Urban Forestry & Urban Greening 32 (2018) 99–112

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

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

Local variation of outdoor thermal comfort in different urban green spaces in Guangzhou, a subtropical city in South China

Yafei Wang[a,b], Zhuobiao Ni[a,b,*], Yuanzhuo Peng[a], Beicheng Xia[a,b,*]

[a] School of Environmental Science and Engineering, Sun Yat-sen University, 135 Xingang Xi Road, 510275, Guangzhou, China
[b] Guangdong Provincial Key Lab of Environmental Pollution Control and Remediation Technology, Sun Yat-sen University, 135 Xingang Xi Road, 510275, Guangzhou, China

ARTICLE INFO

Keywords:
Outdoor thermal comfort
Urban green space
Thermal sensation
Neutral temperature
Preferred temperature
Subtropical microclimate

ABSTRACT

To understand the influence of different urban green spaces on outdoor thermal comfort, researchers have focused on developing a thermal comfort range and estimating neutral and preferred temperatures through questionnaire surveys and microclimatic measurements. The simultaneity of investigation among different sites is often neglected, which decreases the accuracy and reliability of the outcomes. To fill this gap and to better address the local variation of outdoor thermal comfort in different urban green spaces, both surveys and measurements were performed simultaneously at three sites, "central grassland," "pond-side garden" and "grove" in a subtropical urban local area in warm and cool periods. Remarkable differences in microclimatic conditions, thermal sensations, thermal comfort, and both neutral temperatures and preferred temperatures were observed among the three sites and in the two periods. Preferred temperatures were lower than neutral temperatures among different sites in each period or both periods combined, indicating the instinctive preference of people from relatively hot regions for a cooler thermal state. The grove yielded the best cooling capability but was perceived as the hottest and most uncomfortable site in the warm period. The central grassland with the highest air temperature, conversely, was perceived as the most comfortable site. The subjective perceptions were also reflected by lower neutral and preferred temperatures in the grove than those in the central grassland in the warm period. In particular, for preferred temperatures, up to 8.8 °C operative temperature (T_{op}) and 4.3 °C physiological equivalent temperature (PET) differences between these two sites were observed. Hence, a high density of trees does not necessarily result in better outdoor thermal comfort. Future urban planning and management, therefore, should emphasize the types and structures of different urban green spaces. To further comprehensively explore the roles of different urban green spaces in outdoor thermal comfort, high synchronicity among sites during investigation is important.

1. Introduction

Poor thermal comfort not only harms people's mood, memory, ability to learn and concentrate, and job performance, but also compromises their health status and general wellbeing, resulting in more serious health problems (Kovats and Hajat, 2008). The rapid urbanization and population growth changes the urban environment and affects human comfort and health (Millennium Ecosystem Assessment, 2005). A wide range of strategies were proposed to improve urban environment. Among others, urban green spaces are known to have important benefits for human wellbeing. Over the past few decades, considerable research has extensively investigated the role of green spaces in urban habitats due to the increasing urban environmental problems (Costanza et al., 1997; Roth, 2007; Wang et al., 2014). It has become clear that urban green spaces can regulate the microclimate, which directly affects people's thermal environment and comfort level. Numerous studies have focused on this function via field measurements and simulations, in which human outdoor thermal comfort is mainly linked to and evaluated with microclimatic parameters (Shashua-Bar et al., 2011; Willett and Sherwood, 2012; Hedquist and Brazel, 2014; Wang et al., 2015a, b). Examining these physical factors allows quantification of the effects of urban green spaces on microclimate regulation to a certain extent, for example, the temperature reduction by vegetation (Ng et al., 2012; Berry et al., 2013; Wang et al., 2015a, b). However, human outdoor thermal comfort is not only affected by physical factors. It is a combined outcome of both physical and non-physical factors and is closely related to the objective thermal environment and subjective thermal perception. The non-physical factors

* Corresponding authors at: School of Environmental Science and Engineering, Sun Yat-sen University, 135 Xingang Xi Road, 510275, Guangzhou, China
E-mail addresses: nizhuob@mail.sysu.edu.cn (Z. Ni), xiabch@mail.sysu.edu.cn (B. Xia).

https://doi.org/10.1016/j.ufug.2018.04.005
Received 27 December 2017; Received in revised form 27 March 2018; Accepted 6 April 2018
Available online 16 April 2018
1618-8667/

include physiological and psychological conditions of people, such as age, gender, thermal history, thermal behavior and expectation (Lin, 2009; Yang et al., 2013; Wang et al., 2017). When urban green spaces act as the important recreation spots for citizens, the physical outdoor thermal conditions usually do not equal people's thermal sensation and preference (Yang et al., 2013; Salata et al., 2016; Wang et al., 2017). As a consequence, a growing interest in considering the effects of non-physical factors on outdoor thermal comfort by combining physical measurements and social surveys has appeared in recent years (Chen et al., 2015; Li et al., 2016; Salata et al., 2016; Yang et al., 2017).

Besides investigating the physiological and psychological factors, several researchers have also paid attention to the difference in the properties of urban green spaces (Mahmoud, 2011; Chow et al., 2016; Middel et al., 2016; Wang et al., 2017). These properties include location or region of the green spaces, vegetation characteristics, shaded area insides the spaces, and landscape or view of the spaces. People from different climate regions can have diverse thermal expectations and preferences under similar weather conditions due to their various thermal history and thermal adaptation (Yang et al., 2013; Wang et al., 2017). In addition, Mahmoud (2011) demonstrated that the thermal comfort level was different in the nine zones within an urban park in Cairo (Egypt), mainly because of the sky view factors and wind speed. The measured and perceived microclimates also varied among different sites and seasons (Chow et al., 2016). Furthermore, thermal comfort can be increased by shade, despite the non-significant impact of shade type (natural or artificial) on the perceived comfort (Middel et al., 2016).

