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Street tree diversity and canopy quality influences urban microclimate and pedestrian thermal comfort.

In this month's Nursery Paper Ruzana Sanusi and Stephen Livesley from the University of Melbourne report on some ley funded research investigating the impact of street tree diversity and corresponding canopy quality have on pedestrian thermal comfort.

Street tree diversity and canopy quality influences urban microclimate and pedestrian thermal comfort.

Summary

This study investigated the microclimate benefits of street trees with different canopy qualities in Melbourne, Australia. It also extends these microclimate measures to estimate the impact of tree canopy quality upon pedestrian thermal comfort below. This study is collaboration between The University of Melbourne and NGIA. We measured under three street tree species that are commonly planted in Melbourne and other cities in the southern Australian states: *Platanus x acerifolia* (London Plane); *Ulmus procera* (European Elm) and *Eucalyptus camaldulensis* (River gum). It was found that the higher the canopy quality, as indicated by plant canopy index, the cooler the midday microclimate conditions under that canopy in summer. Pedestrian thermal discomfort could be almost 20% better under canopies of high quality, as indicated by a reduction in physiological equivalent temperature (PET) from 43°C to <35°C. The changes in canopy quality largely influenced the amount of solar radiation transmitted below the canopy, and therefore pavement heat gain and pedestrian thermal comfort. These canopy shade benefits are dependent both on the tree species and the canopy quality of that tree. Below *Eucalyptus camaldulensis* canopies, PET conditions remained 'very hot' for pedestrians because of the smaller possible plant canopy index commonly associated with eucalypt canopy architecture and leaf orientation (pendulosity). This study suggests that both tree species and tree canopy quality are important factors to be considered for future urban tree selection and management.

1. Introduction

Effective management of trees in urban areas is important as the different tree species planted are diverse in themselves as well in the age, the health, the different architectural forms, canopy densities and leaf characteristics. Depending upon the urban landscape context, the users of that space, the exposure levels etc., it is important to identify the function of each tree species in the local landscape with regards to the benefits those trees can provide local residents. The urban forest, in its entirety, can contribute to reducing the urban heat island, but individual trees and street tree plantings can contribute to changing the urban microclimatic at the micro-scale; i.e. the street scale,. Many recent studies have highlighted the importance of urban trees for microclimate modification, a key benefit to the local urban residents and street pedestrians (Shashua-Bar et al., 2009, Georgi and Zafiriadis, 2006). Changes in microclimate can greatly benefit pedestrian in the urban landscape by improving the human thermal comfort (Shashua-Bar *et al*., 2011).

However for a single tree species, tree canopy characteristics, such as size, density, leaf clumping, are can vary according to management, environmental growth factors (soil volume, water, nutrients) and tree health (pests, pathogens). Canopies of different quality within a single species will provide different microclimatic benefits and ultimately may have different influence on the pedestrian thermal comfort. Obviously, canopies differ in quality amongst different tree species, so when comparing different tree species it is especially important to compare them across the range of canopy qualities that can be expected and found within an urban streetscape. This study investigated the midday microclimate benefits of three common, yet contrasting, urban tree species: *Platanus x acerifolia* (London Plane); *Ulmus procera* (European Elm) and *Eucalyptus camaldulensis* (River gum). A range of canopy qualities were selected for each tree species to provide an opportunity to investigate canopy quality influence on microclimate and pedestrian thermal comfort from a 'within species' and 'inter-species' perspective.

2. Methods applied

2.1 Canopy quality measurement

This study has been conducted in Melbourne, Australia in one to two storey residential streets with pedestrian pavements. Three street tree species used in this study were Platanus x acerifolia, Ulmus procera and Eucalyptus camaldulensis. A range of trees (n=9) with different canopy qualities was selected for each species. To determine the canopy quality for each tree, cover photography method from MacFarlene et al. (2007) was used to estimate a Plant Canopy Index (PCI) that includes an area estimate of both leaves and branches.

