



A method for microclimate observation and thermal analysis -tropical condition of Kuala Lumpur

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Abstract

Using outdoor public spaces as a place of social interaction is in a great consideration these days. Providing tolerable thermal condition as long as possible is one of the primary stages for people's presence in these places. Outdoor thermal indices are introduced to help architects making appropriate decisions in climate responsive design procedure.

By doing some field study research in extreme climatic condition of tropical city of Kuala Lumpur, this article will introduce a research method of data collecting and data analyzing using outdoor thermal indices. How to do an effective and helpful research for design requirements is the aim of this method. Field data are collected by a mobile Kestrel weather station in different outdoor spaces of the city centre. Weather data are analyzed in three levels of meso, local and microclimate. Architectural properties of the place are explained according to their response to the climatic condition. Software named SIKRON is designed by the author to speed up the analyzing process.

Keywords: Thermal indices, UTCI, Heat stress, Microclimate, Kestrel weather station.

1. Introduction

To explore an appropriate and effective research method for outdoor field study observation this article is trying to find answers to the following questions:

1. How much the outdoor thermal indices are accurate to evaluate thermal condition (especially in extreme hot and humid thermal conditions)?
2. Which index has the most accuracy for a tropical climate? Is there any available index that can be used accurately? (UTCI is examined in this regard)
3. What are the differences between meteorology, local and microclimate data?
4. How much the constructed area base on climatic architectural design will help to modify the outdoor thermal condition?
5. What is the definition of different outdoor thermal conditions according to people's behavior?

Field study research in September 2010 was done in tropical city of Kuala Lumpur as an example for finding a method to answer these questions.

2. Research Method

Public outdoor spaces and walkways are some of the most important places used by many citizens every day.

Preparing amazing and comfortable condition to attract people to these places are important keys to successful design. According to different climatic conditions in a period of a year, predicting outdoor thermal condition is one of the basic requirements for designers. To help architects and designers in this regard, laboratory researches have proposed several indices for outdoor thermal analysis.

The first groups of indices are based on thermal stress model. Heat stress indices such as heat index (HI), Humidex, Tropical Summer Index (TSI), Discomfort Index (DI) and Wet Bulb Globe Temperature (WBGT) are prepared for hot conditions. Cold stress indices such as Wind chill Index (WCI) and Wind Chill Equivalent Temperature (WCET) are prepared for cold conditions. Some of outdoor indices are prepared base on heat budget model. They are capable to evaluate both cold and hot conditions such as Perceived Temperature (PT), Temperature Humidity Index (THI), Physiological Equivalent Temperature (PET) and Universal Thermal Climate Index (UTCI). The last one is being prepared by a group of specialists in a manual called "Cost Action 730" [1]. It is supposed to cover all shortcomings of other indices. To be able to work with these indices and have a comparison opportunity, all of them are converted on a psychrometric chart [2] and the software called SIKRON [3] is prepared to speed up the data input.

In this article the data are gathered in the city centre of Kuala Lumpur in the tropical climate of Malaysia. The field data are collected by a mobile Kestrel weather station

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that is able to collect the data of temperature, humidity and wind; the three out of four important climatic elements of thermal condition. The data is collected each 30 seconds to show the microclimate changes in different outdoor spaces. Using outdoor thermal indices to interpret these data, the thermal condition of observed places are defined on psychrometric chart provided for each index. Sikron software is used to accelerate the process of data transfer to psychrometric chart.

People’s behavior in different thermal condition, is recorded by taking appropriate photos. Special attention is paid to the children, ages and disables as the most sensitive people to the thermal condition. Behavior is identified by clothes, activities, foods and exposure time in each condition. Comparison between people’s behavior and thermal condition predicted by outdoor indices will help to determine the accuracy of the indices’ assessment. The most accurate index for a specific type of climate will be distinguished in this way.

To control the intervening factors affecting the observation method, the collected data of moving Kestrel weather station as the microclimate representative, is compared with three other climatic data in three levels: 1- the meteorology data of the city in a long term period as the representative of the meso-climate, 2- the meteorology data of the observation days as the representative of the short term city climate, 3- the collected data of the reference point (the fixed Kestrel weather station) as the representative of the local climate. Comparing the long term meteorology data with the short term meteorology data will show the thermal condition of the days of observation as ordinary, cold or hot. According to monotone climate of Kuala Lumpur in a year, this level of comparison is eliminated in this article. Kuala Lumpur as a tropical city has only one hot season and the few changes are made in rainy condition. Comparing the meteorology data of the observation days with the data of reference point will show the changes of the local climate according

to the urban construction. Comparing the data of the reference point with the data of the observed places (moving Kestrel weather station) will show the microclimate changes according to the architectural design of the outdoor public spaces.

Constructed condition of the observed palaces is considered as the modifier of the local and microclimate situation by providing appropriate sunshade or sunlit spaces, leeward or windward spaces, heat transfer controllers, moisture and saturation controllers. These conditions will show the thermal modification ability of the architectural design.

3. Tropical Climate of Kuala Lumpur

Kuala Lumpur the capital city of Malaysia is located in the 3.12 north latitude and 101.55 east longitude with elevation less than 100 meter in the centre of Selangor state of Malaysia. Its location on the west coast of Peninsular Malaysia, which has wider flat land than the east coast, has contributed to its faster development relative to other cities in Malaysia [4].

Kuala Lumpur has a tropical rainforest climate which is warm and sunny, along with abundant rainfall, especially during the northeast monsoon season from October to March. Temperatures tend to remain constant. Maximums hover between 31 and 33 °C and have never exceeded 39.3 °C, while minimums hover between 22 and 23.5 °C and have never fallen below 14.4 °C [5, 6]. Kuala Lumpur typically receives minimum 2600 mm of rain annually; June and July are relatively dry, but even then rainfall typically exceeds 133 millimeters per month (Fig 1) [5, 7]. Flooding is a frequent occurrence in Kuala Lumpur especially in the city centre and downstream areas. Dust particles from forest fires are the major source of pollution in the city together with emission from motor vehicles and construction work [8, 9].



Fig. 1. Kuala Lumpur location and climatic data [7, 10]

Average Conditions										
Kuala Lumpur, Malaysia										
Month	Average Sunlight (hours)	Temperature Average, Record Min, Max, Min, Max			Discomfort from heat and humidity	Relative humidity am, pm		Wet Days (>2.25 mm)		
Jan	6	22	32	18	36	High	97	60	158	14
Feb	7	22	33	20	37	High	97	60	201	14
March	7	23	33	20	37	High	97	58	259	17
April	6	23	33	21	36	High	97	63	292	20
May	6	23	33	21	36	High	97	66	224	16
June	7	22	33	20	36	High	96	63	130	13
July	7	23	32	19	36	High	95	63	99	12
Aug	6	23	32	20	36	High	96	62	163	14
Sept	6	23	32	20	35	High	96	64	218	17
Oct	5	23	32	21	35	High	96	65	249	20
Nov	5	23	32	21	35	High	97	66	259	20
Dec	5	22	32	19	35	High	97	61	191	18

The following bar chart for Kuala Lumpur, Malaysia shows the years average weather condition readings covering rain, average maximum daily temperature and average minimum temperature.

Fig 2 (a to g) shows the thermal situation of this city according to outdoor thermal indices. It is clear that during the year the temperature swing is very low and humidity is very high and most of the time heat stress happens. According to Fig 2 thermal analysis of the indices will be explained in three categories. The first group is Heat Index

(Fig 2a) and Temperature Humidity Index (Fig 2b) that define the warmest condition as dangerous [11, 12]. The second group is UTCI (Fig 2c) and Humidex (Fig 2d) that analyze the warmest condition as intense or strong heat stress [13, 14]. The third group is Tropical Summer Index (Fig 2e) that interprets the warmest weather as slightly

warm [15]. Fig 2 (f & g) shows the Climatic calendar and sun-path chart of Kuala Lumpur based on UTCI. All the psychrometric charts of Fig 2 are generated by SIKRON software [3] and Weather Data of Kuala Lumpur available at EnergyPlus website [16].

SIKRON software [3] helps to show thermal condition on each index according to main heat or cold stress zones. Red colors refer to “extreme” and “very strong” heat stress (Heat stress: The physiological strain caused by an increase in core body temperature above safe levels where the individual is at risk of overheating [17].) that may cause “heat stroke” (Heat stroke - Defined by a body temperature of greater than 40.6 °C (105.1 °F) due to environmental heat exposure with lack of thermoregulation. Symptoms include dry skin, rapid, strong pulse and dizziness. [18]). Orange and yellow colors refer to “strong” and “moderate” heat stress that may cause “heat exhaustion” (Heat exhaustion - Can be a precursor of heatstroke; the symptoms include heavy sweating, rapid breathing and a fast, weak pulse. [18].). Green colors refer to “no thermal stress”. It means that

long term exposure (Heat exposure limits are based on some set of assumed physiological, personal, and environmental conditions [17].) in outdoor is tolerable or pleasant. Light blue colors refer to “slight” cold stress (Cold strain disorders include hypothermia (abnormally low body temperature) and frostbite [17].) that will feel cool. Dark blue, light and dark purple colors refer to “moderate cold stress”, “strong”, “very strong” and “extreme cold stress” that may cause “hypothermia” (Hypothermia is defined as a core temperature of the body less than 35 degrees Celsius [19]) and “frostbite” (Frostbite is the freezing of some part of the body. Fingers, toes, and even whole arms and legs can be lost as a result of frostbite [19]. At or below 0 °C (32 °F), blood vessels close to the skin start to constrict, and blood is shunted away from the extremities via the action of glomus bodies. The same response may also be a result of exposure to high winds [20].) Thermal conditions are distinguished visually and easily by using these colors.

