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Research Paper

Designing urban parks that ameliorate the effects of climate change

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HIGHLIGHTS

- During heat waves now and in the future urban microclimates put human health at risk.
- Intercepting solar radiation is the most effective way to reduce the heat load on people.
- Reducing air temperature is the second most effective way to reduce heat loads.
- Evidence-based climate-responsive design can make parks more thermally comfortable.

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ABSTRACT

Many inhabitants of cities throughout the world suffer from health problems and discomfort that are caused by overheating of urban areas, and there is compelling evidence that these problems will be exacerbated by global climate change. Most cities are not designed to ameliorate these effects although it is well-known that this is possible, especially through evidence-based climate-responsive design of urban open spaces. Urban parks and green spaces have the potential to provide thermally comfortable environments and help reduce vulnerability to heat stress. However, in order for them to provide this function, parks must be designed within the context of the prevailing climate and predicted future climates. To analyze the effects of elements that alter microclimate in parks, we used human energy budget simulations. We modelled the outdoor human energy budget in a range of warm to hot climate zones and interpreted the results in terms of thermal comfort and health vulnerability. Reduction of solar radiant input with trees had the greatest effect in all test cities. Reduction in air temperature was the second-most important component, and in some climates was nearly as important as incorporating shade. We then conducted similar modelling using predicted climates for the middle of the century, emphasizing the importance of city-level efforts for park design to assist in minimizing future climate-related urban health risks. These simulations suggested that heat waves in many climates will produce outdoor environments where people will be in extreme danger of heat stress, but that appropriately designed parks can reduce the threat.

1. Introduction

More than half of the people in the world now live in urban areas, and that proportion is increasing, inducing urban growth both in size and in density (Seto, Fragkias, Güneralp, & Reilly, 2011). Physical characteristics of cities such as little vegetation, predominance of hard impermeable surfaces, and anthropogenic heat sources all contribute to the occurrence of the well-documented urban heat island (UHI) (*e.g.* Golden, Hartz, Brazel, Luber, & Phelan, 2008; Oke, 1987; Voogt & Oke, 2003). Enhanced urban heating is affected by two critical current environmental aspects: population growth and climate change (Stewart & Oke, 2012). This poses challenges for urban residents as the inadvertent thermal environment causes discomfort, lower work productivity (Daanen, Jonkhoff, Bosch, & ten Broeke, 2013), and health hazards in circumstances such as heat waves (Golden et al., 2008; Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006). Many of the growing cities in the world are situated in temperate and warm climate regions (Köppen–Geiger zones Af,

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Bsh, Cfa, BWh, Dfa, see Fig. 1) where such problems are already quite prominent. In the context of global climate change, projections of higher summertime air temperatures will cause these problems to worsen (McCarthy, Best, & Betts, 2010). The way cities are built must respond to these challenges and provide better thermal conditions for urban residents (*e.g.* Mazhar, Brown, Kenny, & Lenzholzer, 2015).

There are various options to provide cooling in cities. The best-documented are urban parks and green spaces which have the potential to provide thermally comfortable environments and help to reduce vulnerability to heat stress. These areas are known in the literature as 'park cool islands' (PCIs) (*e.g.* Chow, Pope, Martin, & Brazel, 2011; Oke, 1987; Upmania, Eliasson, & Lindqvist, 1998). Studies have demonstrated that the air temperatures in parks are typically lower than in the surrounding urban environment (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Spronken-Smith & Oke, 1998; Vanos, Warland, Gillespie, Slater, et al., 2012), and the cool air can extend some distance into downwind neighbourhoods (*e.g.* Slater, 2010; Yokohari, Brown, Kato, & Yamamoto, 2001). However, results vary with respect to the local climate and the methods used for assessment (Bowler et al., 2010). For example, a PCI where the air temperature was lowered by 4.9 °C was found for fair-weather summer days in Toronto, Canada (Slater, 2010; Vanos, Warland, Gillespie, Slater, et al., 2012), yet in Phoenix, AZ, summer simulations of a PCI found a maximum air temperature decreases of 1.9 °C (Declet-Barreto, Brazel, Martin, Chow, & Harlan, 2013).

