Outdoor thermal performance investigations towards sustainable tropical environment

ENERGY AND SUSTAINABILITY V
16-18 DECEMBER 2014, PUTRAJAYA
ORGANIZED BY: WESSEX INSTITUTE OF TECHNOLOGY

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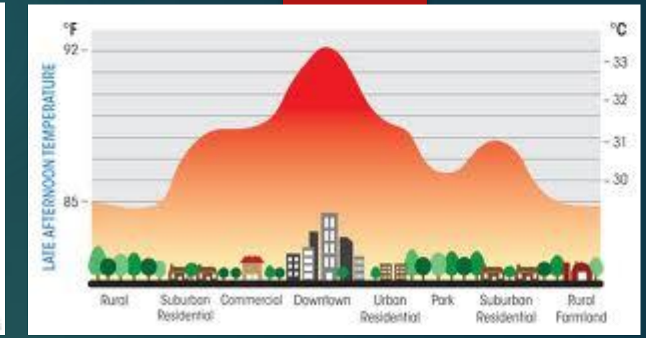
Introduction



- Most of the **developing countries** lay close to **the equatorial line of tropical climates** with their cities experiencing rapid urbanizations, population growths and physical changes. These accelerates the changes in their urban landscape, which results among others **the *urban heat island phenomenon (UHI).***
- The global temperature increment also increases the **cooling load**, thus more energy is consumed. Attention is given on building design and its technological advancement in energy saving and conservation, not much research are being conducted on the Malaysia's microclimate and 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 the landscape design is affecting the microclimate.
- Several past research from ground surfaces effect on the adjacent thermal environment, the impact of landscape setting on the microclimate, to the influence of the physical dimensions of trees in screening the solar radiation are presented.

Urbanization, landscape design and microclimate modification

- 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**
- 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
- '**Urban greening**' has been suggested as a strategy to mitigate the adverse impact of increased temperatures following the climate change. 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 .

Methodology of research for outdoor microclimate:

- The investigation of thermal performance of the outdoor environment is rather complicated as it involves '**uncontrolled**' environment unlike the indoors.
- Investigated components:

1) microclimatical parameters such as air temperature, relative humidity, wind environment (speed and direction), surface temperature, light intensity, solar radiation, and sky condition

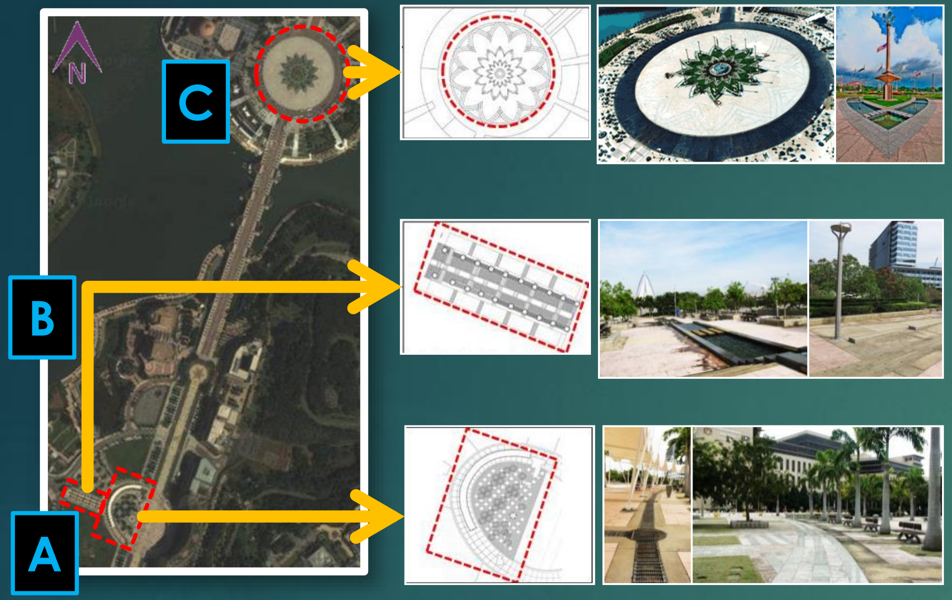
2) soft-scape and hardscapes,

This study presents 3 series of investigations:

- One of the urban characters - 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.
- 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.
- 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.

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 preferred/identified for these investigations.

