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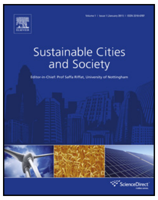

Research article

Study on outdoor thermal comfort on a campus in a subtropical urban area in summer

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ABSTRACT

Most domestic outdoor thermal comfort evaluation indices were proposed by developed, temperate climate regions in Europe. Therefore, the study developed an evaluation index according to subtropical Guangzhou, China to guide outdoor environment work more accurately. A thermal comfort study was conducted for Guangzhou University campus. Field measurements and a questionnaire survey were used to assess the thermal comfort of subjects. The results showed that 90% acceptable thermal temperature limit is 28.54 °C, which is significantly higher than the western/middle European limits. However, 46.7% of humidity sensation votives are neutral. Finally, a new thermal comfort index model was developed for Guangzhou area.

Contents

1. Introduction

Achieving a pleasant outdoor thermal environment is important for any outdoor space. The outdoor thermal environment in subtropical urban areas is extremely hot, and many people suffer summer heat strokes each year (Xi, Li, Mochida & Meng, 2012). Research has shown that a comfortable outdoor thermal environment can promote outdoor activity and improve physical and mental health (Thach, Zheng, Lai, Wong & Chau, 2015).

The outdoor environment has received considerable research attention regarding the improvement of living standards and comfort, including several outdoor thermal comfort studies (Singh, Mahapatra, & Teller, 2015; Lai, Guo, Hou, Lin & Chen, 2014; Yang, Wong, & Zhang, 2013a; Katafygiotou & Serghides, 2014; Rossi, Anderini, Castellani, Nicolini & Morini, 2015). Evaluation indices provide the basis for assessing the outdoor environment. Environmental planners and designers use indices to make clear decisions

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on thermal environment levels. Numerous evaluation indices have been proposed over the past 100 years (Epstein & Moran, 2006). Several indices have integrated thermal environmental factors and human energy balance properties to optimize outdoor thermal comfort. Various comfort parameters include the predicted mean vote (PMV) (Fanger, 1970), the new effective temperature (ET*), the SET* (Gagge, Fobelets, & Berglund, 1986), standard effective temperature for the outdoors (OUT-SET*) (Pickup & Dear, 1999; Spagnolo & De Dear, 2003), the physiologically equivalent temperature (PET) and universal thermal climate index (UTCI).

Bröde, Krüger, Rossi and Fiala (2012) used general additive models to study the effects of temperature, humidity, and wind, long-wave radiant heat fluxes and short-wave radiant heat fluxes as summarized by the recently developed Universal Thermal Climate Index (UTCI). The study suggested that the UTCI provided a suitable planning tool for urban thermal comfort in sub-tropical regions. Cheng, Ng, Chan and Givoni (2012) conducted an outdoor thermal comfort survey based on using longitudinal experiments in Hong Kong to addresses the effects of changing wind and solar radiation conditions on thermal sensation. The study also estimated predictive formulas based on the physiological equivalent temperature (PET) thermal index. Yang, Wong, and Jusuf (2013b) conducted a thermal comfort study of outdoor urban spaces in Singapore and suggested that individuals who typically subsist in outdoor environments are more tolerant to heat stress than those who subsist in indoor environments in tropical climates. Xi et al. (2012) investigated the influences of various design elements on the outdoor thermal environment around campus clusters, noting the subjective responses of Guangzhou students in subtropical urban areas. The study established an outdoor thermal comfort calculation model based on the new standard effect temperature (SET*) evaluation index.

The SET*, PMV and PET indices have been commonly used in recent outdoor thermal comfort studies. The PMV index is based on the predicted mean vote of a large group of people, who assess an actual thermal sensation. The PMV index uses the ASHRAE 7-point scale of thermal sensation scale. However, several studies have reported poor correlations between the PMV and subjective thermal perception (Cheng et al., 2012; Höppe, 2002; Nikolopoulou, 2010; Nikolopoulou, Baker, & Steemers, 2001; Thorsson, Lindqvist, & Lindqvist, 2004). SET* and PET are based on climate-chamber analyses of the human energy balance and integrate the effects of air temperature (T_a), vapor pressure (V_P) (or relative humidity (RH)), mean radiant temperature (T_{mrt}) and air speed (v).

