SUSTAINABILITY-LED DESIGN THROUGH BIM (SuLeD-BIM)

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Venue: Faculty of Built Environment, University Malaya

Urban Outdoor Thermal Comfort of the Hot Humid Region

Aniza binti Abu Bakar
(aaniza@iium.edu.my)

Mohamed bin Gadi
(Mohamed.Gadi@Nottingham.ac.uk)

INTRODUCTION

Previously it has been assumed that indoor thermal comfort theory can be applied to the outdoor environment. Due to the dynamic outdoor environment and such, the thermoregulatory model is seen as inadequate in explaining outdoor thermal comfort conditions. Hence, there is an increasing interest in research on outdoor thermal comfort. Several urban open spaces typology: street plaza, corporate foyer, urban oasis, transit foyer, courtyard, etc

Methodology: equipment used, survey time & spatial categories

This study intended to study human response in terms of thermal comfort within the outdoor urban spaces of hot-humid condition. Thus, **survey on thermal comfort and thermal sensation** by using 123 university students as the sample was conducted together with **collection of physical environmental data**

Three environmental readings were taken with the interval of ten minutes for every session of each site. These readings were then averaged. In each session, the samples were divided into two groups to perform passive (1 to 3 met) and active (3 to 8 met) activities respectively for twenty minutes.

no	equipment	measuring	unit		
i	Whirling psychrometer	Dry & wet bulb temperature	DB (°C)	WB (°C)	RH (%)*
ii	Globe thermometer	Globe temperature	°C		
iii	Digital anemometer	Wind speed	m/s		
iv	Cole-parmer infrared thermometer	Surface temperature (ground and wall)	°C		
v	Illuminance meter	Min/max/avg. illuminance	lux		

Under a tree	Under direct sunlight
0900-0930	0930-1000
1000-1030	
1100-1130	1130-1200
1200-1230	1230-1300
1300-1330	
1400-1430	1430-1500
1500-1530	1530-1600
1600-1630	
1700-1730	1730-1800

Semi-shaded	Open	Covered (alongside the corridors)
0900-0930	0930-1000	1000-1030
1100-1130	1130-1200	
1200-1230	1230-1300	1300-1330
1400-1430	1430-1500	
1500-1530	1530-1600	1600-1630
1700-1730	1730-1800	

Bedford seven-point scale

Scale for thermal sensation	
Scale	Description
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

ASHRAE

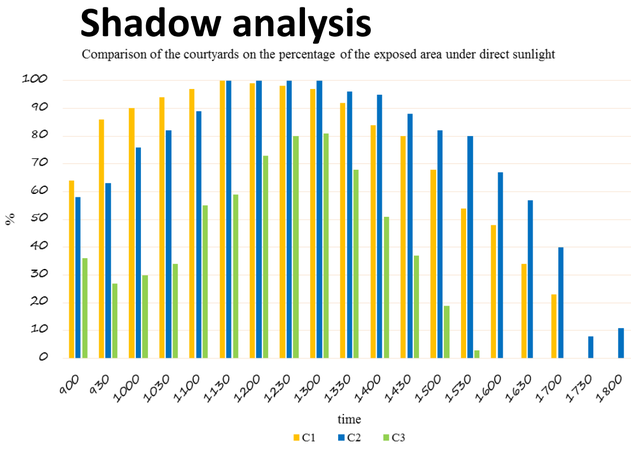
Scale for thermal comfort	
Scale	Description
1	Very comfortable
2	Comfortable
3	Slightly comfortable
4	Neutral
5	Slightly uncomfortable
6	Uncomfortable
7	Very uncomfortable

Surface material of C2	m²	%	Surface material of C2	m²	%
Tarmac area	1350	54	Tarmac area	1350	54
Rubber matt	194	7.8	Rubber matt	194	7.8
Grass/turfed area	184	7.4	Grass/turfed area	184	7.4
Paved area	772	30.8	Paved area	772	30.8
Total area	2500	100	Total area	2500	100

	C1	C2	C3
Orientation	22.5º	22.5º	2º
Aspect ratio	13.81	4.62	1.86

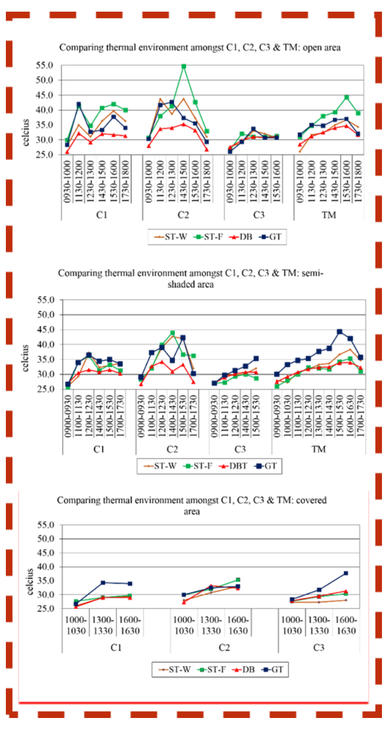
Aspect ratio = area of the courtyard floor / (average height of surrounding walls)² - used to determine the degree of courtyard exposure to the sky openness that permits heating by the sun

Shadow analysis



C2 - the courtyard that is highly exposed to the sun with a higher percentage of sunlit area throughout the day, while C3 is the total opposite in terms of results.

