



## Urban vegetation for reducing heat related mortality



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### ABSTRACT

The potential benefit of urban vegetation in reducing heat related mortality in the city of Melbourne, Australia is investigated using a two-scale modelling approach. A meso-scale urban climate model was used to quantify the effects of ten urban vegetation schemes on the current climate in 2009 and future climates in 2030 and 2050. The indoor thermal performance of five residential buildings was then simulated using a building simulation tool with the local meso-climates associated with various urban vegetation schemes. Simulation results suggest that average seasonal summer temperatures can be reduced in the range of around 0.5 and 2 °C if the city were replaced by vegetated suburbs and parklands, respectively. With the limited buildings and local meso-climates investigated in this study, around 5–28% and 37–99% reduction in heat related mortality rate have been estimated by doubling the city's vegetation coverage and transforming the city into parklands respectively.

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### 1. Introduction

Heat waves have been recognized as one of the major natural hazards and kill more people than any other natural hazards in Australia (PwC, 2011; State of Australian Cities (2013)). The heat wave event in Melbourne, Australia during the summer of 2009 may have resulted in hundreds of excess deaths over what would normally be expected for the period (DHS, 2009). In 2003, the European heatwave resulted in over 70,000 excess deaths (Robine et al., 2008). Indeed, the linkage between mortality and heat has been long recognized (Changnon et al., 1996; Haines et al., 2006; Luber, 2008; Huang et al., 2012). Several earlier studies have tried to quantify the relationship between climate conditions and mortality rate in Australia (Nicholls et al., 2008; Tong et al., 2010; Loughnan et al., 2010; Tong et al., 2014). Nicholls et al. (2008) analysed the mortality rate in Melbourne for people over 65 from 1979 to 2001. They reported that excess heat related mortality amongst the population over 65 years of age may increase rapidly when the mean daily temperatures (the average of yesterday's maximum and this morning's minimum) exceeded about 30 °C.

The impact of heat waves in major Australian cities such as Melbourne and Sydney is likely to become worse due to further urbanization in existing suburbs, the effects of global warming and the ageing population. Further urbanization may potentially intensify the urban heat island (UHI) effect, a phenomenon whereby urbanized population centers experience warmer temperatures compared with surrounding rural areas (Morris et al., 2001; Coutts et al., 2007). At the same time, global warming projections suggest the likely increase in the number of warm nights, heat wave frequency and duration in Australia (CSIRO, 2007; Alexander and Arblaster, 2008). Consequently, it is essential to develop effective strategies to protect urban communities from the impact of heat waves.

In recent years, urban greening and cool surfaces have attracted substantial interests and show promise in mitigating the impact of heat waves (Rosenfeld et al., 1998; Akbari et al., 2001; Liu and Bass, 2005; Rosenzweig et al., 2006; Yu and Hien, 2006; Luber, 2008; Alexandri and Jones, 2008; Memon et al., 2008; Bowler et al., 2010; Wong and Lau, 2013). Urban greening can mitigate heat wave impacts by trees that shade buildings and cool the ambient air by evapotranspiration. Cool surfaces such as reflective roofs and paving surfaces can further reduce heat absorption in the urban area. Urban greening and cool surfaces can also reduce the cooling energy demand and thus green house gas (GHG) emissions in cities (Ca et al., 1998; Susca et al., 2011; Xu et al., 2012; Smith et al., 2012).

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Previous researches in heat related mortality have been focused on the relationship between the ambient weather conditions and the mortality rate (Nicholls et al., 2008; Tong et al., 2010, 2014). Using urban climate modelling, Kalkstein et al. (2014) investigated the cooling effects due to different urban vegetation schemes and surface reflectivity. Based on the relationship between the ambient weather conditions and heat related mortality rate, they estimated that 10% increase in the urban vegetation coverage and surface reflectivity can result in an average 7% reduction in mortality during heat waves in the District of Columbia. It should be noted that heat related death occurs both indoors and outdoors. Cadot et al. (2007) reported that 74% of excess deaths during the 2003 summer heat wave in Paris occurred among those who were living at home. They emphasized that people most at risk from dying were those aged over 75 years and living alone. Although there is no available information on the locations of heat related excess deaths in Australia, the situation in Australia may be similar to that in Paris considering that the most vulnerable population is the elderly people group (DHS, 2009).

Due to the importance of thermal comfort and health safety of the living and working environment, there have been numerous studies on thermal comfort and heat stress in buildings since early last century (Brager and de Dear, 1998; Epstein and Moran, 2006; ASHRAE, 2009; Djongyang et al., 2010). Based on human body heat balance calculations and empirical observations, around 40 indices have been developed for defining thermal comfort and heat stress (Epstein and Moran, 2006). Generally, using these heat stress indices, thermal comfort and heat stress can be qualitatively categorized into different levels. For example, levels of heat stress may be categorized into four groups using the Discomfort Index (DI) which is defined as the mean of the air dry bulb and wet bulb temperatures, i.e.,  $DI < 22$ , no heat stress;  $22 \leq DI < 24$ , mild sensation of heat;  $24 \leq DI < 28$ , hot with difficulties in physical work;  $DI \geq 28$ , severe heat with risk for heat illness (Epstein and Moran, 2006).