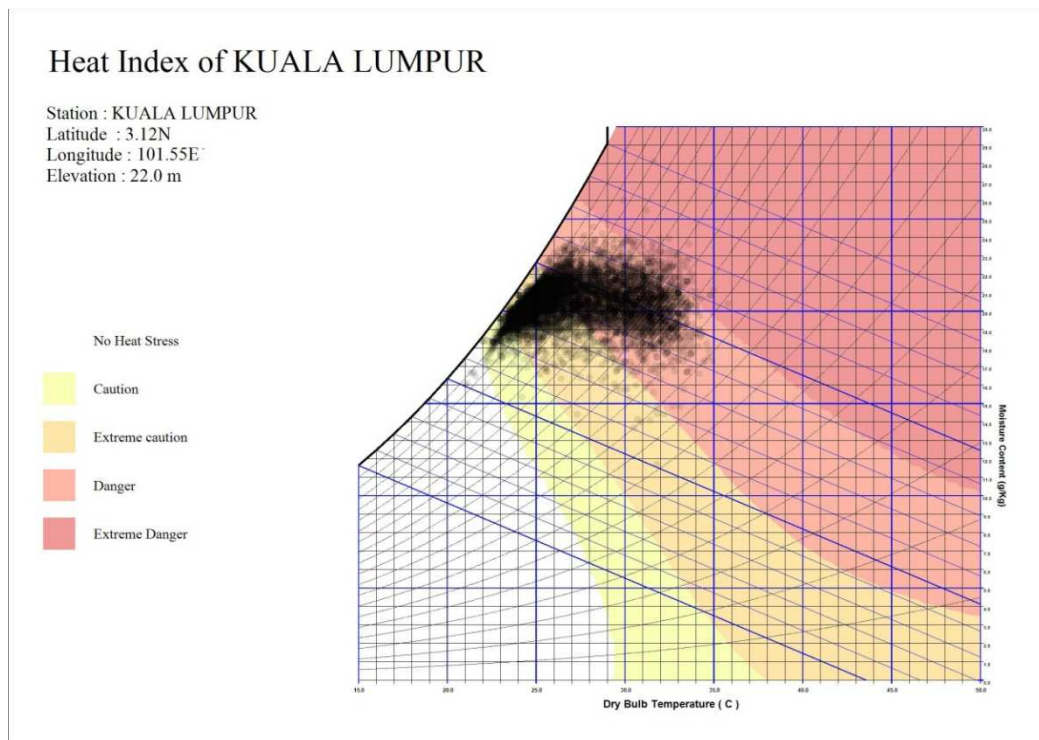


Fig. 2(a). Kuala Lumpur outdoor thermal condition in a year based on Heat Index psychrometric chart

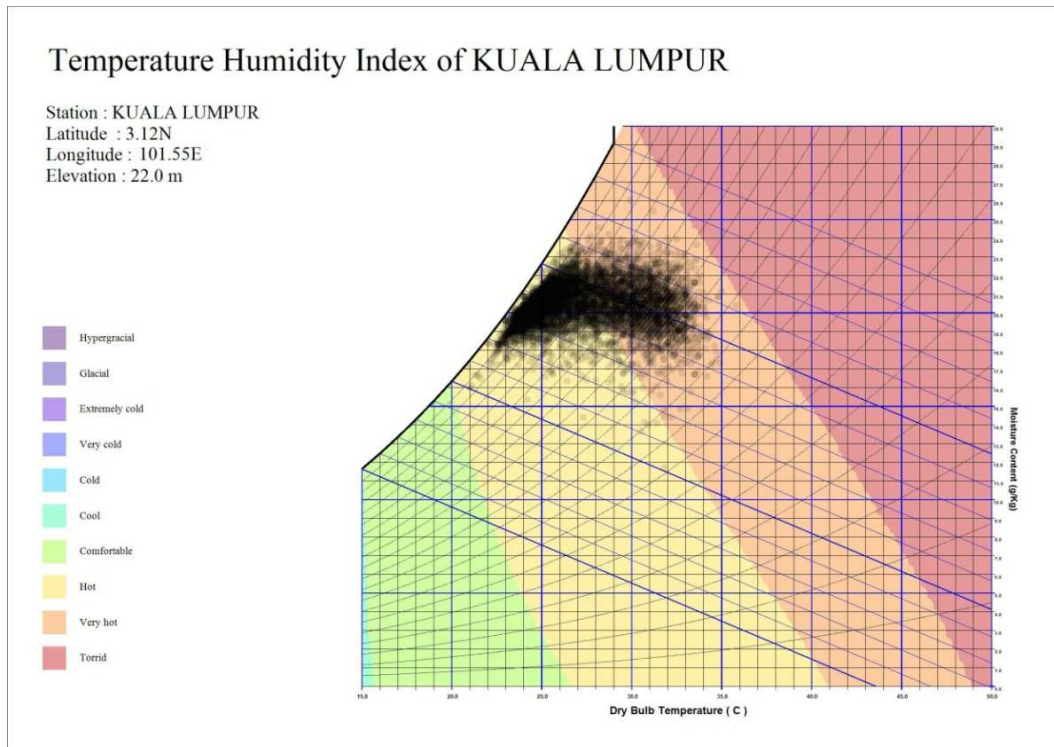


Fig. 2(b). Kuala Lumpur outdoor thermal condition in a year based on THI psychrometric chart

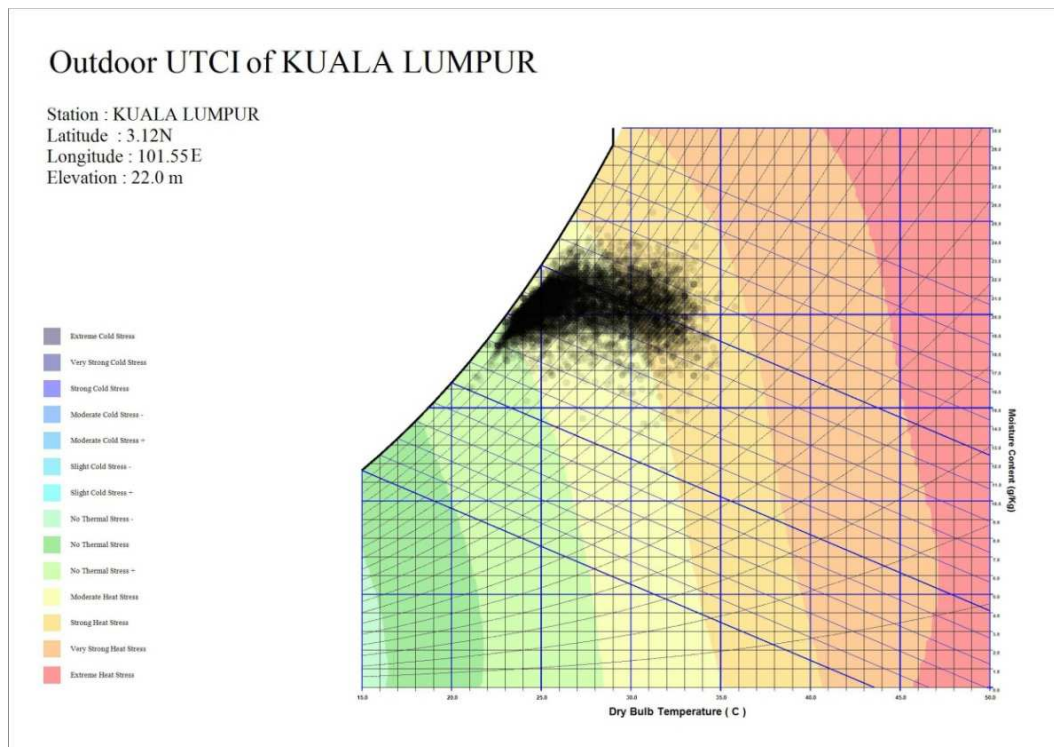


Fig. 2(c). Kuala Lumpur outdoor thermal condition in a year based on UTCI psychrometric chart

