The Influence of Urban Landscape Morphology on the Temperature Distribution of Hot-Humid Urban Centre

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Abstract

The outdoor spaces of hot-humid tropical cities are exposed directly to the high intensity of solar radiation. The increased heat gain contributes to the thermal discomfort in an urban environment. This study investigates the variability of outdoor air temperature produced on the different urban landscape morphology in Putrajaya. Results revealed that the temperature distribution is strongly influenced by the urban landscape morphology where significant temperature differences are observed at various urban areas. The findings could contribute toward a better understanding on the interrelationship between urban landscape morphology and its influence on the microclimatic atmosphere.

Keywords: Urban landscape morphology; outdoor temperature; thermal variation; hot-humid city

1. Introduction

Urban landscapes comprises of various characteristics that give impact to the urban atmosphere. The configuration of urban fabrics, natural and man-made surfaces, urban geometry, street layout, architectural complexity, urban materials and human activities characterised the urban landscape morphology. This characteristic severely impacted many environmental catastrophes especially to the local climate. As a...
result, the composition of urban atmosphere such as microclimate parameters has changed with space and
time due to the urban development (Shaharuddin, 2012).

In tropical region, the rapid growth of urbanisation and socio-economic activities has modified its
urban climate. This is due to the anthropogenic factors resulting from many physical and social urban
activities. Further, the natural climatic condition of hot-humid tropics experiencing hot weather, high
humidity and low wind velocity often leads to thermal discomfort in outdoor environment (Emmanuel and
Johansson, 2006).

Several studies have shown large thermal variations especially during the daytime and high correlation
between land use changes and temperature distribution in urban areas (Shaharuddin et al., 2010, Saaroni et
al., 2000). These changes are closely related to the variation of urban land use and land cover pattern,
urban roughness, physical and morphological factor; in which modify the energy balance of Earth’s
surface (Gartland, 2008:16, Emmanuel, 2005). These factors contribute to the increasing heat storage,
accumulation of net radiation from solar radiation and reduced evapotranspiration process in the urban
environment. This is eventually leads to the formation of Urban Heat Island (UHI) phenomenon. The
urban factors that modify the surface energy balance and induce the formation of UHI phenomenon are
summarised in Table 1.

Table 1. Urban characteristic that contribute to the formation of UHI phenomenon

<table>
<thead>
<tr>
<th>Urban characteristics</th>
<th>Effect on the heat island formation</th>
<th>Effect on energy balance of Earth’s surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of vegetation</td>
<td>Increase solar radiation, air temperature and humidity</td>
<td>Reduces evaporation</td>
</tr>
<tr>
<td>Large impermeable surfaces</td>
<td>Increase heat gain from solar radiation</td>
<td>Reduces evaporation</td>
</tr>
<tr>
<td>Urban materials</td>
<td>Increase thermal diffusivity</td>
<td>Increased heat storage and net radiation</td>
</tr>
<tr>
<td>Urban geometries</td>
<td>Trap heat, slow wind speeds</td>
<td>Increase net radiation and reduces convection</td>
</tr>
<tr>
<td>Land uses and urban activities</td>
<td>Increase level of air pollution and energy use</td>
<td>Increased net radiation and anthropogenic heat</td>
</tr>
</tbody>
</table>

Source: Modified from Gartland (2008)

The characteristics of landscape morphology that characterise cities and its interaction with local
climate create a complex thermal behaviour of an urban area (Saaroni et al., 2000). This is even more
experienced in hot-humid climates where it is hot throughout the year.

This characteristic presents a daunting challenge to relevant professionals in order to incorporate
climate adaptive strategies into the design. However, understanding of the relationship between urban
landscape and its influence on the microclimate could provide useful information in determining the
important design aspects that could significantly contribute to achieve a comfortable thermal environment
(Sharifah Khalizah et al., 2012). According to Shaharuddin (2012:13) and Brown (2011), the knowledge
of the association between the urban landscape and its influence on climatic aspects can be utilised to
create and modify a desired microclimatic impact. The degree of climatic variation exhibited by urban
landscape morphology should be considered in the preliminary site planning phase of design. Hence, the
information can be manipulated to provide sustainable design strategies in landscape and urban planning.

