ANALYSING STREET HERITAGE TREES SURFACE TEMPERATURE FOR UHI MITIGATION USING REMOTE SENSING AND GIS APPLICATION

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ABSTRACT

Urban Trees are important in reducing the heat by providing the shade and cooling effect to the urban environment. Every tree species provides different cooling effect depending on their tree characteristics. Evergreen species such as heritage tree are significant in reducing the surface temperature. In particular, heritage trees do have environmental implications which provide lots of benefits for the environment and human health. The aim of this paper is to analyse the heritage trees surface temperature in mitigating urban heat island (UHI) at Taiping Old Town. The research has conducted utilizing Landsat 8 OLI data and on-site data collection. This research integrated Geographic Information System (GIS) and remote sensing in data processing and SPSS for analysis. The result shows the low significant relationship of tree characteristics and Land Surface Temperature (LST) with (R^2=0.17) indicates that external factors can reduce the cooling effect from heritage trees in reducing the surface temperature in the urban area. Moreover, *there is also an analysis on the LST of land cover features together with the frequency of heritage trees. The findings revealed that the higher frequency of heritage trees planted at the hard surface; the higher the ability to reduce the LST (about 5.3°C) in urban areas.*

Keywords: *Heritage trees, Urban Heat Island (UHI), Land Surface Temperature (LST), Remote sensing, Geographic Information System (GIS).*

INTRODUCTION

The rapid urbanisation has place substantially more pressure on natural resources, changed the urban climate, challenged the city skyline, build the concrete jungle and transformed the river into glasses (Ahmad et.al, 2010; Shaharuddin, Noorazuan & Yaakob, 2011). As a result, the heat has reflected on the urban surfaces and raised the temperature compared to the surrounding area. The direct effect on the local climate has changed the urban spaces indirectly and caused the air and surface temperature to become warmer than those in the rural area. This effect called the 'Urban Heat Island' or UHI can be observed in every town and city (Wong & Yu, 2005). Moreover, removal and replacement of vegetation cover by various built-up structures influence the impact to the environment which cause environmental pollution, climate changes and breakdown of ecological cycles. The impact of the climate change had been investigated by many researchers and they found that the impact include heat stress, air pollution, and the transmission of infectious disease (Salleh, Abd.Latif, Wan Mohd, & Chan, 2013).

Therefore, strategies in the mitigation of UHI have become an important issue in terms of energy saving and thermal comfort (Akbari, Pomerantz, & Taha, 2001; Kong et al., 2016). One of the adaptive strategies that had been addressed by many researchers is to increase the amount of vegetation cover in the urban area (Dewan & Yamaguchi, 2009; Shahidan, 2011; Kong et al., 2016). For example, the strategies of urban greening design could give the effect on providing the shade and cool to outdoor environment (Tan & Ng, 2014; Abreu-harbich, Chebel, & Matzarakis, 2015; Lin, & Tsai, 2017). Previous research revealed that there is a higher effect of larger temperatures in an urbanised area as compared to surrounding areas that relatively have a larger amount of vegetation (Hashim, Ahmad, & Abdullah, 2007). Thus, the contribution of vegetation cover is important in reducing the heat in the city.

A mitigation measurement through sustainable development has to control the adverse effect of UHIs on the environment. The planning of widespread trees and vegetation such as heritage trees for urban landscape is one of the effective methods to reduce the effects of formations of UHI (Jim, 2004; Senanayake et al., 2013; Jim & Zhang, 2013). Establishment of the urban forests for the strategic planting of trees around buildings is an excellent sustainable solution for reducing and mitigation of UHI. Furthermore, the vegetation itself are able to enhance the air quality to the occupant (Akbari et al., 2001). Among the numerous types of vegetation cover, heritage tree has significant environmental implication which provides a lot of benefits to the environment and human health (Sreetheran, Adnan, & Azuar, 2011).

Urban Heritage trees were considered at the canopy layer of vegetation which are the tree features of heritage tree are old trees (near and over 100 years), big in size (height, crowd spread and diameter breast height (DBH)), high density coverage and evergreen (Jim, 2005). The heritage trees are significant because only a few trees can excel under urban stress (Jim, 2004). Some of the matured heritage trees are big which contributes to a wide range of shading that gives the cooling effect to the outdoor environment. The finding by Abreu-harbich et al., (2015) revealed the conceptual evidence of the vegetation parameters on their thermal control strategies, the tree species which are dominant on the plagiotropic trunk and branching structure, tall, has large coverage and small leaves that are a bipinnate type and linear shape contribute to cooling effects. However, the empirical evidence of how heritage trees mitigate UHI in urban areas are still inexplicit.