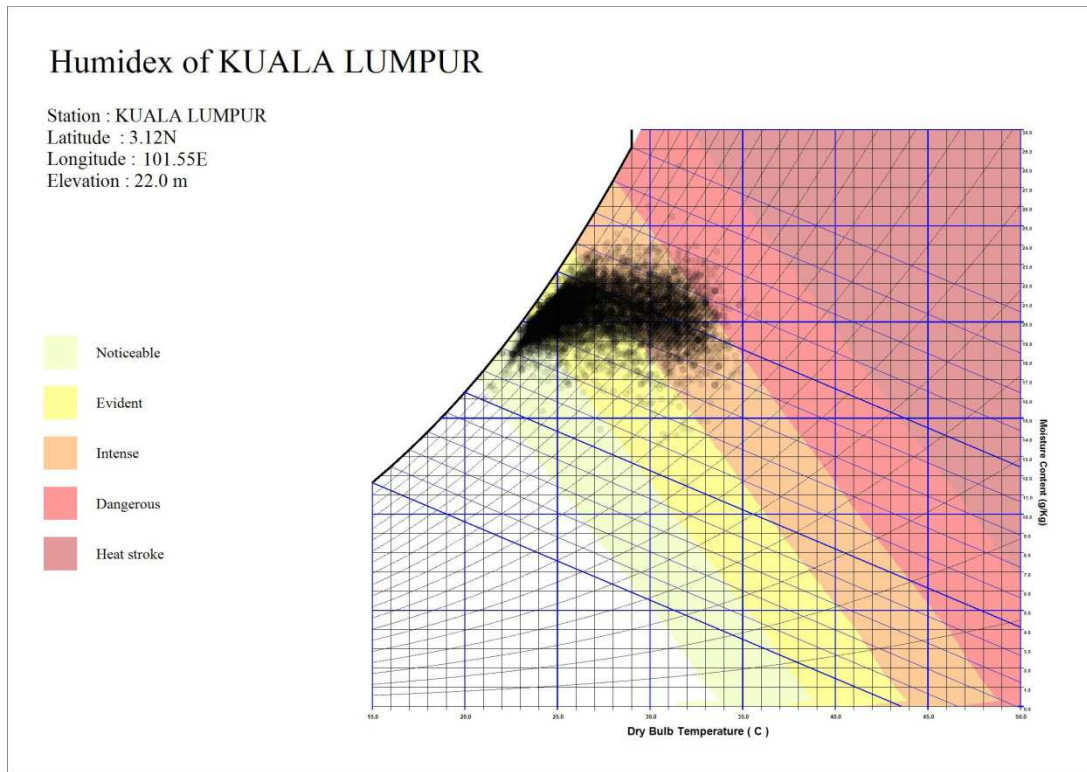


Fig. 2(d). Kuala Lumpur outdoor thermal condition in a year based on Humidex psychrometric chart

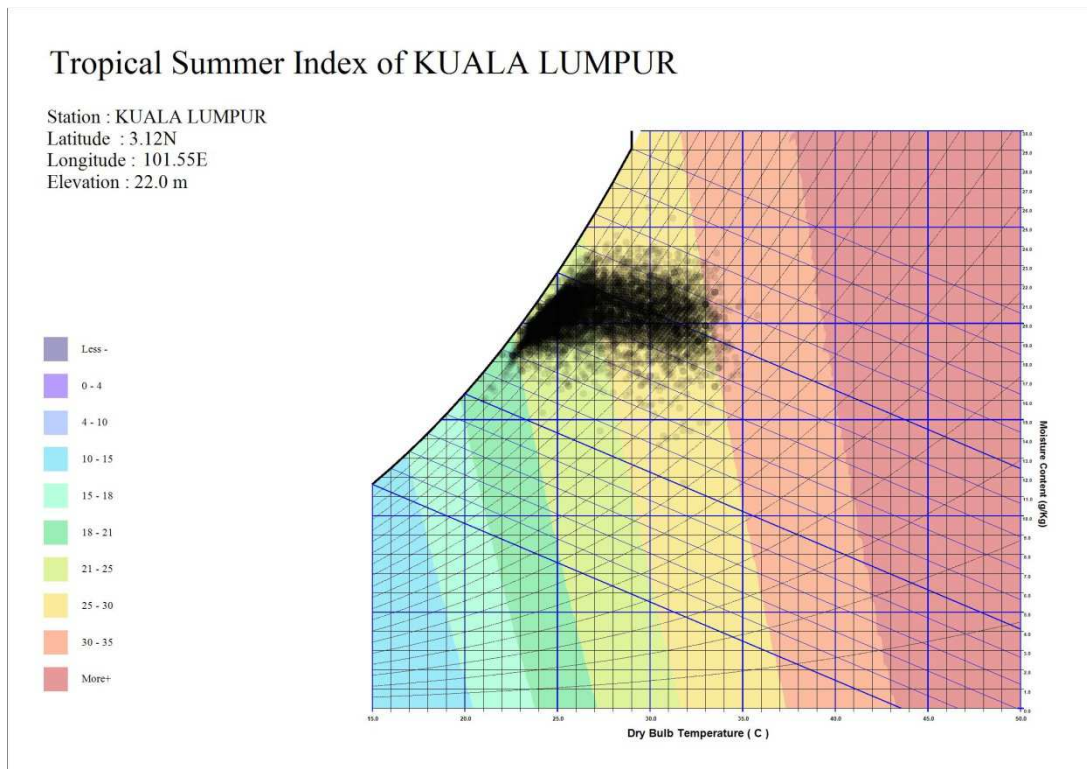


Fig. 2(e). Kuala Lumpur outdoor thermal condition in a year based on TSI psychrometric chart

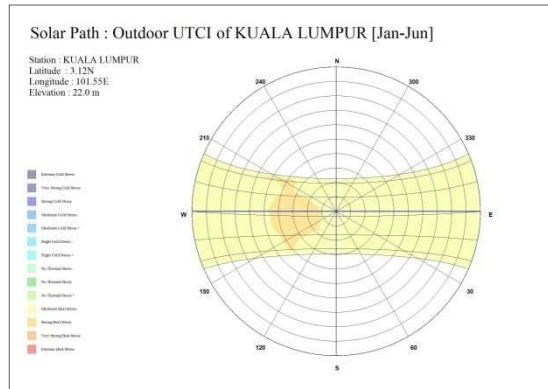
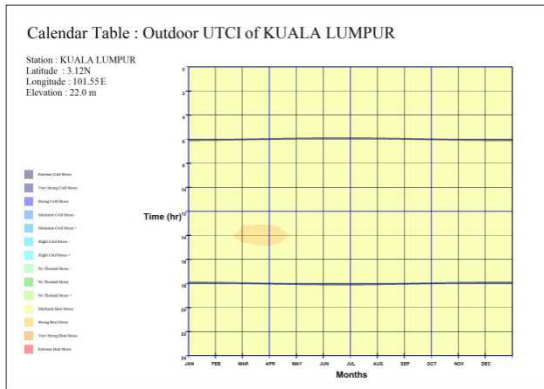


Fig. 2(f). Climatic needs calendar and Sun-path chart of Kuala Lumpur for outdoor thermal condition based on UTCI, it shows very few changes in thermal condition yearly.

4. Field Data Collection

A field study observation was done in the summer of 2010 in Kuala Lumpur, to examine the thermal definition of different outdoor indices in real condition. It shows the local people's reaction to warm weather and clarifies which of these indices are more appropriate for tropical

climate. The field study was done in two days of 3rd and 5th September 2010 as a sunny and rainy day respectively.

Local and micro weather data was gathered by a Kestrel WS-4500-KIT portable weather station data logger [21]. As the comparison of different weather stations kits shows, it has a good overall rating and has an acceptable accuracy for outdoor weather data collecting.

Manufacturer	Model	Price ¹	Wind Speed (mph)	Wind Direction (°)	Outdoor Temperature (°F)	Indoor Temperature (°F)	Outdoor Humidity (%)	Indoor Humidity (%)	Barometric Pressure (inHg)
Kestrel Instruments	WS-4500-KIT [®] 4500 Portable Weather Station Kit	\$308.90	●	●	●	---	●	---	●
	WS-4500NV-TAN-KIT [®] 4500NV-TAN Portable Weather Station Kit	\$368.90	Range: 0-135 Resolution: 0.1	Resolution: 22.5°	Range: -40 - 257 Resolution: 0.1	---	Range: 0 - 100% Resolution: 0.1%	---	Range: 0.3 to 32.5 Resolution: 0.02 inHg
	WS-4500NV-KIT [®] 4500NV Portable Weather Station Kit	\$368.90	Accuracy: ± 3%	Accuracy: ± 5°	Accuracy: ± 2.0 °F	---	Accuracy: ± 3%	---	Accuracy: ± 0.05 inHg

Rainfall (in)	UV	Solar Radiation (W/m ²)	Update Rate (sec)	Ease of Installation	Reliability	Other Optional Sensors	Display Console	Wireless Range (ft)	PC Interface Internet Appliance	Data Logging	Overall Rating	Definitions, Symbols and Footnotes Key:
---	---	---	1 second	●	●	---	✓	---	(Serial or USB) Virtual Weather Station WeatherHub [®]	✓	●	<ul style="list-style-type: none"> ● Fair ● OK ● Good ● Excellent

Fig. 3. Kestrel portable weather station data logger WS-4500 [22] (<http://ambientweather.wikispaces.com/Weather+Station+Comparison+Guide>)

The reference Kestrel data logger was located in the balcony of the 17th floor of a building in the city center.

