded areas when stopping at traffic signals in a hot environment of over 40°C. Moreover, female pedestrians were more careful to protect themselves from solar radiation including ultra-violet rays than males. They also highlighted that "shade design in the city" will be a critical strategy to improve the safety, comfort, and attraction of cities in a hot environment. In relation to this, the Landscape Environmental Settings for Pedestrian (LESP) with shading either with man-made shading or shading by trees hypothetically provide better microclimate in terms of air temperature, surface temperature, relative humidity, mean radiant temperature, and thermal comfort.

Wind causes air movements and may have a cooling effect on people; making them feeling thermally more comfortable in tropical climates. The velocity and direction of wind can strongly affect the thermal comfort of pedestrians along walkways due to its cooling effect known as a "wind chill." It efficiently mixes the differences in temperature or humidity in the landscape. As a result, wind chill is the perceived decrease in ambient temperature due to the flow of air on exposed skin (Toner, 2015). However, wind temperature can also influence thermal comfort. It may become hot and dry as it travels over a mountain range and across the countryside. Thus, it would either increase the temperature to a thermally comfortable level or vice versa. Wind is important in order to overcome thermal discomfort when ambient temperatures are high or when there is direct solar radiation.

Some studies confirmed the effects of wind on human thermal comfort in urban squares microclimatic conditions. Such studies can be found in Ghasemi et al. (2015) where they discussed how the use of urban form and orientation in open spaces influenced the wind velocity indicating different layouts resulting in different wind flows. Indirectly, this will influence the thermal comfort of outdoor users resulting in their willingness to spend more time in outdoor spaces. Another study by Niu et al. (2015) evaluated an open space, open ground level building block, and a courtyard surrounded by building blocks in a Hong Kong university. They used the concept of continuous monitoring of winds at the pedestrian level and also sample thermal parameters for two days during a summer. The sampling includes air temperature, globe temperature, wind velocity, and humidity. Findings of the study indicate that wind velocity and radiant temperature differences made significant dissimilarity in thermal comfort. The study clearly proves that wind amplification combined with shading effects can generate thermally comfortable conditions in the open ground floor areas beneath an elevated building, even on a sunny, hot summer day of a subtropical city. In another study Shi et al. (2015) designed a simulation of the pedestrian wind environment. This enabled them to gauge the impacts of design on wind velocity during the urban design stage. This is crucial because pedestrian wind environment is one of the urban physical environment variables that has a significant impact on the overall wellbeing of city dwellers.

Many researchers measured the parameters of microclimate such as air temperature, globe temperature, mean radiant temperature, wind velocity, and humidity in their studies on human thermal comfort in various urban microclimates (Chatzidimitriou & Yannas, 2016; Ignatius, Wong, & Jusuf, 2015; Nor et al., 2015; Salata et al., 2016; Salata et al., 2015; Sanusi et al., 2017). Included in these studies were urban squares, open spaces, streets, street canyons, pedestrian walkways and a park. Shahab Kariminia et al. (2015) investigated the effects of built environment and geometry within a city structure towards users' thermal comfort in an urban square in Isfahan, Iran. They measured air temperature, wind velocity, and mean radiant temperature. There are studies which proved that proper microclimatic planning and design can ameliorate the negative effects of the walking microclimate (Chatzidimitriou & Yannas, 2016). Previous researches have established that trees can play an important role in influencing the surrounding climate and that a large number of trees can improve thermal comfort in hot climates (Hien & Jusuf, 2008; Nyuk, Puay, & Yu, 2007). In fact, the cooling effect of trees in tropical climates is obvious (Morakinyo, Balogun, & Adegun, 2013). Tree shading from the sun and the process of evapotranspiration are important factors that contribute to this cooling effect (Vailshery, Jaganmohan, & Nagendra, 2013). In addition to moderating microclimate and thermal comfort of pedestrians, Sanusi et al. (2017) suggested that the different types and characteristics of trees surrounding pedestrian routes can result in different cooling effects. However, studies of tree species and their canopy compositions whether based on field measurements or modelling approaches are still lacking in tropical regions.