The research objective is to provide understanding on the influence of urban landscape morphology
and its impact to the climatic variance in hot-humid city. This is conducted through the investigation of
microclimatic effect at various urban spaces in Putrajaya. In order to observe the distribution of outdoor
temperature, field measurement was conducted to provide spot data of selected sampling points that represent various urban landscape morphology of Putrajaya city.

2. Study area

The study was carried out within the city of Putrajaya (Lat. 2° 55' 34.90"N, Long. 101° 41' 47.20"E), the new federal Government Administrative Centre of Malaysia. Approximately 65% of its total land was developed into an administrative centres, neighbourhood and residential precincts, commercial centres, urban parks and water bodies (Draft Structure Plan: Putrajaya 2025, 2011). In general, the urban structures consist of medium rise buildings and a 4.2km long boulevard as the central spine of the city. A huge proportioned of man-made lakes also creates a 38 kilometres long waterfront area. The urban landscapes are distinctively enveloped by huge proportion of green spaces, man-made lakes and at the northern part of the city, a man-made wetlands is created by utilising the small rivers that run through the area. These elements give the unique features of Putrajaya urban landscape. Figure 1 shows the macro view of the study area. The climate of Putrajaya is categorised as typical hot and humid tropics where it is warm and sunny with uniform temperature, high humidity and light winds along with copious rainfall especially during the northeast monsoon.

Fig. 1. The view of the study area through SPOT-5 satellite imagery
Source: Courtesy of Malaysian Remote Sensing Agency (2011)
3. Methodology

3.1. Sampling design and selection of measurement sites

There is no standard of variables to study the urban morphology in relation to meteorological aspects (Giridharan et al., 2007; Emmanuel and Johansson, 2006). Through literature survey, it is found that researchers usually identified the variables based on the specific characteristics and peculiarities of the study site in relation to the purpose of research. Therefore, based on the urban landscape and geographical features of Putrajaya, it is predetermined that the variables influencing the climate of the city would be the landscape morphology, urban geometry, land cover and land use activities. Thus, the variables of sampling points were selected to follow this criterion and adequately considered to represent the distinctive character of Putrajaya city. In order to observe the distribution of outdoor temperature, the stratified random sampling technique was applied in determining the sampling points. Fifteen point sources were selected for temperature measurements within Putrajaya city (Figure 2). The samples are disproportionately taken across all types of land use and land cover (i.e. built-up, green area and water bodies) and varies by dissimilarities of urban characteristics such as at different urban geometry and structures, surfaces, activities and others which are assumed to be representing the characteristics of the city. Most of the sampling locations for field measurements were conducted at accessible and non-restricted area (i.e. roadside, public or recreational area, parking site, sidewalks etc.) due to respect the restriction issued by the local authorities and for safety purposes. Upon limitation, however, the selected sampling stations were still capable to represent the characteristic of urban landscape of the specific area and Putrajaya as a whole entity. Figure 3 presents the general characteristics of selected sampling locations.

![Fig. 2. Selected sampling stations for the study in Putrajaya](image_url)
3.2. Climatic parameter

The parameters used for field measurement are air temperature (°C) and relative humidity (%). These parameters were selected to observe the relationship between these parameters.

3.3. Field measurement

The outdoor air temperature (°C) and relative humidity (RH) measurements were conducted at 1.0m above ground. Few researchers suggest that the ideal position in taking the ground measurement is as close to pedestrian height from the surface (Oke, 2006; Emmanuel and Johansson, 2006). Ground temperature measurements were acquired by using thermo-anemometer model Lutron LM-8000. The instrument had temperature and relative humidity accuracy of ± 1.2°C and ± 4% RH while the resolution was 0.1°C and 0.1% respectively. Before beginning the field work, the instruments were calibrated to ensure it is in good condition and does not affect the measurement taken. Furthermore, the surveyors also waited approximately 20 seconds to stabilize the sensor before taking the measurements at each sampling stations. The field measurements of air temperature and relative humidity were taken from January to
March 2012 between 1100 to 1400 hours (mid-afternoon) for two to three times a week (altogether 35 days of observation). The second measurements were conducted on 15 to 18 July 2012 within one-hour interval from 0900 to 1800 hours (Local Malaysian Time). Due to make simultaneous measurement, several field assistant were assigned to conduct the measurements. These measurements were taken on different weather occasions except for rain. This number of observation provided sufficient information to ascertain the highest and lowest temperature consistently recorded at the study area.