The path of observation was chosen for the most popular outdoor spaces in that area. (Fig 4)

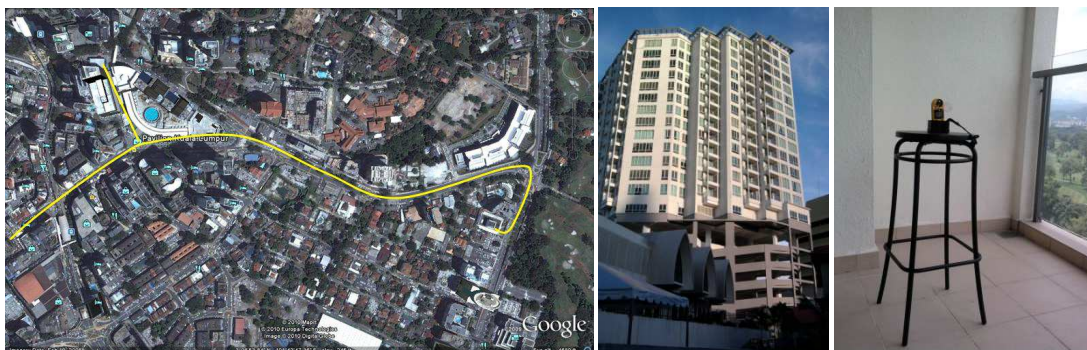


Fig. 4. The path of observation - city centre (left) and the reference Kestrel weather station (middle and right)

5. Meso, Local and Microclimate Analysis

The meteorology station of Kuala Lumpur is considered here as the meso climate. Comparing the meso and local data shows that the local weather of the city is

drier than the meteorology data (meso climate). This shows the effect of city heat island that makes the weather drier, lowers the temperature swing and makes the nights warmer. (Fig 5)

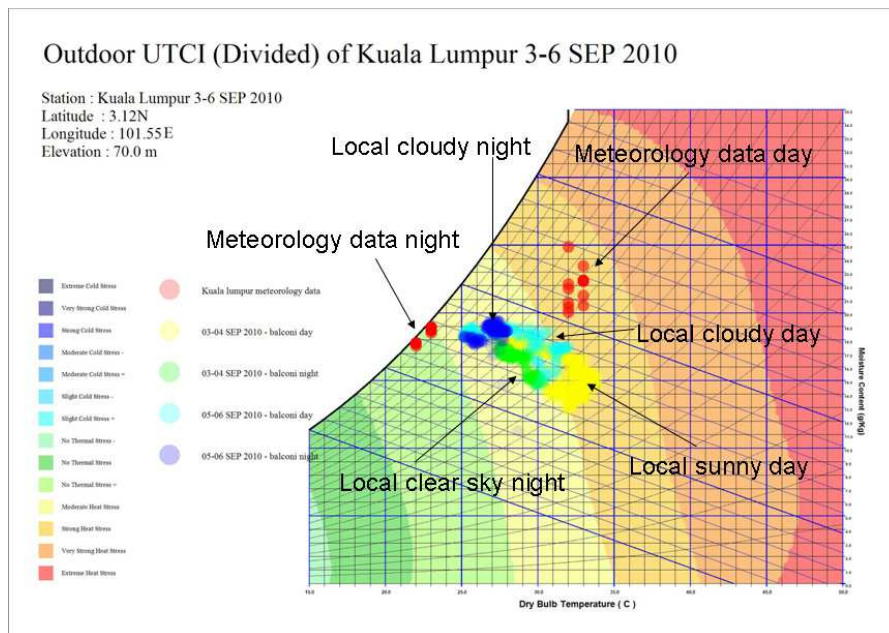


Fig. 5. Meso and local climate in observation days and nights (3-6 SEP 2010)

The observations clarify the local and microclimate condition of the city centre. The microclimate condition in most observed places is warmer than local climate. It may be the result of the special location of the reference Kestrel data logger that is located in a very high and protected position in a roofed balcony. The other reason may be the effect of solar absorption of constructed surfaces in the city centre. It also shows that the sunny days have the warmest condition and may reach the strong heat stress situation (dark yellow zone) if the architectural

construction does not support human thermal needs. Rainy and cloudy days have better thermal condition and with climate responsive design will lower thermal sensation one level to moderate heat stress (light yellow zone) (Fig 6). At night time the weather is in moderate or no heat stress condition (Fig 5 & 7). Observation shows that nightlife is a custom in this city and several outdoor activities are done at night. Therefore it can be realized that moderate heat stress at night is tolerable in tropical climate.

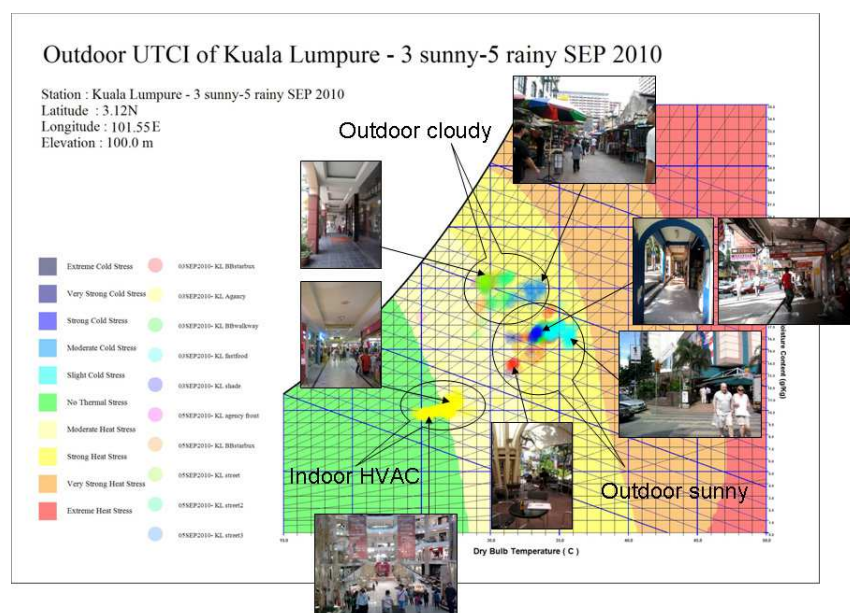


Fig. 6. Sunny and cloudy thermal situation on UTCI index in 3rd and 5th SEP 2010

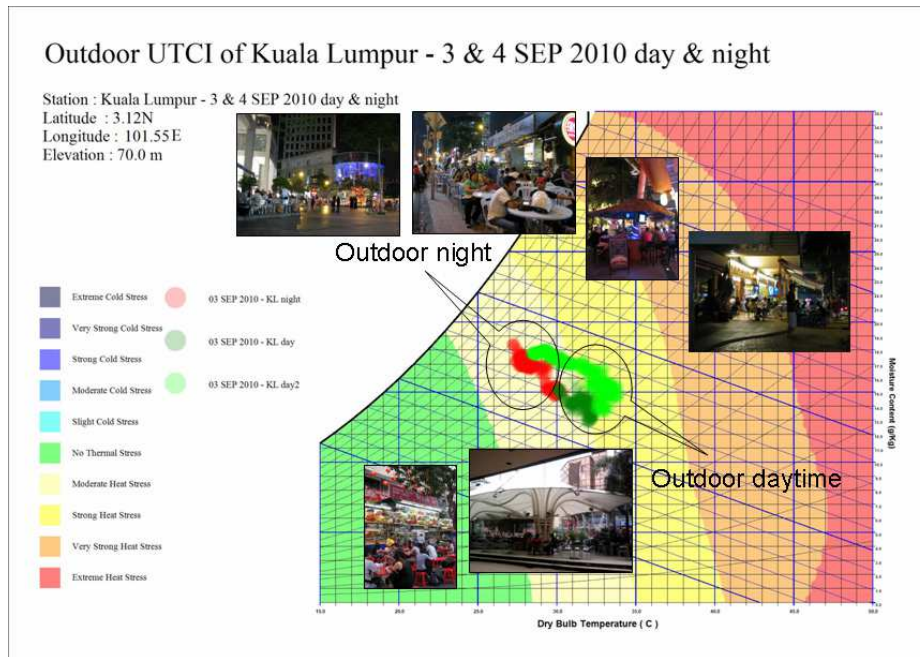


Fig. 7. Day and night thermal situation on UTCI index in observed days, SEP 2010

6. Data Analysis in Outdoor Public Spaces

In spite of warm weather in daytime that is defined as strong and moderate heat stress, outdoor areas are full of population and lots of long term activities such as eating and shopping. In very hard conditions especially in sunny days, some of the outdoor spaces with intolerable microclimate condition will remain empty, while others

with better climatic design will continue their activities by costumers. Some of these outdoor shops use outdoor HVAC systems such as fans and cold water spray to modify microclimate under a sunshade. Fig 8a & 8b shows that bad thermal condition in location 4 has caused it empty while using appropriate sunshade, fan and outdoor cold water spray in locations 5 & 6 has prepared better microclimate for more population presence.