In a tropical environment, pedestrians are often exposed to high thermal loads, which can cause thermal discomfort and even heat-strokes. Makaremi et al. (2012) in a study of pedestrians in a higher learning institution campus found that 77% of the students felt uncomfortable walking. However, Shahidan et al. (2012), suggested that suitable environmental conditions can be created through proper treatment of these environments. By having campus environment conducive for walking outdoors, it can encourage people to walk more (walkability), improve urban microclimate, and reducing energy consumptions. However, studies on understanding tropical microclimate are currently limited to analysis of i) perceptions and preferences of thermal comfort in outdoor urban spaces (Yang, Wong, & Jusuf, 2013), ii) evaluation of the air temperature (Hirashima, Assis, & Nikolopoulou, 2016), and iii) thermal comfort within tree canopies and shade microclimate in urban park (Adawiyah & Sh, 2015). Shade is crucial for pedestrian thermal comfort (Benrazavi et al., 2016). It can prevent pedestrians from direct exposure to solar radiation, which is the most important factor causing discomfort in a tropical climate. Studies on the effects of various types of landscape environmental settings for pedestrians towards microclimate are limited in a tropical climate. Yang et al. (2018) studied the effects of different landscape elements on human thermal comfort in Singapore. They demonstrated that the value of tree shade is critical to human thermal comfort. Another study by Johansson et al. (2018) investigated the outdoor thermal environment during daytime in 5 public places in a city in Ecuador. However, both of the studies did not focus on pedestrian's walkway environment which have various types of landscape settings. Therefore, the objective of this study is to investigate the influence of Landscape Environmental Settings for Pedestrian (LESP) on microclimate parameters towards pedestrian thermal comfort in tropical campus environments.

2. METHODOLOGY

Kasim et al. (2018) study on the use of LESP to enhance campus walkability has defined LESP as "everything that can be seen in the pedestrian's walkway within a 3.0-meter radius that affects the thermal comfort/behaviour of the pedestrians at the particular type of situation". Different types of LESP contribute to different effects on the site microclimate and pedestrian thermal comfort. This study was conducted to answer the research question: How various scenarios of LESP affect pedestrians' thermal comfort in tropical campus environment.

According to Ng and Cheng (2012), it is reasonable to assume a consistent microclimatic condition occurring within a 3.0 meter radius. It can be determined by measuring the physical properties of the landscape setting and its surrounding environment. Five types of LESP were identified this study. They are No shade (T_1), Metal deck (T_2), One row of trees (T_3), Combined deck & trees (T_4), and Two rows of trees (T_5) (See Fig. 1). These were selected based on previous studies (Kasim et al., 2018; Naderi & Raman, 2005; Ng & Cheng, 2012).

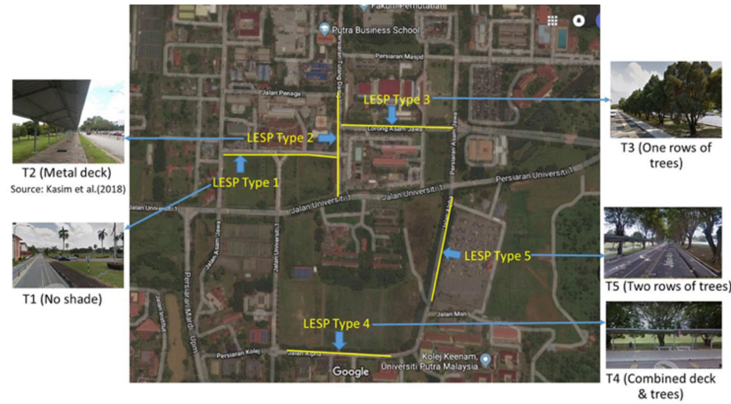

Figure 1: Locations of the 5 LESP Types
(Source: Google Earth and Google Maps)

This is a descriptive study and measured 5 different types of pedestrian environmental settings on a university campus in Selangor. The campus is located (Lat. 03°N, Long.101°E) between Kuala Lumpur and Putrajaya, experiences hot and humid conditions year round, with daily air temperatures varying from a low of 24°C at night and up to 38°C at noon time. The study measured 5 variables: Air temperature (Ta), Globe temperature (Tg), Surface temperature (Ts), Wind velocity (v) and Relative humidity (Rh).

This study applied the Physiological Equivalent Temperature (PET) to identify the pedestrian thermal comfort. PET is a universal thermal index represented in degrees of Celsius which is used to indicate pedestrian thermal comfort in various outdoor environments. In addition, PET can demonstrate the difference between the microclimate parameters in open space walkway (as in LESP T_1: No shade) and those walkways under shade (as in LESP T_2: Metal deck to LESP T_5: Two rows of trees).

PET is calculated using Ray-Man software version 1.2 by computing the value of Ta, Rh, v and Mean Radiant Temperature (Tmrt) of microclimate in each LESP (Matzarakis, Rutz, & Mayer, 2007). The calculation of the Tmrt is by using the ASHRAE formula as shown in Equation (1), with the value of measured Tg, Ta and v at each points in all the LESP (Thorsson et al., 2007). Studies on thermal comfort use PET classification as suggested by Lin and Matzarakis (2008) and as a reference to investigate the impact of LESP in a hot humid tropical climate of Malaysia as shown in the Table 1 (Makaremi et al., 2012).