3.4. Data analysis

The measured data of air temperature and relative humidity at selected sampling points were averaged to represent mean daily values for the month of January to March 2012, and for July 2012. The mean values of temperature and relative humidity were then plotted in graphic diagrams to see the distribution of microclimatic variances at various urban landscapes. Meanwhile, further analysis by using simple statistical technique was applied to test the correlation between air temperature and relative humidity.

4. Results and discussion

4.1. Distribution and variability of climatic parameters

Generally, it can be seen that the results have indicated variation in temperature and relative humidity based on its urban landscape characteristics. The distributions of temperature and relative humidity were varied at different urban landscapes by ranging on average of 32.5 to 39.0°C and 42.4 to 55.9% for the period of January to March 2012. In July 2012, the highest temperature averagely reached to 40.7°C and the hourly relative humidity was ranging between 41.8 to 75.1%.

As plotted on the graphs in Figure 4, 5(a) and 5(b) accordingly, it can be clearly seen that the temperature and relative humidity produces contrasting readings where; in high temperatures, the relative humidity were at a low values whilst in low temperatures, the relative humidity recorded higher readings. This explained the influence of water vapour in ambient air temperature (Shaharudin et al., 2010) to function as a source of urban moisture content (Emmanuel and Johansson, 2006).

![Fig. 4. Average temperature and relative humidity in the study area for the period of January to March 2012](image-url)
Fig. 5. (a) Average daytime temperature in July 2012  (b) Average relative humidity in July 2012
Further analysis by using simple linear regression was applied to test the relationship between two climatic parameters. From the analysis, it is demonstrated that the coefficient value of $R^2 = 0.9382$, meaning that it is almost perfect linear relationship between the two variables where the variation in Y axis (relative humidity) is explained by the variation in X axis (air temperature). From the graph (Figure 6), it is obviously seen that the relationship between temperature and relative humidity produced a significant negative correlation in which the high temperature commonly associated with low humidity. This means that the increase of ambient air temperature will reduce the moisture content (water vapour) in an urban environment and vice versa. The similar finding was observed in other tropical cities like Kuala Lumpur (Shaharuddin et al., 2011/2009) and Singapore (Wong and Yu, 2005).

![Graph](image)

**Fig. 6.** Correlation between temperature and relative humidity in the study area

During the measurements from January to March 2012, the highest temperature (39°C) was recorded at the boulevard area. Meanwhile, the green area (forestland) situated at the northern part of Putrajaya registered the lowest temperature (32.5°C). In July 2012, the boulevard still marked as the warmest area but the temperature increased by 1.7°C. On the other hand, the forested area remained as the coolest sector with average temperature of 36.4°C. However, although similar patterns were observed between the two periods, there were slight differences where the temperatures tend to increase in the month of July 2012. This situation is expected due to the influence of seasonal factors and the daily weather condition of the measured days. This is because; the period of January to March experienced Northeast Monsoon with copious rainfall whereas the month of July was considered as dry season as it is experiencing the Southwest Monsoon (Malaysian Meteorological Department, 2012). In addition, it was noted that under clear and calm days, the intra-urban temperature differences were slightly larger. However, on the cool weather, the gap of intra-urban temperature was marginally small within all sampling locations. This is probably due to the weather condition where on a cool day, the relative humidity is high and there were more water vapour in the ambient air, thus, the temperature does not show a significant difference. This finding agrees with the study by Shaharuddin et al. (2010/2011) that the days with small intensity of a diurnal temperature registered the relatively high humidity. Seemingly, as depicted in Figure 5(a), the
results showed that the peak temperature was recorded in between 14:00 to 15:00 hours during the daytime and gradually decrease thereafter. The similar finding was also observed in Colombo city by Emmanuel and Johansson (2006).

4.2. The variation of heat intensity at various urban landscape morphology

![Diagram of climatic parameter variances within various urban landscapes morphology in Putrajaya city](image)

Fig. 7. The sketch of climatic parameter variances within various urban landscapes morphology in Putrajaya city

The findings indicated that the urban landscape morphology influenced the variability of temperature and relative humidity in the study area and the impacts are clearly displayed through the thermal variances across different urban landscapes. As illustrated in Figure 7, the built-up areas that consist of commercial area (Precinct 15), administrative centres (Precinct 1 to 5) and residential area (Precinct 9) demonstrated highest temperature and lowest relative humidity while the wetlands forest and large water body of man-made lakes indicated vice versa. This finding indicated differences of heat intensity depending on the season. The average thermal differences recorded at selected sampling stations within the city for the period of January to March 2012 was recorded 6.5oC while in July 2012, it was recorded 4.3oC.

