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Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions

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HIGHLIGHTS

- We report data of Urban Heat Island Intensity and Characteristics for 101 Asian and Australian Cities and Regions.
- The relationship between UHI intensity and population is examined.
- The influence of the weather parameters is investigated.
- The daily and seasonal variations of UHI intensity are analyzed.

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ABSTRACT

Urban heat island is the more documented phenomenon of climate change. Information on the magnitude and the characteristics of the canopy layer urban heat island measured in 101 cities and regions of Asia and Australia and collected through 88 scientific articles, are compiled, evaluated and presented. Data are classified in several clusters according to the experimental protocol used and the type of statistical information reported regarding the magnitude of the urban heat island. Results and detailed analysis are given for each defined cluster. Very significant differences on the UHI intensity are found between the clusters and analyzed in detail. The detailed impact of the main weather parameters and conditions on the magnitude of the UHI is also investigated. The specific influence of anthropogenic thermal fluxes as well as of the urban morphological and construction characteristics to UHI is thoroughly examined. The relation between the UHI intensity and the city size is assessed and global relationships of UHI as a function of the urban population are proposed. The seasonal and diurnal variability of the UHI is analyzed and discussed while specific features and conditions like the urban heat island characteristics in coastal cities and the existence of daytime cool islands are explored. Finally, the impact of the selected reference station and its characteristics is considered.

1. Introduction

Urban heat island phenomenon deals with the development of higher ambient temperatures in cities compared to the surrounding rural and suburban areas (Santamouris, 2001). The magnitude of the urban heat island is a function of the urban layout, materials' characteristics, synoptic weather and climate conditions, local meteorological factors, physical, structural and morphological characteristics of the cities and anthropogenic heat released while it also strongly depends on the selection of the reference rural measuring station (Oke et al., 1991).

Urban heat island has a serious impact on the energy consumption of buildings during the summer period and increases highly the cooling energy consumption and the corresponding peak electricity demand (Santamouris, 2014a; Santamouris et al., in press). In parallel, it is associated with an important increase of the concentration of urban pollutants and in particular of the tropospheric ozone (Stathopoulou et al., 2008), serious comfort, health and mortality problems (Pantavou et al., 2011; Santamouris and Kolokotsa, in press; Sakka et al., 2012) and finally an important increase of the city's carbon footprint (Santamouris et al., 2007).

Observations and monitoring data of the urban heat island characteristics are available since the beginning of the previous century and even before. Measured data on the characteristics of the near surface canopy layer urban heat island are available for hundreds of cities and in reality for most of the major cities of the world (Santamouris, 2007). In parallel, hundreds of studies are performed aiming to investigate the impact of urban heat island on human health, energy consumption, urban ecology, economy and well being of humans. At the same time, a highly important scientific activity has been initiated aiming to develop advanced mitigation and adaptation technologies and systems to counterbalance the impact of urban heat island. To this end, the issue

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of urban heat island has acquired an interdisciplinary character by involving climatologists, energy experts, material designers, medical scientists, urban designers, environmentalists, etc.

However, a thorough examination of the existing studies opens a serious discussion on the authenticity of the reported measurements, the accuracy and the representativeness of the results, and the overall validity of the scientific conclusions given (Stewart and Oke, 2012). In fact the knowledge on urban heat island is quite rich but is overshadowed by various inconsistencies as related to the performed experimental and theoretical analysis. Diverse monitoring techniques are proposed and employed involving mobile traverses, standard fixed measuring equipment and non-standard fixed observation stations. In parallel, the duration of the reported experiments, the number of measuring stations used, the season the monitoring has taken place, the format of the reported UHI intensity and the methodology to select the reference rural station, vary considerably between the reported studies making quite difficult any interstudy comparison. Recent analysis of many of the existing urban heat island studies (Stewart, 2011), found that almost 75% of the studies failed to report quantitative information on important factors such as site exposure and land cover.

