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THE COOLING EFFECT OF A MEDIUM SIZED PARK ON AN URBAN ENVIRONMENT

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ABSTRACT: The Urban Heat Island (UHI) effect can best be described as an increase in the temperature of urban areas relative to their surroundings. This effect can exceed 5ºC in places. This study investigates how vegetation, in particular urban parklands, can be used to reduce the intensity of the UHI effect. To achieve this, the study uses a ground based approach relying on high spatial and temporal resolution temperature measurements using both a hand-held weather meter and a hand-held thermal laser-gun. The study focusses on one medium sized park in Melbourne, Australia and samples air temperatures (at 5 cm and 1.5 m above the ground) and land surface temperature profiles six times a day over one month starting within the park and extending to approximately 1 km outside of the park. The study shows that the park has a significant cooling effect for a distance of up to 860 m from its boundaries and that this is most significant in the early morning. The study also shows that land surface temperatures are more sensitive to park cooling effects than are air temperatures.

Keywords: UHI, Cooling Distance, Urban Parks, Air Temperature, Land Surface Temperature.

1. INTRODUCTION

Global warming is of increasing concern around the world with global temperatures predicted to rise by 2ºC or more by 2100. These changes have been attributed to human activities, especially the release of greenhouse gases into the atmosphere from the burning of fossil fuels [1]. A predicted outcome of this warming is that heat waves will become more frequent and severe, particularly in the second half of the 21st century. These heat waves, and the increased temperatures more generally, are (and will be) felt most keenly in cities. This is because cities are already warmer than their surrounding environments due to the "Urban Heat Island" (UHI) effect [2]-[3].

The UHI phenomenon can best be described as a difference in surface air temperature between urban areas and their surrounding non-urban landscapes [4]. The temperature difference that can be attributed to the UHI effect varies from place to place depending on a number of spatial (e.g., degree of urbanization, amount of urban greenspace) and temporal factors (e.g., seasonality, time of day), but is generally within the range of 0.4°C to 11°C although it has been reported as high as 14°C in Moscow [5]-[6]. Many causes have been proposed to explain this phenomenon, all of which are related to urbanization [7] including: a high percentage of low-albedo and impermeable surfaces, a reduction in the cooling effect of shading as trees are replaced by buildings or roads, the urban canyon effect where heat gets trapped and reradiated back to the ground by tall buildings, and a comparatively high concentration of greenhouses gases relative to surrounding areas [8]-[9]-[10]. Temporal parameters that effect UHI intensity include time of day and seasonality with UHI intensity being higher during the night and in summer. Additionally, cloudy conditions can decrease UHI intensity [11]-[12]-[13]-[14] while clear skies and low wind velocities tend to increase UHI intensity [15]-[16].

UHIs have many negative consequences. Increasing temperature discrepancies between urban centers and their surroundings can result in serious social and environmental impacts. For example, UHIs lead to increases in energy use (particularly cooling energy) that further increases urban pollution through emissions and enhances weathering rates [17]. In addition, health issues have been associated with an increase in temperature [18]-[19]. These health issues range from relatively minor impacts, such as heat rash, to potentially life threatening conditions such as heat stroke. Those with weakened immune systems and the young or elderly are especially susceptible to heat related illnesses [20].

To combat these problems, UHI mitigation strategies have been extensively researched in recent years. One of the most promising ways to reduce UHI intensity is through the use of green areas within or adjacent to urban centers [21]-[22]. These can take the form of green roofs, street trees or urban parklands, with research in Taipei and Paris, for example, showing that the temperature in urban parks is cooler than that of the surrounding areas, especially at night [23]. Similarly, research on green roofs show that they have been successful at cooling the air adjacent to concrete roofs in Manchester, UK [24]. Generally, this research indicates that parks and green roofs both contribute strongly to the reduction of surface air temperatures and that urban areas that contain these can be locally cooler than areas that lack these features [25]-[26]-[27]. Although vegetation has been shown to be highly effective at reducing the intensity of the urban heat island effect, there is no generally agreed upon ideal vegetation type, cover or distribution that is most effective at mitigating it [28]. Likewise, there remain many unanswered questions about how best to achieve significant reductions in UHI intensity. These include identifying an effective cooling area (the distance over which cooling benefits are observed) for parks and green roofs.

