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# Seasonal urban heat islands and human comfortability in humid tropical areas

*Seasonal Urban Heat Island and Human Comfortability in Humid Tropical Areas*

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## Abstract
This paper attempts to relate urban heat island and human comfortability in the Greater Kuala Lumpur/Klang Valley region. Based on TERRA/MODIS data of Klang Valley area for the years 2008-2009, supplied by the Institute of Industrial Science, University of Tokyo and MODIS ground receiver of the Asian Institute of Technology, Bangkok, and land surface temperature (LST) was retrieved and mapped from various types of land uses. The spatial extent and the location of Urban Heat Islands (UHIs) were then calculated. The monthly MODIS data were divided into four seasonal periods i.e. Northeast Monsoon (November to March), Southwest Monsoon ((May to September) and two period of intermediate monsoons (April and October, respectively). About 56 locations of known pixels within the area of Klang Valley were selected through systematic sampling to develop GIS contour map using ArcGIS software. The preliminary result showed that the mean highest LST occurred during the Southwest Monsoon period i.e. 309$^{o}$ Kelvin in daytime, while area with high urban imperviousness coverage is the most notable UHI gradient. Surface urban heat islands are typically present during the day and night-time, but tend to be strongest during the day, especially during the Northeast monsoon period. Warm and hot environment due to high temperatures and excessive heat loads will create UHI and thus an uncomfortable environment. The establishment of urban cold island in some seasons can be associated with the occurrences of urban green patches within the metropolitan area. Mitigation must be taken in order to reduce and/or to sustain the establishment of the new UHI centres within and around the study area in future.

## Key Words
Urban Heat Island, Urbanization, Land Surface Temperature, Human Comfortability; Sustainable Development, Microclimate, Urban Morphology.

## *Abstrak*
Makalah ini cuba menghubungkait pulau haba bandar dengan keselesaan manusia di kawasan Wilayah Kuala Lumpur/Lembah Klang. Berdasarkan TERRA/MODIS bagi kawasan Lembah Klang untuk tahun 2008-2009 yang dibekalkan oleh Institut Sains Industri, Universiti Tokyo, MODIS penerima permukaan Institut Teknologi Asia, Bangkok, dan suhu permukaan bumi (LST) data telah diperolehi dan dipetakan bagi pelbagai jenis guna tanah. Kemudiannya dikira

keluasan keruangan dan lokasi Pulau Haba Bandar(UHI) bagi kawasan berkaitan. Data MODIS bulanan dibahagikan kepada empat musim iaitu Monsun Timur laut (November ke March), Monsun Barat daya (Mei ke September) dan dua musim antara monsun (masing-masing iaitu April dan Oktober). Kira-kira 56 lokasi yang diketahui pikselnya di sekitar Lembah Klang telah dipilih menerusi persampelan bersistematik bagi membina peta kontur GIS dengan menggunakan perisian ArcGIS. Hasil awalan mendapati min LST tertinggi berlaku semasa musim monsun Barat Daya iaitu 309° Kelvin pada waktu siang, manakala kawasan bandar yang banyak dilitupan dengan kawasan taktelap air menunjukkan kecerunan UHI yang paling nyata. Secara lazimnya, pulau haba bandar permukaan berlaku semasa waktu siang dan waktu malam tetapi cenderung menjadi lebih kuat pada waktu siang, terutamanya semasa musim monsun Timur laut. Persekitaran hangat dan panas yang berpunca daripada suhu yang tinggi dan beban haba yang berlebihan akan menghasilkan UHI dan dengan itu mewujudkan persekitaran yang tidak selesa. Pembentukan pulau sejuk bandar pada beberapa musim boleh dikaitkan dengan kewujudan tompokan kawasan hijau di kawasan metropolitan. Mitigasi perlu dilaksanakan bagi mengurangkan dan/atau menghalang daripada pembentukan pusat UHI yang baru di sekitar dan di sekeliling kawasan kajian pada masa hadapan.

