THE EFFECT OF GREEN ROOFS ON PEDESTRIAN LEVEL AIR TEMPERATURE

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ABSTRACT

Man made alterations have resulted in higher air temperatures in cities, compared to their surrounding rural areas. There are many attempts to modify the urban design elements to ameliorate urban heat island effect. One among them is the concept of green roofs. There is a potential to incorporate vegetation to the large roof area of the buildings. Several studies investigated the effect of micro and macro scale implementation of green roofs. Most of these studies examined the impact of green roofs on the air temperature variation at the roof level, whereas studies are lacking on the effect of green roof at the pedestrian level. Therefore, this study aims to explore the impact of green roofs on the air temperature at pedestrian level, in the central business district (CBD), using Melbourne as a case study. A generic layout of Melbourne's CBD is modelled using ENVI-met 3.1 BETA 4. A number of different scenarios with different green roof coverages and building heights are examined. It was found that green roofs did not have significant impact on the temperatures at pedestrian level.

INTRODUCTION

According to United Nations (2012), the percentage of the world population that live in urban areas will increase from 50 to 67 % by 2050 (Heilig, 2012). The change in the rate of urbanization will result in temperature rise in cities, which is known as "urban heat island effect" (UHI). Consequently, heat island effect will cause high level of energy consumption, thermal discomfort and increased level of air pollution (Gartland, 2010; Santamouris, 2013). Urban microclimate is largely influenced by human behaviour and decision making (Wong et al., 2007). Thus, better understanding of the causes of intra-urban air temperature difference, is essential in improving the urban design guidelines and thermal condition of the cities (Brown, 2011). UHI phenomenon is known to be the effect of increased impervious urban surface coverage and reduced permeable natural vegetative coverage (Ng et al., 2012). Several studies based on field measurements found that green areas create temperature difference of up to 7 C° at pedestrian level (Shashua-Bar & Hoffman, 2000). Increasing the vegetative surface coverage in urban areas could either occur at pedestrian or roof level. Considering exposed urban areas, roofs consist a higher fraction. A study in United States showed that the roof area fraction varies from 20 to 25% (Akbari & Rose, 2008). On the other hand, the available free ground area in the centre of the cities is usually very limited. Therefore, it is a challenging task to implement large-scale greening coverage on the ground surface of the urban areas (Santamouris, 2004). Several studies indicated that implementing greenery at roof level would result in significant energy conservation, better indoor thermal comfort condition, reduced surface temperatures of the roofs and lower level of sensible heat flux (Theodosiou, 2009; Xu et al., 2012). One-year measurement on the rooftop of a building with 16 meter height, at university of Osaka, Japan, indicated that the air temperature above the vegetated section is about 2°C lower than that above the control section (Harazono et al., 1991). In a similar study, the cooling effect of green roof during summer time was investigated through a mathematical model. The study found that leaf area index (LAI), foliage geometrical characteristics, soil density, soil thickness and soil moisture play significant role in thermal performance of green roofs (Del Barrio, 1998). Another study, conducted at university of Tokyo showed that the green roofs have effective cooling impact on the internal air temperature of the buildings (Takakura et al., 2000). The findings of field measurements and wind tunnel study showed that the surface temperature of a roof lawn garden could be lowered by 30°C (Onmura et al., 2001). In the same year, a study by Niachou et al. (2001) revealed that the surface temperature of green roof varies from 28 to 40°C, depending on the species of the plants. A similar study in Singapore, pointed out that a maximum temperature difference of 18°C can be monitored between the well planted and a bare roof (Wong et al., 2003). Lazzarin et al. (2005) applied a predictive numerical modelling to calculate the energy saving in a building with green roof. The authors concluded that the solar loss is 40% higher in a building with insulated roof.

