CBD greening and Air Temperature Variation in Melbourne

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ABSTRACT

Melbourne, the second most populous city in Australia, is growing rapidly. To accommodate this growth, CBD area is undergoing dense urban development and consequently the microclimate of the city is affected. Understanding how greeneries can influence the air temperature is very important in urban planning. This study presents a simulation approach to examine the impact of CBD greening on the air temperature variation, during a summer day in Melbourne. The numerical simulation system, ENVI-met was used to examine the impact of vegetation on the air temperature in CBD area, under various scenarios. Three scenarios were applied; without any vegetation, with the existing trees (2%), and enhanced number of the trees (6%). The simulation results showed significant lower air temperatures in both greening scenarios compared to the base case scenario without any vegetation. Increasing 4% tree coverage in the study area, led to 0.2 C° reduction in the air temperature. The study also found that the maximum cooling effect, occurs at mid afternoon. The outcomes of this study could be used to assist urban planners in developing policy suggestions for improving Melbourne’s microclimate and offsetting the likely temperature impacts from increasing urban densities.

INTRODUCTION

Consistent population growth and urban development have triggered high demand for built environment and migration of people from rural to urban areas. According to Australian bureau of statistics, population of Melbourne has been increased by 9.7% from 2006 to 2011 (Australian Bureau of Statistics 2000). To accommodate this population growth, natural landscapes and vegetated areas have been replaced by impervious surfaces of buildings and pavements, leading to an alteration in the radiative, thermal and aerodynamic characteristics of the urban surfaces (Morris, Simmonds & Plummer 2001). One of the most significant consequences of the urbanization, is the temperature difference between the urban and rural areas, known as “urban heat island” (Oke 1984). The phenomenon, is mainly a result of high thermal capacity and heat storage of urban surfaces, anthropogenic heat, caused by human activities and reduced rate of evapotranspiration in urban areas (Oke 1988). The temperature rise in cities might be beneficial during winters, but it increases the energy demand and health risks during the summer (Yu & Hien 2006).

Melbourne, with a population over 3.6 million, features UHI consistently throughout the year (Morris, Simmonds & Plummer 2001). In 1992, an automobile transect across the city monitored 7.1C° temperature difference between the central business district (CBD) and surrounding suburban areas, with smaller peaks in industrial areas and the medium-density terrace housing in the inner northern suburbs (Torok et al. 2001). According to CSIRO (2011), the average daytime air temperature in Melbourne tends to rise from15.7 C° to 18.5 C° by 2070. Consequently, the number of the days with maximum air temperature will be increased. A study by Lynch et al. (2011) states that, the mortality rate is likely to be doubled by the latter part of the current century. Four days heat wave in Melbourne was resulted in 374 excess deaths in January 2009. The mortality rate is often maximum among among elderly and people with respiratory diseases (Victorian Department of Human Services 2010). Therefore, the process of urbanization and temperature rise in Melbourne city, presents a clear issue for public health,
sustainability of urban environments and thermal condition of the city, particularly during hot seasons. Microclimatic benefits of vegetation have been extensively investigated in previous researches (Avisar 1996; Huang et al. 1987; Jauregui 1991; Oke et al. 1989; Shashua-Bar & Hoffman 2000). Vegetation not only provides pedestrians with pleasurable visual scenes, but also provides shading, improves air quality, reduces the noise levels and contributes to the mitigation of the urban heat island effect (Dimoudi & Nikolopoulou 2003). Over 25-50% mitigation of heat island intensity can be achieved through greening strategies (Rowntree, Sanders & Stevens 1982). Various greening strategies have been used to reduce the air temperature and the level of air and noise pollution, such as, green roofs, urban parks, trees, shrubs and grass (Oliveira, Andrade & Vaz 2011). The cooling effect of vegetation occurs through the process of shading, evapotranspiration and changing the wind pattern. The average cooling effect of vegetation is between 1 to 4.7 °C, that can be extended by 100 to 1000 meter radius around the vegetated area. The cooling effect also highly depends on the available water for irrigation (Schmidt 2006).