***Kata kunci***
Pulau Haba Bandar; Urbanisasi; Suhu Permukaan Bumi; Keselesaan Manusia; Pembangunan Mapan; Mikroiklim; Morfologi Bandar

## Introduction

Urbanization is a dynamic process which involves expansion of urban related area and conversion of natural physical landscape to more economic land uses. It takes place at a faster rate than expected around the world, including in the developing countries such as in Malaysia. According to United Nation (2009) over 50% of the world population nowadays live in urban areas, especially in Asia and Africa, and by 2050, one-third of all urban dwellers will be concentrated in Asia (Montgomery, 2008). As Huang et al. (2006) stated that Asian cities are the most rapidly growing regions of the world nowadays. They further stated that 16 of the world's 24 mega cities will be located in Asia by the year 2015. The present urbanization projections will definitely have intensified the need to make urban environment more comfortable and livable (United Nations, 2009). Urbanization, not only causes of the degradation of environment quality but also affecting natural and health ecosystem (Douglas, 1983; Hung et al., 2006; Ma et al., 2010). Some studies revealed that urbanization could alter the urban micro climate, especially the frequency of daily precipitation, onset of monsoon season and intensity of precipitation (Cicek & Turgoklu 2005; Jauregui & Romales 1998; Landsberg, 1970; Lowry, 1988; Changnon, 2001). Other studies showed that urban population growth and economic expansion have been considered as the primary drivers of land use and land cover change (Hung et al. 2006; Li et al. 2009). In other words, urban development can profoundly alter the urban landscape structures, and urban thermal environment (Guo et al., 2012). Urban heat budget increased as the city grows and created unhealthy environment and reduced urban comfortability (Lansberg, 1970; Ponce et al., 1997). However, due to majority of urban surfaces are dark /and greyish black bituminous in colour and high atmospheric air pollution, then the urban surface albedo is expected much lower than the surrounding areas (Pandey et al., 2012). Therefore, these conditions could lead to the increment of the urban heat island phenomenon in urban areas.

Study on UHIs can be carried out in two different techniques: First, field measurement of urban air temperature of about two meter from the ground. This technique is carried out either on point measurements of different types of land uses or surface air temperature traverse across various land uses (Stewart, 2011). Second, remote sensing technique is used to derive land surface temperatures (LST) from various thermal emissivities of land uses and then classified into different degrees of UHIs (Voogt & Oke, 2003). One of the advantages of the latest technique of detecting UHI is that its wall-to-wall coverage of the urban surface temperature, thus producing its spatial patterns, although its instantaneous measurement is only for the day time (Li et al., 2011). Since the 1970s, satellite-derived surface temperature data have been used for many purposes such as urban climate studies on different scales. Among thermal data that has been used including Very High Resolution Radiometer (VHRR) data, Heat Capacity Mapping Mission (HCMM) data, Landsat Thermatic Mapper ™ data, Landsat Enhanced Lansat Thermatic Mapper plus (ETM+) data, and Moderate Resolution Imaging Spectroadiometer (MODIS) data.

In Malaysia, the Klang Valley region, as now known the Greater Kuala Lumpur/ Klang Valley (KL/KV) is considered as the most developed and fast growing region. It is identified as the critical economic growth centre in Malaysia nowadays. Greater KL/KV ranks $79^{th}$ out of 130 cities on the EIU's global livability index, and $10^{th}$ out of 31 Asian cities ranks (http://etp.pemandu.gov.my/upload/etp_handbook_chapter5_ greater_kllv.pdf). Because of rapid urban development, massive influx of population, increasing energy consumption, and resultant changes in land uses and industrialization have led to an overall environmental degradation in the KL/KV region. Normally, the term Urban Heat Island (UHI) is used to describe the situation whereby temperatures in urban areas are higher compared to their rural surroundings (Oke, 1995). This is understandably that the thermal properties of the urban areas (concrete materials, glass, tarmac etc.) differ from those in the rural areas (forest, grass, bare soil etc.). Therefore, these materials contribute to heat island intensity by their greater ability to absorb and store heat. Furthermore, during the day the air in the urban areas is often drier than in the rural areas while the opposite condition prevails at night (Lee, 1991; Holmer & Eliasson, 1999). Oke (1978) stated that the combination of increased amounts of water vapour and high concentration of air pollution in the urban areas may initiate and promote cloud formation and subsequently precipitation in the urban areas.