Previous studies have shown that the diversity of urban green spaces has a strong influence on their microclimate regulation capacity and people's outdoor thermal comfort. However, the 'simultaneity' of thermal comfort investigation is often not emphasized during physical measurements and social surveys, as the time of the investigation performed at different locations is not identical. The lack of consideration of simultaneity in methodology, therefore, makes it difficult to accurately compare people's thermal sensitivity and perception (influenced by different weather conditions and survey times) between different urban green spaces. The integration of different site microclimates and survey times, especially in local areas, is generally not sufficient. Hence, we aimed to fill this gap of simultaneity, which has an important influence on the accuracy and reliability of research on outdoor thermal comfort. In addition, cities within (sub)tropical climates experience a greater impact of the urban heat island effect and thermal stress (Chow et al., 2016). Thus, three green spaces with different vegetation characteristics in a local urban area of Guangzhou (a subtropical city in South China) were selected as study sites. To examine the outdoor thermal conditions and people's subjective thermal perceptions among different green spaces during both cool and warm periods, we performed an advanced investigation in which microclimatic measurements and questionnaire surveys were combined and simultaneously conducted at three green spaces in both periods. By comparing the microclimatic conditions, thermal sensations, thermal comfort, and both comfort and preferred temperatures in these three sites, this study aimed to explore the differences in people's thermal comfort perception and preferences among multiple urban green spaces, thereby helping to better understand the capability of different green spaces on regulating microclimate and thermal comfort.

2. Methods and materials

2.1. Climate characteristics of Guangzhou

The investigation was carried out in Guangzhou in the southeast of China. This city has a typical humid subtropical climate with a high influence of solar radiation and monsoons, resulting in high temperature, humidity, and precipitation during the summer time. Summer lasts nearly half a year from May to September, while winter, spring, and autumn are relatively short, from December to January, February to March, and October to November, respectively. During the summer time, typhoons and thunderstorms occasionally pound the city and close-by coastal area (approximately 4–5 times each year), bringing considerable precipitation that contributes to approximately 80% of annual precipitation. The monthly variation of air temperature (Ta) and relative humidity (RH) in the urban district (2010–2015) of Guangzhou is presented in Fig. 1 (GUANGZHOU, 2011–2016). Over the past five years, the annual average Ta and RH were as high as 22 °C and 80%, respectively. In winter, the weather is moderate, cool and dry with relative humidity generally lower than 70%.

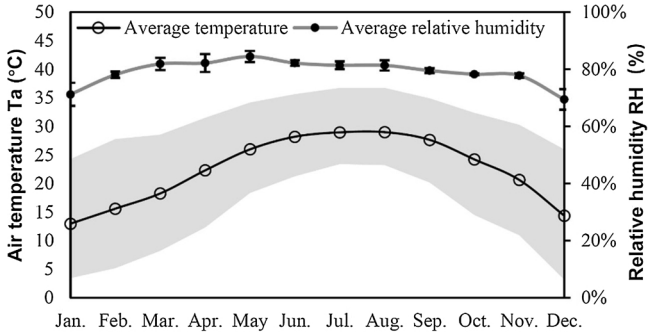

Fig. 1. Ta and RH in urban districts of Guangzhou between 2010 and 2015; the gray area represents the range between the maximum and minimum Ta; error bars indicate the standard deviations of RH (based on (GUANGZHOU, 2011–2016)).

2.2. The study sites

Three different small green spaces located on the South Campus of Sun Yat-sen University (23°5′46.96"N, 113°17′55.78'E) in Guangzhou were selected as the study sites for the social survey and onsite physical measurements of microclimatic conditions. Being a place of historic interest and scenic beauty, Sun Yat-sen University attracts visitors, including those from other cities of China. The three respective investigated sites were "central grassland', 'pond-side garden' and "grove" green spaces (Fig. 2). These sites are less than 1 km away from each other, and each covers an area of approximately 1000 m^2 and is freely accessible to the public. Site one was full of grass and short shrubs with a few trees (mainly are *Ficus microcarpa*) along two sides; leaf area index (LAI) at this site was less than 1 $m^2 m^{-2}$. Site two consisted mainly of a pond, which occupied approximately 50% of the surface area, and dense trees (e.g. *Archontophoenix alexandrae*, *Caryota mitis*, *Cleistocalyx operculatus*); LAI ranged between 2 and 4 $m^2 m^{-2}$. The third site was covered by numerous trees (e.g. *Cinnamomum camphora*, *Eucalyptus*, *Syzygium jambos*) and tall shrubs that provide a large shaded area; LAI was more than 6 $m^2 m^{-2}$. Due to limited time and manpower, and the characteristics of the university, other types of green spaces such as street trees and rooftop gardens were not included or addressed in this study.

Aiming to locally investigate people's thermal perception and thermal preference, as well as how these two thermal indexes differ in different urban green spaces, we conducted questionnaire surveys and onsite physical measurements simultaneously in the three green spaces mentioned above. On each investigation day, such approach with simultaneity proceeded from 10:00 to 15:00 when the sites were most frequently visited. Three days in a warm period representing the typical summer season and 4 days in a cool period representing the typical winter season were selected for the investigations, which were performed on the 4th, 13th and 26th of September 2016, the 29th of December 2016, and the 12th, 13th, and 14th of January 2017. Two main criteria for selecting these survey days were: 1) avoiding summer/winter holidays to ensure enough manpower for the surveys and to