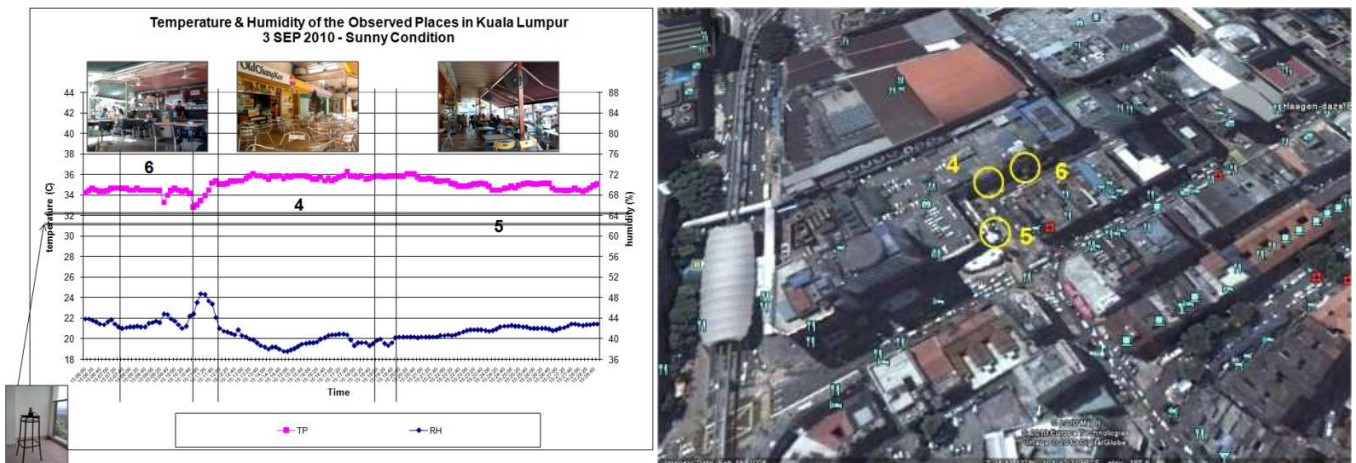


Fig. 8 (a). Bad thermal condition caused Point 4 empty, population presence because of appropriate sunshade, fan and outdoor cold water spray (5 & 6), 3rd SEP 2010

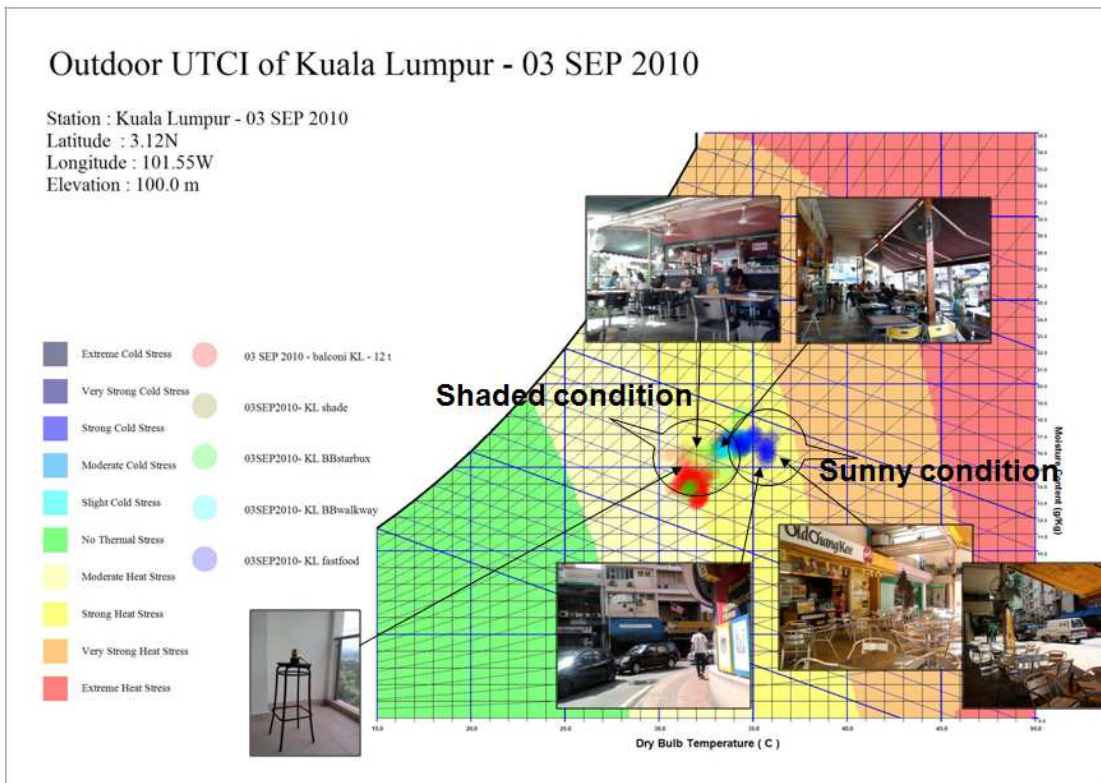


Fig. 8(b). appropriate shade and fan helps to lower thermal condition one level from strong heat stress to moderate heat stress, sunny day of 3rd SEP 2010 at 12-15pm

In cloudy days although the humidity is higher than sunny days, thermal condition falls one level from strong heat stress to moderate heat stress. Therefore it feels more tolerable than sunny days. Fig 9a & 9b shows the effect of

Water as an evaporative cooler in some places. Locations I1 and I2 with fountain effect have more humidity and better thermal condition than adjacent places without evaporative cooling.

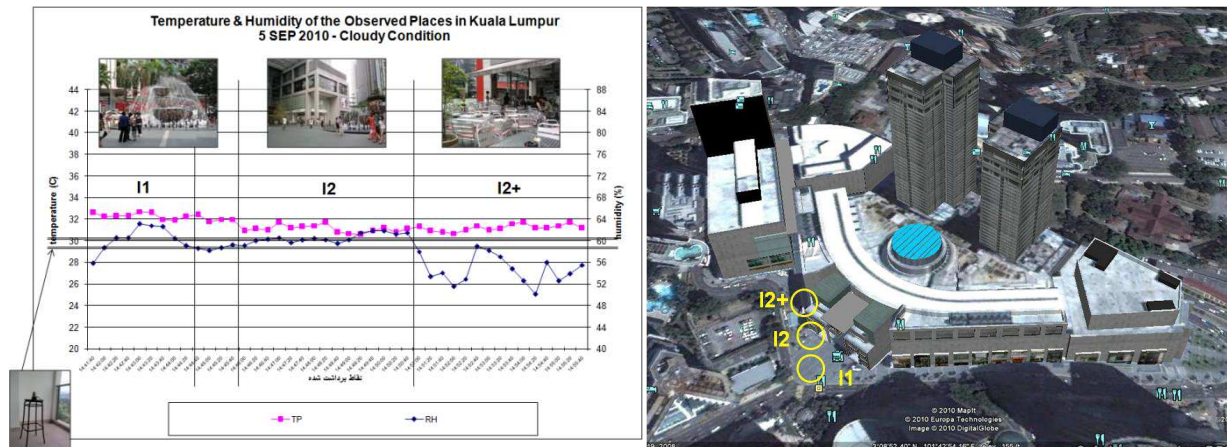


Fig. 9 (a). Water is used as an evaporative cooler in some places: I1 and I2 with fountain effect have more humidity and better thermal condition, 5th SEP 2010

