Outdoor thermal performance investigations: towards a sustainable tropical environment

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Abstract

Most developing countries lay close to the equatorial line of tropical climates with their cities experiencing rapid urbanization, population growth and physical change. This accelerates the changes in their urban landscape, which results in, among others things, the *urban heat island phenomenon* (UHI). The global temperature increment also increases the cooling load and thus more energy is consumed. Attention is given to building design and its technological advancement in energy saving and conservation; not much research is being conducted on the Malaysia's microclimate and the outdoor thermal environment, although they affect the energy consumption of buildings. This paper discusses the approaches adopted in investigating the hot-humid outdoor environment of Malaysia towards understanding how landscape design is affecting the microclimate. Several cases of past research on how ground surfaces affect the adjacent thermal environment, the impact of landscape setting on the microclimate and the influence of the physical dimensions of trees in screening solar radiation are presented. These parameters seem to have a direct influence on the outdoor thermal performance. The findings suggested that the landscape settings influence the microclimate of outdoor spaces, where the high quantity of trees and large tree size seems to lower the ambient temperature. Turfed surfaces seem to lower the ambient temperature compared to tar-mac surfaces. Several recommendations through design initiatives to mitigate the UHI effects in urban areas are made.
Keywords: urban heat island, ground surface material, tree aspect, landscape setting, thermal environment.

1 Introduction

Changes in the landscape can have a significant impact on its microclimate and consequently affect the life of the community involved. This can also happen in reverse where the lifestyle of the community seems to shape the landscape. Rapid urban growth has resulted in most of the soil and natural environment being replaced with paved surfaces and barren terrain shifted to concrete built environment. These changes may have directly altered and modify the local climate or microclimate of the place. When the effect is combined between cities/urban areas, these modifications of microclimate, might influence the climatic conditions at a larger scale.

2 Urbanization, landscape design and microclimate modification

In the hot-humid climate, people are struggling to live comfortably due to the increment of air temperature that is further exaggerated by the urban heat island (UHI) effect where significantly high air temperature in densely built environment as compared to rural temperatures is observed. This is due to the urbanization process where more impervious surfaces are found than grass or green area [1], which allows more heat from the solar radiation being absorbed by these hard surfaces, then reradiated and further heated-up the ambient temperature. Tropical regions where the sun is constantly high in the sky are experiencing intense solar radiation throughout the year. The urban areas where less vegetation is found are the most impacted areas which lead to among others, the investigations of the urban heat island phenomenon [2, 3]. The UHI mitigation is not only to solve the urban-scape temperature issue but could also help in reducing energy consumption in buildings. In Singapore, a study had been carried out on the impact of the surrounding urban topography on energy consumption of a building within the urban-scape. The research concluded that the existence of greenery gave the most significant impact to the building energy saving of up to 4.5% reduction in energy consumption [4]. Another factor that contributes to the global warming is the greenhouse effects whereby heat is trapped in the atmosphere following the presence of greenhouse gases that then warm the environment. This is unfavorable for those who are already living in hot-humid climate.

ASHRAE defined thermal comfort as *"…the condition of mind which expresses satisfaction with the thermal environment, absence of thermal discomfort or conditions in which 80 or 90% of people do not express dissatisfaction*", and the variables that affect thermal comfort are air temperature, radiant temperature, relative humidity, air velocity, activity and clothing [5].

Therefore, in order to manipulate the outdoor elements in controlling the microclimate, these variables must be understood. "*Microclimate is the condition of the solar and terrestrial radiation, wind, air temperature, humidity, and precipitation in a small outdoor space*" [6]. These environmental parameters are influencing the human comfort level thermally and affect their activities as well as the livability of the space in an urban area. In contrast to the indoor environment, the outdoor environment is rather hard to control due to natural factors such as solar radiation, sky condition, wind speed and relative humidity. However, through the application of certain landscape design elements, these factors might be modified as to 'control' the microclimate, thus modify the thermal comfort level of the people [6] as human body responds to the change in the surrounding environment.

The overheated impervious surfaces in urban areas where surface temperature is normally higher than the air have significantly influence the air temperature of the surrounding environment especially those within 200m of the lower atmosphere [7], thus affecting the raising of surrounding temperature through three ways – convection, conduction, and solar and infrared radiation [8]. The basic principle of atmospheric heating process stated that the air is heated from the bottom to top [9]. "*The thermal performance of the materials is characterized by the surface temperature they can reach and is responsible for their radioactive cooling and determines the amount of thermal radiation that is radiated*" [10]. Suitable selection of materials as a cooling factor in an urban environment can improve the thermal comfort condition especially during hot seasons [11]. Albedo is defined as *"…the reflective power of a material indicated by the percentage of incident radiation reflected by a material*" [12] and "*…the physical sciences, the percentage of radiation falling on a surface that is reflected back from it*" [13]. A high albedo surface reflects a higher percentage of solar radiation and absorbed less heat. It was stated that the pavement surface with lower temperature will contribute in reducing air temperature [14]. Surface with higher solar reflectance and infrared admittance have a lower surface temperature when exposed to solar radiation. Light color pavement might create glare problem but the amount of heat being absorbed is less thus, creating a mechanism of cool pavement and on the other hand, darker color will absorb and emit more solar radiation heat to the environment [14], while permeable pavement allows water to infiltrate and help to decrease air temperature by reducing the rate of heat being released to the environment [15].