In summary, literature show that the application of green roofs in cities can contribute to a significant reduction in the ambient air temperature at roof level, whereas only limited number of the studies focused on the potential cooling impact of green roof at pedestrian level. In a study conducted in Hong Kong, a three dimensional microclimatic model ENVI-met was used to model the effect of green roof in a densely built up area. The findings of this study, showed that roof greening is ineffective in lowering the air temperature near the ground. Increasing the vegetative coverage at pedestrian level is one of the potential methods to reduce the air temperature and improve thermal condition in urban areas. However, due to the limited availability of ground surfaces particularly in the centre of the cities, this method may not be applicable at an extensive level. Therefore, this study aims to examine the effectiveness of different green roof coverage on lowering the air temperature at the pedestrian level in the temperate setting of Melbourne Australia. ENVI-met 3.1 BETA 4 was used to model a generic layout of Melbourne CBD. Different building heights and various green roof coverages were modelled. A base case scenario without any greening coverage and other two scenarios with 50 % and 100 % green roof coverage were tested.

METHODOLOGY

Melbourne is one of the fastest growing cities in Australia and its population is expected to reach six million by 2030. Melbourne metropolitan area covers an area of 7,695 km² and comprises 31 local government zones. Rapid urban development has resulted in extensive alterations in the urban surfaces. According to Köppen classification, Melbourne has an oceanic climate, characterised by warm temperate climate with warm to hot summer conditions (December – February). In summer, the mean monthly maximum temperature is 25.3°C. The frequency of temperatures above 21 ºC and extreme temperatures (> 40ºC) is a common occurrence in Melbourne. The average daily maximum temperatures is between 14 to 21 ºC. However, there has been a greater frequency of daily maximum temperatures greater than 21ºC within recent years (D'Argent et al., 2012).

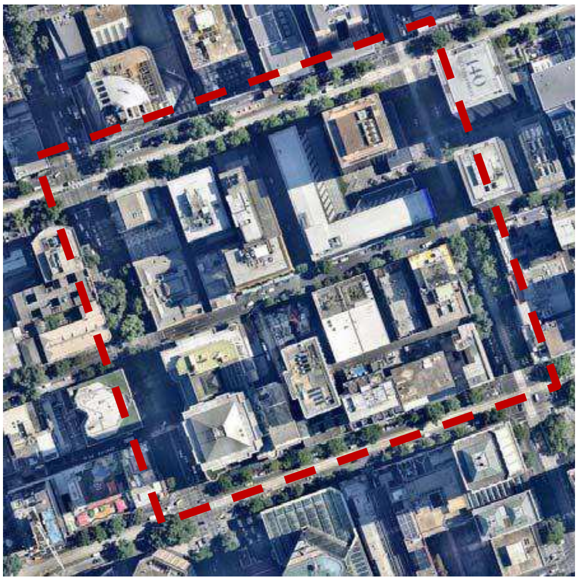


Figure 1 Boundary of the modelled area

This study was conducted in Melbourne's central business district area (latitude, -37.49, longitude 144.58). The day chosen for simulation was 5th January 2015, which represents a typical hot summer day in Melbourne. Figure 1 illustrates the boundary of the study area. ENVI-met 3.1 BETA 4 was used to simulate the surface-plant-air interactions in the study area. ENVI-met is a three-dimensional numerical model with a typical resolution of 0.5-10m in space and 10 s in time. In this study, an ENVI-met model was constructed for a generic layout plan based on the urban morphology of Melbourne's CBD. The building heights were set to be homogenous with 4m, 8m, 12m, 16m and 20 meter. Table 1 summarizes the various green roof coverage as well as different building heights tested.

Table 1
A summary of study cases

BUILDING HEIGHT	GREEN ROOF COVERAGE (%)		
4	0	50	100
8	0	50	100
12	0	50	100
16	0	50	100
20	0	50	100

The green roof was created with 50 centimetres average dense grass. The layout plans of the three different green roof coverage are illustrated in Figure 2. Building materials defined in ENVI-met were kept constant in all the cases (albedo walls-0.3, albedo roofs-0.2), so that the study could focus on the impact of green roof coverage and building height. 15 scenarios were tested by varying the type of the roof greening coverage ratio, and the building heights.

