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Research Paper

Hot playgrounds and children's health: A multiscale analysis of surface temperatures in Arizona, USA

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HIGHLIGHTS

- A mismatch exists between remotely sensed and *in situ* urban surface temperatures (T_s).
- The hottest T_s in a Phoenix area neighborhood were found on playground surfaces.
- Children are more vulnerable to the effects of heat stress and high T_s than adults.
- Shade of any type is found effective in reducing T_s and improving thermal safety.
- Data must be collected at the touch-scale for spatially accurate high T_s mitigation.

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ABSTRACT

Objectives: To provide novel quantification and advanced measurements of surface temperatures (T_s) in playgrounds, employing multiple scales of data, and provide insight into hot-hazard mitigation techniques and designs for improved environmental and public health.
Methods: We conduct an analysis of T_s in two Metro-Phoenix playgrounds at three scales: neighborhood (1 km resolution), microscale (6.8 m resolution), and touch-scale (1 cm resolution). Data were derived from two sources: airborne remote sensing (neighborhood and microscale) and *in situ* (playground site) infrared T_s (touch-scale). Metrics of surface-to-air temperature deltas (ΔT_{s-a}) and scale offsets (errors) are introduced.
Results: Select *in situ* T_s in direct sunlight are shown to approach or surpass values likely to result in burns to children at touch-scales much finer than T_s resolved by airborne remote sensing. Scale offsets based on neighbourhood and microscale ground observations are 3.8 °C and 7.3 °C less than the ΔT_{s-a} at the 1 cm touch-scale, respectively, and 6.6 °C and 10.1 °C lower than touch-scale playground equipment T_s, respectively. Hence, the coarser scales underestimate high T_s within playgrounds. Both natural (tree) and artificial (shade sail) shade types are associated with significant reductions in T_s.
Conclusions: A scale mismatch exists based on differing methods of urban T_s measurement. The sub-meter touch-scale is the spatial scale at which data must be collected and policies of urban landscape design and health must be executed in order to mitigate high T_s in high-contact environments such as playgrounds. Shade implementation is the most promising mitigation technique to reduce child burns, increase park usability, and mitigate urban heating.

1. Introduction

A neighborhood's thermal environment is complex. It is scale dependent and influenced by numerous physical characteristics such as weather, urban design, and the thermal properties of building and ground materials (Yaghoobian, Kleissl, & Krayenhoff, 2010). This complexity results in processes that impact health at several

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scales, yet urban heat-health research often employs coarse scales collected from sparse standardized meteorological observations (BASC, 2012; Kuras, Hondula, & Brown-Saracino, 2015), which gives little evidence of linkages between urban form, air temperature, and surface temperature at the human scale.

Microscale urban climate models and remotely sensed data (on the order of 1 m^2 to 1 km^2) are often employed for heat stress analysis (e.g., Harlan, Declet-Barreto, Stefanov, & Petitti, 2013; Hondula et al., 2012; Masson, Champeaux, Chauvin, Meriguet, & Lacaze, 2003; Mishra, Ganguly, Nijssen, & Lettenmaier, 2015; Stefanov, Prashad, Eisinger, Brazel, & Harlan, 2004), with airborne remotely sensed data providing surface temperatures at a resolution ranging from 7 to 140 m (Stefanov et al., 2004). These scales may possess insufficient spatial resolution to determine certain personal health impacts based on micro-environmental heat exposure. The human-scale ranges from ∼1.0 m for personal interactions with the proximate atmospheric and radiative microenvironment, to ∼1 cm for touch-scale interactions. At this touch-scale, extreme temperatures can cause burns or damage to the skin, with a severity that depends greatly on the object's initial temperature, its material properties, and the contact thermal conductance (ISO 13732, 2010; Ungar & Stroud, 2010). In an outdoor urban environment, touch-scale surface temperature is based on urban design, material, orientation, and sun angle (e.g., Ketterer & Matzarakis, 2014a; Krayenhoff & Voogt, 2007). The touch-scale is on the order of 100× to 10,000× finer than that which remotely sensed data and urban climate models can currently provide. This variance therefore complicates spatially accurate design guidelines and policies.

