Field Observation on Thermal Environment of an Urban Street with Roadside Trees in a Tropical Climate

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Abstract

This study aims to explore the role of street trees in a tropical city. The outdoor field measurements of roadside trees are carried out at two streets with different tree densities at two major cities, Kuala Lumpur and Petaling Jaya of Malaysia. The results of variation pattern of air and globe temperature are presented. To further analyse the thermal environment, thermal images are captured and mean radiant temperature (MRT) are estimated to compare between all cases.

Key words: Field measurement, Roadside trees, MRT, tropical city

1. Introduction

Street trees and urban 'green' areas are one of the popular solutions to mitigate the urban heat islands (UHI) effects where the urban vegetation provide shelter and shade as the direct contribution to lower the temperatures at urban areas (Givoni, 1991). Many studies had been conducted to find the evidence of urban greenery cooling effects and are proved to be an effective method to mitigate UHI effects in temperate climate regions (Park et al., 2012; Huang et al., 2014). On average, city parks showed a passive cooling effect of 0.94°C in the day (Bowler et al., 2010). Heat gain and heat storage capacity of trees are large, alongside with the transpiration mechanism, making street trees effecting in cooling the surrounding, given the trees are well watered and able to keep the leaf surface temperature at moderate level through transpiration (Oke, 1989). The density and height of trees will also influence its cooling effect, sparse and high canopy often resulting in lower cooling power (Jan et al., 2012). Studies in temperate climate (Gomez et.al., 2004; Robitu et.al., 2006; Narita et al., 2008; Kikuchi et al., 2011; Park et al., 2012) provides information on effects of trees on outdoor thermal environment (cooling and wind speed reduction), effects of tree density on pollution, road surface temperature and so on, however, published literature regarding the urban climates and effects of green at tropical urban cities are scarce. Developing countries in tropical climate are facing huge population in the future, and to accommodate this, existing green surfaces are expected to be replaced by artificial materials in the urban causing more distinct temperature difference between the urban and rural area. Therefore, this study is carried out at Kuala Lumpur, Malaysia to clarify the quantitative mitigation effects of roadside trees on the thermal environment of an urban street canyon.

2. Field Measurements

Field measurements were carried out at two different streets, namely Jalan Raja Muda Aziz (Street R) and Jalan Produktiviti (Street P) located near to the capital city of Malaysia, Kuala Lumpur on 8th April, 18th May, 28th May, and 3rd June 2015. The selection of locations for field measurements consists of open, sparse, and dense roadside trees conditions shown in Fig. 1. We categorized the condition of each roadside trees based on sky view factor (SVF) of the measuring point shown by Table 1. SVF was calculated using fisheye photo taken at 1.5m above ground and processed by RayMan 1.2 (Matzarakis et al., 2010). Table 2 shows the measurement details. At each street, air temperature, globe temperature, relative humidity, solar radiation, wind speed and wind direction were recorded at 1.5 m height above the ground surface. Additionally, road and pedestrian pathway surface temperature were recorded at by capturing thermal images from infrared camera. Each session of outdoor measurement lasts for 4 hours, from 9 am to 1.30 pm.

Table 1: Photo of environment, monochrome fisheye photo, SVF for each target street

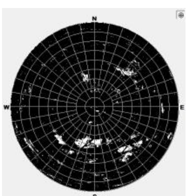
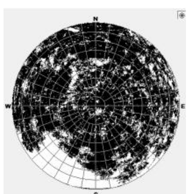
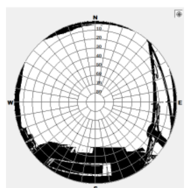
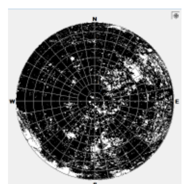
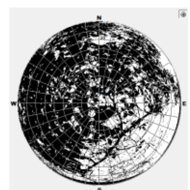
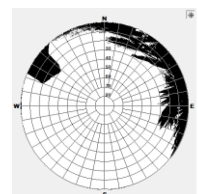
Jalan Raja Muda Abdul Aziz (Street R)			Jalan Produktiviti (Street P)		
Dense	Sparse	Open	Dense	Sparse	Open
					
