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The role of green roofs in mitigating Urban Heat Island effects in the metropolitan area of Adelaide, South Australia

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ABSTRACT

Changing an urban environment and replacing vegetated surfaces with low albedo materials is one of the reasons for increasing temperatures in an urban environment and consequently also one of the key causes of urban heat island effects. In this study, an experimental investigation at the micro-scale and also a numerical simulation at the macro-scale of a typical urban environment in Adelaide were conducted to estimate the potential for mitigating the UHI effect. The results showed that existing low albedo materials such as asphalt, metal roofs and brick pavements contribute to the heat island potential. Also, urban development and a lack of natural vegetation contribute to increased temperatures in cities. The ability of two types of extensive and intensive green roofs to reduce the surrounding micro-climate temperature were monitored. The results showed that they have significant cooling effects in summer time and could behave as an insulation layer to keep buildings warmer in the winter. Furthermore, different scenarios of adding green roofs to the Adelaide urban environment were investigated using the Envi–MET model. The scenario modelling of adding green roofs in a typical urban area in Adelaide, Australia, supported the hypothesis that this can lead to reductions in energy consumption in the Adelaide urban environment. Also an increased use of other water sensitive urban design technologies such as green walls and street trees together with the adoption of high albedo materials is recommended for achieving the optimum efficiency in terms of reducing urban temperatures and mitigating urban heat island effects.

1. Introduction

Urbanisation growth, climate change and water scarcity are current environmental challenges in many cities around the world and it is estimated that more than half of the human population currently lives in cities (United Nations, 2004; Hopkins and Goodwin, 2011). The urban heat island (UHI) effect is one of the main consequences of a changing climate in the cities. The heat island effect is attributed to higher urban temperatures in city districts compared to the surrounding suburban or rural areas. This phenomenon is mainly associated with a high density of buildings and urban structures with low albedo coefficients resulting in the buildings absorbing more solar radiation (Giuseppe and D'Orazio, 2015). Albedo is the ratio of reflected radiation to incident radiation from at a surface. The use of heat absorbing materials, the reduction in vegetated or green spaces, the characteristics of urban canyons and the production of anthropogenic heat have caused the UHI potential to markedly increase in metropolitan areas (Santamouris et al., 2011, 2014; Sun and Augenbroe, 2014). One of the possible solutions to tackle the consequences of urbanisation growth is to introduce green infrastructure to a city's urban environments. The implementation of green infrastructure is of considerable interest because it is a most effective climate change adaptation tool (Carter, 2011; Berardi et al., 2014; Li et al., 2014). Several methods have been proposed in the literature for combatting the Urban Heat Island (UHI) effect. The addition of green roofs and replacing conventional roof with cool roofs are among the proposed mitigation strategies that aim to reduce UHI. The sensible heat available for transmission to the air or to building envelopes is decreased by both strategies. However, the mechanisms for green roofs and cool roofs to reduce UHI are quite different. Generally, a green roof increases the evapotranspiration rate in urban areas through the addition of soil and plants onto rooftops and redirecting available energy to latent heat. In contrast, a cool roof increases the reflection of incoming solar radiation in urban areas by increasing the albedo of roof surfaces (Li et al., 2014).

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A green roof is an engineering multi-layered structure with the outer layer consisting of vegetation. Green roofs are normally categorised into two types, namely extensive (depth < 150 mm) and intensive (depth ≥ 150 mm) roofs (Berndtsson, 2010; Fassman and Simcock, 2012; Roehr and Fassman-Beck, 2015). Green roofs can bring amenity and enhanced aesthetic value (Getter and Rowe, 2006; Razzaghmanesh et al., 2012; Jungels et al., 2013), increased building value (Nagase and Dunnett, 2010), stormwater runoff mitigation (Mentens et al., 2006; Durhman et al., 2007; Voyde et al., 2010), potential for storm water quality improvement (Berndtsson et al., 2006, 2009, 2010; Razzaghmanesh et al., 2014a), noise reduction (Dunnett and Kingsbury, 2004), the ability to mitigate UHI effects (Wong et al., 2003; Castleton et al., 2010; Chang et al., 2011) and other benefits for urban environments. An investigation of the effects of adding green roofs and green walls to the urban environment of 9 cities around the world with different ranges of climate was undertaken by Alexandri and Jones (2008) who showed that they have a significant effect in reducing urban temperatures. Susca et al. (2011) evaluated the positive effects of vegetation at both the regional and building scales. They monitored the urban heat island in four areas of New York City, and found an average of 2 °C difference in temperatures between the most and the least vegetated areas. Temperature decreases due to vegetation are primarily affected by the vegetation itself (amount and geometry), more than the canyon orientation in hot periods. If applied to the whole city scale, green roofs could mitigate increased urban temperatures, and, especially for hot climates, bring temperatures down to more acceptable levels. They could at the same time lower the energy costs associated with cooling buildings by 32 to 100% (Susca et al., 2011).