2.2 Microclimate measurement and pedestrian thermal comfort estimation

The microclimate parameters measured for this study were air temperature, relative humidity, wind speed, solar radiation and mean radiant temperature (T_{mrt}). Mobile climate stations (1.1 m above ground) were used to measure microclimate condition below tree canopy for a range of canopy qualities during mid-day period (Figure 1). All the measurements were made on three days during summer. All the climate stations were positioned below the tree canopy while control measurements were made away from the tree canopy and building shades.

Figure 1: Portable weather station was used for microclimate measurements

All these measured microclimate variables were then used as an input to the estimation the pedestrian thermal comfort by calculating the Physiological Equivalent Temperature (PET) using RayMan software (Matzakaris *et al*., 2007).

3. Results and discussion

The control measurements that were made in the open area were allocated a zero PCI value. The lower the PCI value indicates lower canopy quality for each tree. Figure 2 shows some examples of the tree canopies and their PCI value for each species. PCI for *Platanus x acerifolia* ranged from 0.641 to 5.079, *Ulmus procera* from 2.132 to 6.141 and *Eucalyptus camaldulensis* from 1.308 to 2.747. From the PCI range we could see that *Eucalyptus camaldulensis* had smaller range. The characteristic of the species such as inherent clumped canopy, thin open canopy and pendulous leaf characteristics explained why the species had lower PCI range. On the other

PCI: 5.079

PCI: 5.602

PCI: 2.738

Figure 2: Three street tree species of Platanus x acerifolia (Top), Ulmus Procera (Middle) and Eucalyptus camaldulensis (Bottom) with varying canopy quality measured as Plant Canopy Index (PCI). PCI value of 0 is for open space as control.

hand, *Platanus x acerifolia* is a large broadleaf tree with rounded to pyramidal canopy and *Ulmus procera* a small broadleaf tree with a dense and rounded canopy.

At the microclimatic scale, this study shows that different PCI values influence the microclimate below the tree canopy. Figure 3 shows that solar radiation below canopy for all three species was significantly reduced as the PCI increased. As high PCI relatively has denser canopy, theoretically there were less gaps exist within a given canopy. Therefore less solar radiation was transmitted below the canopy. However, at PCI values > 4 for *Platanus x acerifolia* and *Ulmus procera*, reduction in solar radiation transmittance was relatively small (Figure 3). The benefit of having lower solar radiation below a tree canopy is that greater shading and cooler ground surface temperatures can be achieved (Brown and Gillespie, 2005), Both of the shading and cooling benefits drive the reduction in T_{mrt} and therefore enhanced pedestrian thermal comfort (Shashua-Bar et al., 2011). Furthermore, T_{mrt} significantly correlates with PET (Figure 4) indicating that it highly determines pedestrian thermal comfort (Matzakaris *et al*., 1999).

PET decreased as PCI increased for all three tree species. As *Platanus x acerifolia* and *Ulmus procera* have larger range of PCI, it shows that higher canopy quality can helps in reducing thermal stress. For *Platanus x acerifolia* the difference in PET between PCI 0.64 and PCI 5.1 was 7.2°C that demonstrated the pedestrian thermal comfort changed from 'slightly warm' to 'very hot'. However *Eucalyptus camaldulensis* that has a smaller range of PCI value due to its canopy architecture and leaf characteristics, PET demonstrates that below the tree canopy it remained 'very hot' for pedestrians. The increase in PET below the canopies as the solar radiation increased for all three tree species was the same as indicated by the similar slope in Figure 4. However, the PET value beneath a *Eucalyptus camaldulensis* canopy at any given 'above-canopy' solar radiation load, will be ~3°C greater as compared to the other two species (Figure 4), whereas, despite the differences between *Platanus* and *Ulmus* their thermal benefits are comparable for a given solar radiation load.