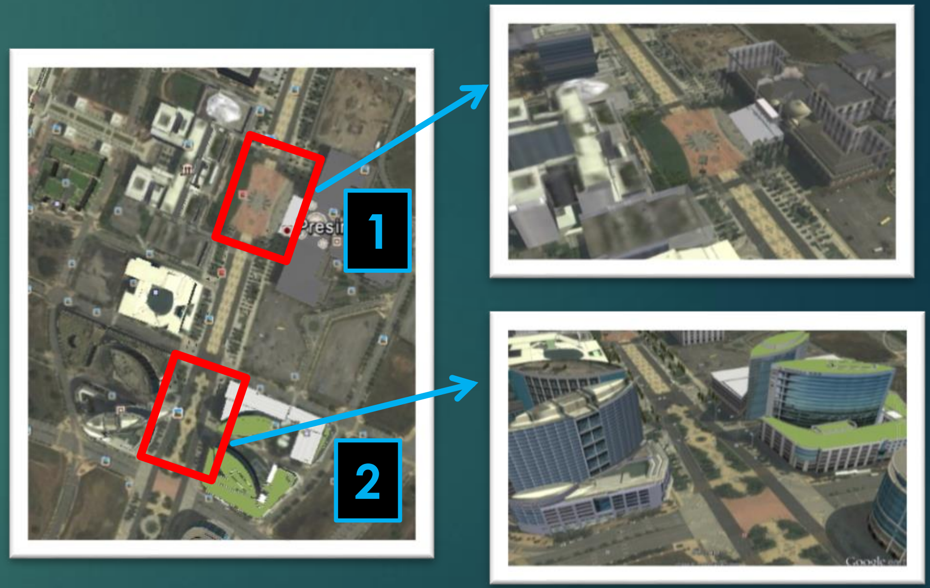
1) Effect of ground surfaces on adjacent thermal environment



Site: Putrajaya (involving 5 plazas)

A: fully shaded & B: partially (in front of the Ministry of Finance)
C: exposed – Dataran Putra (infront Putra Mosque)

Two plazas with similar orientation and dimension but differ in terms of the amount of paved-turfed surface materials and exposure to the sun – namely:
1: Dataran Wawasan and **2: Dataran Rakyat.**
The distance between these two plazas is approximately 200metres.



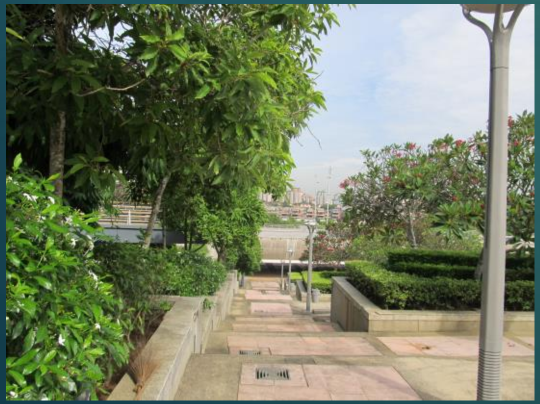
Techniques employed for the data collection involved:

- 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;
- observing and recording the sky condition in oktas unit.

Equipment used

No.	Reading Taken / SI unit	Equipment	Photo
1	Air temperature / (°C) Relative humidity / (%) Solar radiation / (w/m²) Wind speed / (m/s) Wind direction / (°)	Portable Weather Station	
2	Light / (lx)	Heavy Duty Lux Meter	
3	Surface temperature / (°C)	Infrared thermometer	
4	Wind speed (m/s)	Anemometer	

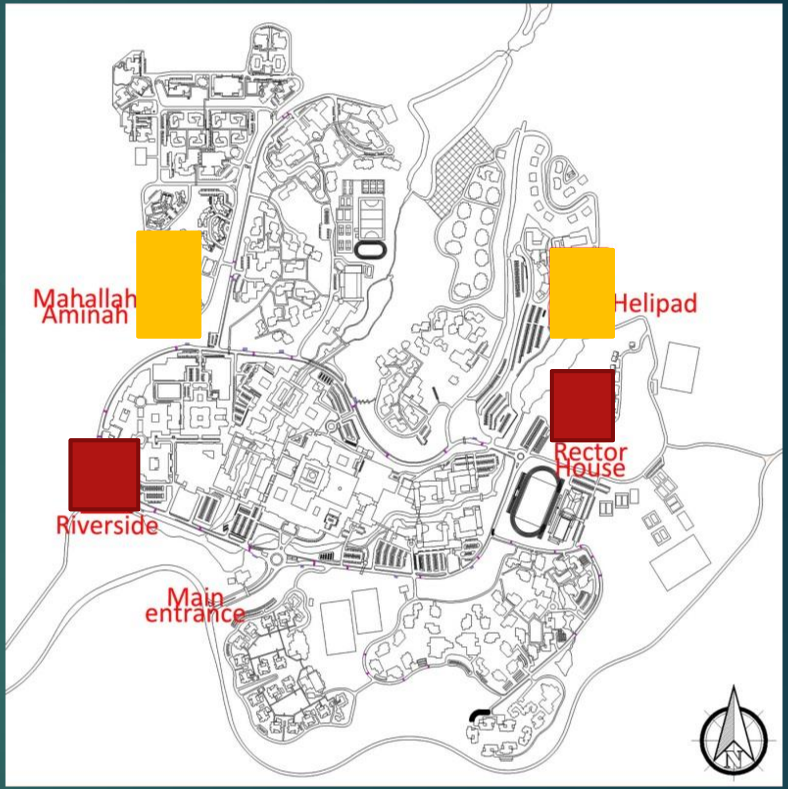
Site inventory on various **type of pavement materials** were identified together with their **color, texture** and **width** as well as the **vegetation**. During the field work, the **sky condition** was also observed based on the **cloud cover** and recorded in ***oktas.*** ***Shadow analysis*** *was also conducted for Dataran Rakyat and Dataran Wawasan* ***- SketchUp software***