Basically, UHIs directly or indirectly affect the thermal comfort and health of the urban dwellers (Stafoggia et al., 2008; Lafortezza et al., 2009). To what extent the environmental degradation especially UHIs will affect urban dwellers well-being is subject to be studied. Therefore, on this note, this paper attempts to look into the effects of urbanization on UHI pattern in the Greater Kuala Lumpur/Klang Valley region for the last few years i.e. between 2008 and 2009 by using MODIS-LST data compiled by the Institute of Industrial Sciences, University of Tokyo. Besides, the paper will also attempts to compare UHI patterns between two major monsoon periods (Southwest monsoon and Northeast monsoon) and the intermediate monsoons. Lastly, the paper will discuss the extent of urban heat island distribution related to human comfortless in the study areas.

## Urbanization in Malaysia

The term urban has been defined as, a gazetted area comprises of built-up and consolidated areas with a minimum population of 10,000 urban dwellers (JPBD, 2006). Malaysia is one of the most developing countries in Southeast Asia which experienced drastic urbanization (McGee, 2010). The last decade has showed that the urban population has increased at the rate of more than 10 percent. According to Economic Planning Unit (2006), approximately 80 % of the population in Malaysia will be living in urban core areas in 2020.

Greater Kuala Lumpur/Klang Valley (KL/KV) is the most urbanized area in Malaysia. The latest statistic has showed that nearly 95% of the population living in urban area (DBKL 2005). Greater KL/KV region has 10 local authorities i.e. City Hall of Kuala Lumpur, Kajang, Subang Jaya, Petaling Jaya, Selayang, Shah Alam, Ampang Jaya, Sepang Municipalities and Putrajaya (Figure 1). Based on the 2010 statistic, the total population of the Greater KL/KV region was estimated around 5.8 million. Kuala Lumpur is the capital and the largest city in Malaysia. The city area comprises an area of 244 km$^2$, with an average elevation of 21 m and surrounded within the Klang Valley region. Historically, urbanization in Kuala Lumpur has taken place quite significantly at the beginning of 1970s after New Economic Policy (NEC). At that time a substantial green spaces, forest and unused lands were converted into commercial and business centres, government offices, residential areas and public amenities. Due to rapid urban development, more people migrated to Kuala Lumpur, hence more areas at the periphery of Kuala Lumpur being developed especially for squatter settlements. In the latest estimation (2010), the population of Kuala Lumpur is about 1.7 million with an average natural population increment of 2% per year. Being a tropical country, Kuala Lumpur has experienced a hot and humid climate with heavy storms occurring in the early evenings. During the day temperature can scale up to 35°C and night time temperature is hardly below 25°C. The average of relative humidity is about 70-85%.

By the year 2020, Kuala Lumpur will accommodate about 2.5 million urban dwellers (DBKL, 2005). The metropolitan city has experienced rapid economic growth especially during the last two decades, with remarkable extension of built up areas to cope up with active urban activities (Shaharuddin et al., 2009). A significant area of agricultural land has been converted into urban impervious areas, hence changed the urban morphology as well as urban microclimate. Among the most significant change in land conversion was the residential land use, where more than 12,000 ha in Kuala Lumpur area considered as housing settlement. The environmental issue was included in the Kuala Lumpur Structure Plan (KLSP) 1984 to secure the best standard through a judicious balance between development, ecology and National heritage. The programme has places greater emphasis on amenity rather than the ambient environment. However, the emphasis has changed because of the realisation that environmental considerations should not be limited to concerns about pollution control but should be more positive in aiming to create more comfortable, pleasant and stimulating surroundings, hence City Hall of Kuala Lumpur has been able to exercise more direct control over such matters as tree planting and cityscape. Such effort is suvmounted by sustainable development.

Since 1970, Shaharuddin (2003) had studied the impact of urbanization on the urban climate. He found that the annual air temperatures varied with the changing size of urban areas. Urbanization was measured by the increase in population with time. The urban annual air temperature for the 30-year period had positive linear correlation with slope coefficients from as low as 0.01 to as high as 0.12. This implies that the urbanization that took place within the last 30 years in most of the urban areas, to some extent, has a significant role in changing the urban air temperature patterns. A various studies of urban heat island within Malaysia also proved that the intensity of the UHI increased positively with the imperviousness of the urban surfaces (Table 1).