Table 1: Thermal perception classification (TPC) for temperate region and (sub) tropical region. Source: (Makaremi et al., 2012)

Thermal perception	TPC for (sub)tropical region (°C PET)	TPC for temperate region (°C PET)
Very cold	<14	<4
Cold	14-18	4-8
Cool	18-22	8-13
Slightly cool	22-26	13-18
Neutral	26-30	18-23
Slightly warm	30-34	23-29
Warm	34-38	29-35
Hot	38-42	35-41
Very hot	<42	<41

Equation (1):

$$T_{mrt} = [(T_g + 273.15)^4 + \frac{1.1 \times 10^8 {V_a}^{0.6}}{\varepsilon D^{0.4}} \times (T_g - T_a)]^{1/4} - 273.15$$

Tmrt = Mean radiant temperature (∘C)

Tg = Globe temperature (∘C)

Va = Wind velocity (m/s)

Ta = Air temperature (∘C)

D = Globe diameter (mm)

ε = Globe emissivity (0.95)

2.1 Study site and measurement period

The study focuses on all 5 types of LESP in order to assess the influence of different landscape settings on pedestrian thermal comfort. These LESP types are represented by different scenarios. The process of selecting suitable sites for this study was done using a site selection survey. The survey was carried out from 21st to 28th of January 2018. First, the researcher identified and labelled the sites according to the LESP types. None of the sites identified have walkways of more than 250m long. Then, the length is marked at 10m intervals, starting with Point 1 until Point 25. Measurements were then made from Point 1 and ending at Point 25.

The field measurements were carried out on the hottest part of the day (12:00 to 15:00) from 7th to 15th of February 2018. On site measurements are critical to investigate the best effect on the pedestrians' thermal comfort from the 5 types of LESP. According to Shahidan et al. (2010), in tropical climate, the best time to measure is when the sun is overhead from 12:00 to 13:00 and the shade is concentrated directly around the tree canopy. Similar shading effects occur until 14:00. After that the shadow will be stretched to the east from 14:00 to 15:00. Thus, the best time for the measurement is from 12: 00 to 15:00. The Air temperature (Ta), Globe temperature (Tg), Surface temperature (Ts), Wind velocity (v) and Relative humidity (Rh) were measured repeatedly for 3 days at each point in order to get the average reading of daily weather. This was done similar studies in Singapore requiring outdoor temperature measurements at different locations (Hwang et al., 2015). Figure 1 illustrates the locations of the 5 types of LESP.

2.2 Field measurement of the site settings

Each LESP type shows differences in site settings. LESP T_1 (No shade) is a walkway measuring 2.0 m in width with concrete interlocking paver as the only landscape element in the walkway environment. LESP T_2 (Metal deck) comprises of both interlocking pavers and metal-deck shade structure. This differs slightly from LESP T_3 (One row of trees) which consists of concrete slabs with white pebbles paving and shade provided by columnar shaped trees (Juniperus chinensis). LESP T_4 (Combined deck & trees) consists of concrete slabs pavement and shading from both a metal-deck shade structure as well as from shade trees (Mimusops elengi). And finally, LESP T_5 (Two rows of trees) has dark coloured asphalt pavement in between two rows of Angsana (Pterocarpus indicus) shade trees.

Each LESP type comprises of five microclimate parameters; Air temperature (Ta), Globe temperature (Tg), Surface temperature (Ts), Wind velocity (v) and Relative humidity (Rh). This study measured the microclimatic parameters for all 5 LESP types. Measurements were taken on three sunny days from 12:00 to 15:00. The measurements were taken at a height of 1.5m from the ground except for Ts which uses the ground as the base for measurement. The data was then analysed and the mean for every parameter of each type was recorded.

2.4 Field measurement equipment and procedure

Measurements for each site were made with the help of two trained research assistants who measured the microclimate parameters at all 25 points on each site.

Table 2: Microclimate measurement parameters and equipment specifications

Measurement parameters	Equipment	Measurement range	Accuracy
Air temperature	Testo 925, with robust air temperature probe (TC type K) with fixed cable 1.2m probe	-50 °C to +1000°C	± 0.5 °C from -40.0°C to + 900°C
Globe temperature	Extech HT30 (Ø = 40 mm)	0 to 80 °C	± 2 °C
Surface temperature	Testo 905-T2, with short measurement type	-50 °C to +350°C	± 1 °C
Wind velocity	Testo 425, thermal anemometer with permanently attached flow probe	0.0 to +20 m/s	± 5% or 0.03 m/s whichever is greater
Relative humidity	Testo 625, thermo hygrometer, with connectable humidity sensor head	0 to +100%RH	± 2.5%RH

Four portable measuring equipment, Testo 925, Testo 905-T2, Testo 425, and Testo 625 were used to measure air temperature, surface temperature, wind velocity and relative humidity, respectively while Extech HT30 with a 40 mm diameter black globe was used to measure the globe temperature. The instruments were chosen due to their quick responses, convenient sizes, and their accuracy conforms to ISO 90001:2008 and German Federal Physical and Technical Institution. The instrumentations are reliable to be measured in outdoor environment (Hwang et al., 2015). Table 2 lists the detail specifications of equipment used during field measurement.