2) Impact of landscape settings on the microclimate

Site: IIUM, Gombak Campus

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 with small amount of trees, and partially surrounded with buildings
	4	Helipad (HP)	Wide tar-mac field with small amount of trees surrounding it



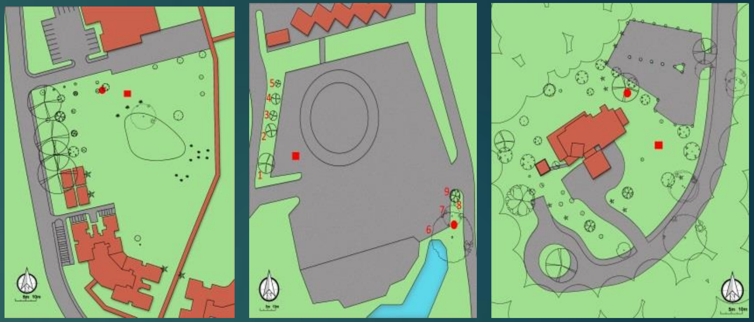
no	equipment	Recorded readings and unit
1	Portable pocket weather station	wind speed (m/s), wind direction (°)
2	Outdoor data logger	air temperature (°C) and relative humidity (%)

Data collection process (June-July 2013) – location, time and weather condition.

Note: 2 locations/day following limitation of equipment (2 sets only)

	location	date	time	remarks	weather conditions: morning	weather conditions: noon	weather conditions: evening
GS vs. GS	RS-RC	27.06.13 (D1)	0800-1600	Haze (<100API)	sunny	sunny	sunny
		03.07.13(D2)	0800-1600		sunny	sunny	sunny
ES vs. ES	MA-HP	28.06.13 (D1)	0800-1600	Haze (<100API)	sunny	sunny	sunny
		04.07.13 (D2)	0800-1545		sunny	sunny	cloudy/ drizzle
		15.07.13 (D3)	0800-1600		sunny	sunny	sunny
GS vs. ES	RS-MA	02.07.13 (D1)	0800-1600		drizzle	sunny	sunny
		12.07.13 (D2)	0800-1600		sunny	sunny	sunny
	RC-HP	17.07.13 (D1)	0800-1600		sunny	sunny	sunny
		31.07.13 (D2)	0800-1600		sunny	sunny	sunny
	RC-MA	01.07.13 (D1)	0800-1515		sunny	sunny	cloudy/ drizzle
		09.07.13 (D2)	0800-1600		sunny	sunny	sunny
		19.07.13 (D3)	0800-1600		sunny	sunny	sunny
	RS-HP	05.07.13 (D1)	0800-1600		drizzle	cloudy	drizzle
		30.07.13 (D2)	0800-1600		sunny	sunny	sunny

no	equipment	readings measured	unit	No. of unit utilized
1	Portable pocket weather station	wind speed	m/s	2
		wind direction	°	
2	Outdoor data logger	air temperature	°C	4
		relative humidity	%	



The locations of 2 sets of equipment for each site are indicated by the red spots

	Canopy diameter (m)	Trunk height (m)	Canopy height (m)	Foliage density
RS	8	5	5	Loose density
MA	3.6	2.3	3	Medium density
RC	12.2	3	15	Dense
HP	26.2	4	20	Dense

Aspects of trees where outdoor data loggers were located

3) Influence of physical dimensions of trees in screening solar radiation

Fieldwork:

tree selection and inventory process

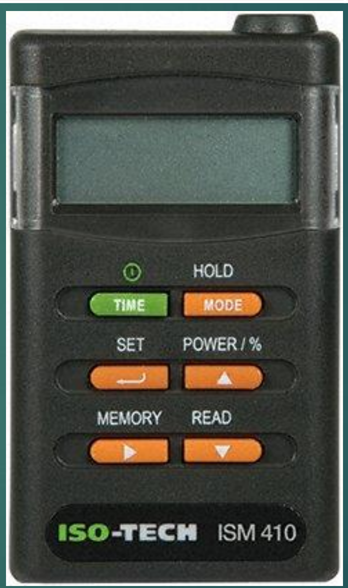
(1) (2) (3)

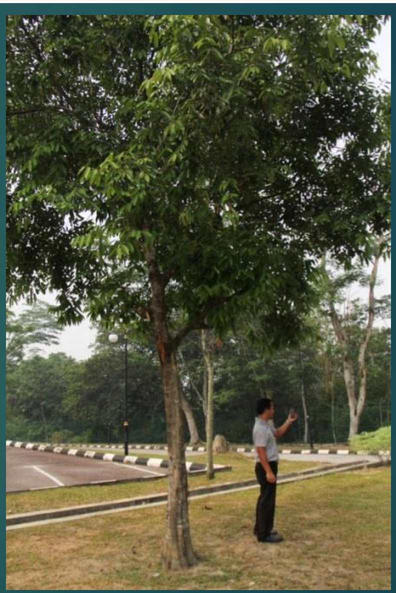
Types of foliage density: (1) loose density, (2) medium density & (3) dense