Studies of PCIs have focused primarily on air temperature, yet human thermal sensation is also affected by other microclimatic aspects of solar and terrestrial radiation and wind (*e.g.* Brown & Gillespie, 1995; Fanger, 1970; Mayer & Hoppe, 1987; Parsons, 2003a, 2003b). While air temperature and relative humidity can be modified slightly by large areas of green space, wind and radiation can be greatly modified through small-scale design interventions (thus slightly altering experienced temperature and humidity), thus having a substantial effect on human thermal comfort (Ahmed, 2003; Brown & Gillespie, 1995; Klemm, Heusinkveld, Lenzholzer, & Van Hove, 2015; Lin, 2009; Shashua-Bar, Pearlmutter, & Erell, 2011). The parameters of wind and radiation vary widely in different parts of the world; hence, we hypothesized that park design must not be a 'one-size-fits-all' schematic, but account for the spatio-temporal variability of specific climate parameters. A landscape element that is effective in providing thermally comfortable conditions in one climate zone might not be effective in another. For instance, in climate zones with sunny summer skies, providing shade for park visitors can be an important contribution to thermal comfort, whereas providing shade might not have the desired effect in a climate with predominantly overcast skies. In order to design parks that will have the greatest cooling effect on people during hot summertime weather, a landscape architect needs to know the relative impact of various design interventions (*e.g.* Brown, 2011).

The goal of this study, then, was to investigate the effects of urban park characteristics on people's thermal comfort in different climate zones, both now and in the future. The results will allow landscape architects to design parks that mitigate negative effects of enhanced heat islands and radiant heat absorption in the context of global climate change and growing cities.

Accordingly, our main research question was: in a range of climate zones, and under various hot season weather conditions, as well as future scenarios of the International Panel on Climate Change (IPCC), what is the effect of microclimate modifications caused by elements in the landscape on the thermal comfort of people in outdoor areas? We focused on the parameters that can both be modified by elements in the parks and have a perceptive effect on human thermal sensation, namely air temperature, short wave radiation, and wind, with humidity changing in concert with air temperature (Brown & Gillespie, 1995). Hence, our research questions were:

1. What are the effects on thermal sensation of reductions in air temperature (by the magnitude found in PCI studies)?
2. What are the effects on thermal sensation of reduction of solar radiation by various species of trees and by solid structures?
3. What are the effects on thermal sensation of reductions and increases in wind speed?

Real-world situations are addressed using the local warm season climate normals and likely weather modifications accounting concomitant changes in variables such as vapour pressure within the model. The answers to these questions can inform the development of design guidelines for improving outdoor human thermal comfort that are specific to different climate zones.

2. Methods

To answer the research questions, we used climate data for five highly urbanized cities in different climate zones. We analyzed the thermal comfort effects of different hot climate situations and also those based on future climate scenarios developed by the IPCC (Seneviratne et al., 2012). Using these climate simulations, we modelled the effects of different types of microclimate modifications that impact changes in air temperature, radiation, and wind speeds, on thermal comfort. As there is minimal evidence that the relative humidity (and vapour pressure) can be altered alone by park design in comparison with these above variables (Brown & Gillespie, 1995; Nikolopoulou & Lykoudis, 2007; Pearlmutter, Bitan, & Berliner, 1999), RH is not modelled in isolation; however, as it responds in concert with air temperature, the relative humidity is accounted for implicitly in the biophysical model.

2.1. Study areas

We selected study sites in five climate zones (see Fig. 1) in which many urbanized areas are found worldwide and that also experience hot weather for at least one season of the year. Based on the Köppen–Geiger classification the zones that we tested were Af, Bsh, Cfa, BWh, Dfa, details of which are listed in Table 1. We used published climate data from the following five cities (one each for the identified Köppen–Geiger zones) to represent typical conditions within each zone:

- Kuala Lumpur, Malaysia (Af)
- Lahore, Pakistan (Bsh)
- Alice Springs, Australia (BWh)
- Kyoto, Japan (Cfa)
- Toronto, Canada (Dfa)

2.2. Modelling the thermal comfort of people in outdoor environments

There are several human thermal comfort models available in the literature (Epstein & Moran, 2006). This study required that the relative magnitude of the streams of energy to and from a person be outputs from the model so the resulting design guidelines would address the main energy flows. On this basis the human thermal comfort model COMFA (Brown & Gillespie, 1986; Kenny, Warland, Brown, & Gillespie, 2009a, 2009b; Vanos, Warland, Gillespie, & Kenny, 2012a, 2012b) was used to simulate the effects of changes in microclimate on the thermal comfort of individuals in outdoor environments. COMFA takes inputs of typical weather data that are universally available and estimates thermal sensation levels, based