2.5 Data Analysis

To investigate the influence of LESP on microclimate parameters, three sets of data were averaged to obtain a single mean of Ta, Tg, Ts, v and Rh for each point in each type of LESP. Then Tmrt and PET were calculated based on the mean of Ta, Tg, Ts, v and Rh for each point in each type of LESP. Data for Ta, Ts, v, Rh, Tmrt and PET were analysed using a One-way Analysis of Variance (ANOVA). A one-way ANOVA was adopted to test the significant differences among 5 types of LESP at $p < 0.05$. Various comparative statistical analyses with Post-Hoc Comparisons test to detect which pair of scores resulted in the significant differences were also performed on the data.

3. RESULTS

Results from data analyses disclosed essential findings of the Landscape Environmental Settings for Pedestrian (LESP) thermal comfort tested. Results for Physiological Equivalent Temperature (PET) are significantly different amongst the 5 types of LESP (T_1= No shade, T_2 = Metal deck, T_3= One row of trees, T_4= Combined deck & trees, and T_5= Two rows of trees) with $p < 0.05$ (Table 3).

Table 3: Result of Post Hoc Tests (Multiple Comparison) for PET

I (LESP)	J (LESP)	Mean PET Difference (I-J)	Std. Error	Sig.
T_1 (no shade)	T_2 (metal deck)	6.11	0.3431	0.000
	T_3 (one row of trees)	4.16	0.3431	0.000
	T_4 (combined deck & trees)	5.43	0.3431	0.000
	T_5 (two rows of trees)	6.74	0.3431	0.000
T_2 (metal deck)	T_1 (no shade)	-6.11	0.3431	0.000
	T_3 (one row of trees)	-1.94	0.3431	0.000
	T_4 (combined deck & trees)	-0.67	0.3431	0.287
	T_5 (two rows of trees)	0.62	0.3431	0.361
T_3 (one row of trees)	T_1 (no shade)	-4.16	0.3431	0.032
	T_2 (metal deck)	1.94	0.3431	0.000
	T_4 (combined deck & trees)	1.27	0.3431	0.003
	T_5 (two rows of trees)	2.57	0.3431	0.000
T_4 (combined deck & trees)	T_1 (no shade)	-5.43	0.3431	0.000
	T_2 (metal deck)	0.67	0.3431	0.287
	T_3 (one row of trees)	-1.27	0.3431	0.003
	T_5 (two rows of trees)	1.30	0.3431	0.002
T_5 (two rows of trees)	T_1 (no shade)	-6.74	0.3431	0.000
	T_2 (metal deck)	-0.62	0.3431	0.361
	T_3 (one row of trees)	-2.57	0.3431	0.000
	T_4 (combined deck & trees)	-1.30	0.3431	0.002

3.1 Air temperature (T_a)

Figure 2 shows the graph of Ta for all types of LESP. In LESP T1 the mean temperature ranges from 31°C to 34.5°C and the mean is 33.1°C. LESP T_2 has a range of 30.2°C to 32.5°C and the mean is 31.6°C. The result for LESP T_3 has a range of 31.6°C to 33.3°C and a mean of 32.5°C. Meanwhile, LESP T_4 and LESP T_5 recorded a range of 30.8°C to 32.2°C with a mean of 31.4°C and 30.7°C to 31.8°C with a mean of 31.3°C respectively.