Therefore, this study intent to analyse the empirical evidence using remote sensing and Geographic Information System (GIS) method at Taiping old town. This study aims to measure the vegetation thermal comfort parameter based on tree characteristics to determine the internal and external factors of heritage trees toward mitigating UHI. The primary data were collected in May and September 2017 while the secondary data used for LST generation were obtained from Landsat 8 OLI.

STUDY AREA

Area of interest in this research is within the city ofTaiping, Perak (lat. 4°51’07”; long.100°44’29”), located about 70 km North of Ipoh and 90 km south of Penang (Yahaya, 2010). The climate in Taiping town can be categorized as tropical rainforest climate in hot-humid climate (Wan Ali, Hassan, & Hassan, 2016).

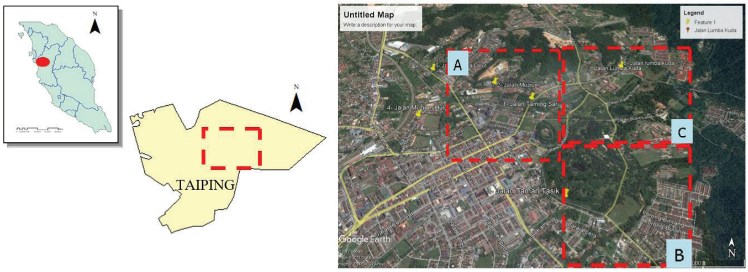


Figure 1: Malaysia Map (top left) and Taiping District (bottom left) with the Site Area for Measurement Heritage Tree Characteristics at Taiping, Perak.

As compared to the average annual rainfall between Peninsula and Taiping town, the average rainfall in Taiping is about 3000mm while 2000 mm-2500 mm for Peninsula's average. The range of temperature at Taiping is 24ºC -34ºC and the warmest months at Taiping in March until October with the average temperature are 31ºC (Climatedata.org). The study area were divided into three zones; A, B, and C (see Figure 1) where was selected based on the temperature variation of LST distribution map which was generated from Landsat 8 OLI image. The study area also selected based on the location of heritage trees which mostly covered the streets in Taiping old town.

DATA COLLECTION

Satellite Images

The data used for LST generation were obtained from Landsat 8 OLI (30/3/2016) which was downloaded from USGS website. The Landsat image was chosen based on limited cloud cover and during summer in order to generate stronger warming effect of UHI (Rogan et al., 2013). The thermal band in Landsat 8 OLI at band 10 (10.60 µm -11.19 µm) and band 11 (11.50 µm -12.51 µm) with the spatial resolution 30m (Department of Interior U.S. Geological Survey (USGS), 2016).

In Situ Data Collection

The data were collected in May 2017 (18 May 2017-22 May 2017) and September 2017 (22 September 2017- 25 September 2017) because of the range of the warmest months in Taiping. There are three (3) species of heritage trees which are Samanea Saman, Pterocarpus Indicus and Swietenia Macropylla where were covered in the study area. The tree characteristics, such as crown diameter (m), tree height (m), diameter breast height (m), tree species, and coordinates of the trees were measured. The tree heights were measured using clinometer which measured the vertical angle and horizontal distance (see Figure 2a).

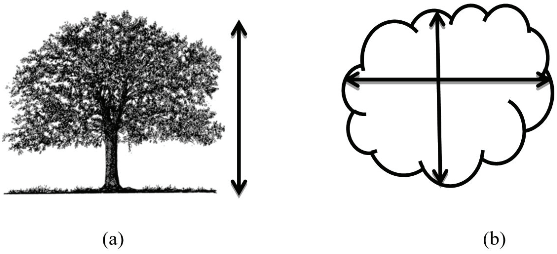


Figure 2: The Tree Height (a) and Crown Diameter (b) Measurement

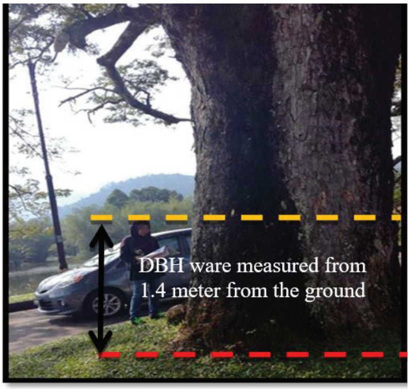


Figure 3: The Measurement of DBH of Heritage Tree

The crown diameter measured using tape from the north-south axis and east-west axis and calculated using arithmetical mean (Lin & Tsai, 2017) (see Figure 2b). The vertical angle measured from the base of the tree until the tip of the tree and diameter of breast height (DBH) were taken using tape from 1.4 meters from the ground (Ali et al., 2016) (see Figure 3). The coordinates of each heritage tree are also taken using GPS Garmin. All the spatial and attribute data of heritage trees characteristics were analysed in Geographic Information System (GIS) using ArcGIS software.