					
SVF= 0.043	SVF= 0.279	SVF= 0.795	SVF= 0.077	SVF = 0.352	SVF= 0.848

Table 2: Measurement details

Parameters	**Instruments / Measurement Interval**
Air Temperature & Relative Humidity	Thermistor thermometer/ capacitive hygrometer sensor (Hobo U12-013) / 1 min
Globe Temperature	Thermistor thermometer (T&D TR-52i) / 1 min
Surface Temperature	IR thermal camera (InfRec) /1 hour
Solar Radiation	Pyranometer (Kipp&Zonen CMP11) / 1 min
Wind Speed	2-D ultrasonic anemometer (R.M. Young 86000) / 1 min

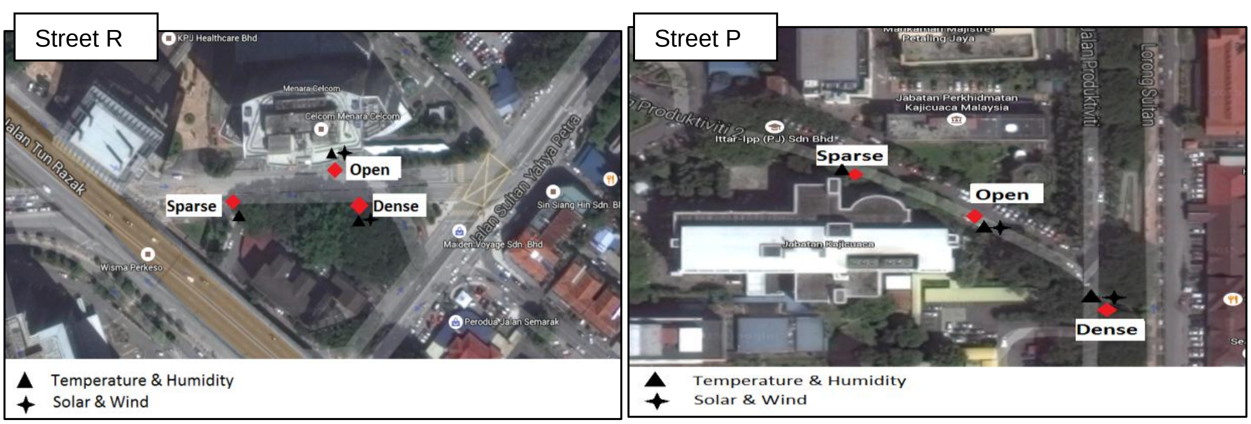


Fig. 1 Aerial view and measurement points of Street R and Street P

3. Measurement data analysis and results

3.1 Variation in globe and air temperature

Figures 2 and 3 show the globe and air temperature variation during measurement period for street P and street R. Generally, globe temperature at open area in both streets showed fluctuation from 30.2 to 46.7°C for street P and 33.6 to 42.4°C for street R. The globe temperature of Street P on 3rd June showed less fluctuation than 28th May on the same street might be due to the cloudy condition on 3rd June. Globe temperature of street R at sparse (31.1 to 37.7°C) and dense area (31.4 to 33.1°C) showed a more steady increase. The large fluctuation of globe temperature at open area might because of the changing cloud condition blocking the sun radiation. Air temperature of street P was rising slightly from 28.0 to 31.5°C while 30.7 to 32.5°C in street R, might due to the increasing solar radiation from 9am to 1pm. Air temperature at both streets showed similar pattern with difference less than 3.8% across all the condition of roadside trees. The results of air and globe temperature indicate that the cooling effect from trees may be attributed to the capability to decrease globe temperature with the shade provided. Figures 4 and 5 shows the difference in globe temperature of sparse and dense area compared to open area for both streets. In our findings, the air temperature difference between open and dense tree condition is not so significant (<1.5°C) when compared with the difference of globe temperature. The maximum difference in globe temperature between open and dense area is 14.7°C. The measurement result shows that air temperature at different tree condition depicts similar pattern and small difference (<3.8%) even at peak hour (12:00pm to 1pm), while the globe temperature is strongly influenced by the condition of trees. This might be attributed to the much more low sky exposure at dense area compared to open area which effectively blocks the sun radiation. Figure 6 is plotted as the overall average of globe and air temperature across three different conditions of roadside trees. The gradient of trend line shows the cooling effect of roadside trees by the shading provided in both streets. Generally, trees in street P provides slighter stronger cooling effect than street R although with slightly higher sky view factor due to the surrounding environment of street P with more trees. In summary, the cooling effect of trees in mainly attributed to the shading effect and transpiration (Jan et al., 2012). Although the evapotranspiration of plants are not recorded, its effect is shown indirectly from the thermal images taken at 12:30am at street P (figure 7). Under dense tree condition, the surface temperature of the tree crown (a) was about 14°C lower than that of ground (b), similar with the air temperature (within ±2°C).