Figure 2 Area input files for base case, 50% green roof and 100 % green roof (from left to right)

The model was simulated for 24 hours, starting at 6 am and ending at 6 am the next day. In fact, the best time to start the simulation is at sunrise and the total running hours is recommended to be longer than 6 hours to overcome the effect of the initialization. ENVI-met was configured with the information in the area input file, outlined in Table 2.

Table 2
Input set up for model domain

Orientation (degree from North)	20
X grid number	54
Size of grid cell (m)	2
Y grid number	54
Size of grid cell (m)	2
Z grid number	20
Size of grid cell (m)	2

The meteorological data obtained from the Bureau of Meteorology, presented in the configuration file is the average values of the climatic condition on 5th January 2015. Table 3 lists the set up for the configuration files for all the scenarios. Three receptors were selected at different parts of the study area to extract the results. Figure 3 depicts the location of the receptor “A”, “B” and “C” in the study area.

Table 3
Configuration set up

Initialisation Time and Date	05.01.2015/ 6:00 AM
Total Simulation Time (Hours)	24
Wind direction (°)	171
Wind speed (m/s)	1.7
Specific Humidity in 2500 m	7
Initial Temperature Atmosphere [K]	296
Relative Humidity in 2m [%]	50

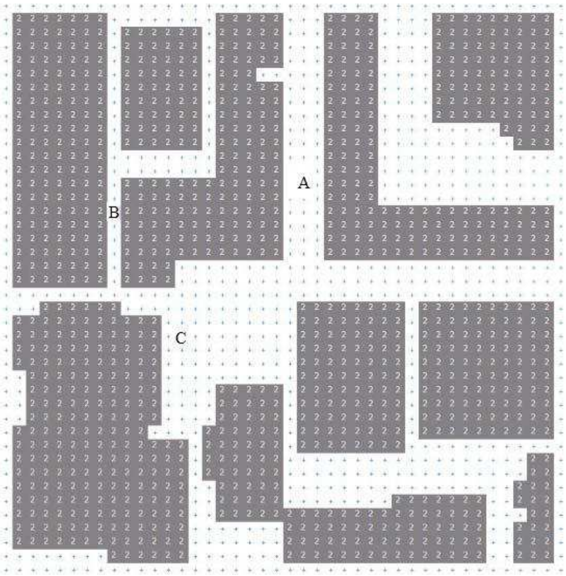


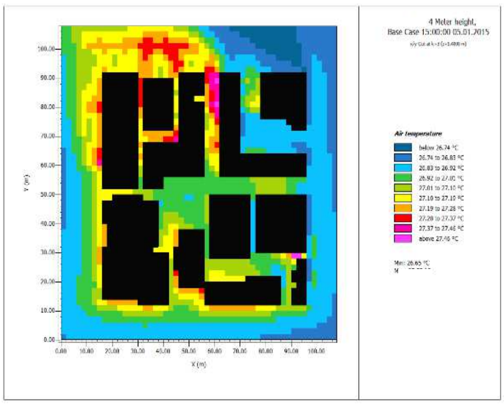
Figure 3 Location of receptor “A”, “B” and “C” in the area input file

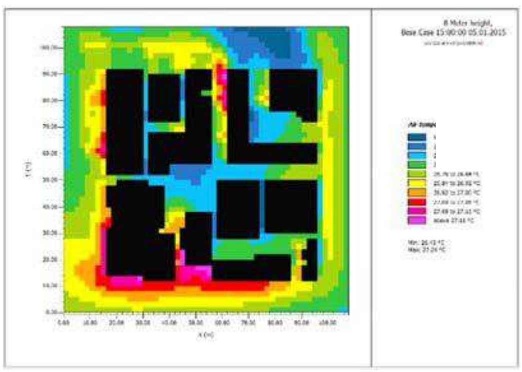
RESULTS AND DISCUSSIONS

Since afternoon hours are the hottest hours during the day, the results of the simulation for 2 pm were reported in detail and discussed for comparing all the cases. The simulation results for all the cases with building heights of 4m, 8m, 12m, 16m and 20 m were reported and compared at 1.40 meter above ground level. The outcomes of the simulations were extracted at three different receptors; “A”,”B” and “C”.