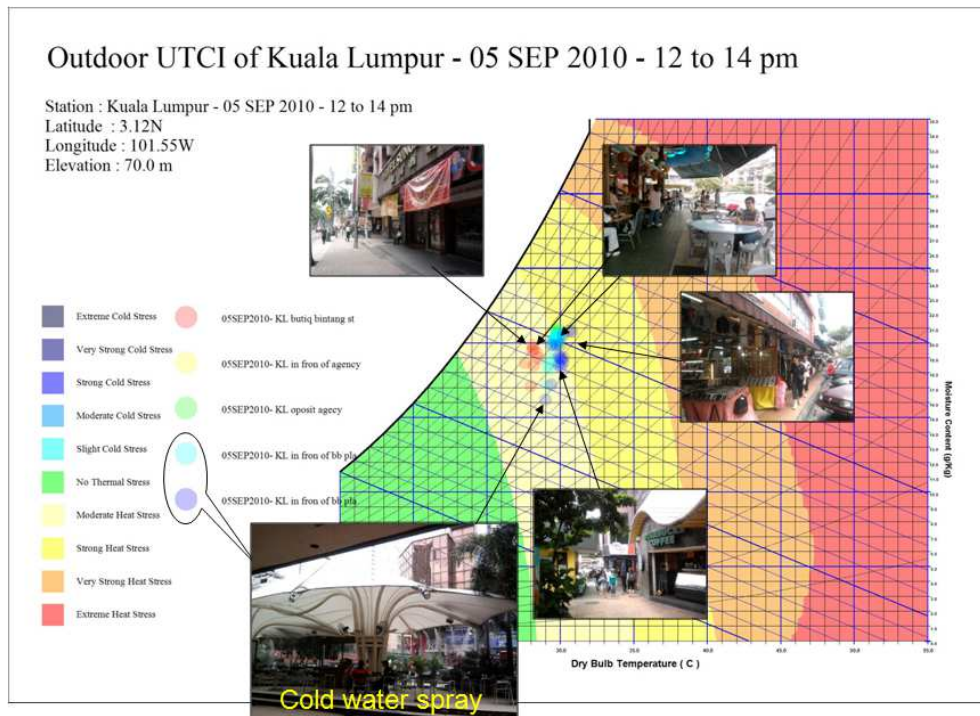


Fig. 9 (b). Thermal condition will fall one level from strong heat stress to moderate heat stress in cloudy days, 5th SEP 2010 at 12-15pm

Walkway is another outdoor space that needs special climatic design for difficult thermal condition. In sunny days walking under sun for a long time is dangerous because it is in strong heat stress zone. Fig 10a location 11 shows temperature increase in sunny walkways. Preparing

shaded walkways will help to reduce temperature and humidity and falls thermal condition to moderate heat stress. Fig 10a locations 9 & 10 and Fig 10b shows the effect of covered walkways on thermal modification.

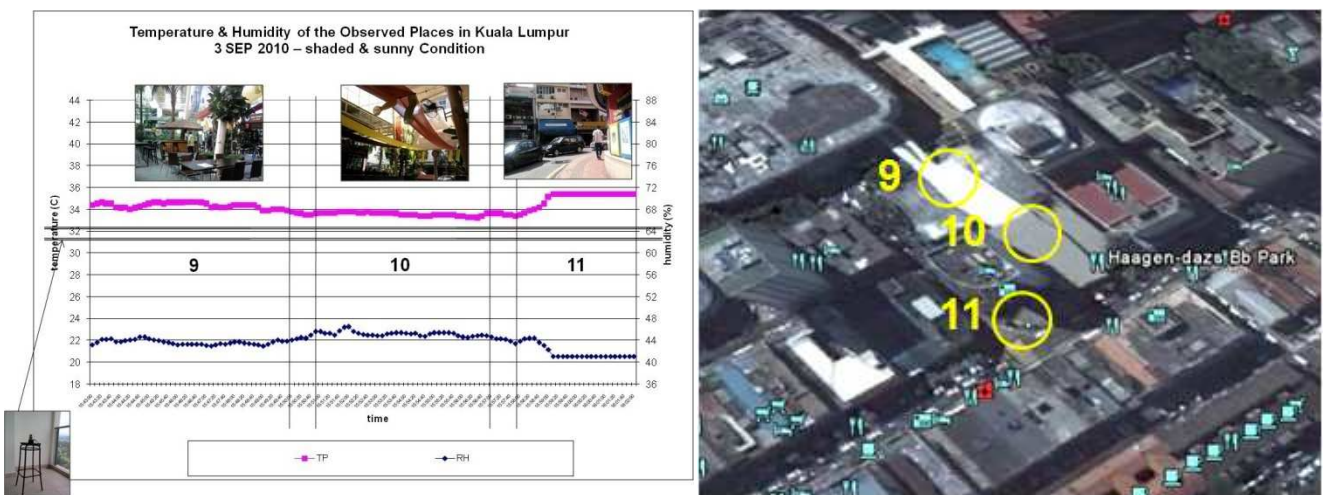


Fig. 10 (a). The effect of covered walkway on temperature reduction and humidity increase: 9 and 10 are in a covered walkway, 11 is sunny

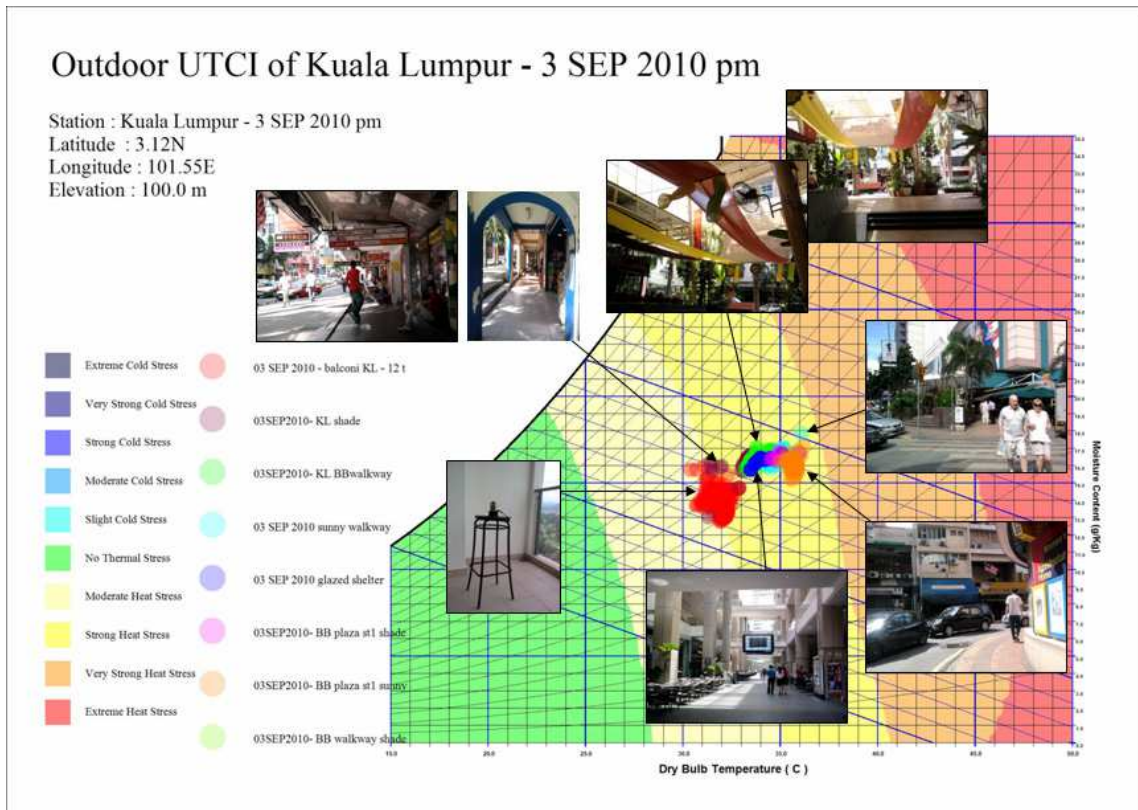


Fig. 10 (b). covered walkways in sunny days will provide better thermal condition, sunny day of 3rd SEP 2010

Rain as a frequent phenomenon in tropical climate is another reason for shelter requirement. Fig 11 (a) and 11 (b) shows that even in cloudy condition covered walkways will help to reduce temperature and modify the thermal condition for one level. Therefore in this city covered

walkways and entrances are very common and are used as shelter for both rain and thermal purposes. These spaces have provided appropriate microclimate situation for shopping facilities and are crowded with people in all sunny and rainy conditions.