Based on shadow simulation, it is concluded that the physical built forms of these sites greatly influence the amount of areas exposed to direct sunlight. Greater aspect ratio reading indicates that wider areas of those sites are being exposed to sunlight.



Thermal environment:
open area is hotter than the semi-shaded area, followed by the covered area.
The difference in every readings seems to be big for the open area, and smaller for the covered area – indicating the role of solar radiation in influencing the thermal environment of the spaces.

Highest surface temperature according to level of each courtyard

Level	C1	C2	C3
1	41°C	45°C	29°C
2	41°C	42°C	29°C
3	41°C	42°C	32°C

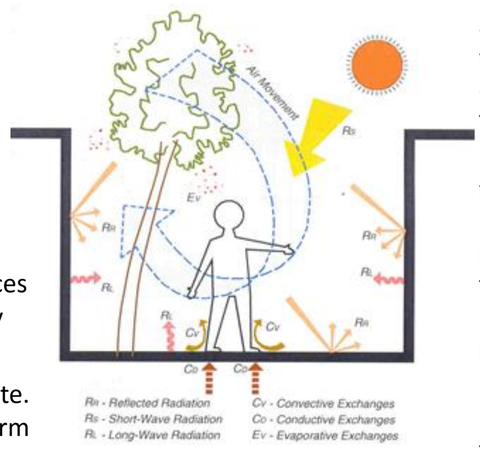
C2 – highest reading, could be due to the existence of tarmac

Minimum and maximum readings of wind speed by sites and spatial categories

	ss	open	covered	ss	open	covered
	C1			C2		
min WS (m/s)	0.1	0.1	0.03	0	0	0.03
max WS (m/s)	4.2	3.5	0.6	3.1	1.8	1
	C3			TM		
min WS (m/s)	0	0	0	0.3	0	-
max WS (m/s)	0.3	0.17	0.5	2.4	3.2	-

The ground wind speed in Kuala Lumpur is mild most of the time where strong wind, or gale, is seldom experienced

Urban open spaces and elements of thermal performance evaluation



Energy exchanges between a person and a courtyard space

Solar radiations (short waves - Rs) - partially absorbed by the wall and floor surfaces, partially **reflected back (R_R)** and partially absorbed for the **evaporation process (E_V).**

The absorbed radiation - heat the surfaces and create temperature difference between the surfaces (high temperature) and the air layer (low temperature) adjacent to it. Thus, the heat accumulated by the surfaces shall be released to the surrounding through the processes of **convection (C_V),** which is emissivity of **long wave radiation (R_L),** and **conduction (C_D).** The long wave radiations are then absorbed again by elements within the space until an equilibrium state is achieved.

Having greeneries is an advantage as they absorb great amount of radiation through their evapotranspiration (combination of transpiration and evaporation) process with less reflection of long wave radiations.

There is a need to lower the ambient temperatures particularly within the hot and humid regions.

The ground surface material used can be classified as 'cool' and 'warm' materials depending on their ability in absorbing heat and reradiating it to the surrounding.

Three main sections of the SQ:
Section A: details on the location, date, day, weather condition and others,
Section B: details of the sample, such as name, age, health condition and others,
Section C: tables on comfort judgment for the sample to tick and a few open-ended questions.
Clo value of respondents: from 0.5 to 0.8 (typical clo value among Malaysians)
Shadow analysis was simulated from 0900h to 1800h except for C3, which ended at 1630h as the whole area was already shaded from then onwards

Locations, orientations, and physical built forms of studied sites

paved courtyard : named as **Courtyard 1 (C1)** – regarded as 100% paved;

partially-paved courtyard : named as **Courtyard 2 (C2)**

turfed courtyard : named as **Courtyard 3 (C3)** – regarded as 100% turfed.

	C1	C2	C3
Orientation	22.5°	22.5°	2°
Aspect ratio	13.81	4.62	1.86

Taman Melati

Sensation and comfort votes

A thermally acceptable environment is where ***at least 80% of the occupants do not express any dissatisfaction* (ASHRAE).** This refers to indoor environment, where the environmental condition is controlled and stable.

However, it is suggested that this percentage should be lowered to **70%** when dealing with dynamic outdoor environment, with great environmental fluctuations throughout the day and, also, taking into account that people nowadays do not normally spend most of their time outdoor. The percentage of 70% represents more than two-third of the number of occupants, which is thought as more reasonable as it still represents the majority.