Measuring trees

Solar radiation measurement

	Date	Start Time
RS	2 July 2013	11.30 am - 12.15 pm
RC	13 July 2013	12 noon - 1.30 pm
HP	13 July 2013	2 pm - 2.30 pm
MA	14 July 2013	12 noon - 1.30 pm





2 units of solar meter (W/m^2) were used: (1) stationary located under direct sunlight – three readings taken throughout the process of each site; and (2) three consecutive readings (1 minute interval) at 1.5m from ground level underneath tree canopy

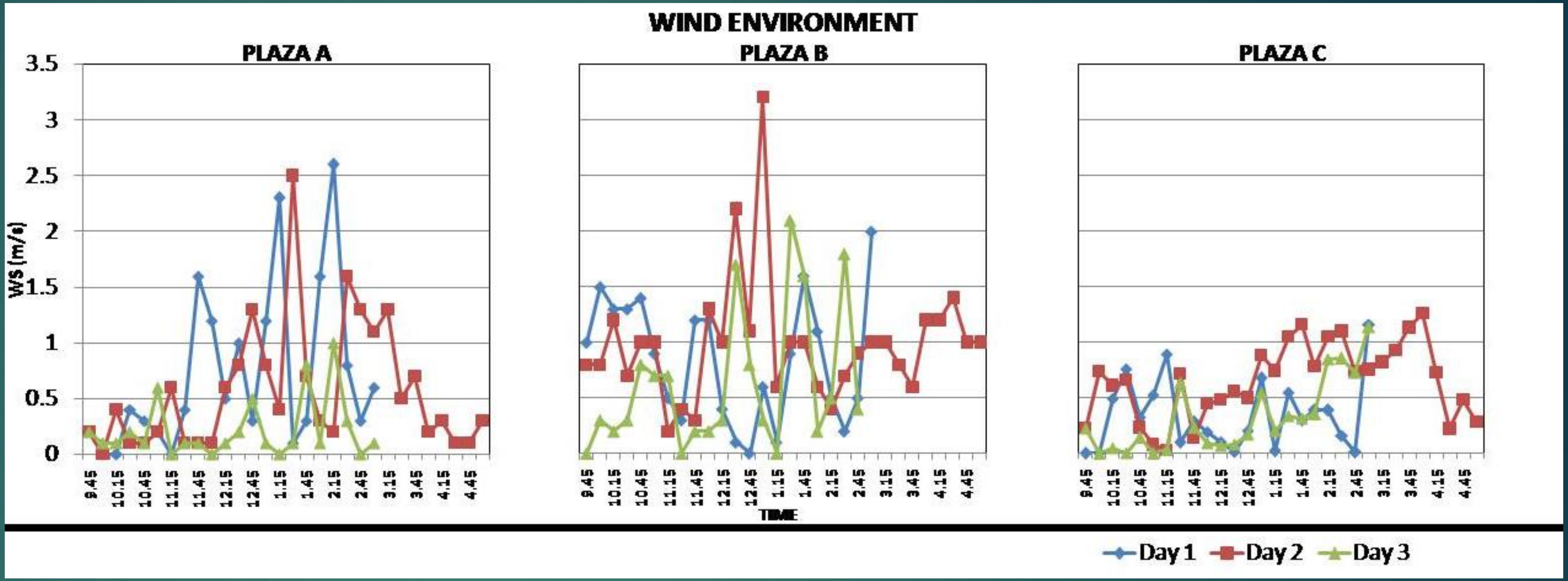
Analyses & results: The impact of ground surfaces on adjacent thermal environment of Plazas in Putrajaya (1/4)

		Material	Texture	* (%)	Colour	** (%)	Area (m²)	*** (%)	**** (%)
PLAZA A (6335.5 m²)	A.	Granite Slab	Very Fine	41.2% Fine texture 32.8% Coarse texture	Light	61.3% Light colour 12.7% dark colour	95.03	1.5	74
	B.	Granite Slab	Very Fine		Dark		982.01	15.5	
	C.	Granite Slab	Coarse		Light		633.56	10	
	D.	Granite Slab	Coarse		Light		715.92	11.3	
	E.	Concrete Slab	Fine		Light		886.98	14	
	F.	Concrete Slab	Fine		Light		570.2	9	
	G.	Pebble Wash	Very Coarse		Dark		728.59	11.5	
	H.	Granite Slab	Fine						
	I.	Granite tile	Very Fine		Dark		63.36	1	
					Very Dark		12.67	0.2	
	J.	Grass	Very Coarse		green		1647.3	26	26
PLAZA B (2347 m²)	A.	Granite Slab	Coarse	64.6% Fine texture 33.8% Coarse texture	Light	63.8% Light colour 34.6% Dark colour	105.6	4.5	98.4
	B.	Granite Slab	Very Fine		Dark		112.7	4.8	
	C.	Concrete Slab	Fine		Light		990	42.2	
	D.	Pebble Wash	Very Coarse		Dark		295.7	12.6	
	E.	Concrete Slab	Fine		Light		270	11.5	
	F.	Granite tiles	Very Fine		Very Dark		105.6	4.5	
	G.	Granite Slab	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 colour 3.5% Dark colour	105	0.5	77.5
	B.	Pebble Wash	Very Coarse		Light		300	1.4	
	C.	Homogeneous tiles	Very fine		Light		1574	7.7	
	D.	Granite Slab	Fine		Dark		725	3.5	
	E.	Granite Slab	coarse		Light		13010	64.4	
	F.	Grass	Very coarse		green		4554	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