To help understand urban heat islands, contemporary researchers often utilize remote sensing data, as they provide a cost effective and time saving method for the analysis of land surface temperatures (LST) over wide areas and at different times of the year or day. Typically, such investigations involve the use of the thermal bands of the Landsat series of satellites or the Moderate-resolution Imaging Spectroradiometer (MODIS) [29]. These approaches have the benefit of assessing temperatures over a wide area. However, remote sensing approaches are limited by the resolution of the sensors and the limited times at which such images are available (once per day for MODIS to once per fortnight for Landsat). Moreover, the images are sensitive to cloud cover, which conceals the temperature signature. In contrast, ground based approaches, although limited in spatial extent compared to remote sensing, allow researchers to sample many times per day and at a very fine spatial resolution.

The aim of this study is to investigate the cooling effect of a medium sized park in Melbourne, Australia on its surrounding urban area. The study adopts a ground based sampling approach and seeks to determine the effective cooling distance from the boundary of the park. Such research will enhance our understanding of the cooling benefits of urban parks and provide specific information about the size and spacing of such parks needed to achieve widespread urban cooling benefits.

2. STUDY AREA AND METHODOLOGY

This research was undertaken in a medium-sized urban park (Carlton Gardens) near the central business district (CBD) of Melbourne in Victoria, Australia (Fig. 1). Carlton Gardens is a World Heritage Site located on the north-eastern edge of the CBD in the suburb of Carlton (37°48′22″S 144°58′13″E). The area of the park is 26 hectares and it contains two major attractions (the Royal Exhibition Building and the Melbourne Museum) and other facilities such as playgrounds and tennis courts.

The study involved collecting air (at ground level and 1.5 m above the ground) and surface temperature data six times a day (one sampling run every 4 hours starting at 8 am) over 24 hours. Air temperature data were collected using a Kestrel 4000 series weather and environmental meter while land surface temperatures were recorded using a Milwaukee laser temperature gun. Prior to using the laser temperature gun, the emissivity of each surface type sampled in the study was determined (using the thermocouple that comes with the Milwaukee temperature gun) and this value was set in the device to ensure that actual surface temperatures were recorded. During each 4 hourly sampling run, at least ten points were sampled at increasing distances (from within the park to 860 m away) from the park's centre. To ensure that representative temperatures were recorded, the land surface temperature (LST) data included the average of three to four readings over a period of 2-3 minutes. Likewise, the air temperature measurements were averaged over a period of 4-5 minutes to ensure that the temperature had stabilized before the values were recorded.

2.1 Sample Date Characteristics

Data were collected on 27-28/04/2015 and 30-31/05/2015, starting from 8 am and ending at 4 am the next day. The weather for the two sampling events was: (1) cloudy with a few showers at midnight on 27-28/04/2015; and (2) partially cloudy for the whole day on 30-31/05/2015. The winds varied between 1.1-16.1 km/h and 1.3-12.5 km/h for the two days respectively (Table 1).

3. RESULTS

3.1 Air Temperature

Ambient air temperature was measured at two heights; one very close to the ground (5 cm above the ground) and the other at 1.5 m above the ground.

3.1.1 5 cm above the ground

The cooling effect of the park at a distance of 5 cm above the ground extended out as far as 860 m (for one measurement at 8 am on 30/05/2015) and exhibited a maximum cooling impact of 6ºC (at 8 am on 27/04/2015) (Figs. 2(A) and 3(A)). Cooling was most evident at this elevation at 8 am and 12 pm (for both sampling dates) with minimal or no cooling exhibited at other times (ranging from no effect to approximately 1.5ºC) with the exception of the 4 am measurement on 27/04/2015 which displayed 3.7ºC of cooling.

3.1.2 1.5 m above the ground

The cooling effect at a height of 1.5 m above the ground displays a similar pattern to that of the near-ground temperatures (Figs. 2(B) and 3(B)). Once again, the maximum cooling effect at 1.5 m extended to 860 m (at 8 am on 30/05/2015), although the maximum cooling effect was lower at 4.3ºC (at 8 am on 30/05/2015). Also similar to the pattern observed for temperatures 5 cm above the ground, the maximum cooling effects were apparent only for the 8 am and 12 pm measurements (for both sampling dates) with all other times (except the 4 am measurement on 27/04/2015 which displayed a 3.6ºC cooling effect) showing minimal or no cooling. For all sampling times and dates, the cooling effect experienced at 1.5 m was lower than or equal to that at 5 cm above the ground (Figs. 2(C) and 3(C)).

