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# Analysis of urban heat in a corridor environment – The case of Doha, Qatar

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## ABSTRACT

Doha, Qatar is one of the arid coastal cities of the Gulf Cooperation Council (GCC) countries. Like similar cities, temperatures can vary widely throughout, with rapid and extensive development that has contributed to micro-climate changes. While numerous studies since the 1950s have assessed urban micro-climates, few have offered insights into urban corridor environments. This research is one of few projects to examine temperature records along two major roadways and identify factors that explain variation. The research uses vehicle-based air temperature traverses during late spring and summer 2016 using a Type T fine gauge thermocouple mounted in a white plastic tube and supported above the vehicle on the passenger-side window. The data were assessed in terms of four factors that may impact temperature along the corridors, including: distance from the coast, traffic volume, vegetation density, and building volume density from 50 m up to 400 m (in 50 m intervals) from the centerline of the traverse. Results indicated that the two most critical variables that predict air temperature patterns along the corridors are the distance to the coast and the traffic volume. This knowledge can be incorporated into urban planning and design practice for extreme arid environments to maintain temperatures that reduce heat-related stress.

## 1. Introduction

The city of Doha, the capital of Qatar, has witnessed the emergence of oil-wealth in the last few decades that has transformed the city from a small fishing, pearling, and trading settlement to a modern city with numerous examples of international architecture, an urban core of high-rise offices and apartments, and a growing number of hotels, museums, and other facilities for hosting international events. The transformation has changed the fabric of the society due to the vast influx of workforce to serve the expanding city. The global competition and the increasing numbers of the population demand massive expansion in infrastructure and urbanization that have changed the overall built environment of the city (Adham, 2008; Wiedmann and Salama, 2012). The exceptional form and pace of urbanization in desert cities, like Doha, Qatar, highlight the need for an experimental detailed study of its potential impact on local microclimate change. Sustaining an adequate quality of life for this increasing population in Doha may be contingent, to a critical extent, on our understanding of the climatic changes induced by urbanization (Charabi and Bakhit, 2011; Pearlmutter et al.,

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2006).

The Urban Heat Island (UHI) has been investigated as one of the most stimulating climatic phenomenon of cities. It can be conceptualized as “the rise in temperature in any man-made area, resulting in a well-defined, distinct “warm island” among the “cool-sea” represented by the lower temperature of the area's nearby natural landscape” (Arrau and Pena, 2016). The main cause of UHI formation is the differential cooling rates of built and natural surfaces, which is most apparent during nighttime (Oke, 1982). Built surfaces comprise a high proportion of water-resistant, low albedo and low emissivity construction materials. Urban areas have been found to have 2–5% lower albedo and 1–2% lower emissivity than surrounding croplands (Jin et al., 2005). As a result, they absorb short-wave radiation, that is released afterwards as heat. Numerous studies have revealed that urban areas, compared to non-urbanized areas in their surroundings with less artificial surfaces, record higher local temperatures as a result of the UHI effect (Arnfield, 2003; Taha, 1997; Wong et al., 2016). The effect of the UHI is not limited to the adjacent urban environment, but also has effects on the global environmental quality. Jin et al. (2005, p. 1552) argue that “land–atmosphere–biosphere interactions cause significant mesoscale circulation anomalies, and these anomalies can propagate to large scale.”

In studying the specific causes and patterns of the UHI for different locations, a number of approaches, measurement methods and scales have been investigated, including ground-based stationary or mobile surveys (Blankenstein and Kuttler, 2004; Yan et al., 2014) of ground-level air or surface temperature (Voogt and Oke, 2003) at scales ranging from the local to *meso* scale up to continental or global studies (Jin et al., 2005) and at levels of the urban canopy layer or urban boundary layer as distinguished by Oke (1976). Remote sensing has also been found to be important, particularly for city-wide, regional or larger scale studies (Jin et al., 2005; Nichol et al., 2009; Streutker, 2002; Voogt and Oke, 2003).