'Urban greening' has been suggested as a strategy to mitigate the adverse impact of increased temperatures following the climate change [16, 17]. Hence, vegetation, thermal environment and its impact on the people have been the interest on many in improving the quality of life leading to several researches [18, 19], as to identify the specific functions of vegetation such as to minimize the effect of solar radiation, and provision of shadowed area and cooler air. Vegetation is said as among the natural landscape element that has a remarkable influence to the urban thermal island intensity as it has the edge effect influence to the ambient temperature [3]. Following the investigation on the physiology of plants and the thermal impact of vegetation and effect of a park on the urban block scale using the Computational Fluid Dynamic (CFD) analysis, it was suggested that several processes were involved in the microclimatic effect of trees such as the reduction of heat gains through effects of shading and cooling effect through evapotranspiration processes where it was concluded that increasing the size and density of the green area reduces the ambient temperature and keeps it relatively local [20]. A reduced penetration of solar radiation on the ground was discovered, as well as on walls, due to the increased partial shaded area [19]. With the existence of forest covers, the temperature was reduced by 2.5°C [21]. Lower maximum temperatures were found in the most established settlements with mature trees [22]. A study using CFD also discovered that plant canopies can reduce ground surface temperature by 2–4°C [23]. A study on the microclimate under three types of shrubs namely *porlieriachilensis (zygophyllaceae), proustiacuneifolia (asteraceae) and adesmiabedwellii (papilionaceous)* within semiarid environment was conducted throughout seasons of the year 2004–2005 [24]. The results indicated that generally the air temperature under shrubs was lower than away from canopies. The investigation on the role of vegetation in the environmental control of outdoor urban spaces in Barcelona, Spain on a street and a square was conducted and concluded that in terms of urban microclimate, vegetation has the most evident effects on solar radiation as it obstructs, absorbs and reflects a high percentage of solar radiation [25]. Thus, it controls radiant temperature by preventing surfaces from heating up and emitting long wave radiation. A simulation conducted also confirms that tree foliage has screening potential with the direct effect of reducing solar radiation absorbed under a tree canopy [26]. However, it was cautioned that trees with high leafs density might trap long-waved radiation by their canopies [27]. It can be said that studies that focus on the detailed physical aspect of trees in modifying the impact of solar radiation within the tropical region is limited [2] and yet to be further explored and expanded. Based on the previous researches, it is thus concluded that apart from the close correlation between urban morphology and its microclimate, vegetation indeed plays a very important role in 'controlling' the thermal performance of the urban area.

3 Methodology of research

The investigation of thermal performance of the outdoor environment is rather complicated as it involves 'uncontrolled' environment unlike the indoors. Several outdoor component such as the soft-scape and hardscapes, as well as microclimatical parameters such as air temperature, relative humidity, wind environment (speed and direction), surface temperature, light intensity, solar radiation, and sky condition were identified to be studied and this led to identification of strategies for this research. One of the main characters of the urbanization process is paved surfaces, and studies have shown that it affects the urban microclimate greatly. Hence, investigation on the ground surfaces effect on the adjacent thermal environment was important [28]. This was continued with the study on different landscape settings as to see their impacts on the microclimate that involve ground surfaces, as well as vegetation [29]. While having a broader perspectives, further investigation was also conducted by narrowing down on the influence of the physical dimensions of trees in screening the solar radiation from reaching the ground [30]. The process of data collection depended on the weather conditions as the process was stopped whenever it rained. Hence, certain months with less rainfall were identified for these investigations.

3.1 Effect of ground surfaces on adjacent thermal environment

Several plazas in Putrajaya, Malaysia were chosen as the studied sites following availability of open spaces with various pavement materials. Altogether there were five sites – named Plaza A, Plaza B, Plaza C, Dataran Wawasan and Dataran Rakyat. Plaza A and B were located in front of the Ministry of Finance while Plaza C was in front of Masjid Putra. Dataran Rakyat is nearby the Ministry of Youth and Sports, while Dataran Wawasan was nearby the Putrajaya Holdings. The data collection was conducted in the March 2012 during day time. For the first three plazas (Group 1) it was conducted simultaneously while for the last two sites (Group 2) it was done alternately following limitation of equipment and enumerators. The process took several days for each group. Plazas in each group were close to one another. Plazas of Group 1 were categorised as shaded (Plaza A), partially shaded (Plaza B) and exposed to sun (Plaza B); while plazas of Group 2 were having similar orientation and dimension with the former was considered as greener and cooler than the later due to grass covering part of its ground surfaces and shadow cast by buildings surrounding provide partially shaded areas at certain time of the day. Dataran Wawasan is regarded as 100% covered by hard surfaces, and exposed to the sun. Various type of pavement materials was identified together with their color, texture and width as well as the vegetation during site inventory. Techniques employed for the data collection involved:

- studying the landscape design elements of the plaza – types and width of pavement materials, and shading elements (vegetation and tensile structure);
- recording the environmental parameters such as solar radiation, wind speed, light intensity and surface temperature; and
- observing and recording the sky condition in oktas units.