3.2 Mean Radiant Temperature (MRT)

Mean radiant temperature (t_{mrt}) was calculated using the black globe thermometers and accounting for the effects of convection and conduction on the black globe given by equation (1) below (Kántor and Unger 2011): $t_{mrt} = [(t_g + 273)^4 + \frac{h_{cg}}{\varepsilon d_g^{0.4}}(t_g - t_a)]^{\frac{1}{4}} - 273$ ------------------- (1)

where t_g is the globe temperature, h_{cg} is the mean convective coefficient ($1.10\ x\ 10^8 v^{0.6}$ where v is wind velocity [ms^{-1}]), d_g is the globe diameter (m), ε is the globe emissivity (0.95), and t_a is air temperature. Figure 8 shows the variation of estimated MRT at Street P. The estimated MRT values of sparse area are lower than the open area. Theoretically, the faster the wind speed travels over the globe thermometer, the closer the globe temperature approaches the air temperature. In this case, the effect of solar radiation on the globe thermometer dominates over the effect of wind.

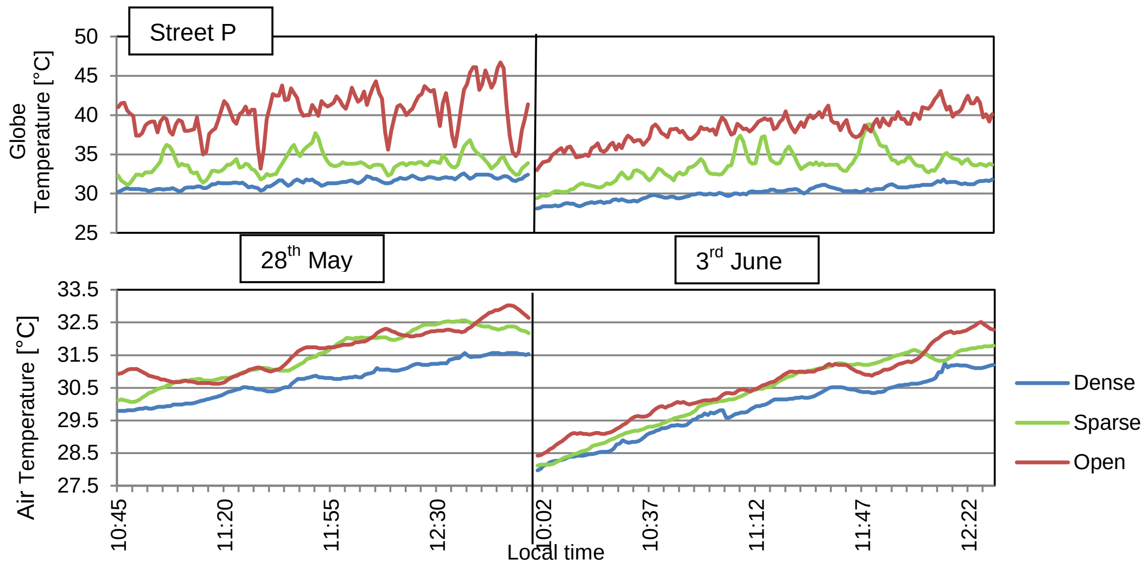


Fig. 2 Globe and air temperature variation for 28th May and 3rd June 2015 at Street P