Land Cover Data

The land cover of the Taiping was extracted from Google Earth imagery (Rogan, Ziemer, & Ratick, 2015). The land cover features such as buildings, main road, street roads, and lake were digitized into vector data which are in polygon for building and lake features and line for the main road and streets features. All the digitized features in WGS 84 (World Geodetics System 84) Coordinate system were exported into shape file (.shp) data for further processed in ArcGIS software. Land cover data were used in the research to determine the external factors of LST distribution at Taiping.

METHOD

LST Distribution Generation

The thermal band of Landsat OLI 8 used in LST estimation were corrected for radiometric correction to reduce any atmospheric effects in images which will influence the analysis results of the research (Vlassova et al., 2014). The LST was generated by ERDAS Imaging software using the formula. The information of Landsat 8 OLI was downloaded together with the images in metadata (.txt) file. The thermal band were first converted, then calibrated the digital number to Top of Atmosphere (TOA) spectral radiance (Vlassova et al., 2014) using the radiance rescaling factors provided in the metadata file. The formula in Equation (1) (Department of Interior U.S. Geological Survey (USGS), 2016) used in converting the digital number to radiance.

$$L\lambda = M_L Qcal + AL \quad (1)$$

Where: Lλ= TOA spectral radiance; ML= Radiance MULT Band; Qcal=Quantized and calibrated standard product pixel values (DN); AL= Radiance ADD Band

Then, the spectral radiance converted into planetary reflectance using reflectance rescaling coefficients provided in the product metadata file to transform brightness temperature in Kelvin (K) that was used in generating the distribution of LST. The Equation (2) (Department of Interior U.S. Geological Survey (USGS), 2016) used to convert a digital number of imagery into TOA reflectance.

$$p\lambda = M_P Qcal + Ap \quad (2)$$

Where: pλ= TOA planetary reflectance, without correction of solar angle; Mp= Reflectance MULT Band; Qcal=Quantized and calibrated standard product pixel values (DN); Ap= Reflectance ADD Band

Equation (3) (Department of Interior U.S. Geological Survey (USGS), 2016) shows the formula of LST to generate the LST distribution from spectral radiance to top of atmosphere brightness temperature using the thermal constants provided in the metadata file from Landsat 8 OLI. The temperature unit also converted from degree kelvin into degree Celsius.

$$\text{Ts} = \frac{K_2}{In\left(\frac{K_1}{L\lambda}+1\right)} \quad (3)$$

Where: T= The brightness temperature in kelvin (k); Lλ= TOA spectral radiance; K_1= Constant thermal band; K_2= Constant thermal band.

Heritage Tree Inventory

The heritage tree inventory were then been layered with the data collected from heritage tree characteristics and land cover features that were inserted into ArcGIS software. By using coordinate of heritage trees collected from in situ data collection were inserted in GIS database in point vector data. Each point of heritage tree included the attribute data showing the characteristics of the heritage tree such as crown diameter, tree height, DBH, coordinate and the ground temperature which was generated from Landsat OLI 8. The heritage tree inventory map was produced.

RESULTS AND FINDINGS

The result of the research in the map form showing the overlaying of the LST distribution map and heritage trees inventory map as shown in Figure 4. The result included the LST distribution, heritage trees and land cover of study areas. From the result below, the average temperature at Taiping old town was 29°C. The map also included the heritage trees spatial data altogether with the features of building, road and water bodies. The temperature variation shows the high temperatures at the hard surface where the surface was covered with the concrete buildings. The temperature at the Lake Garden Park is cooler than around the building with the temperature around 25°C -27°C compared to the heritage trees planted around the building with the temperature around 31°C-34°C.