3.2 Impact of landscape settings on the microclimate

Following the study conducted in Putrajaya, there was a need to explore how landscape settings help to shape and/or modify the microclimate. However, due to logistical constraint, the study could not be continued in Putrajaya. Hence, case study sites within the International Islamic University Malaysia (IIUM) campus were identified for this preliminary study. Two categories of spaces – green space and exposed space – involving four sites were created (see table 1).

Table 1: The four investigated sites in IIUM.

Category		Investigated sites	Specific criteria
Green space (GS)	1	River side (RS)	Plenty of trees, shrubs and has a stream flowing within the site
	2	Rector's house (RC)	On a hill top, surrounded with greeneries and plenty of trees
Exposed space (ES)	3	Mahallah Aminah (MA)	Wide turfed-open field, small no. of trees, partially surrounded with buildings
	4	Helipad (HP)	Wide tar-mac field with small amount of trees surrounding it

Table 2: Equipment used and unit of readings.

No.	Equipment	Recorded readings and unit
1	Portable pocket weather station	Wind speed (m/s), wind direction (°)
2	Outdoor data logger	Air temperature (°C) and relative humidity (%)

Table 2 shows the recorded readings and equipment used. Two units of the portable pocket weather station (PPWS) and four units of outdoor data logger (ODL) were utilized to record readings of two sites at a time. One unit of ODL was located under a tree canopy while the other one is located exposed to the direct solar radiation with the PPWS next to it. All equipment was fixed at human level of about 1.5 meter from the ground using tripods. Readings were taken between 09:00hr until 16:00hr as for Kuala Lumpur, high temperature (≥31°C) was observed approximately between 11:00hr until 15:00hr [5]. This research took place in June and July of 2013 as a drier and hotter season was experienced (see table 3).

Table 3: Data collection schedule: location, time and weather conditions.

	Location	Date	Time	Weather conditions		
				Morning	Noon	Evening
GS vs. GS	RS–RC	27.06.13 (D1)	09:00–16:00	Sunny	Sunny	Sunny
		03.07.13(D2)	09:00–16:00	Sunny	Sunny	Sunny
ES vs. ES	MA–HP	28.06.13 (D1)	09:00–16:00	Sunny	Sunny	Sunny
		04.07.13 (D2)	09:00–15:45	Sunny	Sunny	Cloudy/drizzle
		15.07.13 (D3)	09:00–16:00	Sunny	Sunny	Sunny
GS vs. ES	RS–MA	02.07.13 (D1)	09:00–16:00	Drizzle	Sunny	Sunny
		12.07.13 (D2)	09:00–16:00	Sunny	Sunny	Sunny
	RC–HP	17.07.13 (D1)	09:00–16:00	Sunny	Sunny	Sunny
		31.07.13 (D2)	09:00–16:00			
	RC–MA	01.07.13 (D1)	09:00–15:15	Sunny	Sunny	Cloudy/drizzle
		09.07.13 (D2)	09:00–16:00	Sunny	Sunny	Sunny
		19.07.13 (D3)	09:00–16:00	Sunny	Sunny	Sunny
	RS–HP	05.07.13 (D1)	09:00–16:00	Drizzle	Cloudy	Drizzle
		30.07.13 (D2)	09:00–16:00	Sunny	Sunny	Sunny

This study also focused on the physical aspect of trees in particular the quality of its foliage in screening the solar radiation from reaching the ground. Foliage density varies as it is characterized by the sizes and quantity of leaves, structure of the branches, as well as the shape of the canopy. In investigating the quality of the foliage density of trees in screening the solar radiation penetration to the ground, the foliage density was classified into three categories – (1) loose density, (2) medium density and (3) dense.

3.3 Influence of physical dimensions of trees in screening solar radiation

Together with the exploration of landscape settings in shaping and/or modifying the microclimate, further investigation on trees of those four sites in the IIUM was carried out with attempt to identify the influence of tree aspects in screening solar radiation from reaching the ground. The aspects of trees considered were trunk height (TH), crown height (CH), canopy diameter (CD) and foliage density (FD). Based on field observation and adoption of the Likert scale, the foliage density can be categorised into three which were (1) loose density, (2) medium density and (3) dense. Since the sun position is quite low in the Kuala Lumpur's sky in June and July, it was intended that further investigation should be conducted in the months where the sun's position is the highest in the sky as to compare and contrast the outcome. Investigated trees were identified by their common and scientific names. The trees were examined, measured and inventoried in advanced prior to measuring the solar radiation underneath the tree canopy which took several days (see table 4).The solar radiation readings underneath the tree canopy was captured three times consecutively with one minute interval each, at about 1.5 meter from the ground. This was to ensure that the equipment was positioned well to allow its sensor to capture the solar radiation reading while allowing the reading to be recorded. These readings were then averaged, and further compared with those taken under the direct sunlight. This was done between 11:00hr and 15:00hr following high reading of solar radiation observed with an average reading beyond 400 Wh/m^2 (1-year data) [5]. Two units of solar meter model ISO-TECH ISM 410 were used with one unit was located stationary under the direct sunlight with readings taken three times (one minute interval) for each site – at the beginning (1), half way through (2) and towards the end (3) of the period of the process.