3.2 Land Surface Temperature (LST)

Results for the land surface temperature measurements are presented in Figs. 2(D) and 3(D). As with the air temperatures, the maximum cooling effect extended as far as 860 m from the park's centre (at 8 am on 30/05/2015 when a maximum cooling of 11.7ºC was recorded). For both sampling dates the maximum cooling effect was observed at 8 am and 12 pm, but significant cooling (1ºC or more) occurred for all observation dates and times. Thus, the land surface temperature exhibited greater levels of cooling than either of the air temperature measurements.

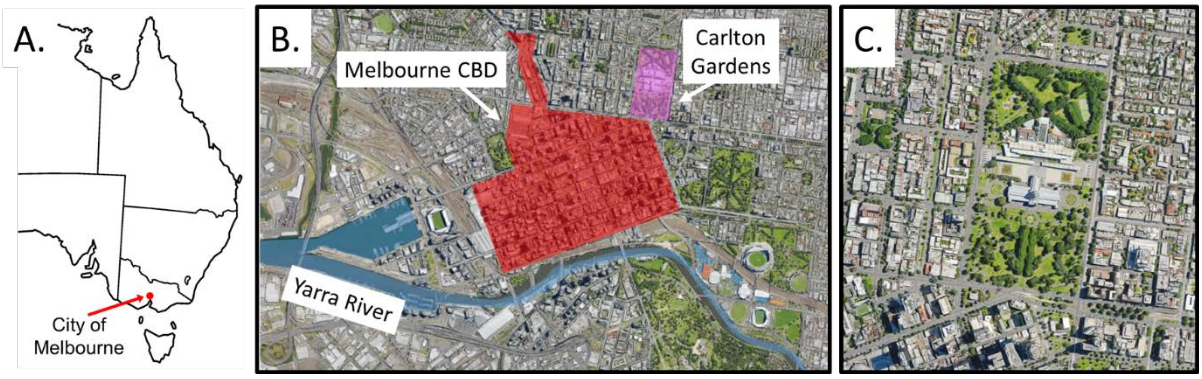

Fig. 1 Location of Melbourne, Australia (A), location of the case study site Carlton Gardens (B), the vegetation cover and surrounding landscape of Carlton Gardens (C).

Table 1 Specifications of the 6 sample periods for each date.

Date	Period (P)	Total travelling time (minute)	Wind speed (km/h)	Humidity (%)	Moisture (g/kg)
27-28/04/2015	P1 (8-10) am	94	2.9	67	7.55
	P2 (12-14) pm	77	7.3	67.5	7.4
	P3 (4-6) pm	53	4.8	65.5	7.1
	P4 (8-10) pm	71	0.8	61.5	9.3
	P5 (12-2) am	45	1.5	68	8.5
	P6 (4-6) am	48	2.4	70	6.2
30-31/05/2015	P1 (8-10) am	89	5.4	61	5.7
	P2 (12-14) pm	100	7.85	41.7	5.7
	P3 (4-6) pm	67	7.3	50	6.3
	P4 (8-10) pm	75	4.1	62.5	6.7
	P5 (12-2) am	67	2.6	68.5	6.8
	P6 (4-6) am	54	5	65	6.25

