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Indoor Heat Stress Mitigation with Urban Vegetation and Tree Shading

In this month's Nursery Paper, Zhengen Ren, Dong Chen, Guy Barnett and Xiaoming Wang from CSIRO's Land and Water Research Flagship, report on levy funded research examining the potential that trees have to reduce the impact of heat waves on health and energy use.

Indoor Heat Stress Mitigation with Urban Vegetation and Tree Shading

SUMMARY

This study investigated the potential benefits of urban vegetation for regional greening and the provision of local tree shade around residential buildings to reduce the impact of heatwaves on occupant health and the energy required for cooling. It was undertaken by a research team from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and involved simulation of the thermal performance of a residential home under various urban greening and tree shade scenarios, using weather observations from the 2009 (Melbourne) and 2011 (Sydney) heatwaves. It was found that doubling the urban green coverage of the Central Business Districts (CBD) in Melbourne and Parramatta, together with proper tree shading around a residential home may reduce the total annual hours of 'severe' heat-related health risk by 14% and 44.6%, respectively. Whereas, covering 50% of the CBD building roof areas with green roofs as well as appropriate arrangement of tree shading around the house resulted in a reduction of the total annual hours of 'severe' heat-related health risk by 14.5% (Melbourne CBD) and 36.2% (Parramatta CBD). The impact on the energy required for space cooling, was similar between the locations for each of the scenarios investigated. The study confirms that urban vegetation and tree shading have a key role in managing impacts of heatwaves.

1. INTRODUCTION

With climate change, heatwaves in Australia are set to become more frequent and severe. Heatwaves, such as those that occurred in Melbourne in 2009 and Sydney in 2011, pose a significant and growing threat to public health as highlighted by the rise in heat-related illness and deaths. For instance, the 2009 heatwave in Victoria caused 374 excess deaths for the week of 26 January to 1 February 2009 (DHS, 2012). More recently in Sydney, there were significant increases in hospital admissions and ambulance call-outs during the heatwave (30 January to 6 February 2011) and 814 deaths compared with an average of 682 deaths for the same time period across previous years (Schaffer et al., 2012).

Health risk during heatwaves not only depends on extreme weather, but also the heat sensitivity of the population and the thermal performance of the housing in which people will retreat for protection. As reported by Cadot et al. (2007), the majority of excess deaths attributed to the 2003 heatwave in Paris occurred in the home. Therefore one important strategy for reducing heat-related health risks during heatwaves is to improve the thermal performance of residential buildings. Using computer modelling, Chen et al. (2014) assessed the potential impact of regional-scale urban vegetation schemes on the urban ambient environment of Melbourne and found that an increase in urban vegetation could reduce the average summer daily mean maximum temperature and as a consequence, the rate of heat-related excess mortality. At the building scale, it has long been recognised that proper arrangement of trees and shrubs around residential buildings can reduce indoor temperatures during summer (Meier, 1990).

In this study, we build on this work by using computer modelling to predict the combined effect of regional-scale urban vegetation schemes to reduce ambient air temperatures and local tree planting to provide direct shade to residential buildings. The effectiveness of these strategies was assessed using a measure of heat-related health risk index and the energy required for space cooling. The geographic focus was Melbourne and Parramatta CBDs using weather from the 2009 and 2011 heatwaves, respectively.

Table 1 The main characteristics of the urban vegetation schemes investigated for Melbourne CBD

Urban Type	Vegetation coverage of entire land area (%)	Vegetation coverage fraction within vegetation area	Leaf Area Index	Green Roof Coverage of Building Roof Area (%)	Building Coverage over entire land area (%)	Building Height (m)	Irrigation
CBD	15	1.00	3	0	65	12.0	Yes
CBD(Double Vegetation)	33	1.00	3	0	62	12.0	Yes
CBD(50% Green Roof)	15	1.00	3 1.5 (GR)	50	65	12.0	Yes