Table 4: The date and time of solar radiation data collection.

	Date	Time		Date	Time
RS	2 July 2013	11:30 am–12:15 pm	HP	13 July 2013	2 pm–2:30 pm
RC	13 July 2013	12 noon–1:30 pm	MA	14 July 2013	12 noon–1:30 pm

4 The analyses and results

The strategies used in the analyses and summary of the results of the investigations on the hot-humid outdoor thermal performance shall be presented in the following section.

4.1 The impact of ground surfaces on adjacent thermal environment of Plazas in Putrajaya

The environmental data collected was analysed using the Microsoft Excel software. The SketchUp software was applied to analyse the shadow pattern of the Dataran Rakyat and Dataran Wawasan as these plazas were surrounded by buildings that could have affected their outdoor microclimate. The analysis of the inventory of surface materials was conducted (see table 5).

Table 5: Inventory and analysis of surface materials.

		Material	Texture	*	Colour	**	Area (m²)	***	****
PLAZA A (6335.5 m²)	A.	Granite	Very fine	41.2% Fine texture 32.8% Coarse texture	Light	61.3 Light color 12.7 Dark color	95.03	1.5	74
	B.	Granite	Very fine		Dark		982.01	15.5	
	C.	Granite	Coarse		Light		633.56	10	
	D.	Granite	Coarse		Light		715.92	11.3	
	E.	Concrete	Fine		Light		886.98	14	
	F.	Concrete	Fine		Light		570.2	9	
	G.	Pebble wash	Very coarse		Dark		728.59	11.5	
	H.	Granite	Fine		Dark		63.36	1	
	I.	Granite tile	Very fine		Very dark		12.67	0.2	
	J.	Grass	Very coarse		Green		1,647.3	26	26
PLAZA B (2347 m²)	A.	Granite	Coarse	64.6% Fine texture 33.8% Coarse texture	Light	63.8% Light color 34.6% Dark color	105.6	4.5	98.4
	B.	Granite	Very fine		Dark		112.7	4.8	
	C.	Concrete	Fine		Light		990	42.2	
	D.	Pebble wash	Very coarse		Dark		295.7	12.6	
	E.	Concrete	Fine		Light		270	11.5	
	F.	Granite tiles	Very fine		Very dark		105.6	4.5	
	G.	Granite	Coarse		light		18.76	0.8	
	H.	Homogeneous tiles	Fine		Very dark		176	7.5	
	I.	Grass	Very coarse		Green		37.5	1.6	1.6
PLAZA C (20201 m²)	A.	Homogeneous tiles	Very fine	8.2% Fine texture 69.3% coarse texture	Light	74% Light color 3.5% Dark color	105	0.5	77.5
	B.	Pebble wash	Very coarse		Light		300	1.4	
	C.	Homogeneous tiles	Very fine		Light		1,574	7.7	
	D.	Granite	Fine		Dark		725	3.5	
	E.	Granite	coarse		Light		13,010	64.4	
	F.	Grass	Very coarse		Green		4,554	22.5	22.5

* Percentage of total light to dark colour material
** Percentage of total fine to coarse texture material
*** Percentage of surface material to the area of plaza
**** Percentage of total paved surface to grass

Among the components observed for further analysis were the widest and smallest plaza with their size ratio, percentage of paved and turfed surfaces, the percentage of coarse paved surfaces, dark coloured paved surfaces as well as the common/same material found in all plazas. For hot-humid outdoor environmental research with focus on the thermal performance, it is very important to capture data on the sunniest day – in order to see the optimum if not the maximum effect of the hottest day following high solar radiation intensity that reaches the ground level. The sky condition which is observable by using the *oktas* unit as well as the measurable solar radiation (Watt/m^2) are studied. The sunniest or hottest day was selected for further analysis. Solar radiation intensity pattern was observed as the reading generally gets higher between 11 am to 3 pm [5]. The clouds also affect the amount and intensity of solar radiation that reaches the ground – please refer to fig. 1.

Wind environments of the plazas affect specifically the air temperature and relative humidity and eventually the microclimate of the sites. Stagnant wind environment (0 m/s) in unfavourable for hot-humid climate, especially when it is prolonged, while air movement results in thermally comfortable environment. Please refer to the following fig. 2 of the analysis of the wind environment.

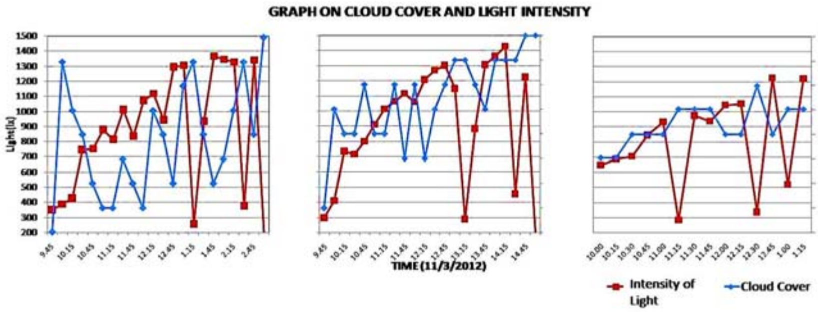

Figure 1: The effect of cloud cover (%) on sunlight intensity (lux) reaching the ground surface at Putrajaya.