Percentage of samples voting according to comfort votes by spatial categories

	semi-shaded			open			shaded		
	Passive	Active	Sub total	Passive	Active	Sub total	Passive	Active	Sub total
Comfortable	15.5	12.9	28.4	11.7	13.3	25	15.9	14.6	30.5
Neutral	14.1	14	28.1	13.3	13.7	27	16.9	16.9	33.8
Uncomfortable	20.8	22.7	43.5	27.6	20.4	48	19.8	15.9	35.7
Total	100%			100%			100%		

More samples felt uncomfortable throughout the survey period, this also means that outdoor environment in hot-humid climate were not preferable most of the time.

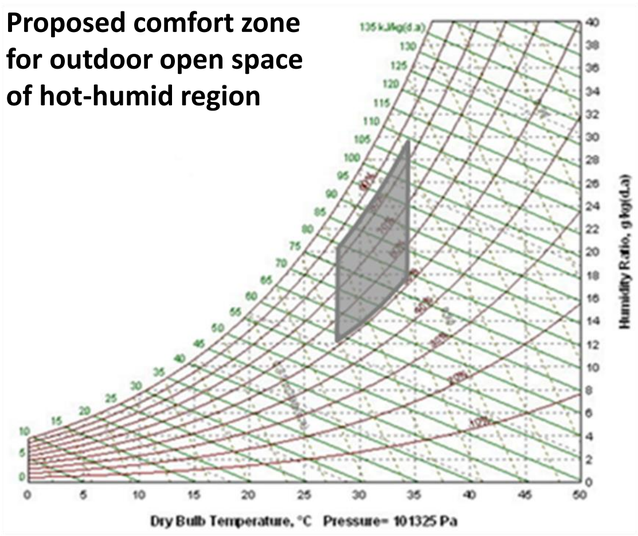
Minimum and maximum readings of illuminance by sites and spatial categories

	ss	open	covered	ss	open	covered
	C1			C2		
min ILL x 1000 (lux)	2	1.2	0.16	0.3	2	0.12
max ILL x 1000 (lux)	114.4	94.5	0.5	64.5	91.6	0.9
	C3			TM		
min ILL x 1000 (lux)	2.5	3.1	0.19	16.4	3.3	-
max ILL x 1000 (lux)	166	111.6	0.9	106	41.7	-

Minimum and maximum readings of the RH by sites and spatial categories

	ss	open	covered	ss	open	covered
	C1			C2		
Min RH (%)	50.7	55.7	67.7	49.3	50.7	53
Max RH (%)	79.3	89.7	87.3	80.3	78	74.7
	C3			TM		
Min RH (%)	63.3	70	61	51.7	49.7	-
Max RH (%)	81	82	78.7	85	82.3	-

Proposed comfort zone for outdoor open space of hot-humid region



							WS		ST	
comfortable		time	DBT	WBT	RH	GT	min	max	floor	wall	avg ill
semi-shaded	C2	1100-1130	32.7	25.5	54.7	37.3	0.1	1.2	32	32.3	417.3
		1400-1430	31	25.8	66.3	34.7	0	0.5	44	42.7	895.3
	C3	1400-1430	30.7	25	63.3	32.7	0	0.4	30	30.3	5498.3
	TM	0900-0930	27.5	25.5	85	30	0	0.1	26	28	10945
open	C2	1130-1200	33.7	25.3	50.7	41.7	0	2.8	38	43.7	557.8

Averaged DBT = 31.12 ºC, administered in thermal neutrality models

i. Thermal neutrality model 1 [19]:

$T_n = 17.6 + 0.31T_{ave}$ = 17.6 + 0.31(31.12)
= 27.25ºC

(where T_{ave} is the outdoor average dry bulb temperature)

ii.Thermal neutrality model 2 [20]:

$T_n = 2.56 + 0.831T_m$
= 2.56 + 0.831(31.12)
= 28.42ºC.

(where T_m is the mean temperature for the study on indoor comfort in tropical region)

the thermal neutrality model 2 is more appropriate for Kuala Lumpur as the value of 28.42ºC falls within the range of dry bulb temperature.

It is reasonable to take a minimum of **27.5ºC** and a maximum of **33.7ºC** from the readings of dry bulb temperature and a minimum reading of **50.7%** and a maximum reading of **85%** for relative humidity to propose the comfort zone for hot-humid urban outdoor spaces of Kuala Lumpur, Malaysia. However, it should be remembered that the presence of wind speed of at least **0.1m/s** is a requirement in light of this scenario.

The proposed comfort zone of the outdoor environment of Kuala Lumpur can be used **to monitor the climatical environmental condition**. If the climate range falls within the zone, then it is suggested that the outdoor environment is thermally comfortable most of the time for users.

Thermal comfort can be perceived as one of the tools used to study the quality of the environment in which humans live. It may function as an **indicator to study changes in the physical environment in relation to human comfort level.**