Analyses & results: The impact of ground surfaces on adjacent thermal environment of Plazas in Putrajaya (2/4)

Wind environment for Plaza A, B and C on days of data collection

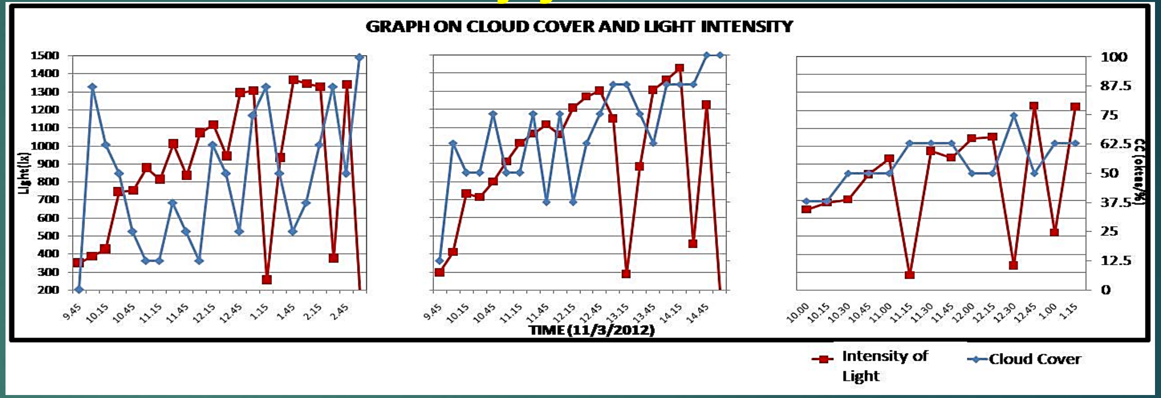


- Wind plays a vital role in giving comfort to the people in particular in hot-humid condition.
- Generally, Day 2 - the most dynamic wind environment with generally consistent wind.
- Plaza C experienced stagnant wind environment the most as it recorded the highest amount of 0m/s reading. As for Plaza A and B, the wind environment is more dynamic with less stagnant condition and the highest reading recorded is slightly above 2.5m/s and 3m/s respectively.

Analyses & results: The impact of ground surfaces on adjacent thermal environment of Plazas in Putrajaya (3/4)

- **The effect of cloud cover (%) on light intensity (sunlight)(lux) reaching the ground surface at Putrajaya**

As **cloud cover increases**, the **amount of sunlight that reached the ground surfaces decreases**



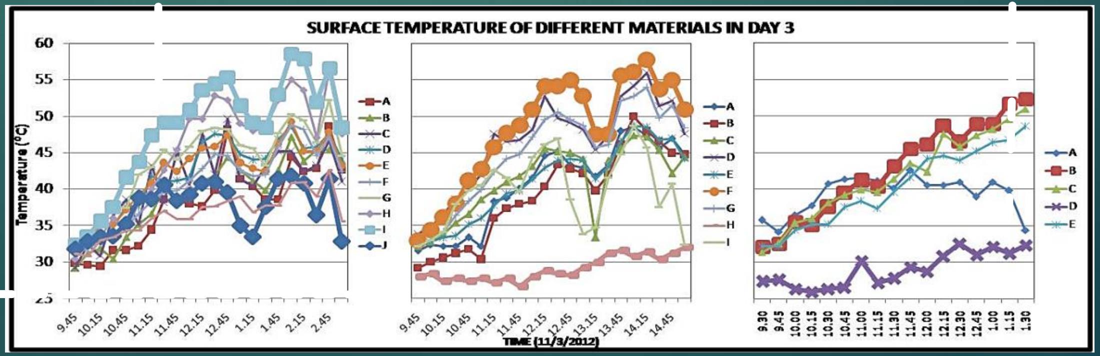
- **Surface temperature of different materials for three plazas in Day 3 (sunniest day)**

Granite tile (very dark/very fine) in both plazas A and B performs the **highest surface temperature**

Colour of the material seems to influence surface temperature reading more than texture