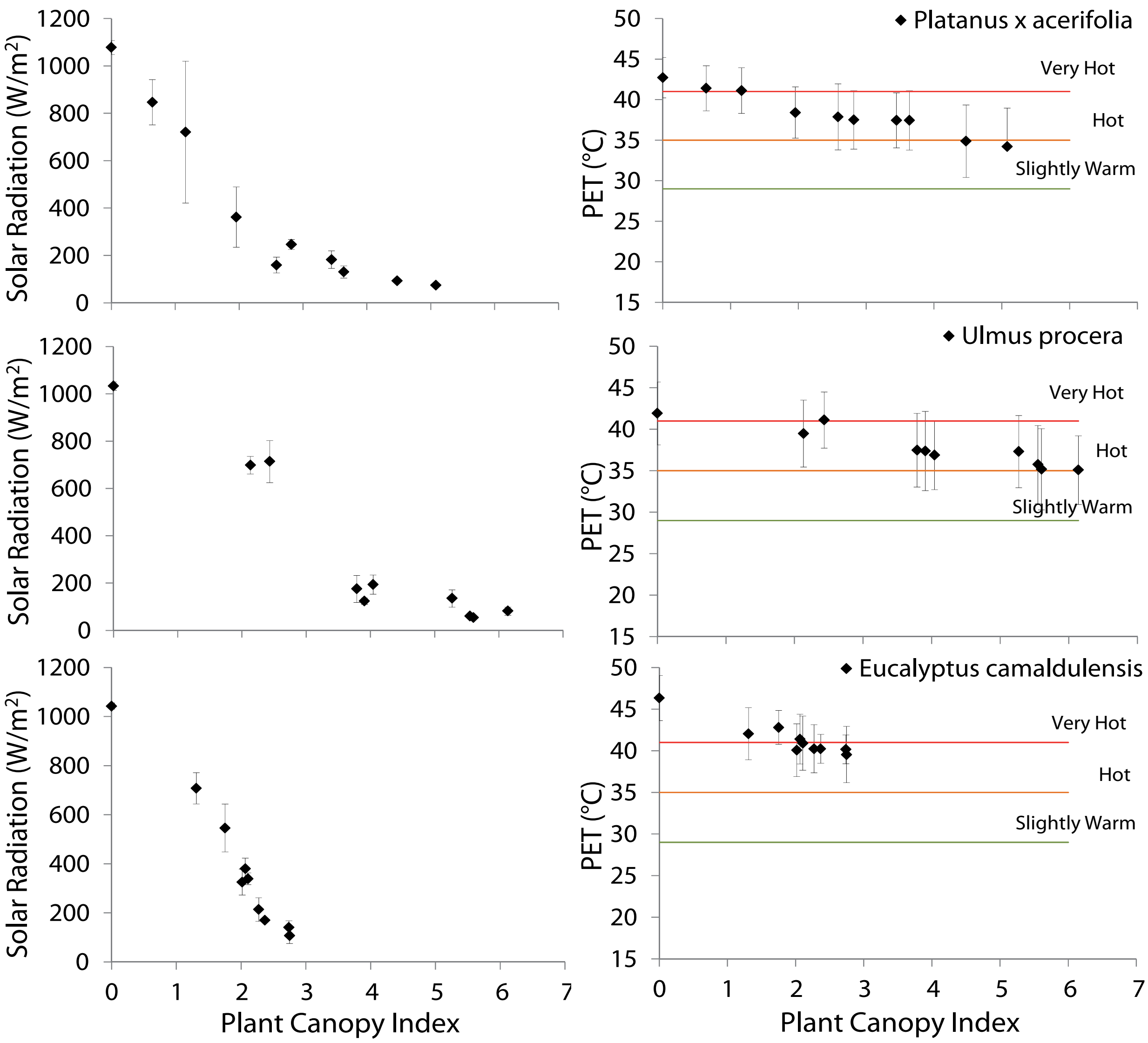

Figure 3: Plant Canopy Index (PCI) and average solar radiation and Physiological Equivalent Temperature (PET) for three street tree species. These results are the average of three day measurements during summer 2014 in Melbourne, Australia.