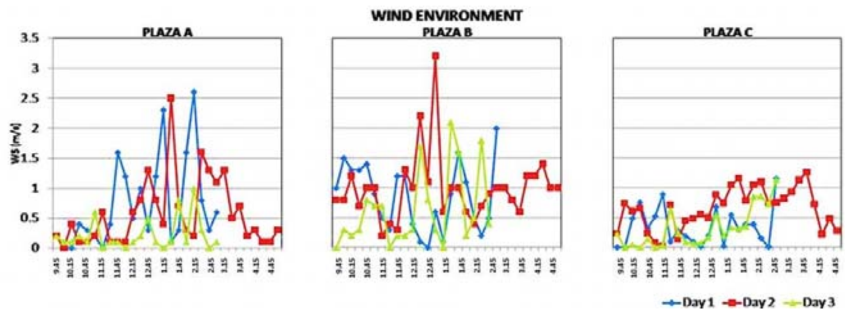

Figure 2: Wind environment in Plaza A, Plaza B and Plaza C.

The material with the highest and lowest surface temperature was identified. The character of the materials was further analysed. The different performances posed by each materials can be due to their heat conductivity, color and texture where most of the materials with highest surface temperature recorded are characterized with darker color with very fine texture as observed at Plaza A and Plaza B (no fine texture for pavement at Plaza C except for one material which is covered by water element). It is to be noted that coarse texture would absorb heat more than fine texture. The following graphs (refer to fig. 3) are generated to analyse the surface temperature of the investigated ground surface materials.

The surface temperature of the same material available at these plazas was compared. Here, the materials were granite and pebble wash. The criteria (color and texture) of these materials for every plaza was studied together with the highest and lowest recorded readings. The categories of these plazas – exposed, shaded and partially shaded were also considered. Hence, it was observed that granite of exposed plaza seemed to demonstrate the highest surface temperature reading. The percentage of cloud cover also seemed to affect the surface temperature reading in negative association (the lower the percentage of cloud cover, the higher the surface temperature). Similar approaches were applied in analysing between Dataran Rakyat and Dataran Wawasan but with extra analysis on the shadow pattern following the adjacent buildings surrounding these sites – please refer to fig. 4.

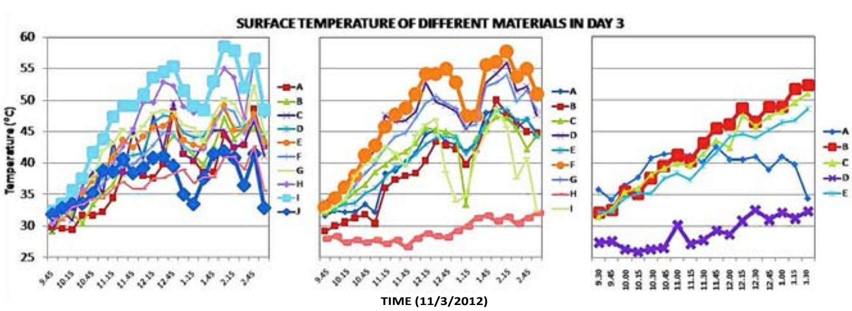

Figure 3: Surface temperature of different materials for three plazas on day 3 (sunniest day).

LOCATION	DAY	MORNING	AFTERNOON	EVENING
Dataran Wawasan	D4 11/03/12			
Dataran Rakyat	D5 26/03/12			

Figure 4: The shadow analysis in the morning, afternoon and evening.

4.2 The impact of landscape setting on the microclimate, IIUM

Similar to the investigation of plazas in Putrajaya, the physical aspects of the studied sites such as the settings, ground surface materials and vegetation were analysed – refer to the following tables 6 and 7.

Table 6: Size and percentage of ground surface types of investigated sites.

	RS		MA		HP		RC	
Elements	**(m^2)**	**%**	**(m^2)**	**%**	**(m^2)**	**%**	**(m^2)**	**%**
Turfed/vegetated	5,608	**66**	11,003	**66**	7,460	32	11,300	**72**
Tarmac	2,182	25	3,171	19	14,467	**62**	3,767	24
Water	749	9	0	0	771	3	0	0
Building	0	0	2,407	15	608	3	625	4
Total site area	8,538	100	16,581	100	**23,306**	100	15,692	100

Table 7: Quantity and percentage of tree canopy diameter.