Table 2 The main characteristics of the urban vegetation schemes investigated for Parramatta CBD

Urban Type	Vegetation coverage of entire land area (%)	Vegetation coverage fraction within vegetation area	Leaf Area Index	Green Roof Coverage of Building Roof Area (%)	Building Coverage over entire land area (%)	Building Height (m)	Irrigation
CBD	18	1.00	3	0	46	9.0	Yes
CBD(Double Vegetation)	36	1.00	3	0	46	9.0	Yes
CBD(50% Green Roof)	18	1.00	3 1.5 (GR)	50	46	9.0	Yes

2. METHODOLOGIES AND MODELLING RESULTS

2.1 Urban climate modelling and weather data preparation

An urban climate model UCM-TAPM (Thatcher and Hurley, 2012) was applied to predict the impact of different urban vegetation schemes on the local climate of Melbourne and Parramatta CBDs with regard to changes in mean monthly ambient temperature, mean monthly daily maximum temperature, mean monthly daily minimum temperature, and mean monthly relative humidity. Vegetation schemes that were investigated included doubling the CBD vegetation and covering 50% of the CBD buildings with green roofs. These were then compared with the existing CBD vegetation scheme. Tables 1 and 2 provide details of the urban vegetation schemes used for Melbourne and Parramatta, respectively.

To enable simulation of building thermal performance, hourly weather station data for Melbourne (1st July 2008 to 30th June 2009) and Parramatta (1st June 2010 to 31st May 2011) was modified to account for the simulated effects of the various urban vegetation schemes on the three mean monthly air temperatures and relative humidity. The methods for preparing the weather data for building simulation using the regional simulations from UCM-TAPM are described in Ren et al. (2014) and Chen et al. (2014).

2.2 Building thermal performance simulation

The space cooling energy requirement and thermal performance, including the indoor air temperature, relative humidity and Discomfort Index (DI), were estimated using the AccuRate software developed by CSIRO (Delsante, 2005). DI is a commonly used index for heat-related health risk (Epstein and Moran, 2006). For indoor conditions, it is calculated as the mean of the indoor dry-bulb and wet-bulb air temperatures. The risk of heat stress is considered to be 'moderate' for DI values in the range of 24–28°C and 'severe' for DI values above 28°C (Epstein and Moran, 2006). The higher the DI index the greater the heat-related health risk and potential for adverse health consequences for the occupants.

Simulations were performed on a typical residential house that was assumed to be of detached brick veneer construction and comprising four bedrooms. There was no insulation installed in the walls or ceilings as the aim was to represent older housing stock and to simulate the maximum exposure of building occupants to heat-related health risk. For the simulation of heat-related health risk, the house was assumed to operate without space heating and air-conditioning i.e. using natural ventilation and associated occupant behaviours. On the other hand, for the simulation of cooling energy requirement, the house was assumed to operate with space heating and air-conditioning, with common thermostat settings for the respective climate (i.e. Melbourne and Parramatta) and consistent occupant behaviours.

2.3 Analysis of indoor heat stress and space cooling load

Simulations were carried out for the CBD area of Melbourne from 1 July 2008 to 30 June 2009 and Parramatta from 1 June 2010 to 31 May 2011. The results are shown in Figures 1 and 2 for Melbourne and Parramatta, respectively. For tree shading, it was assumed that all the trees are 10m high and are planted along the northern and western walls with a distance of 3m between the trees and the building.