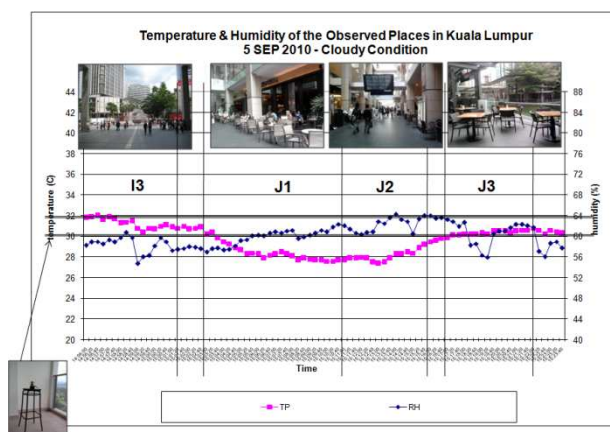


Fig. 11 (a). The effect of covered walkway on temperature reduction and humidity increase: J1 and J2 are in a covered walkway. 5th SEP 2010



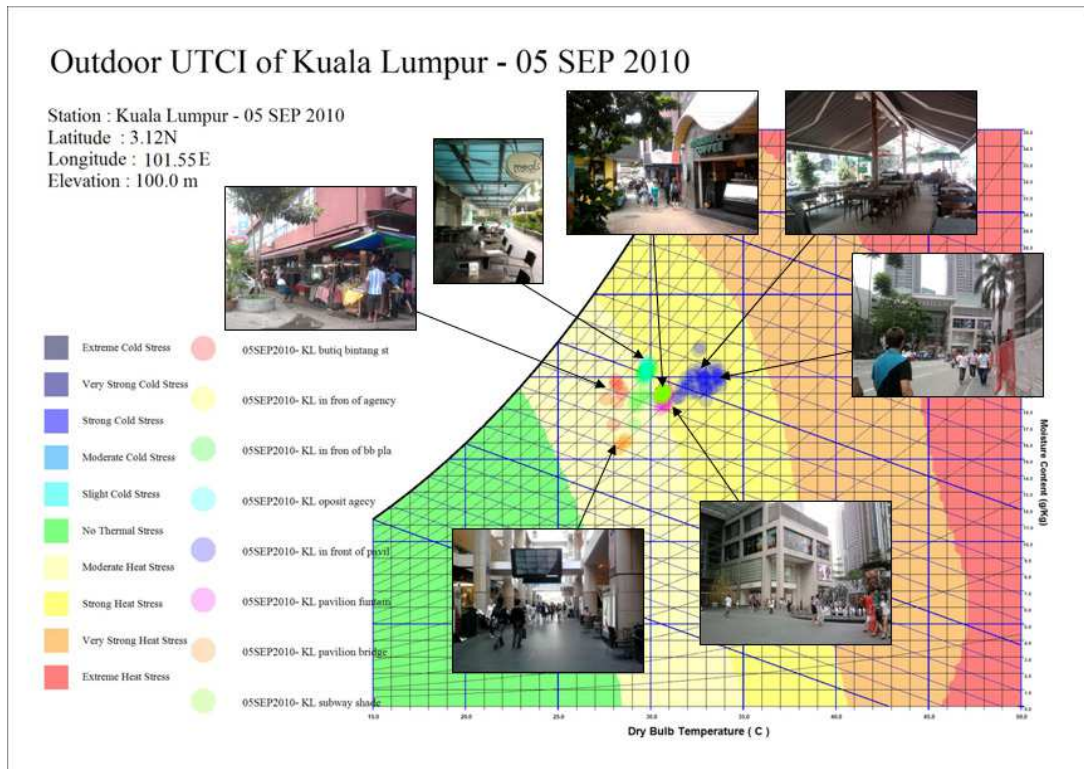


Fig. 11 (b). Covered and shaded walkways will modify thermal condition from strong heat stress to moderate heat stress, cloudy day of 5th SEP 2010

In Kuala Lumpur there are different models of sheltered walkways such as covered walkways and entrances. Underground walkways are another solution to this requirement (Fig 12). In streets with shopping

facilities, temporary sunshades that are provided by the sellers or hawkers help to produce better microclimate for pedestrians and costumers. (Fig 13)

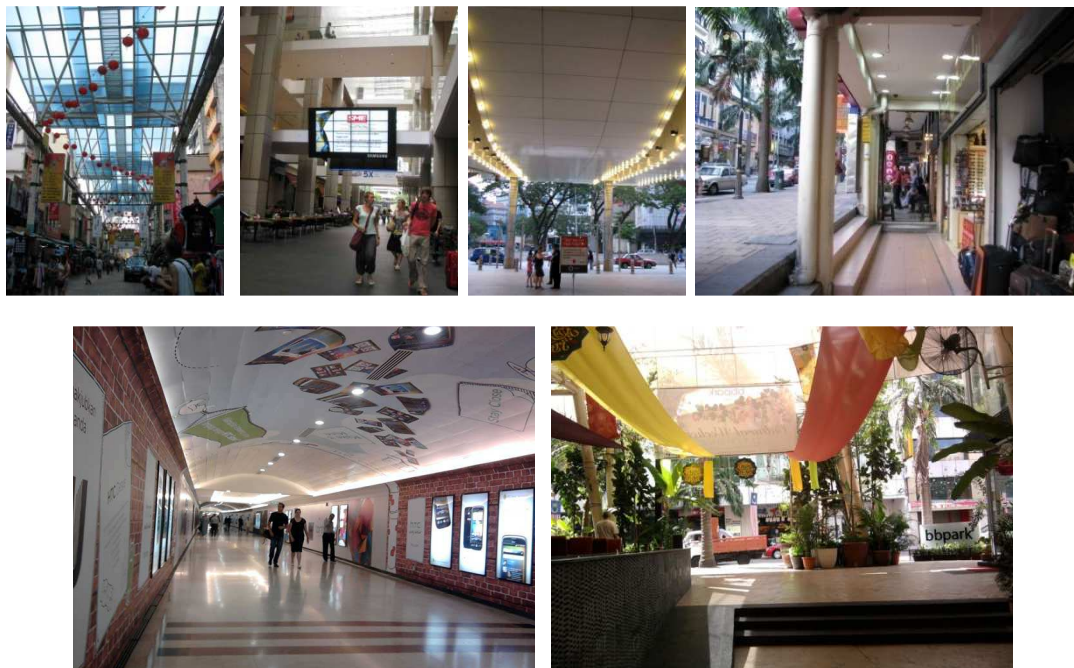


Fig. 12. Different solutions for covered and shaded walkways in Kuala Lumpur



Fig 13. Temporary sunshades provided by shopkeepers and hawkers in walkways

The final strategy for long term outdoor stay is using HVAC systems such as outdoor fans and cold water spray for small areas. They cannot improve thermal condition to comfort zone but because of providing continues ventilation

and evaporative cooling, they can increase tolerable exposure time (Fig 14a & 14b). Even at night this is a common way to provide better thermal condition. (Fig 15)

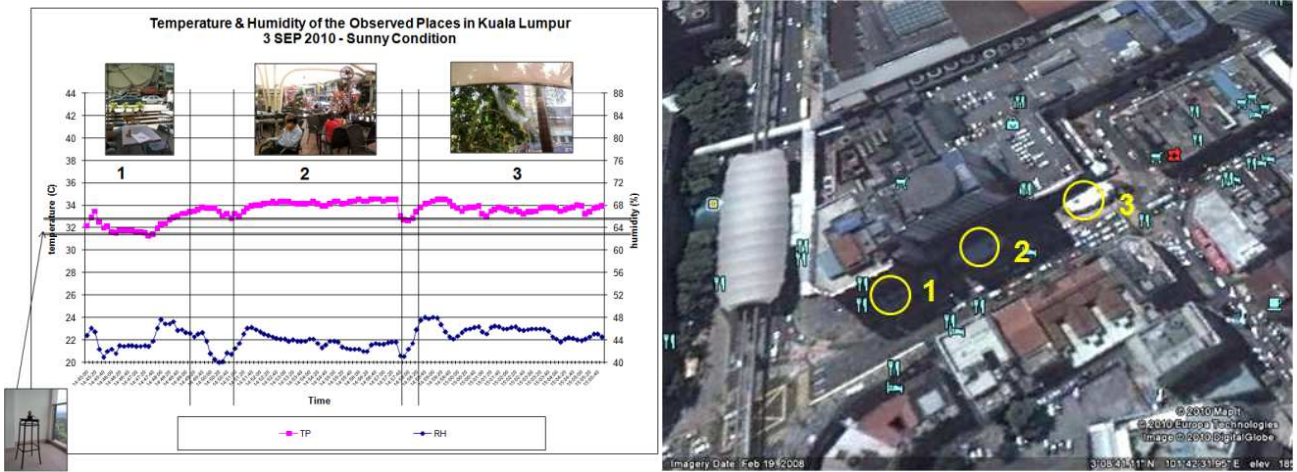


Fig.14 (a). Cold water spray and fans are common solutions to increase exposure time in small shopping areas such as point 3, sunny day of 3rd SEP 2010

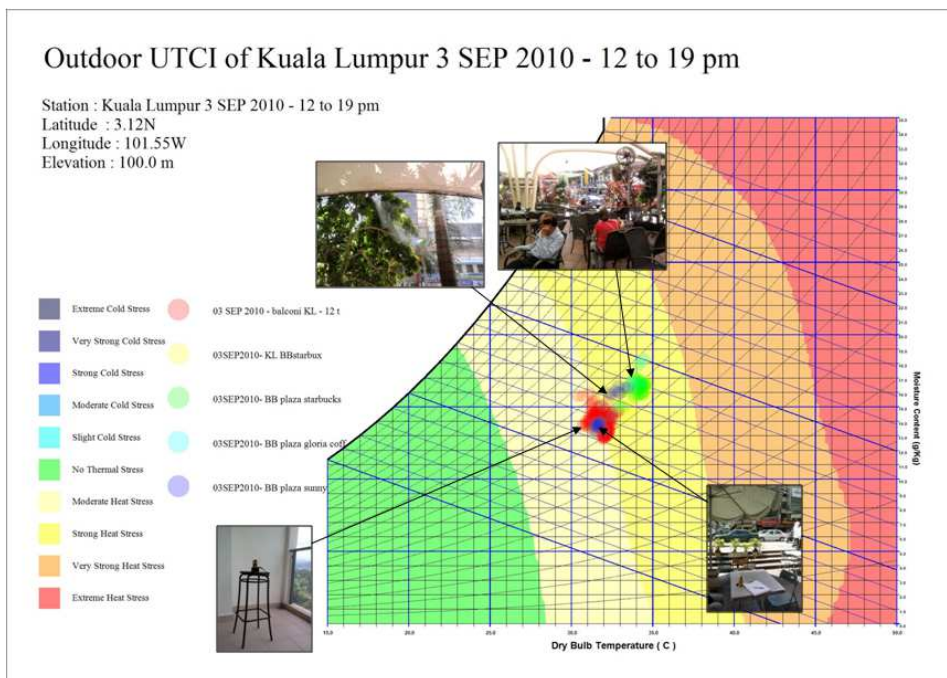


Fig. 14 (b). Cold water spray and fan will provide continues ventilation and evaporative cooling for longer exposure time, sunny day of 3rd SEP 2010