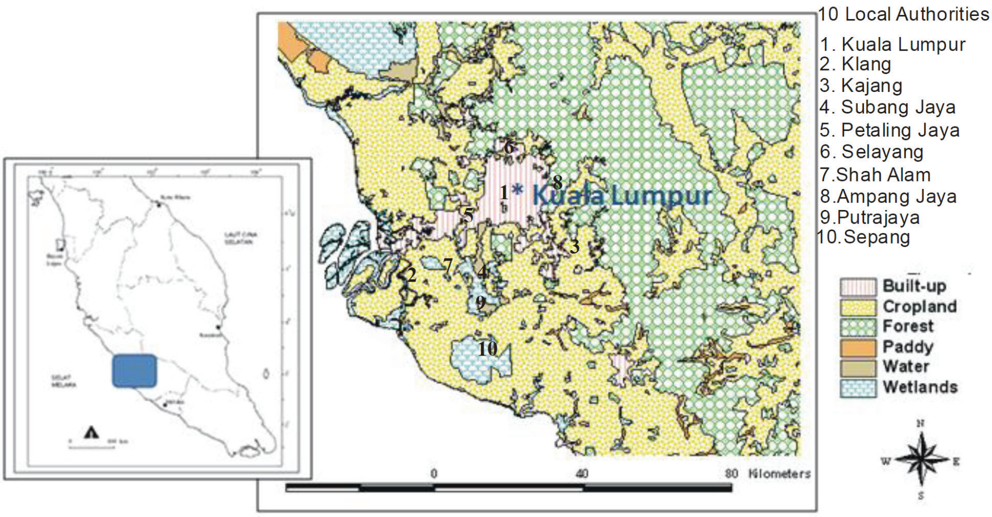



**Figure 1** The location of Greater Kuala Lumpur/Klang Valley

**Table 1** The urban heat island intensities in Malaysia

| Location | Urban heat island intensity (in °Celcius) | References |
|---|---|---|
| Johor Bahru | 3 | Zainab (1980) |
| Georgetown | 4 | Lim (1980) |
| Lembah Kelang | 3.5 | Sham (1986) |
| Kuala Lumpur | 7 | Sham (1984) |
| Kuala Lumpur | 8.1 | Wataru et al.(2010) |
| Kuala Lumpur | 9.3 – 9.7(July) | Shaharuddin et al.(2011a) |
| Putrajaya | 1.5 | Shaharuddin et al.(2010) |

Source: Shaharuddin et al. (2011a) and Wataru et al. (2010)

## Data and method

This study applies TERRA/MODIS data from The Institute of Industrial Science, University of Tokyo and MODIS ground receiver of Asian Institute of Technology, Bangkok. Data were gathered for two years i.e. 2008–2009. TERRA /MODIS has 3 different modes of spatial resolution – 250m, 500m and 1000m – with 36 spectral bands in total and it covers the whole region of the earth both in day-time and night-time every day. The combination of spatial, spectral and time resolutions is considered to be more effective to monitor the regional heat environment associated with the land cover than the data of NOAA/AVHRR.

TERRA/MODIS viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands including several infrared thermal bands. These data will improve the understanding of global dynamics and processes occurring on the land as well as the lower atmosphere. Daytime image of TERRA/MODIS is recorded around 10am-14pm and Night-time Land Space Temperature (LST) is around 7pm – 11pm local Malaysian Time (LMT). Figure 2 shows the data processing flow in this study. The first step of the study is to make the geometric correction and land cover classification by using the optical TERRA/MODIS 250 m resolution visible and near infrared bands. The major land uses derive from the classification includes build up (representing urban cores), permanent agricultural land, forest, grassland, water body and bare soil.