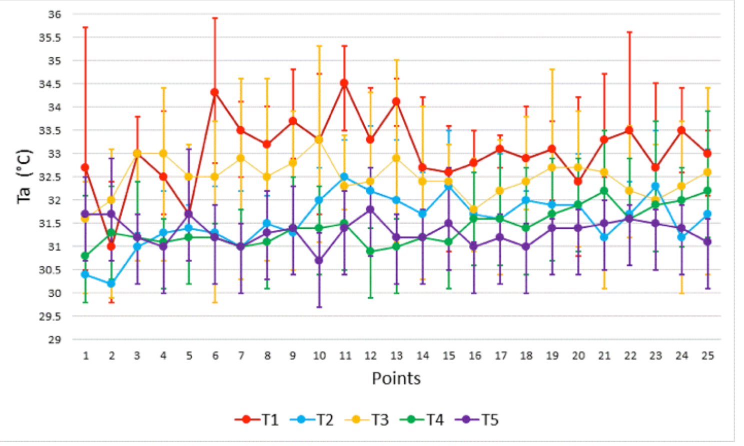

Figure 2: Air temperatures (Ta) between LESP Types

In term of LESP type, LESP T_5 is considered as the most stable as it presents a minimum gap in Ta which is 1.1°C. This is followed by LESP T_4 at 1.4°C, LESP T_3 at 1.7°C, LESP T2 at 2.3°C and LESP T_1 at 3.5°C. The ranking in means for the five types of Ta is LESP T_5, LESP T_4, LESP T_2, LESP and LESP T_1. T_5 recorded the lowest mean for air temperature and the lowest gap in temperature range. The comparison of two microclimates, LESP T_4 has man-made shading (metal-deck shade structure) and shading by trees. Meanwhile, LESP T_5 has two rows of dense vertical trees (Pterocarpus indicus) on both sides providing the walkway with some shade and breeze.

3.2 Surface temperature (Ts)

Surface temperature (Ts) is measured by positioning the head of the instrument directly on the surface of walkway pavement to record the minimum, maximum, and mean of the surface temperature. Materials used for LESP T_1 and LESP T_2 are interlocking concrete paver, LESP T_3 is concrete slabs with white pebbles finishes, LESP T_4 is concrete slabs while LESP T_5 is dark grey asphalts. The lowest temperature recorded is 31.8°C (in LESP T_3 and T_4) and the highest is 43.4°C (in LESP T_1). In terms of differences in range, LESP T_2 has the smallest range which is 4.8°C and this is followed by LESP T_1 and LESP T_4 with a similar value of 6.3°C. LESP T_5 has a range of 8.2°C and the biggest range value is 9.0°C recorded for LESP T_3.

In Figure 3 the graph shows the fluctuation of temperature at every point in each type. It is clearly shown that LESP T_1 has the highest range of temperatures. The trend of LESP T_2 to LESP T_5 is almost similar although LESP T_5 illustrates a stable range of temperature as compared to the others. LESP T_5 recorded the smallest mean value of 33.8°C and followed by LESP T_4 with 34°C. The mean values in LESP T_2 and LESP T_3 are 34.4°C and 34.6°C respectively. LESP T_1 recorded the highest mean for Ts with the value of 40.7°C. The mean value ranking of Ts for the 5 types is LESP T_5, LESP T_4, LESP T_2, LESP T_3 and LESP T_1.

Ts at point 1 and at point 12 in LESP T_5 are hotter compare to other points. The recorded temperature for these points are 38.9°C and 36.6°C respectively. In LESP T_5, point 1 recorded the highest temperature. This is caused by lack of shading at that particular point.

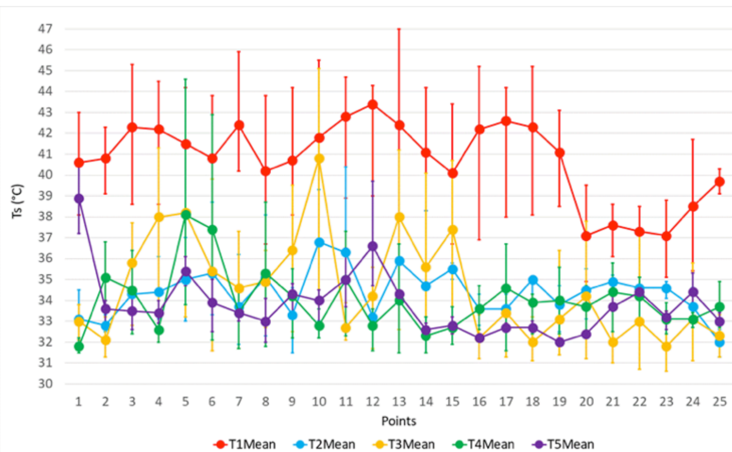

Figure 3: Trends of Ts in all LESP Types

The point acts as the beginning of LESP T_5. The case is almost similar with point 12 as the gap between trees are larger compare to other points. This results in the absence of tree shades, hence the temperature at that point is higher. The case is repeated in LESP T_3, where Ts has increased by 4.4°C from 36.4°C to 40.8°C taken at Point 9 to Point 10. This is due to the larger distance between trees as compared to other points along the walkway. In LESP T_1 there is a big drop in Ts from Point 19 to Point 20 (41°C to 37.1°C). This decreased in Ts by 3.9°C was due to the row of trees present near to Point 20 and onwards.