Homogenous tile in both plazas B and C shows **lowest surface temperature**

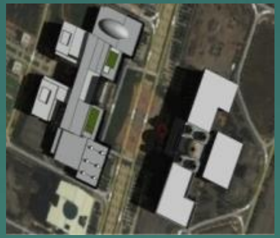
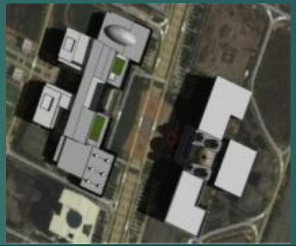
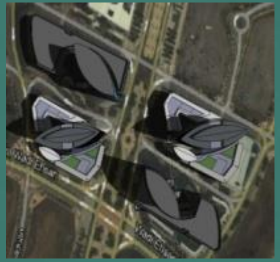
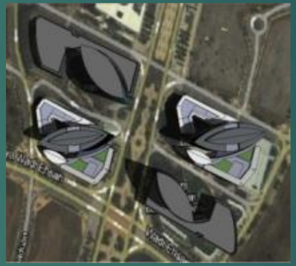
Grass shows the **lowest surface temperature**



presence of water on homogenous tile surface significantly reduce the heat absorbance

Analyses & results: The impact of ground surfaces on adjacent thermal environment of Plazas in Putrajaya (4/4)

Shadow analysis of DW and DR

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

- the buildings surrounding Dataran Wawasan do not cast any shadow on the plaza at any time. In contrast to Dataran Wawasan, Dataran Rakyat is partly shaded by the buildings. It is to be noted that generally the buildings surroundings Dataran Rakyat is higher (about 11 storeys) and close to the plaza, compared to buildings surrounding Dataran Wawasan (about 9 storeys) and a bit further from the plaza.

Analyses & results: The impact of landscape setting on the microclimate, IIUM (1/3)

	RS		MA		HP		RC	
Elements	**(m²)**	**%**	**(m²)**	**%**	**(m²)**	**%**	**(m²)**	**%**
Turfed/vegetated	5608	**66**	11003	66	7460	32	11300	**72**
Tarmac	2182	25	3171	19	14467	62	3767	24
Water	749	9	0	0	771	3	0	0
Building	0	0	2407	15	608	3	625	4
Total Site Area	8538	100	16581	100	**23306**	100	15692	100

The widest site - HP followed by MA, RC and RS.
Green spaces: RS – 66% turfed and RC – 72% turfed with plenty of mature and big trees. Exposed spaces: MA – 66% turfed but small nos of big and mature trees to provide shade; HP – 62% tarmac.

canopy diameter - CD	RS		MA		HP		RC	
	nos	**%**	**nos**	**%**	**nos**	**%**	**nos**	**%**
1m-6m	6	30	38	86	4	44	57	84
7m-13m	9	45	1	2	4	44	7	10
14m-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		44		9		68	

Site with plenty of trees: RC (68) but Ø range of 1m to 6m, MA (similar to RC – 86%), RS and HP. Generally all sites do not have many trees with canopy diameter beyond 14m. As for the HP - the site with the largest tarmac covering its ground surface, there is only one big tree exists.

	RS	MA	HP	RC
no. of tree	20	44	9	68
area size (m²)	8538	16581	23306	15692
tree/m²	0.0023	0.0027	0.0004	0.0043
a tree for an area of (m²):	427	377	**2590**	**231**
comparing between sites ratio	1.8	1.6	11.2	1.0

"A tree at RC is for an area of 231m²", that makes it the 'greenest' among all. The greenest site to least greenest: RC, MA, RS and lastly HP. A tree at HP seems to be 'covering' 11.2 times the function of a tree at RC (literal comparison based on tree quantity – not taking the detail aspect of its physical and biological functions).


1- loose density


2 – medium density


3 - dense

focus on physical aspect of trees: the quality of 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, the shape of the canopy.

The trunk height has in some ways affected the quality of shades too – which implies the quality of screening the solar radiation.

Analyses & results: The impact of landscape setting on the microclimate, IIUM (2/3)

A comparative analyses on the microclimate of investigated sites: Strategies in analyzing the microclimate of sites

1. comparisons between green spaces (RS vs. RC),
2. comparisons between exposed spaces (MA vs. HP),
3. comparisons between green spaces and exposed spaces: RS vs MA, RC vs HP, RC vs. MA, RS vs. HP

- **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 1100hr until 1500hr – due to high temperature observed for Kuala Lumpur (analysis on meet. Data)**

Wind analysis – the directions are based on the following defined angles:

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

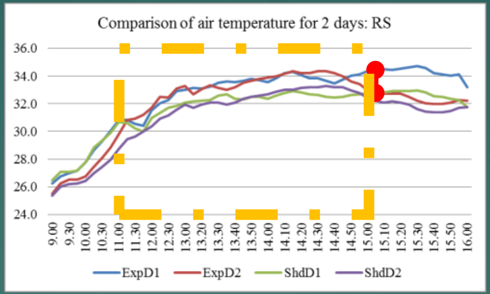
Analyses & results: The impact of landscape setting on the microclimate, IIUM (3/3)

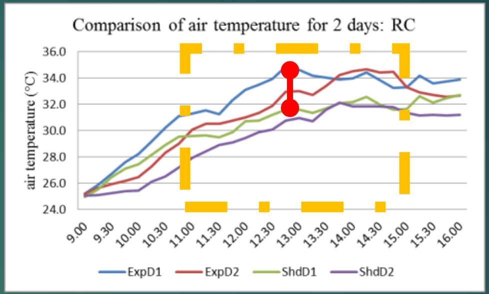
General observations across all studied sites were made prior to detail observations such as the air temperature reading for exposed area is higher than shaded area for every site, and as **the air temperature increases, the relative humidity decreases.** Thus, it can be said that these two variables have negative association.