For the Melbourne CBD area (see Fig. 1), the total annual hours with DI above 28°C (severe heat stress threshold) for all the habitable spaces (four bedrooms, kitchen/family, dining/lounge, bathroom, laundry, entry hall, toilet, walk-in robe and ensuite) was predicted to be 311 for the existing CBD vegetation scheme with no tree shading. With tree shading alone, the energy required for space cooling (i.e. cooling load) and the total annual hours with DI above 28°C were both reduced by 6.8%. Doubling the CBD green coverage could reduce the total annual hours with DI above 28°C and the cooling load by 6.8% and 6%, respectively. Whereas 50% green roof coverage of the CBD area could reduce the total annual hours with the DI above 28°C by 7.4% and the cooling load by 7.9%. With a doubling of the CBD green cover and residential tree shading, the total annual hours with DI above 28°C and the cooling load are both reduced by 14%. Assuming a 50% green roof coverage of the CBD area combined with residential tree shading,

the total annual hours with DI above 28°C is reduced by 14.5% and cooling load by 15%. These latter scenarios show the benefit of multiple levels of green strategies.

For the Parramatta CBD area (see Fig. 2), the total annual hours with DI above 28°C for all the rooms was predicted to be 686 for the existing CBD vegetation scheme with no tree shading. With tree shading alone, the total annual hours with DI above 28°C is reduced by 10.6% and the cooling load by 5.5%. Doubling the CBD green coverage alone could reduce the total annual hours with DI above 28°C by 37.1% and the cooling load by 8.7%. 50% green roof coverage of the CBD area could result in a reduction of the total annual hours with DI above 28°C by 27.6% and the cooling load by 1.7%. If we consider both doubling the CBD green coverage and residential tree shading, the total annual hours with DI above 28°C may be reduced by 44.6% and the cooling load by 13.4%. With both 50% green roof coverage of the CBD area and residential tree shading, the total annual hours with DI above 28°C could decrease by as much as 36.2% and the cooling load reduced by 7.0%. The results indicate that increasing green cover and/or the proportion of green roofs in the Parramatta CBD may result in a larger reduction in heat-related health risk than similar strategies in the Melbourne CBD, while the impact on energy requirements for space cooling are similar between the two locations.

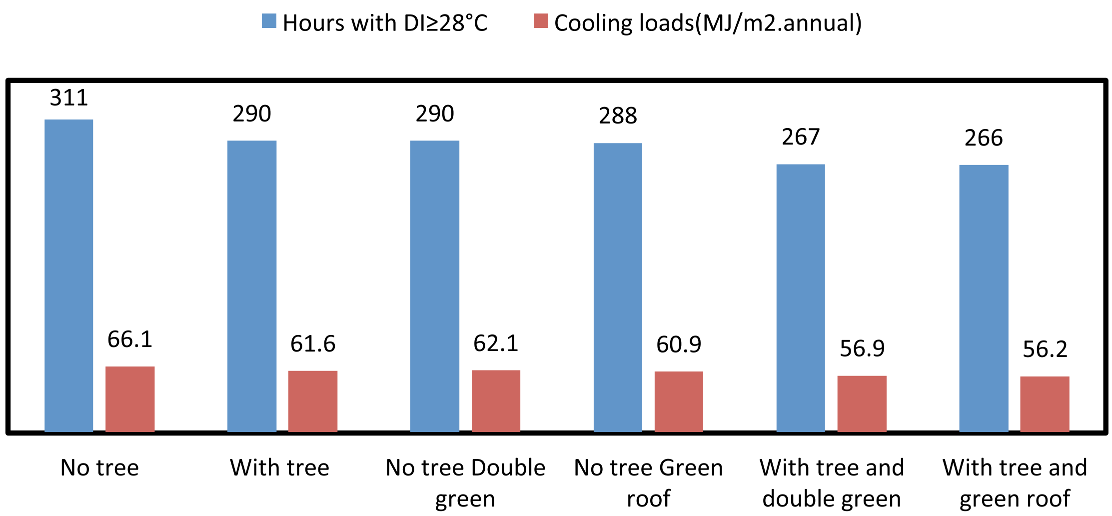


Fig. 1. Predicted total hours with DI above 28°C and cooling load of the house in Melbourne CBD from 1st July 2008 to 30 June 2009.