There are two numerical models commonly used for urban micro-climate studies and particularly for UHI investigations, namely the RayMan (Matzarakis et al., 2007) and Envi–Met (Huttner and Bruse, 2009) models. In this study the three-dimensional microclimate model Envi–Met model was selected for modelling UHI effects. Skelhorn et al. (2014) used Envi–Met to investigate seven green space scenarios that might be applied at a block or neighbourhood level in a temperate city (Manchester) in north-west England. The changes in air and surface temperatures were compared on a warm summer day in July 2010. The modelling demonstrated that even in suburban areas in temperate cities, a 5% increase in mature deciduous trees can reduce mean hourly surface temperatures by 1 °C over the course of a summer's day.

Perini and Magliocco (2014) used the Envi–Met model to investigate the effects of several variables that contribute to the UHI effect and to outdoor thermal comfort in dense urban environments. The effects of building density (% of built area) and canyon effect (building height) on potential temperature and mean radiant temperature were quantified. The influence of several types of green areas (vegetation on the ground and on roofs) on temperature mitigation and on comfort improvements was investigated for different atmospheric conditions and latitudes in a Mediterranean climate. It was found that vegetation on the ground and on roofs mitigated summer temperatures, decreased the indoor cooling load demand, and improved outdoor comfort. The results of this study also showed that vegetation is more effective with higher temperatures and lower relative humidity. UHI effects have significant impacts on building energy consumption and outdoor air quality (Mirzaei and Haghighat, 2010; Mirzaei, 2015). There are several approaches to studying UHI effects, including multi-scale phenomena, observation and simulation techniques to understand the causes of UHI formation. Because of the complexity of UHI effects, the multi-scale phenomenon is not generally feasible and instead observations or theoretical approaches have most often been employed to investigate the UHI phenomena. However, the causes of UHI effects are not the same in different climates or city features. Therefore, general conclusions cannot be made based on limited monitoring data. With recent progress in computational tools, simulation methods have been used to study UHI effects. In this study, both field investigations and modelling approaches have been used to address the following questions:

1 What are the macro- and micro-scale UHI potentials in a typical Adelaide urban environment?
2 To what extent can intensive and extensive green roofs potentially mitigate UHI effects?
3 How can different scenarios of adding green roofs to a typical Adelaide urban environment be best modelled numerically?

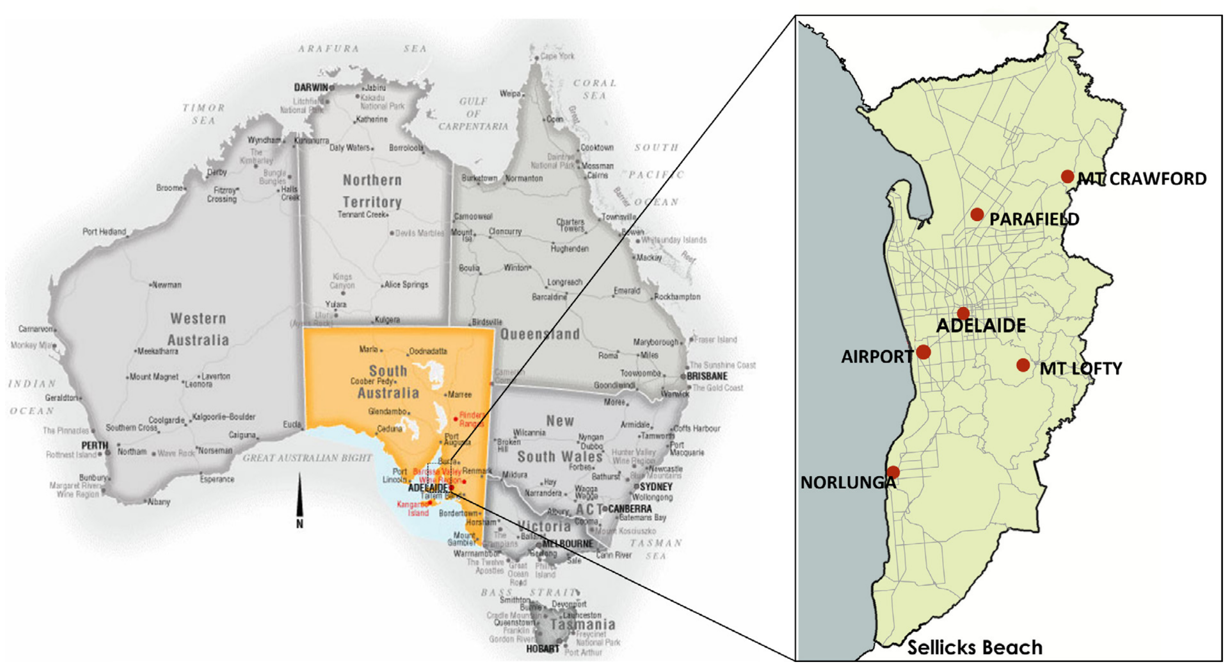

Fig. 1. Study location.