Sustainable Cities and Society 14 (2015) 187–199

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

An integrated study of urban microclimates in Chongqing, China: Historical weather data, transverse measurement and numerical simulation

Runming Yao [a,*], Qing Luo [b], Zhiwen Luo [a], Lai Jiang [a], Yu Yang [b]

[a] School of Construction Management and Engineering, University of Reading, United Kingdom
[b] Key Laboratory of the Three Gorges Reservoir Region's Eco-Environment under the Ministry of Education, Chongqing University, PR China

ARTICLE INFO

Article history:
Available online 30 September 2014

Keywords:
Urban microclimate
Chongqing
Urbanization
Field measurement
Mobile transverse
Urban heat island

ABSTRACT

Chongqing is the largest central-government-controlled municipality in China, which is now undergoing a rapid urbanization. The question remains open: What are the consequences of such rapid urbanization in Chongqing in terms of urban microclimates? An integrated study comprising three different research approaches is adopted in the present paper. By analyzing the observed annual climate data, an average rising trend of 0.10 °C/decade was found for the annual mean temperature from 1951 to 2010 in Chongqing, indicating a higher degree of urban warming in Chongqing. In addition, two complementary types of field measurements were conducted: fixed weather stations and mobile transverse measurement. Numerical simulations using a house-developed program are able to predict the urban air temperature in Chongqing. The urban heat island intensity in Chongqing is stronger in summer compared to autumn and winter. The maximum urban heat island intensity occurs at around midnight, and can be as high as 2.5 °C. In the daytime, an urban cool island exists. Local greenery has a great impact on the local thermal environment. Urban green spaces can reduce urban air temperature and therefore mitigate the urban heat island. The cooling effect of an urban river is limited in Chongqing, as both sides of the river are the most developed areas, but the relative humidity is much higher near the river compared with the places far from it.

1. Introduction

The proportion of the global population in urban areas has increased conspicuously from 29% in 1950 to 49% in 2005, and urbanization is projected to increase even further to 60% in 2030 (NU, 2005). There is a much higher urbanization rate and total population in developing countries, but China is among the highest. China now has 89 cities with a population of a million or more compared to 32 in India and 37 in the United States. The government estimates that 44% of China's population lives in cities, this figure will be 60% by 2020 (Normile, 2008).

This rapid urbanization brings about a series of environmental consequences. In one way, cities strongly contribute to the greenhouse gases emissions and consequently to global warming (IPCC, 2007). It is reported that cities are responsible for 75% of global energy consumption and 80% of greenhouse gas emissions (Ash, Jasny, Roberts, Stone, & Sugden, 2008). And they create a district urban climate at the city scale (Grimmond, 2007). An urban climate differs from its rural counterpart in its unique underlying surface characteristics and the anthropogenic activities within it (Oke, 1988). Urban infrastructures, together with changes to the morphology and materials of the surface, alter the energy and water exchange between surfaces and the adjacent atmosphere, as well as the airflows (Belcher, 2005). In the coming decades, the complex interaction between the effects of global change at a regional scale and the evolution of cities themselves will probably lead to a deep change of urban climate. A better scientific understanding of urban environmental physics can help optimize urban planning to achieve a sustainable city development (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Mills, 2007) and seek useful mitigation solutions to fight against climate change.

Urban climate is characterized by a higher temperature, lower humidity, and weaker winds than surrounding rural areas. The first urban climate study was carried out by Luke Howard in London. He found that the night in the city of London was 3.7 °C warmer than in the countryside in the early 1800s (Howard, 1833). Since then, many studies have attempted to address the impact of urbanization on the urban microclimate in other different cities worldwide

* Corresponding author.
E-mail address: r.yao@reading.ac.uk (R. Yao).

http://dx.doi.org/10.1016/j.scs.2014.09.007
2210-6707/© 2014 Published by Elsevier Ltd.

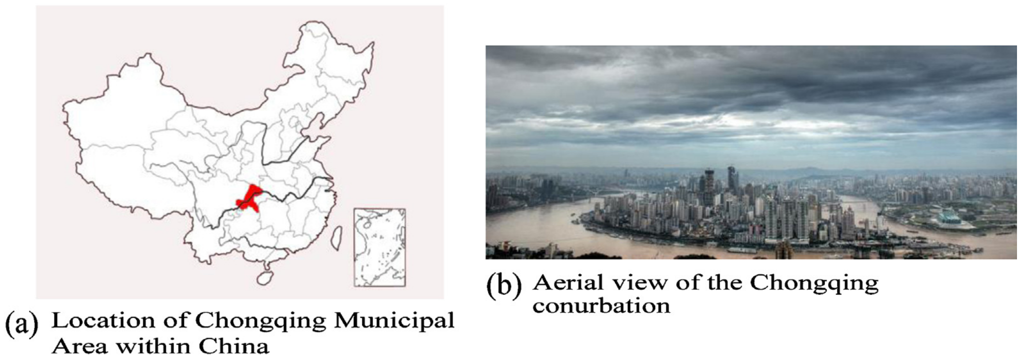

Fig. 1. Location and morphology of Chongqing City.

such as New York City (Bornstein, 1968), Cairo (Robaa, 2013), South Africa (Kruger and Shongwe, 2004), East China (Si, Ren, Liang, & Lin, 2012; Wong & Yu, 2005), and a medium-sized Mediterranean city (Busato, Lazzarin, & Noro, 2014; Papanastasiou & Kittas, 2012). We also reviewed most relevant studies for cities with a similar climate to Chongqing, i.e., a mild climate but with hot summers and cold winters. Huang, Li, Zhao, and Zhu (2008) examined the impacts of different ground covers on the urban heat island in Nanjing, China during the summer period. Their results showed that bare concrete cover had the highest daytime air temperature, while the woods or the shade of trees had the lowest. Strong urban heat island (UHI) effects occurred around midnight. However, comparison between different seasons was not possible since measurements were only made in summer. However, Zeng, Qiu, Gu, He, and Wang (2009) identified the seasonal pattern of the UHI in Nanjing from 1961 to 2005 based on four meteorological stations in Nanjing. Temperatures were highest in summer and lowest in winter and the average UHI intensity was about 0.5 °C. The annual increasing rate of mean air temperature was 0.109 °C/10a. In Shanghai, the spatiotemporal patterns of UHI were quantitatively examined for the years 1997 and 2008 using remote sensing and GIS. The unprecedented land use/land cover (LULC) change and population shift from 1997 to 2008 had resulted in an expanding UHI effect both in the extent and magnitude (Zhang et al., 2013). Locally, Yang, Lau, and Qian (2010) investigated the relationship of building layout and density with the summer time UHI in high-rise areas in Shanghai. They found that the day-time UHI was closely related to the site shading factor, while the night-time UHI was more influenced by local anthropogenic heat. Likewise, a study in Wuhan also indicated that land-use patterns had significant impacts on the UHI, and forest and cropland can effectively mitigate the UHI in Wuhan due to its large spatial extent and homogeneous spatial distribution (Wu, Ye, Shi, and Clarke, 2014).

However, Chongqing is very different from the above-mentioned cities due to its very complex geographical settings, though it shares a similar climate. Chongqing has a land area of 82,401 km^2, of which 42% could be classified as urban. It is located in the southwest part of China on the southeast edge of the Sichuan Basin between the Tibetan Plateau and the Yangtze Plain, as shown in Fig. 1. It is adjacent to Hubei, Hunan, Shaanxi,

Fig. 2. Distribution of weather stations in Chongqing (Zhang et al., 2009).