The comparative results of various green roof coverages for different building heights for receptors A, B and C are illustrated in Figure 5, Figure 6 and Figure 7 respectively. According to these figures, implementing grass surface on the rooftop could not yield useful cooling effect at pedestrian level. As the maximum temperature reduction recorded in 4-meter case, was found to be only 0.24°C, between the base case without any greening coverage and 100 % green roof coverage. The maximum temperature difference between the base case and 100% green roof for the other building heights (8, 12, 16 and 20 meter), was found to be lower than the one for 4 meter height. As Figure 5 illustrates, only 0.04 and 0.05°C, temperature difference was monitored in these study cases. Thus, one may conclude that the cooling benefits of greening when building heights are lower (at 4m) are higher than the cooling benefits when buildings are taller (at 8m,12m, 16m and 20 m). Wong et al. (2003) reported that the cooling effect of green roof can be considered as significant for the building height less than 10 meter. However, in this study, no significant cooling effect was detected for 4-meter building height. Similar pattern of the air temperature was found in receptor “B”. According to Figure 6, the temperature difference between the base case and 100% green roof was found to be 0.2, 0.05, 0.06, 0.07 °C, and 0.07 for 4m,8m,12m,16m and 20m building height respectively. LEONARDO images presented in Figure 4 depict the variation of the pedestrian-level air temperature for the base case, without any green roof coverage, for different building height. LEONARDO images indicate that the pedestrian level air temperature is generally lower with taller buildings. This may be due to the effect of shadings from the surrounding buildings. Figure 7, shows the same pattern for the air temperature behaviour at receptor “C”. The maximum cooling effect of the green roof was recorded between the base case and 100% green roof, by only 0.04°C, for 16meter building height. The value is lower for the other cases; 0.03 and 0.02 for 4 m and 8m, 12m and 20 m building height respectively.

Overall, the findings of this study are in agreement with research in Japan, which showed that even with the introduction of 100% roof greening, benefits to the pedestrian-level air temperature are negligible when buildings are tall (Chen et al., 2009).