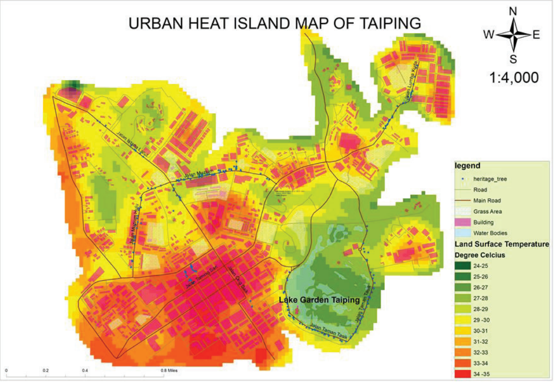


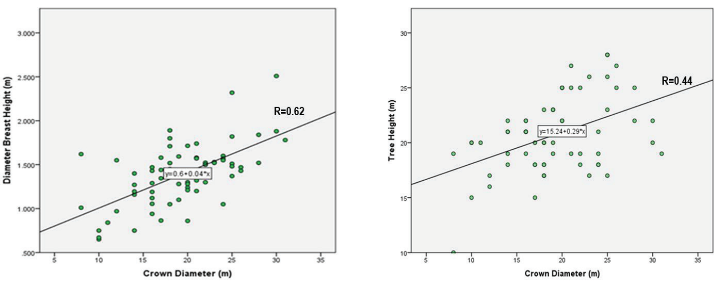
Figure 4: Urban Heat Island Map of Taiping

The interpretation from the map in figure 4 shows that the species of Samanea saman were planted along the streets at Lake Garden and a few of them at compact building (right bottom of the map). Majority of the heritage tree species at Taiping such as Pterocarpus indicus which was planted along the streets near to the compact buildings altogether with the tree species Swietenia macropylla.

Relationship between Crown Spread, Tree Height and DBH

The database of heritage trees consist of 206 trees were surveyed in the study area. According to the database, the average of crown diameter is 21.19m. Meanwhile, the average of tree height is 19.36m and the average of DBH is 1.21 m.

Figure 5 shows the relationship between crown diameters, DBH and tree height of heritage trees in the study area. From the result shows in Figure 5(a); the given the regression coefficient (R=0.62) which demonstrated a high correlation between crown diameter and DBH of heritage trees in the study area. Figure 5(b) shows the relationship between crown diameter and tree height which the regression coefficient is (R=0.44) indicated the medium relationship between crown diameter and tree height. The conclusions from the result of Figure 5 shows the positive linear relationship for both DBH and tree height with crown diameter. The hypothesis shows the DBH increased with the increasing of crown diameter. Based the result from database shows the tree species with the longest DBH and the widest crown diameter are Samanea saman. From the result in figure 4 shows the tree species of Samanea saman were mostly planted at Lake Garden which showed the low LST recorded in this area.



(a) (b)

Figure 5: The Relationship between Crown Diameter Versus DBH (a) and Crown Diameter Versus Tree Height

Relationship between Crown Spread and LST

Figure 6 shows the relationship between crown diameter and LST in the study area. The regression coefficient (R^2=0.243) shows the small relationship between the crown diameter of heritage trees and LST in the study area. This result indicates the heritage trees which are dominant in the vegetation parameter for thermal comfort to the environment were able to slightly contribute to the reduction of temperature. This is because the modification and ground surface give the high significant in influencing the temperature variation (Shahidan, 2011). Furthermore, in order to improve cooler temperature to meet the thermal comfort is not easy to control by tree characteristics (Lin & Tsai, 2017). They were influenced by various external factors in changes of temperature around the heritage trees which make it difficult in giving a cooling effect to the environment.

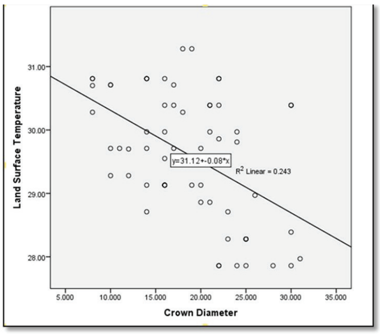


Figure 6: The Relationship between Crown Spread and LST

Relationship between Land Cover Features and LST

Based on the result from internal factors of heritage trees in Figure 6 shows the changes of LST distribution around heritage trees were influenced by external factors. The Figure 7 below shows the land surface temperature versus the frequency of heritage trees around the land cover features (Leuzinger, Vogt, & Ko, 2010). The histogram shows the most heritage trees were planted at the main road of Taiping showing the surface temperature around 28°C-29°C. The lower temperature spectrum marks at Lake Garden of Taiping with the surface temperature around 26°C-27°C. The small frequency of heritage tree planted at compact buildings showed the highest surface temperature up to 32°C-34°C. A non-shaded surface like grass area and the bare surface has resulted in the surface temperature around 30°C-31°C at Taiping. The result showing the loss of vegetation cover could increase the surface temperature at the city.