3.3 Wind velocity (v)

Figure 4 shows the graph of v in all types of LESP. LESP T_2 has the biggest range with 1.5 m/s followed by LESP T_5 with value of 1.2 m/s, and LESP T1 with value of 1.1 m/s. LESP T_3 and LESP T_4 share a similar range of v with the value of 1.0 m/s. Among all the types of LESP, LESP T_2 records the highest mean for v (mean = 0.87 m/s). The lowest mean

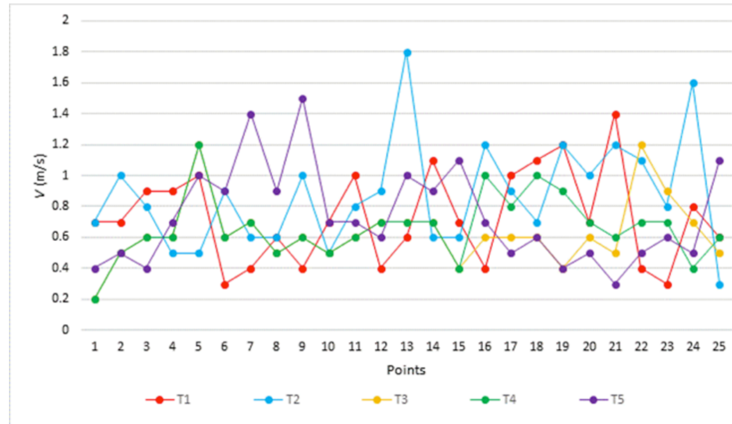

Figure 4: Trends of v in LESP Type 1 to LESP Type 5

for v is in LESP T_3 with the value of 0.63 m/s. The v in all types of LESP can be regarded as very weak as the highest value is only 1.8 m/s (6.5km/h). It is very difficult to find a relationship between LESP types with v results in each LESP largely due to the microclimate space of only 3.0 m radius covered in this study.

3.4 Relative humidity (Rh)

As can been seen in Figure 5, the graph clearly indicates the lowest Rh occurred in LESP T_1 as compared to a small difference between other scenarios. These results indicate that trees affect the Rh value of the surrounding microclimate. Rh value is higher in a microclimate that has a lot of trees through their evapotranspiration.

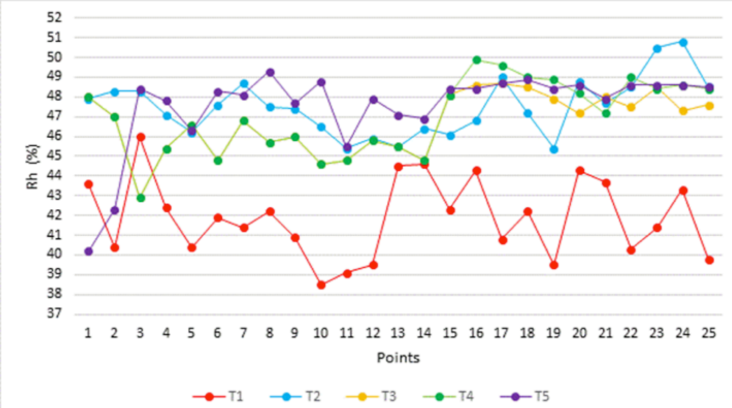

Figure 5: Trends of Rh in LESP Type 1 to LESP Type 5

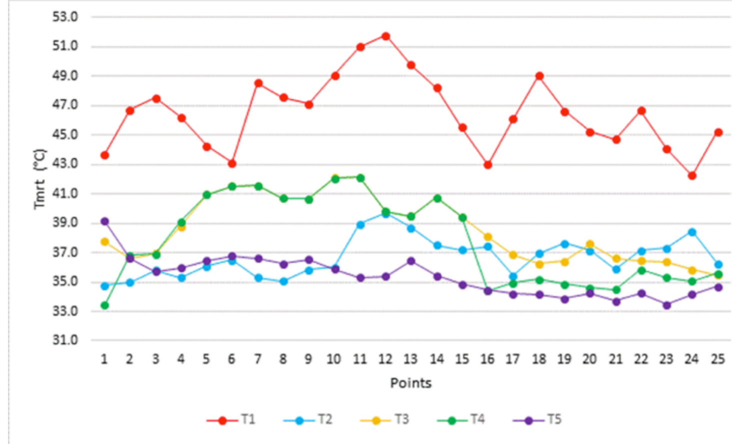

Figure 6: Trends of Tmrt in LESP Type 1 to LESP Type 5

3.5 Mean Radiant Temperature (Tmrt)

The Tmrt is defined as the 'uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure' (ASHRAE, 2001). Tmrt shows the actual radiations (short and long radiation) exposed to the pedestrian and one of the most important meteorological parameters to the outdoor thermal comfort.

Tmrt is calculated by replacing the values of Ta, v and Rh (from field measurement) into the ASHRAE formula as shows in Equation (1). Figure 6 shows the graph of Tmrt in all types. The graph clearly indicates the difference between LESP T1 (no shade) with LESP T_2, T_3, T_4 and T_5 (have shades). In LESP T_1, the mean temperature ranges from 42.3°C to 51.8°C. Meanwhile in LESP T_2 to LESP T_5 ranges below 43°C. Generally, this data has proven that shading over pedestrian can reduce the radiation effects. In contrast to Ta, the Tmrt value in LESP T_2 is lower than LESP T_4. LESP T_2 and LESP T_4 have a range of 34.8°C to 39.7°C and 32.2°C to 42.1°C respectively. LESP T_2 and T_4 are similar as both have continuous man-made shading. But it is interesting to note that LESP T_4 has higher Tmrt than LESP T_2. Tmrt's findings show clearly the difference effects of trees shading in LESP T_3 and LESP T_5.