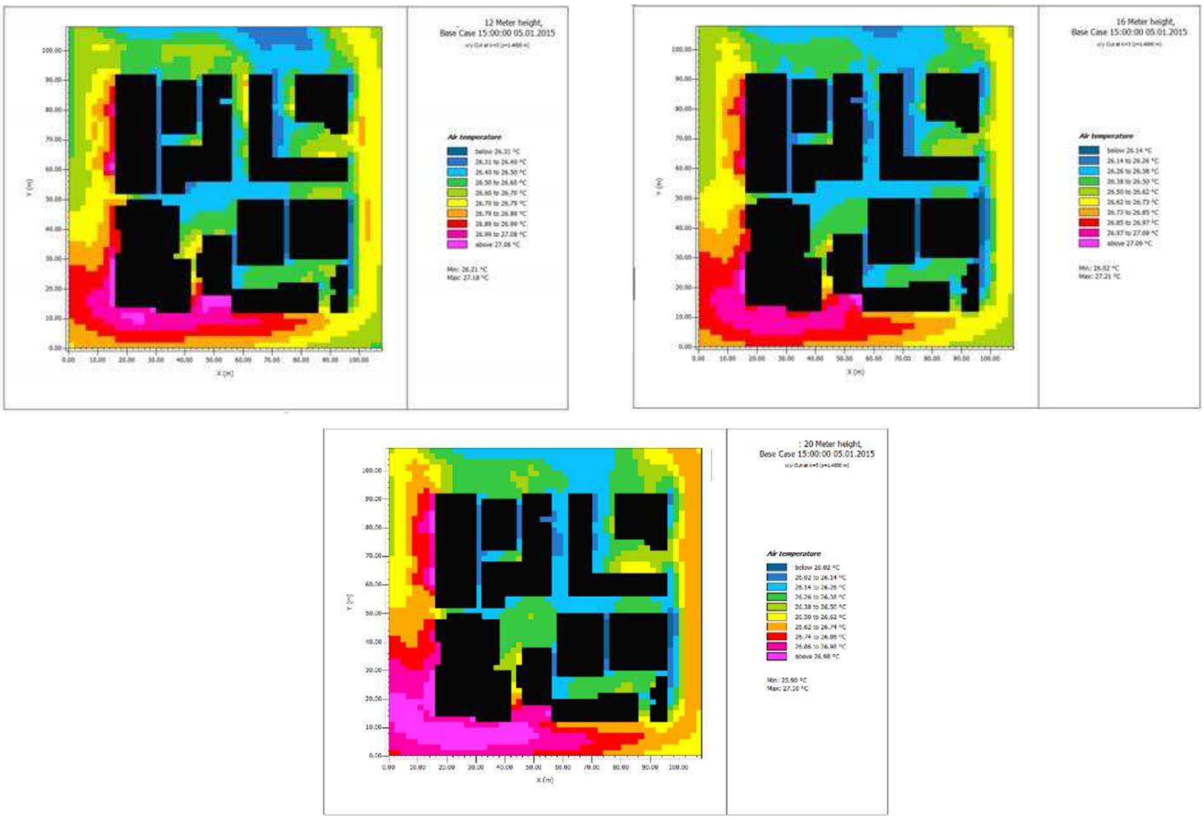


Figure 4 Air temperature variation for 4, 8, 12, 16 and 20 meter height (base case)

Figure 5 Air temperature variation for different study cases at receptor "A"

Figure 6 Air temperature variation for different study cases at receptor "B"

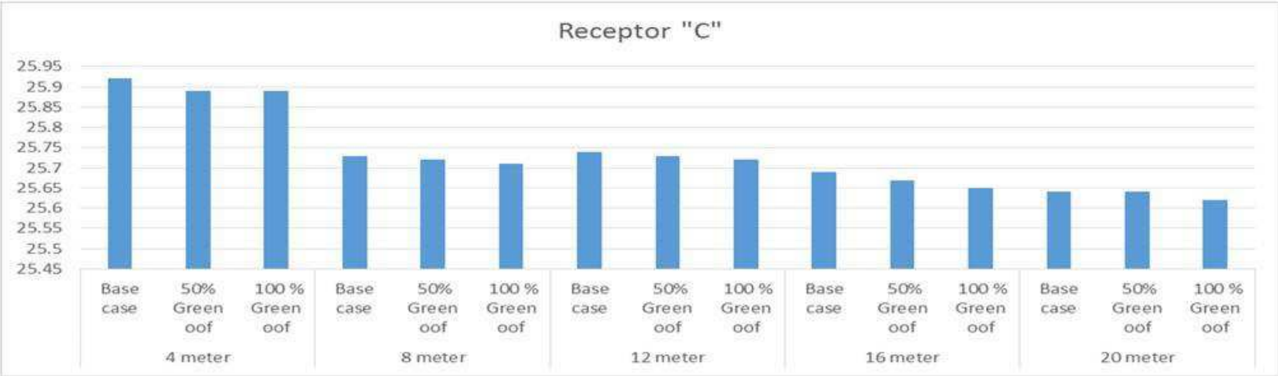


Figure 7 Air temperature variation for different study cases at receptor "C"

CONCLUSIONS

This study investigated the effect of roof greening on pedestrian-level air temperature distribution using ENVI-met simulations. The results of this study showed that planting grass on the rooftop is not effective in cooling the pedestrian environment in high-rise, high-density urban areas, in the temperate climate of Melbourne. However, building height seems to have some impact on the cooling benefits of green roof: by reducing the building height, the cooling effect of green roof increases. The results may be different if trees were planted instead of grass. However wind load may be an issue for large trees. The microclimatic conditions in our cities has to become an integral aspect in the planning practices, particularly in highly urbanized cities. This study suggests that other greening strategies such as street trees, ground level grass and green walls should be examined in order to quantify the effectiveness of these methods in decreasing the adverse impact of urbanization and providing better pedestrian thermal comfort.

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