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RESEARCH ARTICLE

Daily variation of urban heat island effect and its correlations to urban greenery: A case study of Adelaide

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Abstract
Urban structure and landscape cause an artificial temperature increase in cities, known as the urban heat island effect. The magnitude of such urban-rural temperature difference varies in daily and seasonal basis. Daily patterns of urban heat accumulation in Adelaide is under investigation. In this paper, East-West air temperature profile of Adelaide metropolitan area was mapped in 60 journeys alongside a straight cross route connecting Adelaide Hills to the West Beach under clear sky between 26 July and 15 August 2013. The most intense urban-rural temperature differences of 5.9 °C occurred during midnight in Adelaide. However, maximum urban heat variation occurred during the late afternoon when the near-surface urban heat fluctuates by 2 °C between the CBD East and Western Parklands. During summer heatwaves, the afternoon heat stress limits public life vibrancy in Adelaide. Increased urban greenery can facilitate resilience to heat by providing shadow and evaporative cooling. A better understanding of daily urban heat variations and the cooling effect of urban greenery assists urban policy making and public life management in the context of climate change.

1. Introduction

Australia is likely to experience 3.8 °C increase in its surface temperature by 2090 (CSIRO, 2014). Such regional warming will have a severe impact on local climate regimes, natural ecosystems and human life. In this context, heat stress can

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become up to 8 °C higher in urban settings compared to their rural counterparts (Gartland, 2008; Kolokotsa et al., 2009). Urban structure, hard surfaces and shortage of vegetation cover in cities are cited as the major contributors to the artificial temperature increase in cities, commonly known as the urban heat island (UHI) effect (Stone, 2012).

Due to variations in the UHI effect and its lower magnitude during the day, very limited research is available on daily variations of urban heat in cities when the UHI effect threatens usability of outdoor public spaces (Nikolopoulou, 2011; Santamouris et al., 2015; Sharifi et al., 2016). In response to substantial excess heat in cities, people increasingly move into air-conditioned buildings to benefit from indoor thermal comfort. Meanwhile, resulted anthropogenic heat generated from indoor air-conditioning causes an ever-increasing outdoor temperature.

In this context, this paper analyses daily variations of urban heat in Adelaide metropolitan area. Results assist urban policy and place making in the context of climate change.

2. The urban heat island (UHI) effect

In the early 19th century, Howard compared urban heat in London and reported that the mean annual temperature (20-years average) is 2.5 °C higher in London than its countryside. The peak air temperature variation of 3 °C was recorded during February (mid-winter) (Gartland, 2008). Similar macro-scale urban heat investigations contribute to the understanding of the UHI effect mechanism via comparing city centres and their rural surroundings (Bourbia and Boucheriba, 2010; Mirzaei and Haghighat, 2010). Gartland (2008, p. 2) enumerates five common characteristics for the UHI effect:

- UHIs are warmer than their rural vicinities.
- The urban-rural temperature difference is higher in calm and clear weather, at night, and in winter.
- The UHI effect occurs due to human-made modifications in urban surface covers.
- More urban development and less greenery correlate to the intensity of UHIs.
- UHIs create a dome of warmer air above cities.

Heat islands are uneven in their spatial distribution and magnitude, especially during daytime (Oke, 2006a) and can vary based on the space configuration and urban features in smaller scales (Erell, 2008). Figure 1 illustrates that the magnitude of urban-rural temperature differences is usually reported to be higher at night time; Thus, (Runnalls and Oke, 2000; Arnfield, 2003). The urban-rural temperature difference starts to develop during the day under clear sky due to solar gain of urban surface materials (Ashie, 2008). Calm weather causes the warm air to be kept in the built environment for an extended time (Morris et al., 2001; Wong and Yu, 2008).

2.1. UHI contributing factors

Oke (2006b, p. 184) highlights urban structure, surface cover, fabric and metabolism as the major contributing factors to the UHI effect.

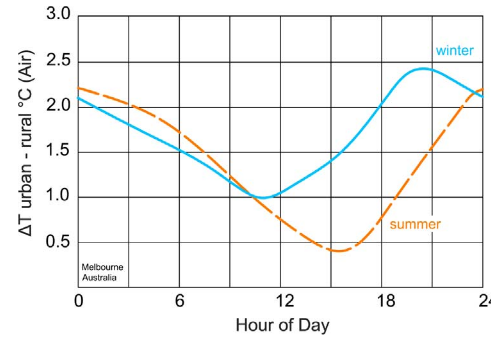

Figure 1 The UHI effect peaks at the clear and calm weather at winter nights. It also peaks earlier during winter Schematic representation based on Gartland (2008, p. 4).

2.1.1. Urban structure

Buildings' volume, orientation and the aspect ratio of the spaces between them (measured by the sky view factor) affect the exposure of urban surfaces to the solar radiation. Thus, urban structure affects shadow patterns and heat exchange in the built environment (Johansson, 2006; Lin et al., 2010; Krüger et al., 2011; Andreou, 2013). The complex heat exchange between buildings' mass and adjacent air changes the intensity and patterns of airflow in urban canyons where wind patterns also affected by the canyon-like structure of streetscapes surrounding by tall buildings.

2.1.2. Urban surface cover

Urban surface materials' thermal characteristics (specific heat, mass, conductivity and diffusivity), color, texture and coverage alter heat exchange in urban settings. Distribution and ratio of land cover classes including paved, vegetated and bare land and surface water contribute to the heat exchange between the urban area and the adjacent air (Karatasou et al., 2006). Due to land cover differences and their respective roughness layers (with temperature differences) local air turbulence occurs in the urban settings which mix the hotter and cooler air and affects the UHI effect intensity.

2.1.3. Urban fabric

The overall ratio of residential, commercial and industrial land use, roads and open spaces, parklands and wetlands affects the intensity and distribution of UHIs. Lack of sufficient greenery – as a common characteristic of urban areas – contributes to the accumulation of heat in the built environment thermal mass (Gartland, 2008; Wong and Jusuf, 2010; Coutts et al., 2012). Typology, distribution and intensity of urban greenery also affect local wind patterns.

2.1.4. Urban metabolism

Urban life is associated with energy consumption, causing additional waste heat production in cities (Soltani et al., 2012). Such anthropogenic (human-made) heat is mainly related indoor air-conditioning and transportation (Arnfield, 2003; Ichinose et al., 2008; Rizwan et al., 2008; Samuels et al., 2010). Resulted excess heat can increase the need for even more intense indoor air-conditioning. Figure 2 illustrates the interplay between UHI contributing factors.

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