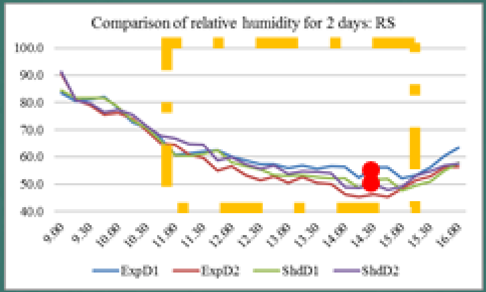
The **highest and lowest readings** were identified too. This general observation was made on the wind environment too.

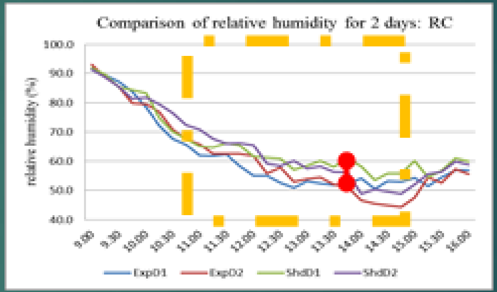
Next, detail comparisons were made between sites (comparing between green spaces, exposed spaces, and between green spaces and exposed spaces) by analysing the range of air temperature, range of relative humidity, range of wind direction and wind speed.

Example of analysis:



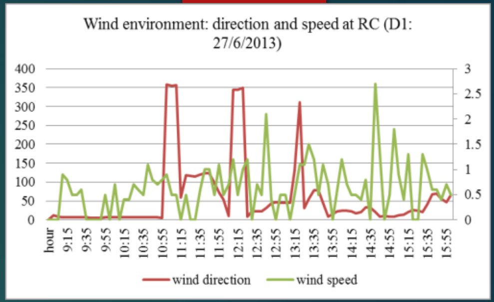


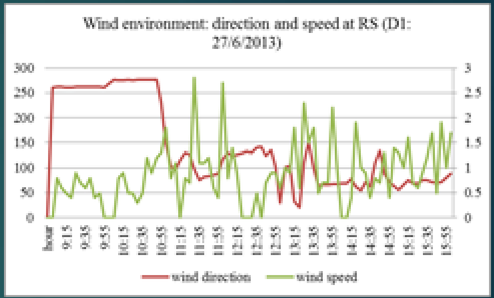


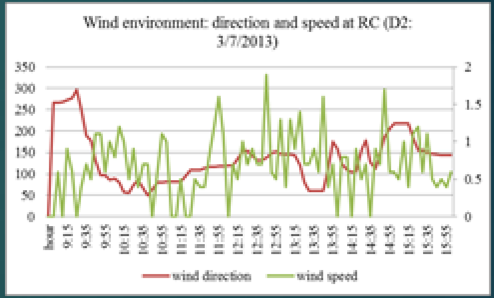


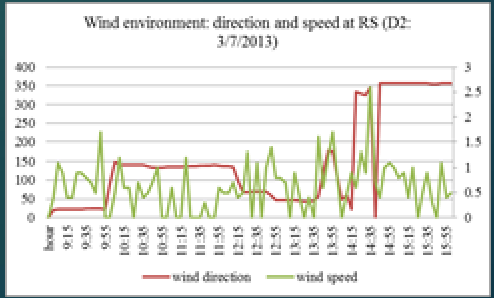
RC is having cooler environment. (RC has lower ratio of a tree to area and higher number of trees.

D1: the **wind environment for RS can be said as more dynamic** than RC. It is interesting to note that although RS is more dynamic, RS is also suggested as hotter than RC. It is observed that the air temperature reading for D1 is higher than D2 for both sites and the maximum wind speed is also higher for D1. This could be due to the difference of temperature that affect the pressure .









Analyses & results: The influence of tree aspects in screening the solar radiation, IIUM (1/5)

Inventory and analysis on tree aspects and solar radiation penetration

- The trees are first identified and grouped based on their common and scientific names.
- These trees are further analysed based on the trunk height (TH), crown height (CH), diameter of canopy (DC) and foliage density (FD) accordingly.

- Hypothesis: The combination of smaller dimension of trunk height (TH), bigger dimension of crown height (CH) and denser foliage (FD) would best screen solar radiation, while the crown diameter* (CD) might not have significant screening effect.