The response to the above questions is not obvious, a fact which leads to a serious need for the systematic analysis of the existing fragmented literature in order to examine and classify existing knowledge in an uncontestable way and comprehensively explain recent scientific findings. The present study aims to analyze in depth the characteristics of UHI experimental studies performed for 101 Asian and Australian cities and regions. The magnitude of the heat island as well as the main parameters influencing the characteristics of the heat island are analyzed and discussed. The overall analysis offers coherent scientific explanations and pertinent results to be used by all relevant scientific disciplines working on the topic of urban heat island.

2. Density of the study

This study presents and analyzes published experimental data on the urban heat island magnitude and characteristics for 101 Asian and Australian cities and regions. It is based on information collected from 88 scientific articles published from 1966 to 2014 in peer review journals, conferences, books, research reports or other original articles published in accredited media. Only articles providing sufficient information on the spatial area considered, the type of experiments and the equipment used are taken into account. Studies not officially published were excluded. Articles published by the same authors in different sources reporting the same experiment were considered when different spatial or temporal data were reported. Many of the considered studies reported experiments and data for more than one city, thus in total the paper includes data from 133 observations performed in the 101 considered cities and regions. The study focuses on canopy layer ground basis observations of the near surface air temperature while articles addressing boundary layer heat island, surface heat islands using remote sensing equipment, subsurface and non-urban heat island are not considered. Only studies aiming to quantify urban heat island based on experimental methodologies are considered while articles investigating urban heat island characteristics using simulation techniques are rejected. The specific cities and regions considered as well the sources of information used for each case study are given in Table 1.

Table 1
Cities and regions and heat island studies in Asia and Australia considered in the present work.