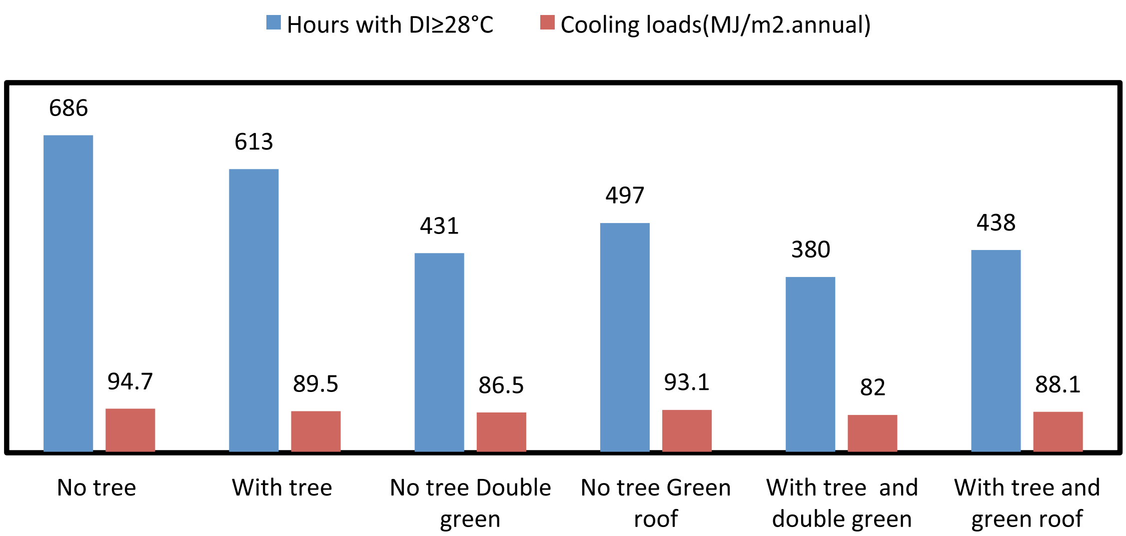
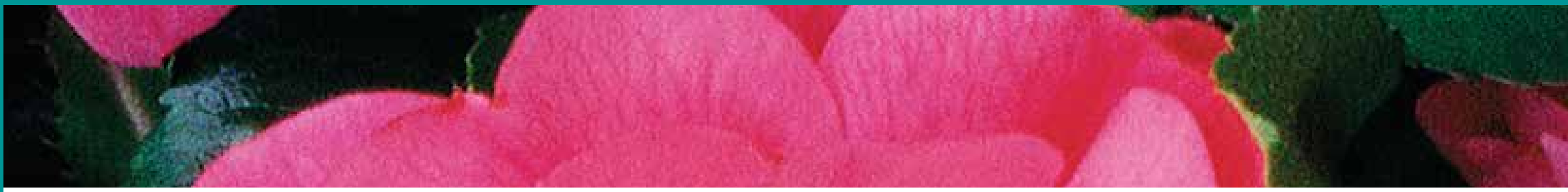


Fig. 2. Predicted total hours with DI above 28°C and cooling load of the house in Parramatta CBD from 1st June 2010 to 31 May 2011.



3. CONCLUSIONS

The potential of urban vegetation and tree shading around residential buildings in reducing indoor heat-related health risk and the energy required for space cooling were investigated for Melbourne and Parramatta CBDs, using weather data from 2009 and 2011, respectively. The results show that in the Melbourne CBD area, 50% green roof coverage and proper tree arrangement may reduce the total annual hours of 'severe' heat-related health risk (DI≥28°C) and the energy required for space cooling by 14.5% and 15%, respectively. In the Parramatta CBD area, reductions in the total annual hours of 'severe' heat-related health risk (44.6%) and energy required for space cooling (13.4%) were greatest when doubling the CBD green coverage together with proper tree shading of the house. This study confirms urban vegetation and tree shade are both important elements in mitigating heat wave impacts.

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