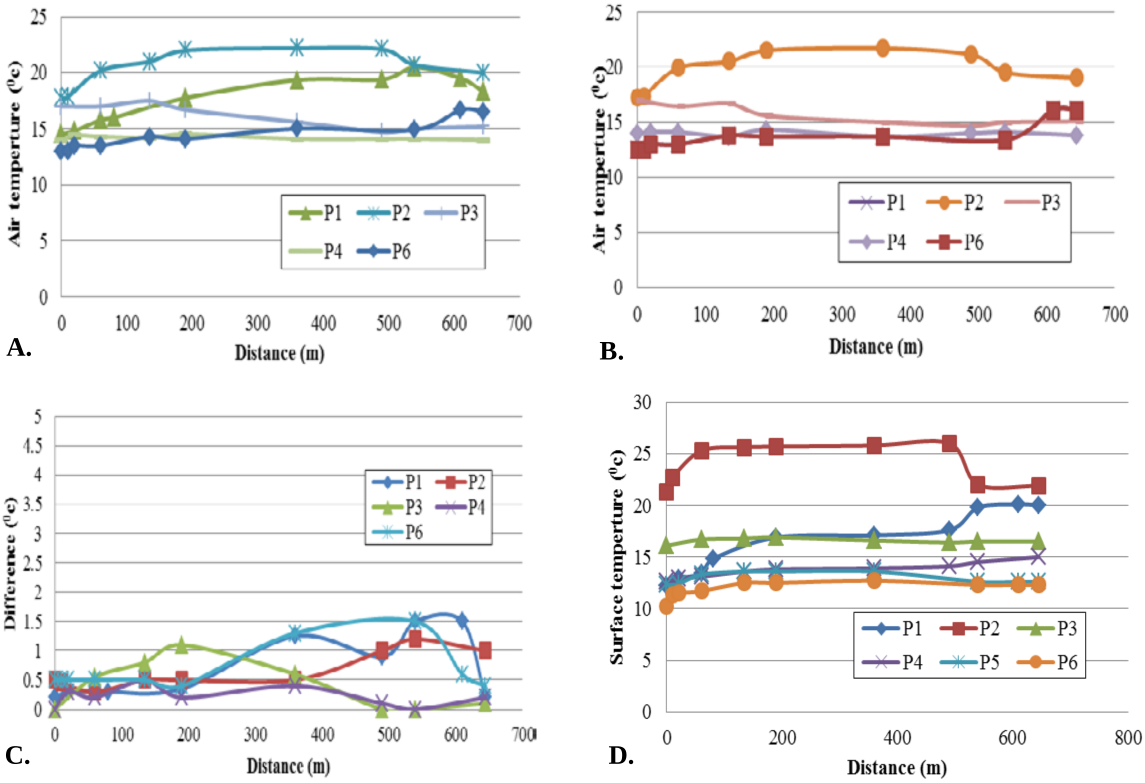

Fig. 2 Temperature measurements for 6 periods on 27-28/04/2015. (A) 5 cm above the ground (B) 1.5 m above the ground (C) the difference between the measurements at 5 cm and 1.5 m (D) land surface temperature.