Over the last decade, several studies have been conducted in various climatic conditions, to investigate the detailed relationship between different greening scenarios and urban microclimate (Lin, Matzarakis & Hwang 2010; Ng et al. 2012; Shashua-Bar et al. 2010; Wong et al. 2007), but the number of the number of these studies in Australia is lacking. Therefore, this study aims to examine the effect of different greening scenarios on the air temperature variation in Melbourne, by using a numerical modeling system, ENVI-met.

Many methods have been applied to investigate the effect of vegetation on microclimate, such as numerical modelling (Avisar 1996; Pearlmutter, Krüger & Berlimer 2009; Spronken-Smith & Oke 1999), empirical analysis, on-site measurement (mobile traverse, weather station data) (Jonsson 2004; Sani 1987; Upmanis, Eliasson & Lindqvist 1998) and satellite images (Ooka 2007). But, numerical modeling has become more popular than on-site field measurements during recent years. Because researchers have greater control over modeling in regards to the time and resources (Arnfield 2003). Additionally, numerical models are capable of coping with the complexities and non-linearities of urban structures.

Some recent studies used three-dimensional numerical model, ENVI-met to simulate the effect of vegetation on microclimate (Ali-Toudert & Mayer 2007; Fahmy & Sharples 2009; Fahmy, Sharples & Eltrapolsi 2009; Spangenberg et al. 2008; Yu & Hien 2006). ENVI-met, simulates the microclimatic changes within urban environments in a high spatial and temporal resolution (Bruse & Fleer 1998). It can also calculates all important meteorological parameters, such as the solar radiation, air temperature, relative humidity, wind speed, as well as the mean radiant temperature. Buildings, overhangs, galleries and setbacks can be illustrated via ENVI-met (Hedquist et al. 2009).

This study, uses numerical simulation model, ENVI-met (Bruse M 2011a) to generate the air temperature data for the central business district area, and to examine the effect of different greening scenarios on the air temperature variation in Melbourne’s CBD. Three scenarios are examined; a base case scenario without any vegetation, scenario “1” with existing trees in the site which cover 2% of the study area and scenario “2” with uniformly enhanced trees, placed at the fixed distance from each other, which cover 6% of the study area. Table 2 lists the detailed characteristics of each scenario.

**METHODOLOGY**

Melbourne, is the capital and most populous city in the state of Victoria, and is the second most populous city in Australia. Geographical coordinates of Melbourne are (37°49′S, 144°53′E) and according to Köppen climate classification, Melbourne has a moderate oceanic climate. The city has been well reputed for its unstable weather condition (Sturman & Tapper 2006). Melbourne summers are notable for the occasional days of extreme heat (Bureau of Meteorology 2009). The highest temperature recorded in Melbourne city was 46.4 °C (115.5 °F), on 7 February 2009.

To investigate the impact of different greening scenarios on the air temperature, a typical urban environment was selected in the central business district area in Melbourne. The Hoddle Grid with the dimensions of 1.61 by 0.80 km, forms the center of Melbourne's central business district. Most of the buildings in this area are 8 to 12 storey and streets have 15 and 30 meter width. Figure 1, shows the boundary of the selected site.
Most of the studies using ENVI-met, conducted comprehensive field measurements to validate the outputs of the software with on-site measurement. Thapar and Yannas (Thapar & Yannas 2007), used field measurements to validate the findings of ENVI-met on the air temperature and wind variation around specific urban forms. Hedquist et al. (2009), used the software along with CFD and field measurements to report the temperature variation in high density areas.