Qualitatively, an indoor environment with high DI index, especially for DI over 28, may potentially present high risks in causing heat illness including heat related mortality. However, quantitative relationships between heat related mortality rate and the DI index, or any other heat stress index, in residential buildings are not available. At least two reasons may attribute to the difficulties in obtaining such relationships. First, heat stress indices are normally developed based on the heat balance for maintaining the body-core temperature around 37 °C or empirical tests with relatively healthy population groups such as workers in the working environment (Epstein and Moran, 2006). However, the sensations and responses of vulnerable population groups to heat stress are different from healthy population groups (Hwang et al., 2007). Second, information about the indoor thermal environment in which heat related deaths occurred is hardly available.

Consequently, although urban greening may have the potential in mitigating the impact of heat waves, there is currently no established methodology in quantifying its benefit in reducing heat related mortality in individual buildings. In this study, the role of urban vegetation in reducing heat related mortality in the city of Melbourne, Australia was investigated using a two-scale modelling approach. First, a meso-scale urban climate model was used for quantifying the effects of ten different urban vegetation schemes on the local climate in Melbourne. Then, the indoor thermal performance of five individual residential buildings was simulated using a building simulation tool using these vegetation modified local climates. The potential reduction in heat related mortality rate was then estimated from the correlation between the simulated indoor mean daily temperature and 20 year daily mortality rate records.

## 2. Methodologies

### 2.1. Urban climate with various urban vegetation schemes

In this study, the long term average impact on the urban climate was first established with urban climate modelling for the Melbourne Central Business District (CBD) area assuming various urban vegetation schemes. Hourly climate files for 2009, 2030 and 2050 with various urban vegetation schemes were then generated for building thermal performance simulations using a ‘morphing’ approach.

#### 2.1.1. Urban climate model

A recently developed urban climate model (UCM-TAPM) (Thatcher and Hurley, 2012) was used for the investigation of the impact of urban vegetation schemes on local urban climate. The UCM-TAPM combines an urban canopy model (UCM) with The Air Pollution Model (TAPM), a meso-scale climate model developed by CSIRO (Hurley et al., 2005). The UCM includes an efficient big-leaf model to represent in-canyon vegetation in the predominately suburban component of Australian cities.

The model employs a multiple one-way nesting procedure to dynamically downscale meteorological reanalyses/forecasts, typically in steps of 30 km, 10 km, 3 km and 1 km. The meteorological component of UCM-TAPM is nested within synoptic-scale analyses/forecasts which drive the model at the boundaries of the outer grids. In the UCM-TAPM, a grid tile of the land surface can assign one of 39 surface types that include a wide range of natural and built surface types such as water body, forest, shrub land, grassland, pasture, CBD, urban, and industrial. The characteristics of the surface types such as the average building height, building height to street canopy width ratio, vegetation coverage, leaf area index, surface albedos etc. can be adjusted for specific urban surface conditions. The UCM-TAPM has been validated against the measurements from several urban and rural weather stations (Thatcher and Hurley, 2012). Using UCM-TAPM, the impact of various urban vegetation schemes on the local urban climate can be quantified.

When modelling the ‘current’ Melbourne climate under various urban forms and vegetation schemes, the downscaled reanalysis climate data from the National Centre for Environmental Prediction (NCEP) were used for the lateral boundaries of the outer grids for the UCM-TAPM. For ‘future’ Melbourne climates under various urban forms and vegetation schemes, UCM-TAPM simulations were carried out with the boundary conditions based on the downscaled climate data from GFDL2.1 under the A2 emission scenario.

#### 2.1.2. Urban vegetation schemes

As illustrated by the green square in Fig. 1a, the Melbourne CBD area is represented by nine 1 km × 1 km grids in the UCM-TAPM. Fig. 1b shows the corresponding map for Melbourne which covers an area approximately 12.5 × 12.5 km<sup>2</sup> surrounding the Melbourne CBD area. In this study, four level nesting grids were used in the UCM-TAPM model, i.e., 30 km × 30 km, 10 km × 10 km, 3 km × 3 km and 1 km × 1 km grids. There are 25 × 25 grids for each grid level and the total simulation domain covers an area of 750 × 750 km<sup>2</sup> with a spatial resolution of 1 km at the finest grid level.

The impact of urban vegetation on the Melbourne CBD local climate was investigated using the UCM-TAPM by replacing the Melbourne CBD areas with the ten urban forms listed in Table 1. The CBD urban form (Urban Form Number 6) represents the existing Melbourne CBD with the vegetation and building coverage percentages estimated from Google images. Urban Form Number 9, i.e., CBD with 50% green roof, assumes 50% green roof coverage on all the building roofs in the Melbourne CBD area. Although

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