Canopy diameter (CD)	**RS**		**MA**		**HP**		**RC**	
	nos	**%**	**nos**	**%**	**nos**	**%**	**nos**	**%**
1–6m	6	30	38	**86**	4	**44**	57	**84**
7–13m	9	**45**	1	2	4	**44**	7	10
14–19m	3	15	4	9	0	0	3	4
>19m	2	10	0	0	1	12	1	2
Dimension not available	-	-	1	2	-	-	-	-
Total	20	100	44	100	9	100	**68**	100

The size of each site and their classification whether green or exposed area were identified. The components of the ground surface materials and its percentage, and the inventory of trees were observed for further comparisons. Shrubs were not included in this study as the focus was given on trees and their shading effect. Site with the largest and smallest amount of trees was identified. However, this may not be effective in measuring the impact of trees on the microclimate following the difference in terms of size of each site. Hence, the ratio of tree and the area was calculated where a conclusion can be derived and the example is as such – “a tree at RC is for an area of 231m^2 that makes it the ‘greenest’ among all”. These sites were ranked accordingly following this ratio.

For each site, analysis on the categories of foliage density and their percentage was conducted as to see the significance of foliage density in modifying the sites’ microclimate. From the analysis, it was found that the canopy diameter of trees also plays significant roles on top of foliage density and the ratio of tree and size of the site. Other factors to be observed include whether the trees were in a clump and having continuous canopies.

For the purpose of the analysis on the microclimate, it is being strategized according to three categories which are comparisons between green spaces (RS vs. RC), comparisons between exposed spaces (MA vs. HP), and comparisons between green spaces and exposed spaces. For each category, the range of readings for each variable is being studied. The maximum and minimum differences of each variable are also observed. For the two or three days data, focus is given to the day with the highest air temperature reading and then between 11:00hr until 15:00hr. As for the wind, the direction is identified based on the eight angles as follows:

North (N): 337.5–22.5°
North-east (NE): 22.5–67.5°
East (E): 67.5–112.5°
South-east (SE): 112.5–157.5°
South (S): 157.5–202.5°
South-west (SW): 202.5–247.5°
West (W): 247.5–292.5°
North-west (NW): 292.5–337.5°

General observations across all studied sites were made prior to detail observations such as the air temperature reading for exposed area is higher than shaded area for every site, and the air temperature increases, the relative humidity decreases. Thus, it can be said that these two variables have negative association. The highest and lowest readings were identified too. This general observation was made on the wind environment too. Next, detail comparisons were made between sites (comparing between green spaces, exposed spaces, and between green spaces and exposed spaces) by analysing the range of air temperature, range of relative humidity, range of wind direction and wind speed. Figures 5–7 are examples of the analysis conducted.

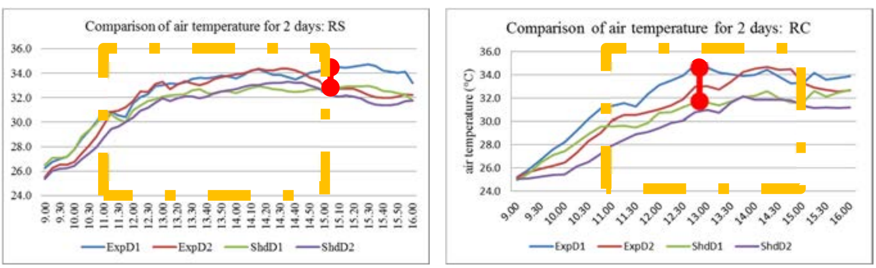

Figure 5: Range of air temperature at exposed and shaded areas of RS and RC.

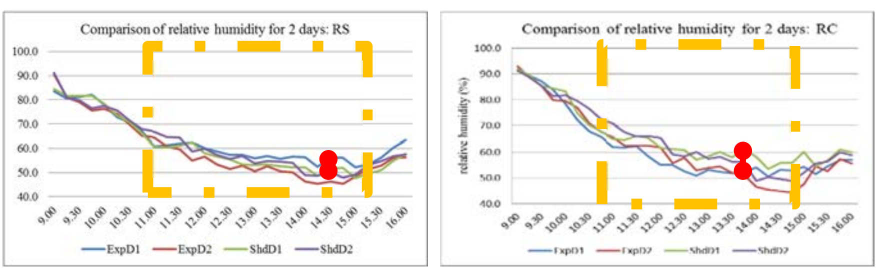

Figure 6: Range of relative humidity at exposed and shaded areas of RS and RC.

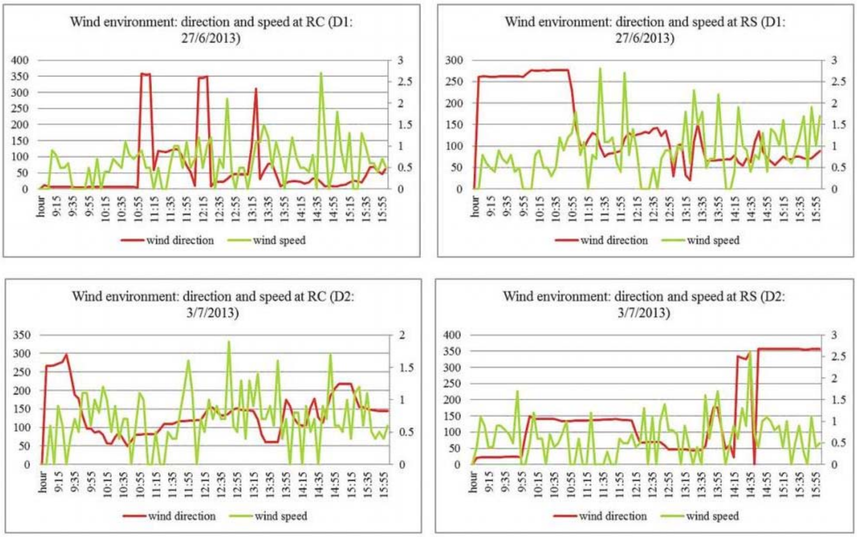

Figure 7: Wind environment of RS and RC for 2 days.