**Figure 1.** Boundary of the study area in central business district of Melbourne, Australia, Red color circles indicate the spot points for field measurements (Left) 3D view of the study area (Right)

In this study, three points were selected in the study area, to verify the results of the simulation with the on-site measurements. Hobo data loggers were used to monitor and compare the air temperature variation at the selected points. The location of each point is shown in Figure1. An ENVI-met model was first created, according to the exact urban geometry and vegetation coverage of the site. Climatic data, such as the initial air temperature, relative humidity, cloud cover and wind speed (19 December 2013) were initially given to the model, according to the data obtained from the “Australian Bureau of Meteorology”. The model was then run for 24 hours, starting from 6 am and ending at 6 am the following day. The simulation results for the air temperature (Ta) were extracted, plotted and compared with the air temperature measured at the site, for four different times of the day; 9 am, 12 noon, 3 pm and 6 pm. These periods of the time were selected, because they cover the times when the temperature is minimum, when it reaches to its maximum and when the temperature begins to drop. Comparison between the measured values and simulated data was made by conducting a regression analysis. Figure 2, shows a reasonable agreement between the measured and simulated data, with R value of 0.8. The usefulness of ENVI-met in predicting the air temperature variation, in Melbourne’s urban environment during summertime was therefore confirmed. The verified simulation settings are given in Table 1. These settings were then applied in simulating different scenarios.
Figure 2  
Comparison of the averaged measured and simulated air temperatures (Ta) in 19 December 2013

Table 1. Verified ENVI-met simulation settings

<table>
<thead>
<tr>
<th>Time</th>
<th>Initial Temperature</th>
<th>Start Time</th>
<th>Relative Humidity at 2 m (%)</th>
<th>Wind Direction</th>
<th>Wind Speed at 10 Meter level (m/s)</th>
<th>Albedo of the Roofs</th>
<th>Albedo of the Walls</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 December 2013</td>
<td>300.5 K</td>
<td>6:00 am</td>
<td>49%</td>
<td>North</td>
<td>15</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

One approach in urban climate modeling, is simplifying the complex urban structures into generic urban layouts, in order to understand the effect of altering a certain parameter in a system (Robinson et al. 2007). This method is also applicable in modelling the global climate, economic or ecological systems, as well as in biology and health studies. Therefore, to understand the impact of trees on the air temperature variation, a generic layout of the selected site was created. Climatic data and geographical features of the site, such as the average building height (30 meter) and the widths of the streets (15, 30) were given to the model. Mature 20m dense distinct crown trees were used in the model. A snapshot of the generic urban layout of the study area was created by ENVI-met in Figure 3. The detailed inputs for configuration file is also presented.

Figure 3  
(Left) Aerial view of the study area (right) Snapshot of the ENVI-met model
% ---- Basic Configuration File for ENVI-met Version 3 ---------------
% ---- MAIN-DATA Block -----------------------------------------------
Name for Simulation (Text): = Base Case Scenario
Input file Model Area =C:\Users\User\Desktop\paper 2\Base Case Scenario.in
Filebase name for Output (Text): =model1 base
Output Directory: =C:\Users\User\Desktop\paper 2
Start Simulation at Time (HH:MM:SS): =06:00:00
Total Simulation Time in Hours: =24.00
Save Model State each? Min =60
Wind Speed in 10 m ab. Ground [m/s] =15
Wind Direction (0: N...90: E...180: S...270: W...) =0
Roughness Length z0 at Reference Point =0.1
Initial Temperature Atmosphere [K] =300.5
Specific Humidity in 2500 m [g Water/kg air] =7
Relative Humidity in 2m [%] =49
Database Plants =C:\ENVImet31\sys.basedata\Plants.dat

Table 2. Different scenarios

<table>
<thead>
<tr>
<th>Base case scenario, Without any tree (0% tree coverage)</th>
<th>Scenario 1, Existing trees (2% tree coverage)</th>
<th>Scenario 2, (6% tree coverage)</th>
</tr>
</thead>
</table>

RESULTS AND DISCUSSIONS

A typical summer day, 19 December 2013 was simulated, using verified settings of the model (Table 1). The simulations were run on a core 2 quad processor 8 and GB of RAM. Each run took about 7 to 8 days.
Figure 4  Variation of the air temperature in different scenarios