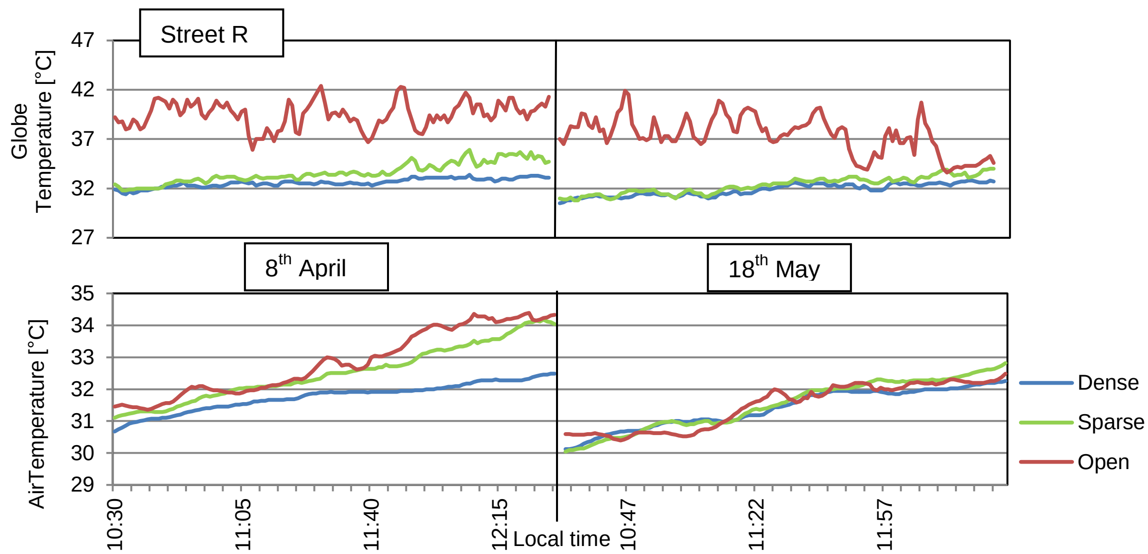


Fig. 3 Globe and air temperature variation for 8th April and 18th May 2015 at Street R

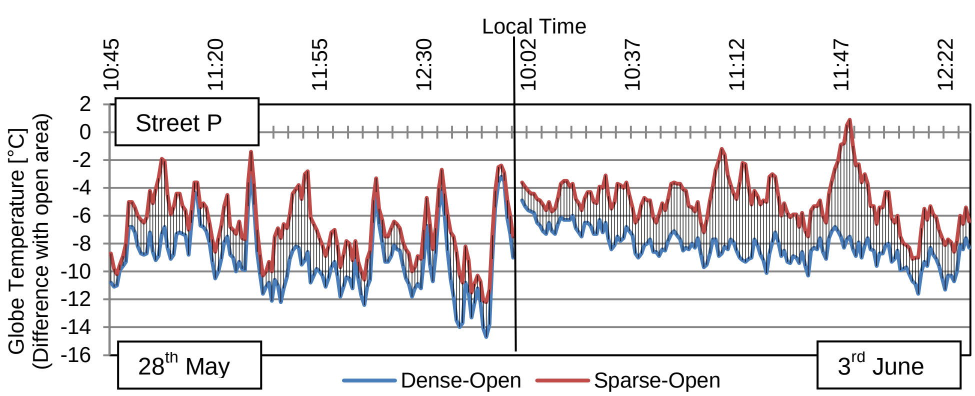


Fig. 4 Globe temperature difference (compared to open area) at Street P on 28th May and 3rd June 2015

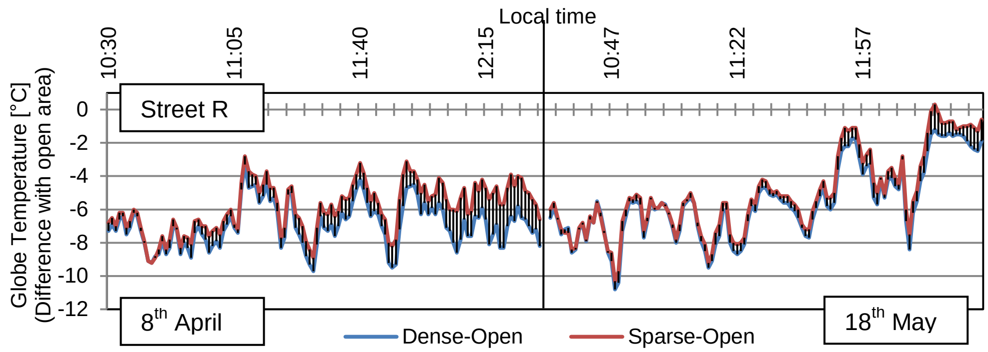


Fig. 5 Globe temperature difference (compared to open area) at Street R on 8th April and 18th May 2015