4.3 The influence of tree aspects in screening the solar radiation, IIUM

In order to analyse the influence of tree aspects in screening the solar radiation from reaching the ground surfaces, first these trees were identified based on their common and scientific names, and grouped according to their species. The investigated tree aspects were the trunk height (TH), crown height (CH), canopy diameter (CD) and foliage density (FD). There were six species with 89 trees altogether (see table 8).

Table 8: The classification of the investigated trees following their location, common and scientific names, and quantity (nos).

Location	**Scientific name**	**Common name**	**No.**
RS, MA, HP	*Samanea saman (SS)*	Rain tree	18
MA, RC	*Cinnamomum verum (CV)*	Cinnamon	18
RS, HP	*Lagerstomia speciosa (LS)*	Pride of India	10
MA	*Phoenix roebelenii (PR)*	Dwarf date palm	12
MA	*Mangifera indica linn. (MIL)*	Mango	7
RC	*Hopea odorata (HO)*	Merawan siput jantan	24
		Total number of trees	**89**

To start with, general observations were made on the maximum range of solar radiation recorded under the direct sunlight for all four sites within the three days of data collection, followed by the minimum and maximum range of solar radiation readings underneath every tree. This gave some general perspective on the influence of trees in screening the solar radiation where obviously the recorded readings were lower than under the direct sunlight. These TH, CH, CD and FD of these six species were compared based on intra-species (within the same species) followed by comparison on the averaged solar readings underneath their canopies. The following figures 8 and 9 are examples of the analysis and applied for all species.

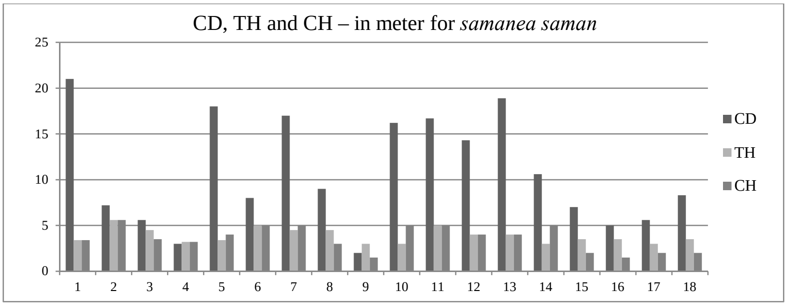

Figure 8: Dimensions of canopy diameter (CD), trunk height (TH) and crown height (CH) of 18 no. of *samanea saman.*

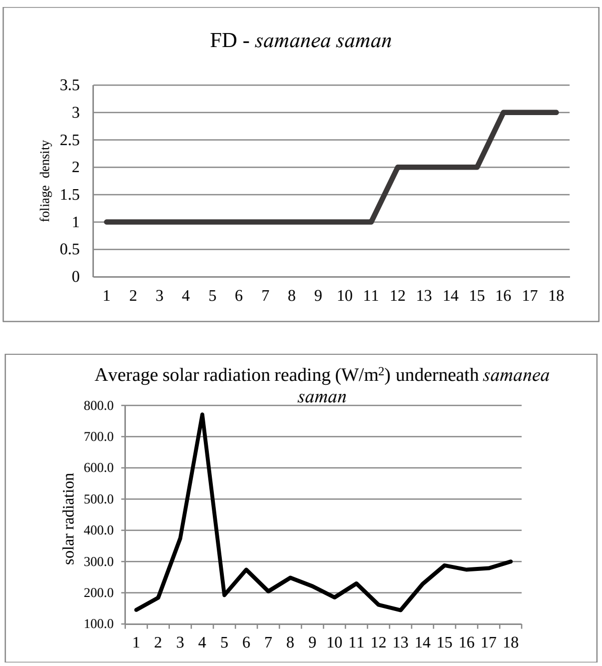

Figure 9: Categories of foliage density (FD) for 18 no. of *samanea saman* (top), and average solar radiation readings (W/m^2) underneath 18 no. of *samanea saman* (bottom).

Referring to table 9, further steps were taken where on top of analysing the range of TH, CH, CD and FD literally, the analysis was done based on identified ratio of CH to TH and CD to CH as to relate and test these aspects. Finally, an attempt to identify the best tree species in screening the solar radiation from penetrating to the ground was made. Cross-analysis was conducted and examined between the time and dates when the measurement was conducted, the sites with types of tree species, the range of solar readings recorded under direct sunlight throughout the measurement process, and the range of solar radiation readings underneath tree. Table 10 shows the results.