Australia: Adelaide (Erell and Williamson, 2007), Melbourne (Morris et al., 2001; Morris and Simmonds, 2000; Torok et al., 2001), Camperdown (Torok et al., 2001), Colac (Torok et al., 2001), Hamilton (Torok et al., 2001), Hobart (Nunez, 1979), Sydney (Parliament NSW, 2014)
Bahrain: Bahrain (Radhi et al., 2013)
Bangladesh: Dhaka (Ershad and Nooruddin, 1994)
China: Beijing (Miao et al., 2009; Ren et al., 2007; W. Liu et al., 2007; J. Liu et al., 2007; Yu and Fei, 2006), Wuhan (Ren et al., 2007), North East China (Wang et al., 1990a, 1990b), Northern Plains (Wang et al., 1990a, 1990b), Middle Lower China (Wang et al., 1990a, 1990b), South East Coast (Wang et al., 1990a, 1990b), South West (Wang et al., 1990a, 1990b), North West (Wang et al., 1990a, 1990b), Shanghai (Cui et al., 2007; Zhao et al., 2006; Tan et al., 2010; Zhu et al., 2003), Large Cities (Hua et al, 2008), Medium Size Cities (Hua et al., 2008), Small Size Cities (Hua et al., 2008), Six cities in the Liaoning Province (Li et al., 2012), Guangzhou (Mo, 2014), Nanjing (Huang et al., 2008), Shenzhen (Zhang et al., 2008), Xi'an (W. Liu et al., 2007; J. Liu et al., 2007), Urban areas around Yangtze River Delta (Yin et al., 2007), Hong Kong (Giridharan et al., 2004; Giridharan et al., 2005; Giridharan et al., 2004), Suzhou (Zhang et al., 2011)
Japan: Tokyo (Kataoka et al., 2009; Saitoh and Shimada, 1996; Sakakibara and Owa, 2005), Osaka (Kataoka et al., 2009; Nabeshima et al., 2006; Masumoto et al., 2006), Kumamoto (Saito et al., 1990), Kyoto (TakahashI et al., 2004), Tachikawa (Kohji et al., 1986), Fuchu (Kohji et al., 1986), Fussa (Kohji et al., 1986), Higashimurayama (Kohji et al., 1986), Akigawa (Kohji et al., 1986), Sedai (Sakaida, 2014; Sakaida et al., 2011), Nagano Area (Sakakibara and Owa, 2005), Kumagaya (Kuwagata et al., 2014), Hakuba (Sakakibara and Morita, 2002), Matsumoto (Sakakibara and Mieda, 2002), Asashina (Sakakibara and Kitahara, 2003), Akaiwa and Tokida (Sakakibara and Kitahara, 2003), Tomono (Sakakibara and Kitahara, 2003), Koundai (Sakakibara and Kitahara, 2003), Obuse (Sakakibara, 1999), Kofu Basin (Akatsuka et al., 2011), Tsukumba (Kusaka et al., 2011).
India: Delhi (Mohan et al., 2013; Mohan et al., 2013), Guwahati (Borbora and Das, 2014), Pune (Deosthali, 2000), Visakhapatnam (Suryadevara, 2006), Chennai (Sundunndersingh, 1990), Thiruvananthapuram (Ansar et al., 2012), Bhopal (WMO, 1986), Calcutta (WMO, 1986), Mumbai (WMO, 1986), Vijayawada (WMO, 1986), Koshi, (Thomas AND Zachariah, 2011)
Indonesia: Jakarta (Kataoka et al., 2009)
Iran: Teheran (Mousavi-Baygi et al., 2010)
Iraq: Mosul (Turki and Shaheen, 2013)
Israel: Beer Sheva (Goldreich, 1995), Ashdod (Goldreich, 1995; Sharon and Koplowitz, 1972), Netanya (Goldreich, 1995), Tel Aviv (Goldreich, 1995; Saaroni et al., 2000), Eilat (Sofer and Potchter, 2006)
Korea: Seoul (Kataoka et al., 2009; Kim and Baik, 2002; Kim and Baik, 2005; Lee and Baik, 2010; Kim and Baik, 2004; Park, 1986), Incheon (Kim and Baik, 2004), Daejeon (Kim and Baik, 2004), Daegu (Kim and Baik, 2004), Gwanglu (Kim and Baik, 2004), Busan (Kim and Baik, 2004)
Kuwait: Kuwait (Nasrallah et al., 1990)
Malaysia: Kuala Lumpur (Elsayed, 2011; Sani, 1990), Various Cities in Klang Valley (Sani, 1990), Georgetown (Sani, 1990), Johor Bahru (Sani, 1990; Kubota and Ossen, 2014), Kota Kinabalu (Sani, 1990), Muer (Rajagopalan et al., 2014)
Mongolia: Ulaanbaatar (Ganbat et al., 2013)
New Zealand: Christchurch (Tapper et al., 1981; Kingham, 1969)
Oman: Muscat (Charabi and Bakhit, 2011)
Pakistan: Karachi (Sadiq and Ahmad, 2010), Hyderabad (Sadiq and Ahmad, 2010)
Philippines: Manila (Kataoka et al., 2009)
Saudi Arabia: Jeddah (Abdullah and Abar, 1991), Al-Hassa (Alghannam and Al-Qahtnai, 2012)
Singapore: Singapore (Tso, 1996; Nieuwolt, 1966; Chang and Goh, 1998; Wong and Yu, 2005; Rajagopalan et al., 2008; Chow and Roth, 2006)
Sri Lanka: Colombo (Emmanuel, 2005)
Taiwan: Taipei (Kataoka et al., 2009; Lin et al., 2008)
Thailand: Bangkok (Kataoka et al., 2009; Jongtanom et al., 2011), Chiang Mai (Jongtanom et al., 2011), Songkhla (Jongtanom et al., 2011)
Turkey: Izmir (Tayanc and Toros, 1997), Adana (Tayanc and Toros, 1997), Bursa (Tayanc and Toros, 1997), Gaziantep (Tayanc and Toros, 1997), Ankara (Karaca et al., 1995)

3. Classification of the studies and main characteristics

Studies are classified according to two specific criteria:

a) The experimental protocol used to collect the urban heat island data in each place. In particular articles are classified in three clusters according to the main experimental protocols mentioned in (Voogt, 2014): a) studies using standard experimental stations and equipment b) studies using non-standard experimental equipment and c) studies based on mobile traverses around the concerned area. Seventy five studies belong to the first cluster, ten studies in the second, and 48 cities in the third cluster.
b) The form and type of the UHI intensity reported. Given that studies based on mobile traverses and non-standard measuring equipment