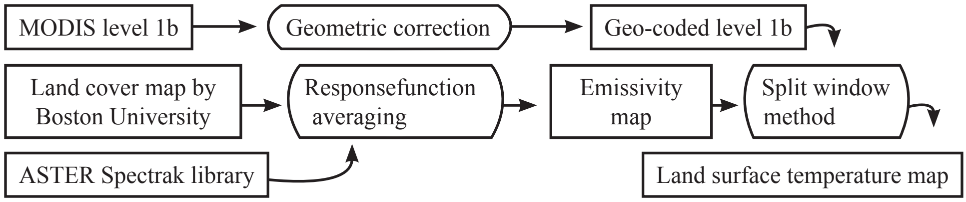



**Figure 2** The flow of data processing in this study

The classification result is used to provide the emissivity of the land cover categories so that 'split window algorithm' for the thermal bands (MOD31 and MOD32) can be done effectively (Ochi et al., 2002). The information of land emissivity gathered from the ASTER spectral library will be used to estimate the land surface temperature from the brightness temperature value in the thermal band image with 1km resolution. The reason why split window method is applied is to minimize errors originated from atmospheric contamination (Wataru, 2009). However, the land surface temperature is influenced by the geographic conditions such as the climate and local weather. For example, it is difficult to compare temperatures of all areas to locate urban heat island intensity if cloudiness presence along the path of the satellite. Thus, cloud detection and cloud masking are carried out to display only cloud free region for the study area. For this study, the display of LST can only be carried out based on monthly composite images. Figure 3 shows the geocorrected LST image, 360 x 240 pixels subsetted image of the Greater Kuala Lumpur/Klang Valley area with the upper left pixel approximately at 4°N, 100'E and the lower right pixel approximately at 2°N, 103'E. The LST image with BIL data format and in Unsigned 16 data type is displayed and analysed within ERDAS-IMAGINE environment.

There were 56 point sources scattered within the urban corridor of Greater Kuala Lumpur/Klang Valley area have been selected for this study (Figure 4). These point sources were representing of all types of land uses involved in this study. All points/locations involved were registered as X-Y GIS coordinate in DbaseIV file using ArcGIS software in order to establish UHI continuous contour system based on different periods. Inversed Distance Weighted (IDW) method was used to develop isotherm line for the UHI in Spatial-Analyst ArcGIS. Urban Heat Island Intensity (UHII) was then calculated by subtracting the minimum from maximum value of urban heat islands. Besides, the LST result for the selected locations were categorized into four different periods, i.e., the Northeast Monsoon period (November to March), the southwest monsoon period (May to September) and both intermediate monsoon, April and October, respectively.