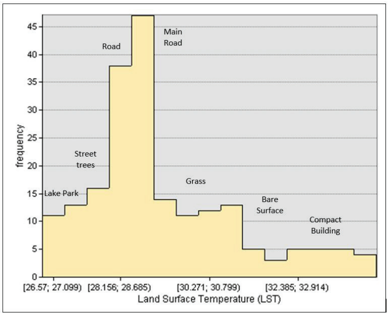


Figure 7: The Frequency of Heritage Trees at Land Cover Surface at Taiping versus LST Distribution

The group of trees also play an important role in producing the cooling effect in the environment. Even the frequency of heritage trees are higher at road and main road than the park, the effect appear from the most lower tree crown temperature in the park tree compared to the street trees. As the study from Leuzinger et al.,(2010) stated the similar loss of latent heat from both park and street trees however because of the higher radiation energy flux load of the surrounding fabric around street trees, the higher reflectance of sunlight make the surface temperature become warmer.

The shade of the mature tree like heritage tree at the hard surface can reduce the LST by 6°C by comparing the frequency of heritage trees at the main road and compact building. Thus, the loss of mature tree canopy cover over the impervious hard surface leads to the increasing of the surface temperature and remove the cooling effects of vegetation (Rogan et al., 2015).

Temperature Profile of Land Cover Features at Taiping Street

The previous section discussed the amount of heritage trees around land cover features in the reduction of LST at Taiping area. The detailed explanation discussed in this section on the street surface temperature in the main city's routes are recorded and presented. The streets are mapped in Figure 8 from google earth and the characteristics of the streets are tabulated in Table 1.

Table 1: Taiping Street Characteristics

Colour	Street Name	Length (meter)
Red	Jalan Istana Larut	1180
Purple	Jalan Panglima Ah Chong, Jalan Chung Thye pin,Jalan Sultan Abdullah (Taiping City Centre)	978
Blue	Jalan Lumba Kuda	1223
Orange	Jalan Muzium	903
Yellow	Jalan Muzium Hulu	933
Green	Jalan Taman Tasik	1991

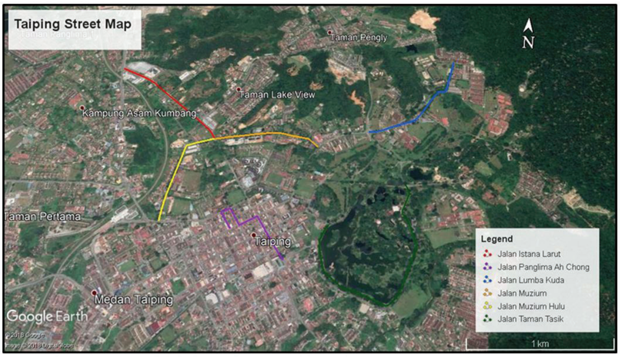


Figure 8: Taiping Street Temperature Plan

Taiping street temperature profiles were presented in corresponding Figure 9 until Figure 14 below. All streets indicated that there is a temperature increment when the area covered with the hard surface or impervious surface materials such as buildings. On the other hand, the land surface covered with the heritage trees and urban trees showing temperature decreases compared with the buildings features. The highest temperature profile was recorded at Jalan Panglima Ah Chong, Jalan Chung Thye Pin and Jalan Sultan Abdullah (Figure 10) which were located at Taiping city centre. The land cover features of these areas were covered with buildings and asphalt surface. In contrast, the lowest temperature profile was recorded at Jalan Taman Tasik (Figure 14) which is located at Lake Garden Taiping. This area was covered with the natural features such as heritage trees, urban trees, water bodies, and several buildings. The temperature difference takes the maximum values almost 5.3°C for both temperature profiles.