While many urban climate studies have been documented for mid-latitude cities (Arnfield, 2001; Oke, 1986), fewer studies can be found for cities in arid tropical or sub-tropical regions (Lazzarini et al., 2013; Pearlmutter et al., 1999; Sofer and Potchter, 2006), which are perhaps some of the most challenging climate regimes for thermal comfort. Research in the desert city of Muscat, Oman used mobile traverses to examine the UHI in selected sites. Results indicated that UHI magnitude is greatest in summer and that it is located along narrow roads with low ventilation, multi-storied buildings, high business activities and heavy road traffic (Charabi and Bakhit, 2011). Another study in the arid desert city of Phoenix, Arizona examined the seasonal relationship of urban plant cover, land use, and micro-climate in the city. Near-surface temperatures were measured along several transects. Land use was identified as the most evident impact on microclimate, especially during summer, with residential and agricultural land uses recording the lowest air temperatures, while industrial and commercial land uses recorded the highest temperatures (Stabler et al., 2005).

## 2. Study background

Doha is the most densely populated city in Qatar with approximately 40% out of a total population of 2.4 million in 2015 (Qatar Ministry of Development and Planning Statistics, 2015). For this study, the climate of Qatar is significant in that it constitutes the combined effects of extremely hot, and sometimes humid summers, a coastal location, and the formation of the UHI induced by rapid urbanization (Golden, 2004; Ferwati et al., 2016). Due to its hot climate from mid-April through November and the expanding infrastructure, residents experience a high degree of thermal discomfort during this part of the year. For example, summer outdoor temperatures frequently exceed 40 °C, whereas humans are most comfortable during summer with ambient temperatures ranging from 23 to 27 °C (Epstein and Moran, 2006; ASHRAE, 1992). Of course, an individual's perception of thermal comfort is much more complex and dependent on physical parameters other than the ambient air temperature alone. This topic has been widely researched to increase the understanding of the physical parameters that impact thermal comfort leading to the development of numerous models for both indoor and outdoor comfort (Coccolo et al., 2016; Cheung and Jim, 2017; Rupp et al., 2015).

Summer heat will be intensified by the effect of the UHI, and this is likely to have negative impacts on the welfare and health of city residents, making it important to examine the factors that contribute to increased temperatures in such a city. A previous study in Doha, which found a maximum UHI intensity of 3.5 °C in summer and 1.5 °C in winter, attributed the UHI effect to the desert environment, heat exhaust emitted by vehicles and air conditioning, reductions in vegetation, as well as heat that is trapped by buildings and other built surfaces (e.g., roads and pavements) during the day and then released at night (Sasidharan et al., 2009). Other studies have highlighted the role that land use types have on the thermal pattern of the UHI (Feizizadeh and Blaschke, 2013; Hart and Sailor, 2009; Middel et al., 2014) as well as the wall-to-wall distance and height of buildings, leading to formation of urban canyons that, in some locations, constrain the rate of escape at night of sun energy absorbed by construction materials during the day.

Remarkably, earlier research identifies transport corridors and roadways, in general, as major contributors to urban heat (Sasidharan et al., 2009; Wong et al., 2016). Yet, at the same time, we have not fully identified the characteristics of urban corridors that are responsible for generating such acutely higher temperatures. Corridors offer an immediately fruitful opportunity to impact the growth of rapidly urbanizing regions. They are larger than an individual parcel/tax lot, and smaller than city-wide analysis, but offer the possibility of examining a range of building densities, configurations, land uses, and traffic patterns within a well-defined spatial element. Rapidly urbanizing regions require particular attention to the scale of corridors for three reasons: (1) many rapidly developing cities are composed of sprawling areas of low-density and often irregular, minimally planned growth patterns; (2) they are often the first to be planned; and (3) they attract future development. Therefore, a central aim of this research is to explore the UHI patterns that emerge from urban corridors, and develop methods of analysis and planning that may offer insights for reducing heat trapping design that are consistent with rapidly changing cities.

This study utilizes a fine-scale approach of mobile air temperature traverses for studying the thermal regimes in two major urban corridors of the city. In particular, these major corridors are long, nearly straight roads, running from the coast to more than 20 km inland, which provide a distinct opportunity for studying coastal influences compared to other built environment variables. The study