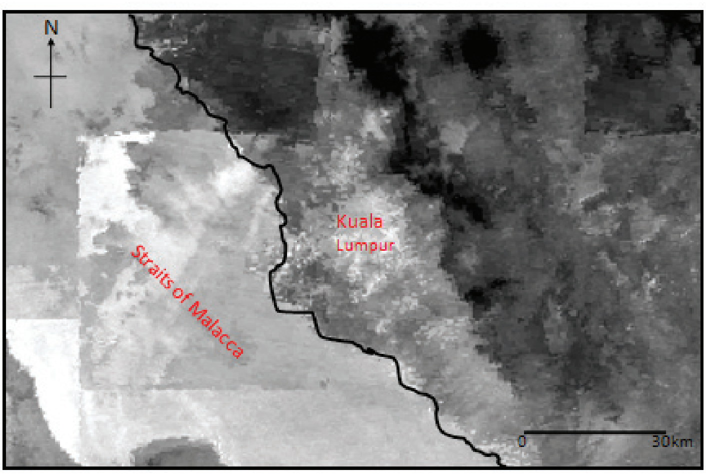



**Figure 3** LST image of the Greater Kuala Lumpur/Klang Valley

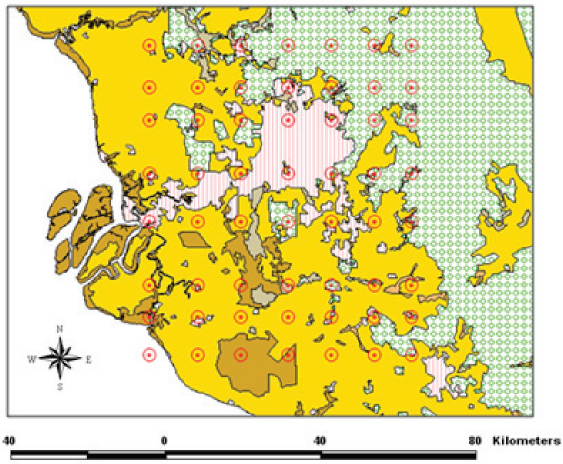


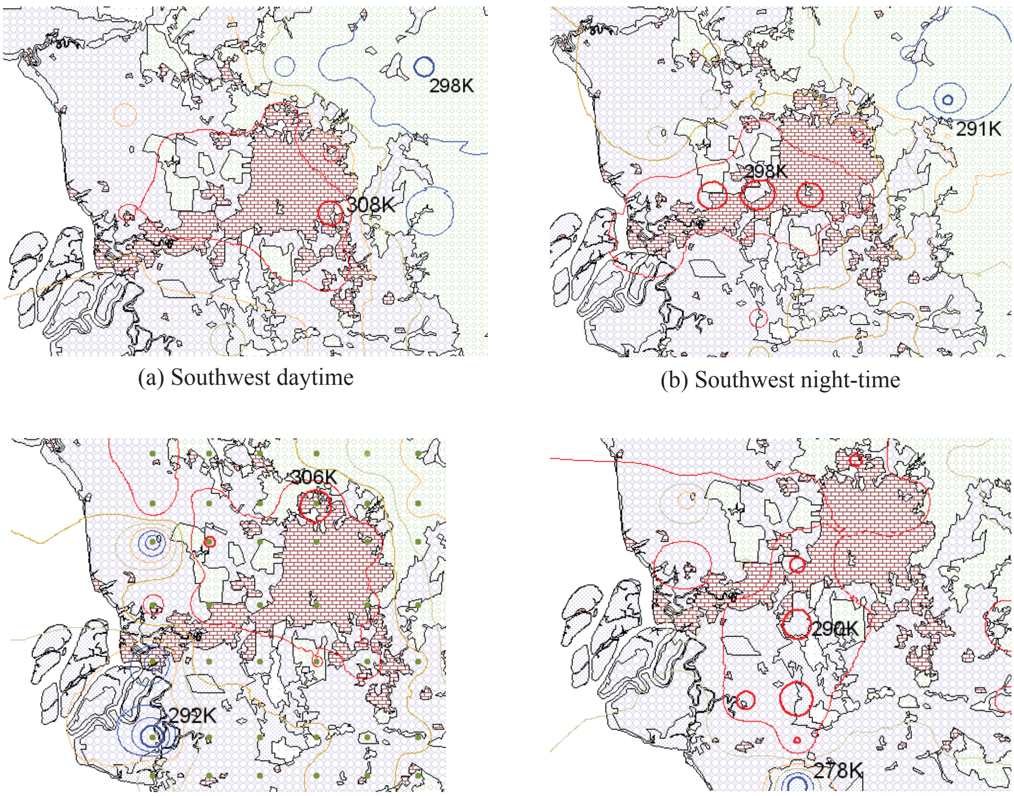

**Figure 4** Distribution of the 56 selected locations in the study area

## Result and discussion

Figure 5 shows the distribution of UHI centres within the study area. It is clearly indicated that the monsoonal periods displayed different effects of maximum UHI bubbles development during daytime and night-time. It is noted that the maximum UHI occurred within the urban impervious area of the Greater Kuala Lumpur/Klang Valley region, except for the night-time in Northest monsoon period. Even though the UHI centres located outside of the bussiest areas of the study area during the Northeast monsoon period, the centres were still established within the town areas such as Kajang and Salak Tinggi, peripery area of Kuala Lumpur. Perhaps, night activities in those areas such as night markets produced a significant volume of air pollution and heat energy (Shaharuddin & Noraziah, 2011). Air pollution concentration reacted as blancket to heat release from the surface at night, thus warming the lower atmosphere of the earth. In general, urban areas within the Greater Kuala Lumpur/Klang Valley region were still displayed high surface temperatures during the Northeast monsoon period. One of the common features was that the highest intensity of UHI occurred and recorded during the day regardless the monsoonal periods as the highest solar heat energy received in the morning and afternoon.

The urban cool islands were located either at the periphery of Greater Kuala Lumpur/Klang Valley region or further outside of the study area. This was observed for all monsoonal periods. The value of the urban cool island was much lower during the night-time as compared with the daytime. This can be explained in terms of the process of latent heat release during the night was faster at the country side than at the urban areas. Comparatively, countryside is more green and moist environment as compared with urban areas. Moreover, less percentage of impervious surfaces at the countryside as compared with in the urban areas. Therefore, less heat stored within the countryside areas that capable of warming the atmosphere significantly during the night.