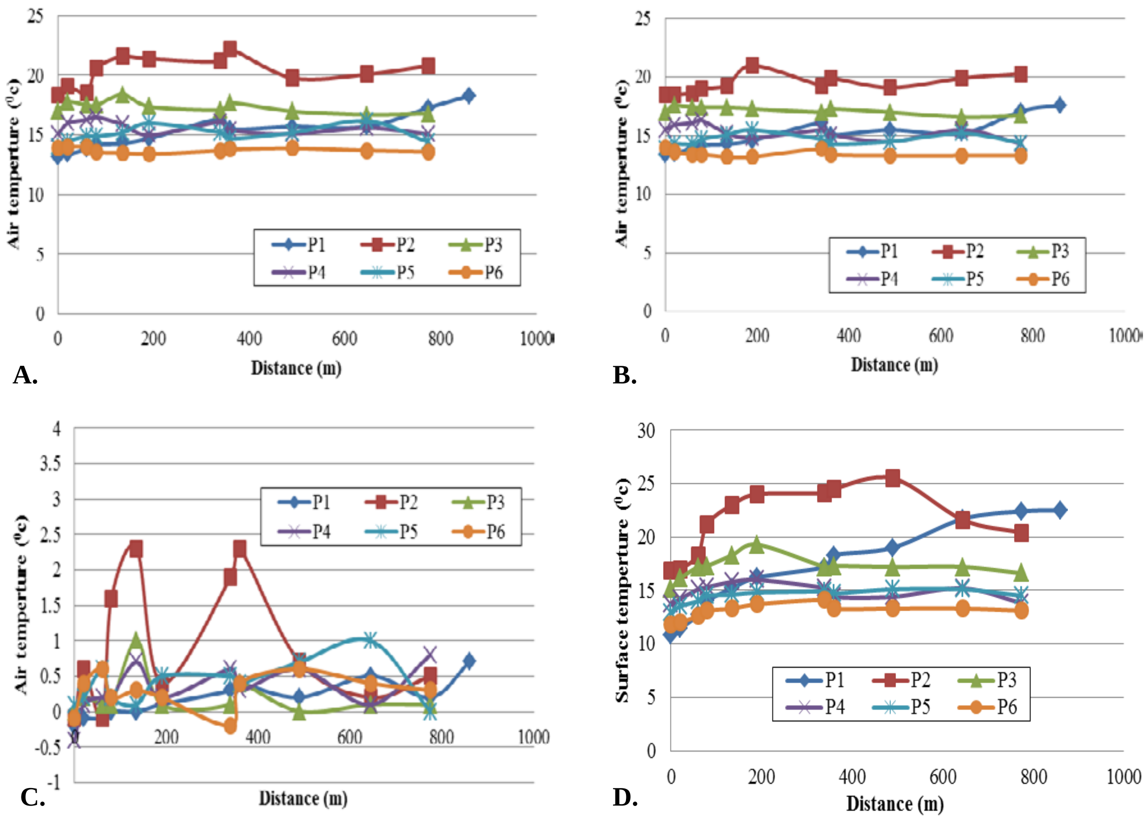

Fig. 3 Temperature measurements for 6 periods on 30-31/05/2015.(A) 5 cm above the ground (B) 1.5 m above the ground (C) the difference between the measurements at 5 cm and 1.5 m (D) land surface temperature.

4. DISCUSSION

A medium sized urban park in Melbourne, Victoria is shown to exert a considerable cooling impact on the surrounding city. This effect is most pronounced during the morning until around noon, with the maximum observed cooling at 8 am and the second highest cooling effect observed at 12:00 pm for both sample dates. Although cooling was also observed to occur at other times of the day it was less significant. These results contrast with those of [16] who found that maximum cooling occurred at night although their study was conducted in the summer, not the winter as was this study. Interestingly, the cooling effect of the park in this study is most pronounced for land surface temperatures (rather than air temperatures) which exhibit a cooling influence from the park at all times of the day.

The distances over which these cooling effects were observed ranged from relatively short (100-200 m) during the late afternoon and evening (4 pm and 8 pm) to as much as 860 m at 8 am in the morning, which is similar to the results of [30] who showed that park cooling effects extended as much as 840 m. This indicates that the park has a significant cooling effect that extends well out into the surrounding city, but that this is not equally true at all times of the day.

In terms of the three different temperature measurements (near-ground, above-ground and land surface), the land surface temperatures are affected the most by the presence of the park (up to 11ºC) followed by near-ground air temperatures (up to 6ºC) and then air temperatures at 1.5 m above the ground (up to 4.5ºC). These results compare well with those of [31] who showed park cooling effects of 5-7ºC and who also showed that land surface temperatures were more sensitive to cooling than were air temperatures. These results mean that studies that focus solely on measuring temperatures at 1.5 m (which is common in the literature) are less likely to see the true cooling potential of the park. However, as this height above the ground is the most significant for people in terms of their experience of urban heat, it also suggests that the park is less able to provide cooling for comfort than it is at providing overall cooling of the environment.

In addition, it should be noted that the much higher levels of cooling displayed by land surfaces means that the park could potentially reduce temperatures within buildings by cooling external surfaces. This may even reduce the need for artificial cooling (which also contributes to the UHI effect). Likewise, other urban surfaces such as cars, roads and footpaths can be impacted upon, which may help to mitigate against general increases in atmospheric temperature.

5. CONCLUSION

Urban parks have been demonstrated to have a significant cooling effect on surrounding urban areas. This effect is strongest for land surface temperatures (compared to air temperatures) and in the early morning and around noon. The cooling effect can be felt as far as 860 m from the park boundary and can exceed 11ºC for land surface temperatures and 6ºC for air temperatures. These results suggest that parks represent a viable means of controlling urban temperatures and that a strategic increase in parklands could offset even the worst predicted temperature rises associated with global warming (i.e., 2-5ºC).

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