Location	Scientific Name	Common Name	nos
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**

Analyses & results: The influence of tree aspects in screening the solar radiation, IIUM (2/5)

Site	W/m²		
	1	2	3
MA	1020.0	932.9	497.4
HP	388.0	398.9	453.4
RC	730.2	801.2	821.0
RS	837.5	1020.6	938.9

The three solar radiation readings recorded under direct sunlight throughout the measurement process

Low readings in average

Highest readings in average

It is observed that reduced amount of solar radiations readings are recorded underneath those investigated tree canopies as compared to the higher range of solar radiation which are recorded under direct sunlight.

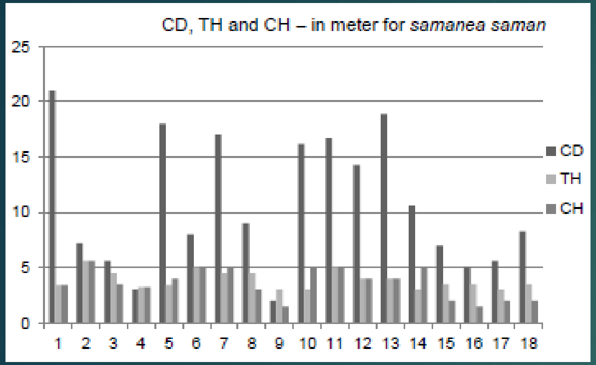
Tree Type	W/m²	
	min	max
SS	50	750
CV	100	350
LS	100	340
PR	180	340
MIL	110	210
HO	283	565

The approximation of range of solar radiation readings (minimum and maximum) underneath every tree specie

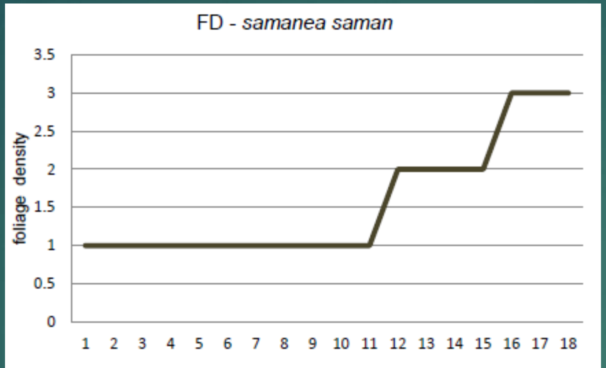
Strategy in the analysis:

i. Intra-species: the tree aspects and the average solar readings underneath the canopies are compared and contrasted within species [eg: the 18nos of samanea saman, etc]
ii. Inter-species: the six tree species are further compared and contrasted in an attempt to rank the tree types that best screen the solar radiation from penetrating to the ground.
iii. The physical aspects of the two tree species which are ranked as the best and the worst solar radiation screener (among these six species studied) are further analysed.

Analyses & results: The influence of tree aspects in screening the solar radiation, IIUM (3/5)



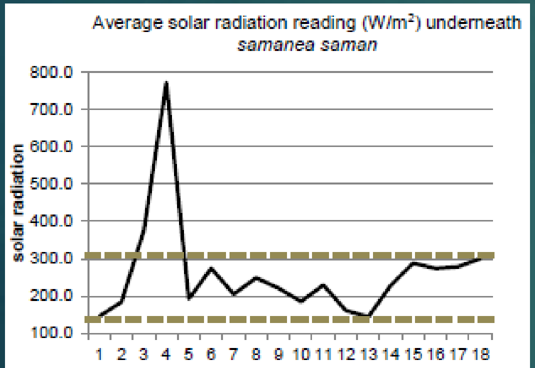
Dimensions of canopy diameter (CD), trunk height (TH) and crown height (CH)



Categories of foliage density (FD)

Example of strategy i: intra-species analysis – samanea saman

Samanea saman



Average solar radiation readings (W/m^2) underneath 18 nos.of samanea saman

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) loose density,
(2) medium density,
(3) dense

The analysis continues for the next five species

Analyses & results: The influence of tree aspects in screening the solar radiation, IIUM (4/5)

Strategy ii – Inter-species comparison: An attempt to rank the tree types that best screen solar radiation penetration

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

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.

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.

Analyses & results: The influence of tree aspects in screening the solar radiation, IIUM (5/5)

Strategy iii – The physical aspects of the LS and HO which are ranked as the best and the worst solar radiation screener are further analysed

	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

Generally for *lagerstromia speciosa:*
CH > TH, CD > CH & TH
While for hopea odorata is otherwise.

*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

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 at 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 having loose density [96% or 23/24]

Conclusions

1) Investigations on plazas in Putrajaya

- **surface with darker color and coarse texture** will result in a higher reading of surface temperature,
- **color seems to be an influencing factor** that enhances the materials heat absorbing capability **more than texture**.
- 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.

Conclusions

2) Landscape setting investigation - IIUM

- relatively **cooler site** would normally be **more humid** while **hotter site** would normally demonstrate more **dynamic wind environment**.
- 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.

3) Aspect of trees and solar radiation penetration investigation

lagerstromia speciosa is 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.

More outdoor microclimate investigations of Malaysia environment is needed in order to assist the designers and other key players in the Built Environment towards sustainable tropical environment – socially, economically and environmentally.

THANK YOU FOR YOUR ATTENTION