Table 2 shows the value of urban heat and cool islands as well as the urban heat island intensities within the study area according to monsoon periods. In general, the average UHII was much higher during the day (10.1°C) as compared to the average of UHII at the night-time (6.1°C). In terms of monsoon period, it is clearly showed that the daytime of UHII during the intermediate monsoon, especially in October was much higher (14.5°C) than the rest of the monsoon periods. The second highest average of daytime UHII was during the Southwest monsoon i.e. May to September (10.5°C). At




(a) Southwest daytime

(b) Southwest night-time

(c) Northeast daytime

(d) Northeast night-time

**Figure 5** The distribution of Urban Heat Island in the study area according to monsoon periods

night, the highest UHII was calculated for Southwest monsoon i.e. 7.7°C followed by Northeast monsoon (5.7°C).

The highest daytime of UHII during Southwest monsoon is due to fact that during this period of the time the Greater Kuala Lumpur/Klang Valley region experiences 'dry' season and relatively recorded more solar radiation. The same reason can be applied for explaining the highest daytime of UHII during the intermediate monsoon in October

**Table 2** The UHI result according to monsoon periods

| No | UHI period | UHI for Urban (in Kelvin) | UHI within forest (in Kelvin) | UHI Intensity |
|---|---|---|---|---|
| 1 | Daytime of Southwest M | 309.14 | 298.66 | 10.48 |
| | Night-time of Southwest M | 298.5 | 290.8 | 7.7 |
| 2 | Daytime of Northeast M | 307.8 | 296.6 | 11.2 |
| | Night-time of Northeast M | 290.2 | 284.5 | 5.7 |
| 3 | Daytime of Intermediate M (Apr) | 309.1 | 299.9 | 9.2 |
| | Night-time of Intermediate M (Apr) | 298.4 | 294.4 | 4.0 |
| 4 | Daytime of Intermediate M (Oct) | 307.5 | 293.0 | 14.5 |
| | Night-time of Intermediate M (Oct) | 297.5 | 293.0 | 4.5 |
| 5 | Annual Daytime (average) | 308.0 | 297.9 | 10.1 |
| | Annual Night-time (average) | 296.1 | 290.0 | 6.1 |

whereby high intensity of solar radiation is prevailed during this time of the year. The relative humidity in the urban areas during this period of the year was relatively very low and therefore the environment was quite warm and humid condition. Normally, this situation tends to influence the urban ambient air temperature to the extent of beyond and above the annual mean temperature. Because of the thermal properties of the urban areas that are highly capable of absorbing and storing heat during the day, more latent heat is released during the night. Even though the same amount of solar radiation received at the surface of rural areas, the characteristics of the rural areas of more trees, bare soil and grass, to certain extent; prevent the storage of more heat during the day. Furthermore, more solar radiation is used by trees, grass and other vegetation to perform ecological processes such as photosynthesis, transpiration and evaporation. Thus, less heat stored during the day and released as latent heat during the night at rural areas. This in turn will create more pleasant and cool environment in rural areas.

The result of this study is slightly different than the study by Shaharuddin et al. (2011b) and Shaharuddin (2012) for Kuala Lumpur city. They found that the daytime UHII was about 9.3°C whereas the night-time UHII was about 9.7°C. The different result could be due to the time frame of the study in which the data for the presence study were gathered for two years whereas Shaharuddin et al. (2011b) data were only for one month i.e. in July 2008. The result of the presence study was also different from the study by Zeng et al. (2009) in Nanjing, China and in Tokyo by Wataru et al., (2010) whereby the UHII during night-time was greater than during daytime. This difference can be explained in terms of different location i.e. cities in the tropical region like Kuala Lumpur located at the equatorial region (highest incoming solar radiation during daytime) whereas cities at the mid latitudes such as Tokyo received less incoming solar radiation (Figure 6).