3.6 Physiological Equivalent Temperature (PET)

Figure 7 shows the graph of PET values for all LESP types. It clearly indicates that LESP T_1 has the highest range of PET whilst LESP T_5 recorded the lowest range of PET. The ranking in mean values for PET in all 5 types is LESP T_5, LESP T_2, LESP T_4, LESP T_3, and LESP T_1 in ascending order. PET values of all types were generally above the upper comfort range limit of 30°C. PET values in LESP T_5 and LESP T_2: metal deck (with mean value of 32.7°C and 33.3°C respectively are in a range of slightly warm which is considered in an "acceptable range". According to Lin and Matzarakis (2008), the "acceptable range" is for slightly cool, neutral, and slightly warm condition which ranges from 22°C to 34°C. PET values in LESP T_3 and LESP T_4 are in the range of warm whilst PET for LESP T_1 is in the range of hot.

The results of PET indicate the effects of different types of LESP on pedestrian thermal comfort in a tropical climate. PET values in LESP T_1: no shade (without shading and in the hot range), represents the actual thermal condition faced by pedestrians during the hottest time of the day, which is from 12:00 to 15:00. Thus, the findings show that there is only a statistically significant differences between no shade (LESP T_1) and all the others in shading (LESP T_2 to T_5) as proven by Post-Hoc Comparisons statistical test (see Table 3). Indeed, Table 3 indicates that the LESP T_5 recorded the biggest mean for

PET differences between LESP T_1, followed by LESP T_2, T_4, and T_3. These findings are in line with the findings by Makaremi et al. (2012) in connection with the shaded outdoor spaces in Malaysia.

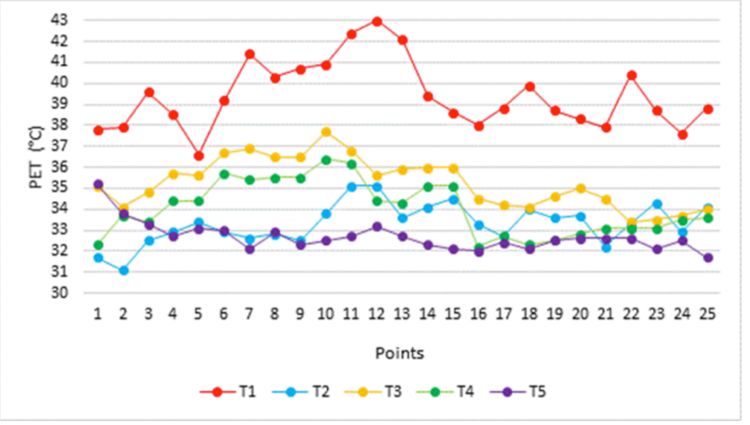

Figure 7: Trends of PET in LESP Type 1 to LESP Type 5

4. DISCUSSION

This study investigates the influence of Landscape Environmental Settings for Pedestrian (LESP) on microclimate parameters towards pedestrian thermal comfort in tropical campus environments. Results indicate that the importance of using sandwiched tree-shading to reduce the Ta as mentioned in a study done by Crum et al. (2017). The shading reduces Ta through reductions in heat fluxes from shaded pavement surfaces. In another microclimate situation, continuous man-made shading in LESP T_2 (metal deck) provides better protection, hence reducing Ta compared to shading by trees which do not provide continuous shade as illustrated in LESP T_3 (one row of trees). This fact supports the results found in Hwang et al. (2015) which highlighted the value of shade especially in terms of volume and continuity over the length of the walkway.

Dark grey asphalt materials have low albedo. However, when there is shading from the tree canopy as in LESP T_5 (two rows of trees) situation, Ts is reduced. Similarly, shade is needed to reduce the surface temperature when interlocking pavers and white pebbles pavers are used in LESP T_3 and in LESP T_1 (no shade) situations respectively. These findings conform to an earlier study suggesting that shade is more significant than water in influencing Ts reduction in a tropical climate (Benrazavi et al., 2016). In addition, the results support the idea that the use of high-albedo materials for urban surfaces is not significant for pedestrian users' thermal comfort (Erell et al., 2014).