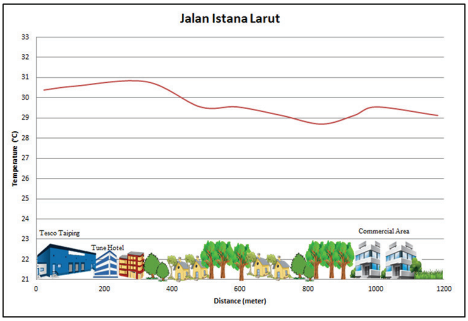


Figure 9: Jalan Istana Larut Temperature Profile

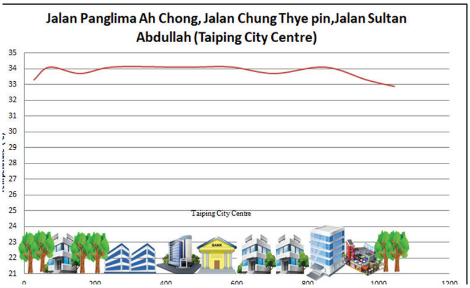


Figure 10: Jalan Panglima Ah Chong, Jalan Chung Thye Pin, Jalan Sultan Abdullah Temperature Profile

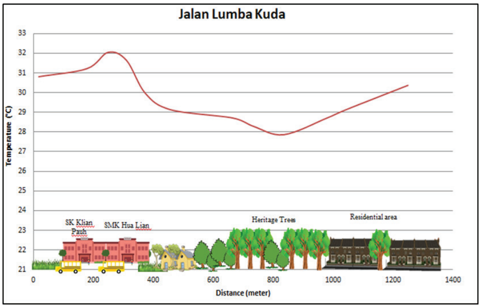


Figure 11: Jalan Lumba Kuda Temperature Profile

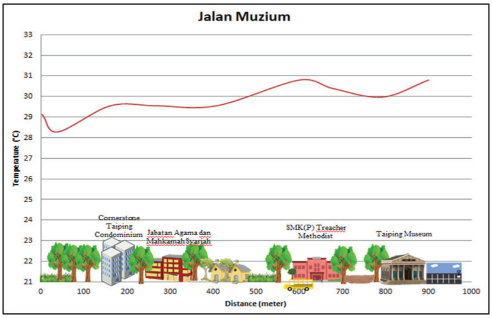


Figure 12: Jalan Muzium Temperature Profile

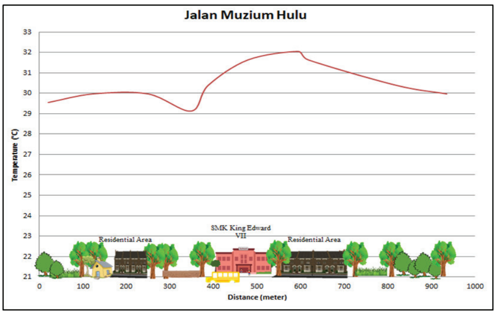


Figure 13: Jalan Muzium Hulu Temperature Profile

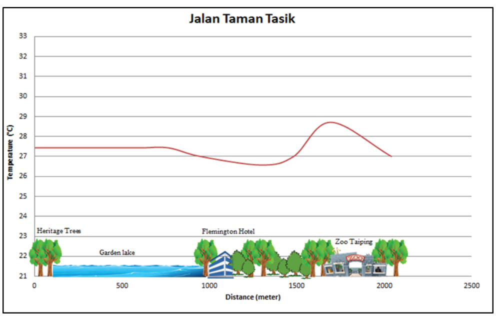


Figure 14: Jalan Taman Tasik Temperature Profile

Based on the result of street temperature profile, the land cover features play an important role in the changes of surface temperature from heritage trees. The surface temperature of heritage trees around man-made features could not give the maximum cooling effect to the surrounding environment because the materials content lower albedo values. However, the extensive shading of group heritage trees over man-made features such as street road could lower the surface temperature due to the prevention of solar radiation penetration from reaching the land surface. On the other hand, the higher amount of heritage trees produce higher evapotranspiration process that could reduce the surface temperature. Therefore, it is important to keep the mature trees such as heritage trees at the hard surface or impervious surface features such as man-made features in order to maintain the surface temperature and cooling effects.

CONCLUSION

The conclusion of the research shows the urban heritage tree temperature depends on the tree characteristics, the group number of the trees and other trails of external factors such as canopy architecture around heritage trees. Based on the research findings, it was discovered the higher group of heritage trees contribute to a higher reduction of LST. The result discovered the reduction of LST by 6°C at the main road represent the higher group number of heritage trees compared individual heritage trees planted at compact building. Thus, the group number heritage trees were able to give the cooling effect to the environment although the external factors can contribute to the raising of temperature and removing the cooling effect at urban area. Furthermore, to improve outdoor thermal comfort also requires the appropriate urban design. The tree species dominates in vegetation parameter for cooling effect should be planted at the hard surface which could improve the thermal comfort of the outdoor space.

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