Table 9: The physical analysis of *samanea saman* and general range of solar readings (W/m^2).

Range of TH (m)	3.0–5.6	
Range of CH (m)	1.5–5.6	
	Ratio	**Nos**
Ratio of CH/TH	= 1.0	7
	< 1.0	7
	> 1.0	4
Ratio of CD/CH	= 1.0	0
	<1.0	1
	>1.0	17
FD*	1	11
	2	4
	3	3
General range of solar readings underneath tree (W/m^2)	150–300	
* 1: least dense; 2: medium dense; 3: dense		

Table 10: Ranking the tree types that best screen solar radiation penetration.

Tree types	**Range underneath the tree (W/m^2)**	**Location – Nos.**	**Rank**	**Tree types**	**Range underneath the tree (W/m^2)**	**Location – Nos.**	**Rank**
SS	150–300	RS – 8 MA – 5 HP – 5	4	PR	330	MA – 12	5
CV	100–250	MA – 6 RC – 12	3	MIL	107-209	MA – 7	2
LS	100–200	RS – 9 HP – 1	1	HO	400-500	RC – 24	**6**

Lagerstromia speciosa is suggested as the best solar radiation screener while *hopea odorata* seems to be the worst among these six tree types. Therefore, the physical aspects of tree which are the CD, TH, CH and CD for these two tree species are further analysed. When compared and contrasted, the following results are found:

Table 11: Analysis on the physical aspects of *hopea odorata* (HO) and *lagerstromia speciosa* (LS).

	HO	LS
Dimension of CH bigger than TH	9 (38%)	7 (70%)
Dimension of CH smaller than TH	15 (62%)	2 (20%)
Dimension of CH = TH	0 (0%)	1 (10%)
Dimension of CD smaller than CH and TH	21*	0

*The dimensions of CD, TH and CH for the other 3 are: i – 1.2m, 2.5m, 1.0m; ii – 6.0m, 2.0m, 6.0m; iii – 4.1m, 3.0m, 4.0m.

Referring to table 11, it can be said that generally for *lagerstromia speciosa* its crown height is bigger than its trunk height, and the dimension of its diameter of the canopy is bigger than its crown height and trunk height – while *hopea odorata* is otherwise. Hence, it can be suggested that trees with bigger dimension of crown height than trunk height, with bigger dimension of diameter of canopy than that of crown height & trunk height seem to screen the solar radiation penetration to the ground better. Looking into the foliage density, as for *lagerstromia speciosa* it falls within medium dense (6/10 – 60%) and dense (4/10 – 40%); while for *hopea odorata* it can be categorized as least dense as 96% (23/24) falls under least dense (1/24 of was identified as dense).

5 Conclusion

Based on the investigation on ground surface materials at plazas of Putrajaya, it can be suggested that surface with darker color and coarse texture will result in a higher reading of surface temperature, with color seems to be an influencing factor that enhances the materials heat absorbing capability more than texture. Based on the analysis, concrete surfaces with light color and fine texture show a medium reading of surface temperature. Between granite, concrete and pebble wash, granite is preferred following the lower surface temperature reading demonstrated. High surface temperature observed at the exposed plaza suggested more heat being absorbed by the ground surface materials following high intensity of solar radiation reaching them as well as heat reradiated to and from the surrounding elements. Cloud covering the sky also seems to result in lower ground surface temperature. The ground surface materials in a shaded area tend to demonstrate lower surface temperature readings which indicate the influence of landscape setting. It was also found that the presence of water on top of ground surface material will reduce the surface temperature significantly regardless of its color. It was also observed that grass plays a very important role in reducing the ambient temperature. Hence, grass and trees should be incorporated in plaza's design of hot-humid climate as much as possible as they warm the surrounding less.

For the study on the impact of landscape setting conducted in the IIUM, it can be seen that relatively cooler site would normally be more humid while hotter site would normally demonstrate more dynamic wind environment. Other conclusions are as follows:

- When compared among green spaces, the RC seems to be cooler. RC has abundance of trees compared to RS although RS has a river flowing through it.
- When compared between exposed spaces, MA seems to be cooler than HP. MA has the advantages of having 66% of vegetated/turfed surfaces with a larger amount of trees than HP, which has an about 32% smaller amount of trees. The fact that HP is widely covered with tarmac (62%) could also contribute to this.
- If ranked from coolest to hottest environment, it can be suggested as: RC, RS, MA and HP.
- Aspect of trees seem to be influencing the air temperature underneath the tree, thus collectively it can significantly influence the sites' microclimate.

The field investigation on the influence of tree aspects in screening the solar radiation from reaching the ground is concluded with *lagerstromia speciosa* as the best among the six tree species investigated. Its significant physical aspect identified are its crown height is taller than its trunk height, and the dimension of its diameter of the canopy is larger than its crown height and trunk height. As for its foliage density, *lagerstromia speciosa* falls between medium dense (6/10 – 60%) and dense (4/10 – 40%). Thus, the analysis and result may provide some guidelines to designers in choosing appropriate tree species by its physical characters towards controlling the microclimate of the space to be designed.

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