The dominant urban heat island phenomenon in urban areas such as within the Greater Kuala Lumpur/Klang Valley region could trigger negative effects to urban dwellers. Excessive heat load due to high temperature will produce an uncomfortable warm environment, and in the most severe case, mortality may result from heat stroke. Outside activities such as hawkers, will be affected by such extreme weather condition. Recreational activities will not be suitable to carry out during the day except late evening due to hot and warm condition. If the presence high temperature in the study area is not mitigated accordingly it might be contributed to another related problems in future, such as increased energy required for air conditioning and refrigeration in cities. Therefore, the increased use of air conditioning under warm and hot condition not only violates the principles of sustainability, but also contributes to the greenhouse effect. This problem has been studied in Taiwan (Chang et al., 2007) whereby an increase of 1°C in summer temperature resulted in a 6% rise in electricity usage due to air conditioning. Increased in greenhouse gases will also produce an impact on the local meteorology by altering local wind patterns, forming cloud and fog, increasing humidity and changing the precipitation rate (Taha, 1997). A study carried out by Shaharuddin et al. (2009) revealed that the urban imperviousness within Kuala Lumpur has produced extra heat which was sensed and quantified via remotely sensed thermal infrared band data. The correlation between urban imperviousness and land surface temperature was also significant. According to Embi and Norlida (2004), even the newly administration centre of Putrajaya has joined the ranks of Kuala Lumpur, Petaling Jaya and Penang in experiencing hotter phenomenon.

## Conclusion

This study suggests that the MODIS-LST data retrieved from the University of Tokyo and from the Asian Institute of Technology, Bangkok are the most viable information

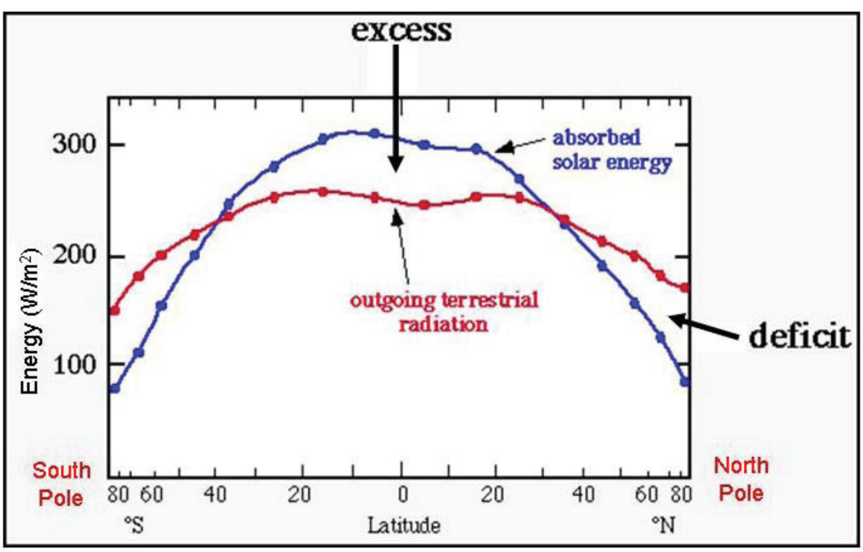



**Figure 6** The different of solar radiation received based on latitude

to monitor urban heat island patterns in Malaysia. The study found that the presence of the surface urban heat islands within the Greater Kuala Lumpur/Klang Valley region was typical phenomena during the day and night-times. The average Urban Heat Island Intensity (UHII) was observed higher during the day than at night. Moreover, the intermediate monsoon, especially during daytime of October displayed the highest UHII. Out of the two monsoon seasons, the UHII was calculated higher during the Northeast monsoon rather than during the Southwest monsoon. The existence of urban cold islands in some seasons can be associated with the occurrences of urban green patch within the metropolitan area.

The establishment of urban heat island phenomenon within the Greater Kuala Lumpur/Klang Valley region can cause negative effects to urban dwellers. Warm and hot environment due to high temperatures and excessive heat loads will create an uncomfortable environment, and in the most severe case, mortality may result from heat stroke. The problem will not be resolved; in fact, it will create other problems such as increase of air pollution and green house effects. This is in relation to the increase of energy consumption in city because of the high demand for air conditioning and refrigeration. Therefore, the increased use of air conditioning under warm and hot condition not only violates the principles of sustainability, but also contributes to the greenhouse effects. Mitigation must be taken and implemented in order to reduce or to sustain the establishment of the new UHI centres within and around the study area in future.

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