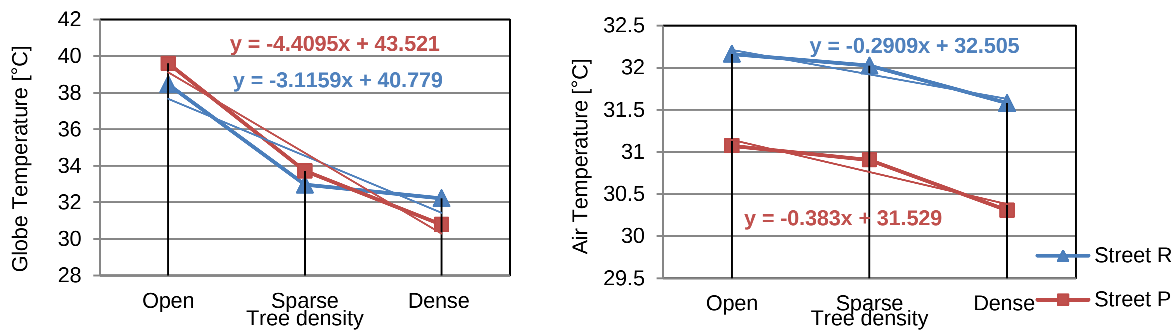


Fig. 6 Time average of globe (left) and air temperature (right) of Street R and Street P at daytime (4 days, 10:30am to 12:30pm)

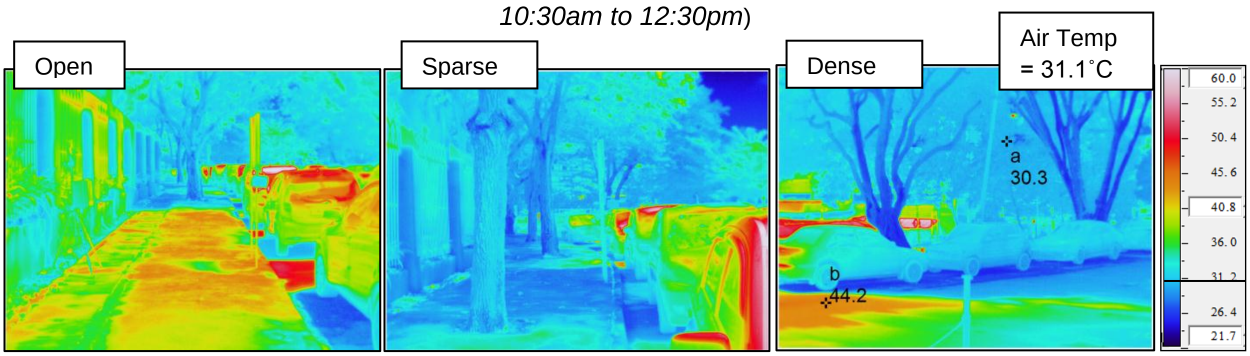


Fig. 7: Thermal images of Street P at 12:30pm on 3rd June (point (a) refers to tree crown surface temperature, (b) refers to road surface temperature [˚C])

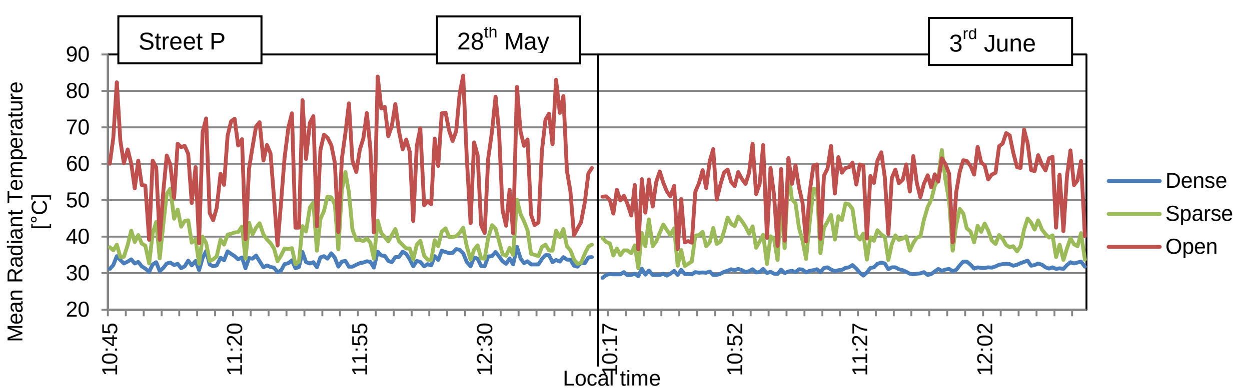


Fig. 8 Mean radiant temperature variation for 28th May and 3rd June 2015 at Street P

4. Conclusion

This study aims to investigate the effects of roadside trees on outdoor thermal environment by field measurement of real outdoor environment in tropical climate. The mitigation effects of roadside trees are revealed on the decrease of globe temperature and MRT over three different tree density when compared in this study. However, the effects of trees on air temperature are lower. The result shows that the cooling effects of roadside trees are mainly contributed from the shading and transpiration of trees.

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