The current study addresses the surface temperatures (ground and equipment) in small urban public playgrounds frequented by children aged 2–12 (ASTM F1487, 2011; CPSC, 2010). Urban parks, childcare play spaces, and urban playgrounds are important resources for urban sustainability, physical activity, and community health (Moore & Cosco, 2014; Vanos, 2015; Wolch et al., 2011). In the absence of design measures to mitigate heating, surfaces may become dangerously hot (e.g., Fig. 1), and playgrounds may become microscale heat islands that enhance, rather than mitigate, the larger urban heat island effect (UHI) (e.g., Moogk-Soulis, 2010). On clear, warm days with direct solar radiation, exposure to the mean radiant temperature (T_{mrt})—the combination of all short- and long-wave radiant fluxes (Thorsson, Honjo, Lindberg, Eliasson, & Lim, 2007)—becomes the most significant agent of heat gain to humans (Johansson, Thorsson, Emmanuel, & Krüger, 2014; Kántor & Unger, 2011; Mayer & Höppe, 1987), as well as to surfaces. The open design of urban parks with high radiant heat loads does not provide conducive spaces for safe physical activity and thermal comfort compared to shaded areas on warm–hot days (Koppe & Jendritzky, 2005; Matzarakis & Endler, 2010; Vanos, 2015; Vanos, Warland, Gillespie, Slater, et al., 2012). However, T_{mrt} can be reduced through design by (1) controlling incoming solar radiation with shade, indirectly reducing surface temperatures; and (2) by modifying surface materials to reduce surficial longwave radiation flux, indirectly reducing surface and air temperatures.

Quantifying temperature exposures (surface and air) in urban areas conserved for active use (i.e., parks and playgrounds) is important for understanding health effects (McGeehin & Mirabelli, 2001), and to adapt to future urban heating effects (Harlan & Ruddell, 2011; McCarthy & Sanderson, 2011), urban land use change (Adachi et al., 2013), and increasing temperatures with projected climate change (Meehl & Tebaldi, 2004; Tebaldi, Hayhoe, Arblaster, & Meehl, 2006). Most cities are not designed to ameliorate the effects of warming, although it is well known that this is possible through evidence-based climate-responsive design of urban spaces (Brown, Vanos, Kenny, & Lenzholzer, 2015; Erell, Pearlmutter, & Williamson, 2012; Masson et al., 2014; Middel, Chhetri, & Quay, 2015). Properly designed playgrounds contribute to microscale cooling, serving as heat refuges through the summer season (Cheng, Wei, Chen, Li, & Song, 2014; Chow, Pope, Martin, & Brazel, 2011; Vanos, Warland, Gillespie, Slater, et al., 2012), as well as comfortable and safe places for children to play and engage in activities for improved health and well-being (Ciucci et al., 2013; Moore & Cosco, 2014; Vanos, 2015; Wolch et al., 2011).

Children are uniquely sensitive and vulnerable to hot ambient environments as compared to adults (Balbus & Malina, 2009), mainly due to their high ratios of both metabolism-to-surface area, and surface-area-to-body-mass (Falk & Dotan, 2008; Wenger, 2003), resulting in thermoregulatory inferiority relative to adults during physical activity in hot conditions (Falk & Dotan, 2008). Such hot conditions result in air temperature becoming greater than skin temperature, and convective heat (which is normally a loss of heat from the skin's surface) becomes a gain and thus a quicker path to heat stress for children. In the same sense,

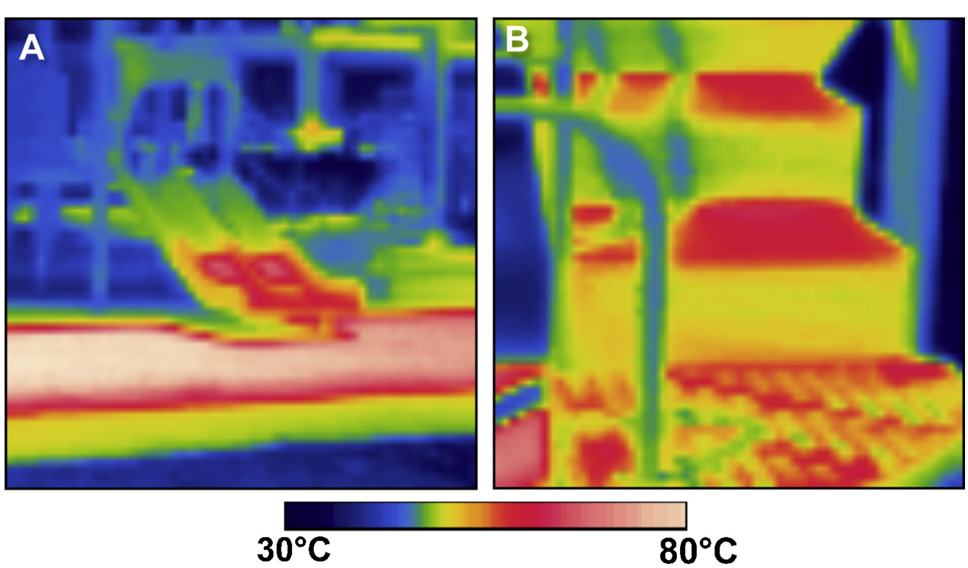

Fig. 1. Surface temperature images photographed in the study playgrounds using Infrared Thermography (IRT) (FLIR camera, TG165). (A) Slide and black/green rubber ground surface in sun (71 °C on slide; 82 °C on rubber), and under shade sail (blue/green); (B) playground steps in sun, black powder-coated metal (58 °C). Photos were taken at 1045 h LST. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)