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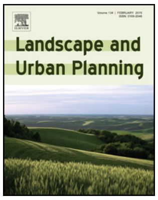

Research Paper

Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes

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HIGHLIGHTS

- Review of cooling potential from green infrastructure in cities with hot, dry summers.
- Presents a hierarchical process to prioritise urban areas for green infrastructure.
- Framework to strategically select green infrastructure that is 'fit-for-place' and '-purpose'.
- Case study of framework applied to local government planning scale.

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ABSTRACT

Warming associated with urban development will be exacerbated in future years by temperature increases due to climate change. The strategic implementation of urban green infrastructure (UGI) e.g. street trees, parks, green roofs and facades can help achieve temperature reductions in urban areas while delivering diverse additional benefits such as pollution reduction and biodiversity habitat. Although the greatest thermal benefits of UGI are achieved in climates with hot, dry summers, there is comparatively little information available for land managers to determine an appropriate strategy for UGI implementation under these climatic conditions. We present a framework for prioritisation and selection of UGI for cooling. The framework is supported by a review of the scientific literature examining the relationships between urban geometry, UGI and temperature mitigation which we used to develop guidelines for UGI implementation that maximises urban surface temperature cooling. We focus particularly on quantifying the cooling benefits of four types of UGI: green open spaces (primarily public parks), shade trees, green roofs, and vertical greening systems (green walls and facades) and demonstrate how the framework can be applied using a case study from Melbourne, Australia.

1. Introduction

Globally, extreme heat events (EHE) have led to particularly high rates of mortality and morbidity in cities as urban populations are pushed beyond their adaptive capacities. Recent EHE examples include: Chicago, USA (1995; 31% mortality increase) (Whitman et al., 1997), Paris, France (2003; 130% mortality increase) (Dhainaut, Claessens, Ginsburg, & Riou, 2003), Moscow, Russia (2010; 60% mortality increase) (Revich, 2011) and Melbourne, Australia (2009; 62% mortality increase) (Department of Human Services, 2009). Many cities expect catastrophic EHEs more often, as the frequency, intensity and duration of EHEs are projected to increase with climate change (Alexander & Arblaster, 2009).

There is evidence that increased mortality and morbidity from EHE are exacerbated in urban populations by the urban heat island (UHI) effect (e.g. Gabriel & Endlicher, 2011). Modified land surfaces from urbanisation lead to the formation of distinct urban climates (Coutts, Beringer, & Tapper, 2007). Natural surfaces and vegetation are replaced with a complex, three-dimensional impervious surface

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Table 1
Existing grey and green infrastructure to be documented as part of the process of selecting and integrating new green infrastructure to mitigate high temperatures in high priority, vulnerable neighbourhoods.

Urban green infrastructure	Grey infrastructure
Irrigated and non-irrigated green space	Street orientation
Location of trees	Building heights (*H*)
Trees species mapping	Street widths (*W*)
Tree health mapping	Height to width ratio (*H*:*W*)
Green roofs	
Green walls	

that absorbs large amounts of solar radiation during the day and this energy is then slowly released at night, keeping urban areas warmer than the surrounding rural countryside and leading to the UHI (Oke, 1982). Rainfall is rapidly drained via stormwater pipes leaving little moisture in the urban landscape, which reduces evapotranspiration and increases sensible heating of the local atmosphere (Coutts et al., 2007). Several studies have shown that higher night time temperatures limit people's recovery from daytime heat stress (Clarke & Bach, 1971). Consequently, many urban populations must adapt to the compounding effects of the UHI, climate change and EHE (Bi et al., 2011).

Many governments are now strategically planning for EHE (O'Neill et al., 2009), often with a focus on short-term preparation and prevention, for example warning systems, promoting behavioural change and preparing emergency services (Kovats & Hajat, 2008; Queensland University of Technology, 2010). Increasing the amount of vegetation, or green infrastructure, in a city is one way to help address the root cause of the problem, by reducing urban air and surface temperature maxima and variation (Bowler, Buyung-Ali, Knight, & Pullin, 2010). However, to substantially reduce the UHI, widespread implementation of green infrastructure is required. For example, measurements during an EHE in Melbourne, Australia, suggested a 10% increase in vegetation cover could reduce daytime urban surface temperatures by approximately 1 °C (Coutts & Harris, 2013).