This further indicates that reduction of solar radiation in cities is highly important to maintain pedestrian thermal comfort. Noteworthy, better cooling capacity from trees may reduces the chances of urban residents to get heat related illness such as heat stroke and heat stress during summertime which at certain high heat intensity level may lead to mortality.

4. Conclusions

The influence of different canopy quality from street trees was investigated in Melbourne, Australia to look at its effect on street microclimate especially for pedestrian thermal comfort estimation by using human thermal index, PET. In this study, it was clearly found that higher canopy quality (PCI) had modified the microclimatic condition below tree canopy in summer. Through these studies, reduction of solar radiation with higher canopy quality also highlights the importance of shading benefits that relatively cooling the surfaces below the canopy and improves PET. Noteworthy, selection of tree species that can provide better canopy quality or managing existing trees for better canopy quality is therefore needed during hot and dry summers as the reduction of heat load at street level is important for pedestrian thermal comfort. These findings can further assist the planners and managers for future species selection and the street tree canopy management in urban forest for the benefits of urban residents.

Figure 4

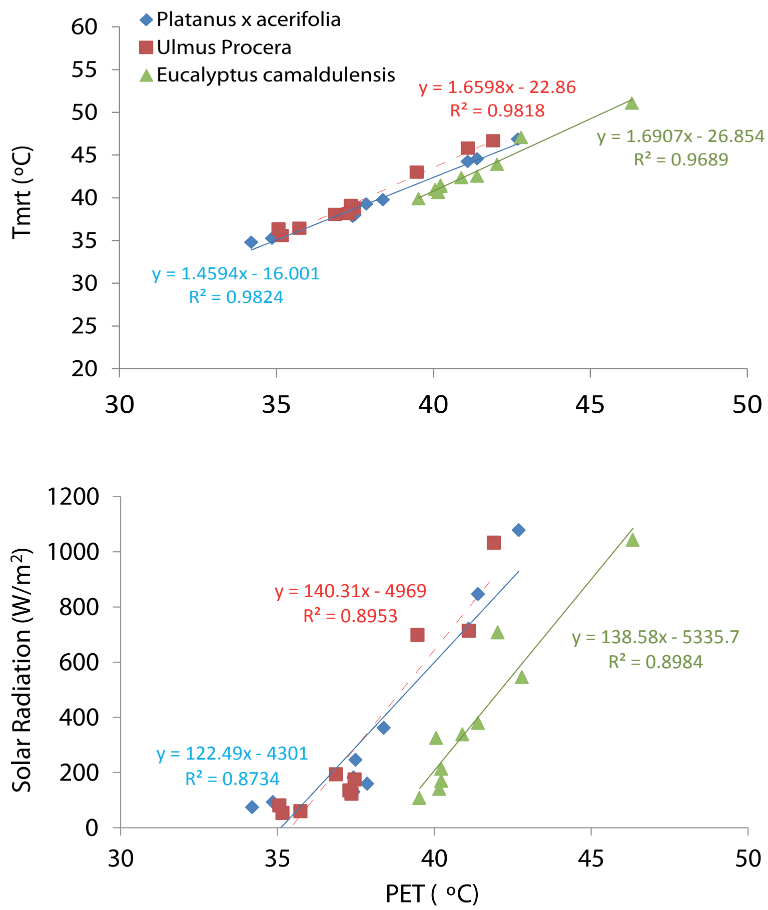

Figure 4: Relationship between mean radiant temperature (T_{mrt}) and solar radiation with Physiological Equivalent Temperature (PET) for three street tree species. This result is the average of all three days of measurement during summer 2014 in Melbourne, Australia.

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