Theoretically, the built-up area of paved surfaces and buildings are intensely warmed by the solar radiation and tend to store heat more rapidly than natural materials. Furthermore, the characteristics of the coolest spot which are densely planted with natural vegetation provide tree-canopy shading and located close to water areas. These characteristics have shown lower daytime temperature due to low capacity of thermal composition in the natural materials (Gartland, 2008: 18).

Apart from urban landscape form, the intra-urban thermal differences show remarkable variances between different urban surfaces. Figure 8 shows the temperature pattern that discerned on three generalized land cover types. From the findings, the thermal differences recorded at built-up, vegetated
and near water body were ranging by the differences of 3.6 to 6.5°C (39.0°C>32.5°C<34.1°C). This indicates that the soft surfaces provide significant thermal benefits rather than built-up surfaces. However, the difference was small and almost no significant impact. The possible reason is maybe the natural or grassy surfaces are more capable to keep moisture in a longer duration, thus prevent the surface run-off unlike the impermeable surfaces of heavily built-up areas.

Other than urban surfaces, significant temperature differences can be seen between shaded and open areas where the distribution of the outdoor temperatures were also influenced by shading factor (Figure 9). Typically, shaded areas recorded a consistent lower temperature readings compared to open spaces. The results of field measurement observed that sampling points that were located at fully or partially shaded areas commonly produce lower temperature readings compared to open spaces. In general, the open surfaces were recorded higher temperature and low humidity than the areas covered by tree canopies or shadowed by buildings. In this study, it was found that, despite the warm streets due to the openness of the boulevard area, the planted trees along street in Precinct 4 (streetscapes) provide some shades and reduce the temperature 2.8 to 4.3°C from the open surface.

Fig. 8. The temperature pattern within three generalised urban surfaces
These findings confirm the conclusion made by Shashua-Bar and Hoffman (2000) and Rabiatul et al. (2012) that the shading effects provide by trees could provide significant comfort in thermal experience. Other than tree shading effects, the high rise buildings at Precinct 4 also casts shadows on the street, making the air temperature slightly cooler than the areas or surfaces without shading. This indicates that to promote urban thermal comfort in hot-humid cities, the importance of design aspect that should be considered is to provide shading either through natural vegetation (trees) or by man-made shading devices.

Overall, it was clearly indicated that the area with most greenery were the coolest sector while the architectural complex spaces with least greenery were the hottest sector in Putrajaya. Meanwhile, the area with modest urban structures and certain greenery such as the residential and neighbourhood area experienced average readings with small temperature differences. In addition, the covered surfaces either by tree canopies or shadow casts by orientation of the buildings was consistently provide shading and the air temperature were slightly lower than open surfaces. Other than that, the area nearby water body recorded lower temperature than built-up area, but slightly higher than vegetated surfaces. However, the measured data showed that the water areas fringed by dense vegetation (in this study at the wetlands water recreational centre) recorded a lower temperature than the water areas surrounded with sparse greener.

This supports the theoretical understandings that bioclimatic components have significant impact to the modification of urban temperature in built environment through evaporative cooling mechanism. Thus, based on the findings, it can be concluded that there were significant relationship between urban landscapes and the climatic variations where the morphology and characteristics of urban landscape have great influence to the microclimatic effects in the study areas. These results support the findings of
previous researchers on the influence of urban design factors to the uprising temperature in the urban centre.

5. Conclusion

It is important to understand the landscape morphology and its interaction with the climate atmosphere before considering any design aspect in an urban development. Thus, the applied understanding on the influence of landscape and urban morphology could provide detailed information to planners and architects especially in determining the design aspects that promote outdoor thermal comfort. Although the understanding on landscape influences to the thermal environment could assist the practitioners in identifying good climate-design elements, nevertheless, achieving outdoor thermal comfort in hot-humid climate is not an easy operation. Therefore, such studies regarding hot-humid thermal comfort especially on the ability of natural vegetation and hydrological aspects to regulate local climate should be expand and further refined to gain better understanding on the specific climatic needs. With such knowledge, it could serves as preliminary strategies to outline the design schemes that can induce outdoor thermal comfort and climatic aspects that need to be further improved in future urban development of hot-humid tropical cities.

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