Fig. 15. Creating tolerable microclimate using cold water spray and fan even at night

Large open spaces are not appropriate for long term stay outdoor. They can receive maximum solar energy and rain fall. Providing besieged fences and using green plants and water surfaces will lower the ambient temperature as heat sink. Kuala Lumpur as a tropical city with huge

yearly rain has very good potential for this solution. Water play games and green surfaces in luxury open spaces such as modern shopping malls has helped to provide better microclimate for long term outdoor stay in sunny days. (Fig 16)



Fig. 16. Using green plants and water surfaces as thermal condition modifiers

Vehicle station is another place that is used as a short term outdoor stay. It will be used in all thermal conditions and people have no choice to leave it for a better situation. Providing tolerable microclimate for these places is the responsibility of designers. In Kuala Lumpur with tropical hot climate, stations are designed as great sunshades. They

are made of light color materials with the lowest solar absorption and thermal mass. Although their temperature will not decrease to the lower heat stress level but natural ventilation under the sunshade helps to increase thermal transfer and decrease feeling temperature. (Fig 17)



Fig. 17. Using light color materials with low thermal mass in station as a sunshade

People walking between indoor and outdoor spaces will experience a temperature shock because of cold weather created by HVAC systems inside the buildings (Fig. 18). This is not appropriate for people who have used to outdoor warm condition. In more high class buildings

such as luxury shopping centers temperature is fixed at lowest thermal comfort zone (21-23 C) that will cause even more thermal shock (Fig. 19). These complain is mostly announced by tourists and non local people who are not used to such thermal shocks.

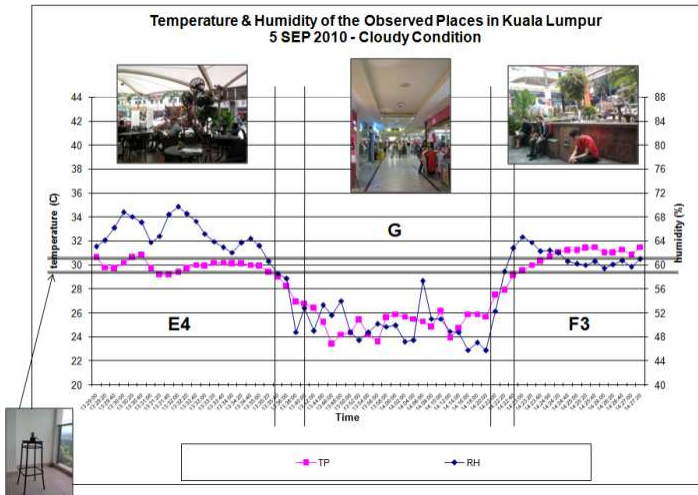


Fig. 18. Temperature shock between indoor (G) and outdoor (E4 & F3) that is not pleasant for pedestrians

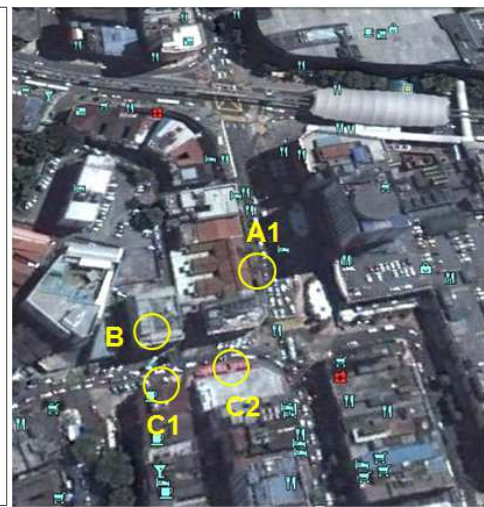
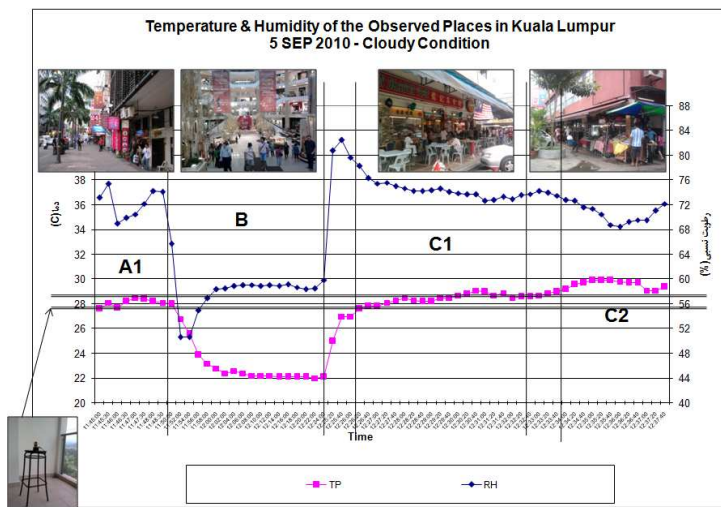


Fig. 19. Temperature shock is higher in high class buildings (B) in compare with outdoor surroundings (A1, C1 and C2)

7. Discussion

Observing different outdoor places in the city centre of Kuala Lumpur, people's presence and their behavior shows that for local citizen thermal situation are tolerable in most conditions. Existence of different tourists from different climatic origins proved that tropical climate of this city is not as hard as it is analyzed "dangerous" or "very hot" by the first group of outdoor thermal indices such as Heat Index (Fig 2a) and Temperature Humidity index (Fig 2b). The second group of the indices such as UTCI (Fig 2c) and Humidex (Fig 2d) defined thermal situation in middle noon as "strong heat stress". People's presence and their long term stay in outdoor spaces shows that they are able to tolerate this weather by the help of responsive climatic design or outdoor HVAC systems such as fans and cold water spray. The only index that defined this weather as "slightly warm" for acclimatized people is tropical summer index (Fig 2e) [15]. It shows that the thermal zones that are introduced by these indices need to be clarified by some more researches to find out the exact and reliable interpretation of design strategies.

Two main results can be summarized here: 1- Acclimatization gives local people the ability to learn how

to adapt their body and their behavior with hot condition. For example my self-experience of 6 months living in Kuala Lumpur shows that taking a shower before going out in very hot weather will clean the skin pores and prepare it for a better convection and evaporation heat loss. 2- Long term presence of people in some outdoor spaces shows that strong heat stress condition in hot humid tropical climate has the ability to be modified by appropriate climatic design and/or outdoor HVAC systems.

8- Conclusion

In this article hot tropical climate of Kuala Lumpur was studied considering outdoor thermal requirements of pedestrians. Using field study observation the microclimate data of different urban open spaces in the central city was collected by mobile Kestrel weather station. The results were compared by higher climatic levels of meso (meteorology data) and local climate (fixed Kestrel in reference location). The comparison showed that: 1) the local climate is dryer than the meso climate, 2) its temperature swing is less and 3) its night temperature is higher because of heat island effect. According to the outdoor thermal indices the local weather in sunny days is

in strong heat stress level while in cloudy days it is more tolerable and in good climatic design places will lower to moderate heat stress.

Constructed places in open spaces will play a great role to modify thermal situation. In places such as outdoor shopping areas and coffee shops with long term stay, even in strong heat stress condition, it is possible to provide better microclimate by good climatic design and at last using outdoor fans and cold water spray. In walkways, appropriate shade and cover is required to protect pedestrians from sunshine and heavy rain. Temporary shades or underground walkways are another solution in this regard. Great open spaces require green plants and water surfaces as heat sink to reduce solar gain in sunny days. Vehicle stations as short term outdoor stay should be in special consideration because they are used in all weather conditions. Light color materials with low thermal mass are needed to create shade and natural ventilation simultaneously in these places.

How to interpret the definition of thermal outdoor indices was another result of this article. It was proved that strong heat stress condition in tropics has the ability to be modified by a good climatic design or outdoor HVAC system as a final solution.

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