Urban green infrastructure (UGI) can be defined as the network of planned and unplanned green spaces, spanning both the public and private realms, and managed as an integrated system to provide a range of benefits (Lovell & Taylor, 2013; Tzoulas et al., 2007). UGI can include remnant native vegetation, parks, private gardens, golf courses, street trees and more engineered options such as green roofs, green walls, biofilters and raingardens (Table 1). This paper focuses on the integration of UGI into the public realm to mitigate high urban temperatures and considers the various UGI types and possible locations.

UGI research is not well integrated with urban design and planning, which contributes to the lack of guidance on how best to implement UGI (Bowler et al., 2010; Erell, 2008). UGI is a particularly good option for temperature mitigation in Mediterranean or warm temperate climates due to the greater relative cooling benefits in hot, dry climates (Ottelé, Perini, Fraaij, Haas, & Raiteri, 2011), particularly if water is available to maintain vegetation health and evapotranspiration. Yet, there is a dearth of empirical evidence regarding the benefits of UGI in cities experiencing a Mediterranean climate, nor information on successful and cost effective UGI implementation strategies (Williams, Rayner, & Raynor, 2010). Clearly a cross-disciplinary approach is required.

We present a framework, supported by relevant literature, for green space managers, planners and designers to most effectively integrate UGI into existing urban areas for the primary goal of improved urban climate. With the aid of thermal mapping, a decision framework was developed for local government authorities in Melbourne, Australia. A step by step case-study implementing the framework is provided, drawing on high resolution, airborne thermal mapping as a tool within this framework. Melbourne (37°49′ S; 144°58′ E), on the southern coast of south eastern Australia, has a warm Maritime Temperate climate (Peel, Finlayson, & McMahon, 2007), but has long periods of summer drought and extreme heat. This framework can be applied to cities with classic Mediterranean climates (e.g. Perth, San Francisco, Seville, Beirut and Athens) and those that experience extended summer periods of hot, dry conditions, such as Adelaide and Melbourne. Cities in colder or more humid climates may have different considerations, for example in humid areas there can be a greater emphasis on maximising air flow (Emmanuel, 2005).

2. A framework for using UGI to mitigate excess urban heat

We propose a hierarchical, five step framework to prioritise urban public open space for microclimate cooling (Steps 1–4) using the most appropriate 'fit for place' UGI (Step 5) (Fig. 1). The same principles will apply to privately-owned outdoor space, although this may be complicated by issues of multiple ownership (Pandit, Polyakov, Tapsuwan, & Moran, 2013).

The framework operates firstly at the 'neighbourhood' scale, then the 'street' scale and finally the 'microscale' (Fig. 1). While the actual area would be defined by organisation implementing the framework, a neighbourhood would encompass hundreds of houses and urban features such as a shopping precinct, a school, a railway station, parks and playing fields. The street scale is a smaller unit within a neighbourhood, for example some houses and a strip of shops. The microscale is an area within a street canyon, equivalent to one or more property frontages perhaps. Integrating these three scales is central to this framework, and is important to the strategic integration of UGI for microclimate cooling (Dütemeyer, Barlag, Kuttler, & Axt-Kittner, 2014). This framework is flexible and can be applied and adapted by green space mangers, planners and designers to meet their local circumstances. Local stakeholders can also be involved in the decision framework at any, or all, stages as determined by budget, time and engagement philosophy of the local government authority.

2.1. Step 1—Identify priority urban neighbourhoods

Specific neighbourhoods are prioritised by identifying areas with the largest numbers of people that may be exposed and/or are vulnerable to excessive urban heat. A risk of mortality and morbidity from excessive urban heat is based on a combination of *heat exposure*, *vulnerability* to extreme heat (Dütemeyer et al., 2014), as well as the *behavioural exposure* occurring, in terms of the number of people using public open spaces (Fig. 2). When these three risk drivers intersect (C), a high priority neighbourhood has been identified. However, it is hard to predict the amount of *behavioural exposure* in public open spaces such as community health centres, so neighbourhoods where *heat exposure* and *vulnerability* intersect (B orange) can also be regarded as a priority (Fig. 2).

2.2. Heat exposure

Areas within cities that experience extreme heat are not evenly distributed spatially and 'hot-spots' occur where there is intense urban development with little vegetation and/or water. Consequently, air temperatures predicted from coarse resolution models (e.g.100–200 km) can frequently be exceeded in susceptible urban neighbourhoods or 'hot-spots' (McCarthy, Best, & Betts, 2010). To adequately assess how exposed a neighbourhood population may be to high temperatures, temperature information that is specific to that location is important (Kovats & Hajat, 2008). Satellite or airborne remotely sensed thermal data can provide a snapshot in time of land surface temperature across a large spatial area,