A larger environmental setting is needed to see the relevance of v in the outdoor environment. Previous studies proved the effects of wind towards human thermal comfort in bigger microclimate such as an urban square, a campus open space and an open ground level building block (Liu, Niu, & Xia, 2016; Shi et al., 2015; Zheng, Li, & Wu, 2016). Therefore, it is safe to deduce that wind is not a key determinant in pedestrian thermal comfort in this particular study. Furthermore, results show that Rh value is higher in a microclimate that has a lot of trees through their evapotranspiration. When humidity of the surrounding increases and thus reduces the hot tropical air temperature and enhances pedestrian comfort. This has been proven in many studies (Jiao et al., 2017; Rahman et al., 2017; Wu & Chen, 2017).

The effects of different LESPs on pedestrian thermal comfort can be clearly seen from the results discussed earlier. The final ranking of LESP types for pedestrian thermal comfort are i) LESP T_5 (two rows of trees), ii) LESP T_2 (metal deck), iii) LESP T_4 (combined deck & trees), iv) LESP T3 (one row of trees), and v) LESP T_1 (no shade). There is a difference between LESP T_2 and LESP T_4, where LESP T_2 provides more comfort to pedestrians than LESP T_4. LESP T_2 gives better comfort to pedestrian users due to a wider shading area (3.43 meters wide) when compared to LESP T_4 (2.5 meters wide). Wider shading area provides more thermal comfort for pedestrians in this situation. LESP T_2 produces a better result in v, Rh, Tmrt and PET values when compared to LESP T_4 even though there is no significant difference in the findings of Ta and Ts for both LESPs. The 0.93 meters difference in the width of the shading area has changed the pedestrian thermal comfort level from "warm" to "slightly warm". This is an equivalent of 1.2°C difference. The findings also illustrate the different effects of trees shading in LESP T_3 and LESP T_5. In LESP T_3 discontinuous tree shading provide less thermal comfort to pedestrians than LESP T_2, T_4, and T_5. Pedestrian walkways with continuous tree shading provide thermal comfort to users as shown in the case of LESP T_5.

In general, results of this study suggest that different types of LESP have different impacts on pedestrians' thermal comfort. This finding is supported by Bakar and Gadi (2016), in a study on thermal comfort on a university campus in Kuala Lumpur, Malaysia. Their study also suggests that different sites produced different microclimates and highlighted that solar radiation plays an important role in influencing the pedestrian thermal comfort. Furthermore, results clearly indicate that the thermal environment for walkway without shading (LESP T_1) is hotter than semi-shaded walkway (LESP T_3) and the semi shaded area is hotter than the covered walkway (LESP $T_2/T_4/T_5$). In addition, good quality shading by trees can provide the thermal ameliorating effects (LESP T_5). This is supported by a previous study Nouri et al. (2018) suggesting that it is possible to reduce PET values by as much as 16.6°C with public space design interventions. In other words, trees enhance the outdoor thermal comfort as reported by Amani-Beni et al. (2018). They reported that urban trees modify microclimate by reducing human thermal comfort index by 1.41 on hot summer days in Beijing, China. In another study (Xu et al., 2017) also indicates that trees, through their evapotranspiration shading, reduce PET by 2°C on hot summer days.

This study provides a preliminary assessment of the potential role of LESP in microclimate amelioration to enhance pedestrians' thermal comfort in the tropical outdoor environment. It investigated several types of landscape environmental settings of pedestrians' walkways in a tropical university campus. However, this study has several limitations. These include the difficulty in finding a uniform characteristic of the 5 LESP types in a 250.0 m length. It also lacks the same species of trees and their characteristics in the 5 LESP types, and it is hard to make sure every measurement at 25 points (250 m length) in the five LESP types is made at the same time in the 3-day field measurements. Nevertheless, despite these limitations, this study provides some clear evidences to landscape architects, urban planners and others on how different types of LESP can influence the microclimate and thus, pedestrians' thermal comfort in a tropical walkway environment.

5. CONCLUSION

The study concluded that pedestrian walkways with shading, either man-made shading or shading by trees, provide better microclimate in terms of air temperature, surface temperature, relative humidity, mean radiant temperature, and thermal comfort. The shading quality, either by man-made shading or shading by trees, affects the comfort of pedestrians. A continuous and wider shade can increase pedestrian comfort. It is suggested that a minimum width of man-made shading is 3.4 meters. Appropriate planting distances of trees are also important in providing continuous shading along the walkways. Walkways with continuous shading, either man-made shading or shading by trees, provide comfortable thermal environment for pedestrians. Continuous shading is essential to provide a consistent thermal comfort in pedestrian microclimate environment. High albedo pavement materials still require shading to lower the surface temperature for the comfort of pedestrian users. Low albedo pavement has low surface temperatures with shading. Finally, providing a continuous row of tree planting on both sides of the walkway is suggested to enhance the quality of landscape environmental settings for pedestrian's thermal comfort in tropical climates.

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