The results of the simulations for 9 am, 12 noon, 3 pm and 6 pm were extracted and analyzed. Figure 4, shows the variation of the air temperature in each scenario and Table 3 illustrates the LEONARDO images of the outputs for various scenarios, in different times of the day. Some preliminary findings can be derived from Figure 4 and Table 3. The main finding is that, both greening scenarios (existing trees and uniform enhancement of the trees) significantly modify the air temperature. The maximum level of modification occurs at 12 noon. Compared with the base case scenario without any tree, scenario 1, with the existing trees in the site contribute to 4.8 °C, 7.5 °C, 6.1 °C and 5.5 °C reduction in the air temperature at 9am, 12 noon, 3 pm and 6 pm respectively. The existing tree case (scenario1), can provide more shade, therefore, from the LEONARDO images, it can be seen that, under the trees, the reduction of the air temperature is more intense. Uniform enhancement of the tree (scenario 2) also decreases the air temperature, compared to the base case scenario. As Figure 4 shows, 4.9 °C, 7.8°C, 6.5 °C and 5.9 °C temperature difference is recorded between the base case scenario and scenario

Table 3. The spatial distribution of the air temperature in different scenarios at 9 am, 12 noon, 3pm and 6 pm (From top to bottom)

<table>
<thead>
<tr>
<th>Base case scenario, Without any tree (0% tree coverage)</th>
<th>Scenario 1, Existing trees (2% tree coverage)</th>
<th>Scenario2, Uniform greening (6% tree coverage)</th>
</tr>
</thead>
</table>
These results are in accordance with the findings of similar studies on the impact of city greening on the air temperature (Bowler et al. 2010; Yu & Hien 2006). In regards to the air temperature reduction caused by greening scenarios, the result of this study is comparable to Taipei study, which showed 0.81K temperature reduction caused by urban parks (Chang, Li & Chang 2007) and Singapore study, which monitored 1.3 K decrease in the air temperature, due to urban greening (Yu & Hien 2006). A general conclusion can be achieved that, urban greening in the forms of trees can provide cooling effect to the urban environment. LEONARDO images in Table 3, show that, the air temperature in deep canyons is slightly lower than the air temperature in shallow canyons. More shading in deep canyons and less exposure to the direct sun are the plausible explanation of slightly lowered ambient temperature in narrow canyons for most of the locations. Explanation for the smaller temperature difference between base case scenario and scenario 1 compared to the base case scenario and scenario2, relates to the lower level of tree coverage in scenario 1. Because in scenario1, the existing trees are quite sparse, in comparison with scenario 2 with uniform trees planted through the site. As Figure 5 indicates, the maximum temperature difference between the base case scenario and greening scenarios was monitored 12 noon.

Figure 5  Temperature difference between greening scenarios at 9am, 12 noon, 3 pm and 6 pm

The findings of this study serve as a proof of concept to show how numerical microclimatic modeling can help to incorporate the urban greening schemes into CBD planning, urban development and visualize the potential cooling benefits of various greening and design scenarios. This study was limited to the impact of urban greening in the form of trees on the air temperature. However, the study
aims to include the impact of urban parks, Australian native trees and leaf area index will be studied on the air temperature variation in Melbourne. Furthermore, the effect of building layouts, street orientation and urban layouts on the air temperature will be also addressed.

**CONCLUSION**

This paper presented a preliminary study on the cooling effect of street trees in the CBD of Melbourne. Numerical modeling system, ENVI-met was verified through conducting field measurements. Verified settings were applied to the model, to simulate the air temperature variation in a generic urban layout of the CBD. Three scenarios were simulated; a base case scenario without any vegetation, scenario “1” with the existing trees in the site (2% tree coverage) and scenario “2” with uniform tree enhancement (6% tree coverage). It is found that both greening scenarios, contribute to the significant air temperature reduction. The maximum cooling effect of trees was detected at 12 noon. The study also revealed that 4% increase in tree coverage would lead to 0.2 °C reduction in the average air temperature. This study demonstrates how the simulation approach can help urban planners to better understand, visualize and analyze the potential cooling effect of urban greening and design related strategies.

**REFERENCES**


Bruse M. ((2011h)). ENVI-met. Overview of model layout. doi: www.envi-met.com