SET* is considered one of the most widely used indices for outdoor thermal environment studies (Xi et al., 2012). Compared to other evaluation indices, SET* aims to improve warm or humid condition evaluations (Blazejczyk, Epstein, Jendritzky, Staiger & Tinz, 2012) and comprehensively consideres the effects of outdoor thermal parameters on the human body heat balance. The index has been verified via numerous experiments and theoretical studies (Xi et al., 2012; Gagge et al., 1986). In addition, the American Society of Heating Refrigerating and Air-conditioning Engineer (ASHRAE) has adopted the SET* analysis process. Because this study is also concentrate on university in Guangzhou of subtropical area, this article take SET* as evaluation index. The analysis focuses on revising the thermal comfort evaluation index for students on the subtropical region campus based on field measurements and a questionnaire survey. The questionnaire survey and field measurement results were then used to develop the new evaluation index model. The newly developed thermal comfort calculation model provides an appropriate evaluation index for designing a green campus environment and is suitable for Guangzhou inhabitants.

2. Methodology

2.1. Study area

The study area encompasses Guangzhou University in south China. The university is located at a longitude of 112.8°E and latitude between 22.3°N and 24.1°N. The summer season lasts for six months from May to mid-October. The daily mean air temperature is approximately 30 °C. The humidity is typically high, often exceeding 90%. Guangzhou is a typical subtropical city with uniformly high temperatures, high humidity and abundant summer rainfall.

The field surveys and measurements were conducted daily in August through mid-October 2014 from 9:00 to 18:00. Most university students are from the Guangzhou area and represent the characteristics of the local residents. The sampling points were established at popular student locations. Each study area was carefully selected to represent different microclimatic conditions, including shaded roads in living areas, sidewalks, recreational areas and teaching areas. The sampling points shown in Fig. 1(c) and (e) represent shaded locations, which can reduce the summer temperature and improve comfort. The former point is located under a pavilion, while the latter is located under trees. The points shown in Fig. 1(b) and (d) are not shaded. The main difference between these two points is related to the ground composition. The point in Fig. 1(b) is characterized by grass, while ceramic tiles characterize the point in Fig. 1(d). Therefore, these sampling points encompass various characteristics of the study area and represent different microclimates.

This study chose sampling locations with significant microenvironmental similarities. The sampling points are separated by long distances, ensuring that each respondent has walked for a significant period before arriving at a sampling point. Thus, the respondents can sufficiently adapt to the microenvironment, which is shown in Fig. 1.

2.2. Data collection

The investigation includes physical measurement and subjective assessments. All field surveys were conducted on days with suitable weather to avoid extreme weather interference.

The physical measurement aimed to collect microclimatic parameters such as air temperature, relative humidity, globe temperature and wind velocity. The two former parameters were measured using a ZDR-20 at a 5-min interval. A JTR10 recorded the global temperature, which is a combination of air temperature, wind velocity, air humidity and the radiation emitted from the surroundings. KANOMAX MODEL KA22 and CASELLA units measured the wind velocity. The KA22 unit measured smaller speeds, while CASELLA unit measured higher speeds. The measurement height was 1.1 m, corresponding to the average height of the centre of gravity for adults. The objective physical measurements lasted 15–20 min during each visit. The subsequent analysis used the average values of each measured variable. Table 1 summarizes detailed measurement instrument information for each physical parameter.

1582 samples were collected via the survey. The questionnaire consisted of Parts A and B. Part A asked the respondents to access the thermal sensation, thermal acceptability and thermal preference. The analysis used the traditional ASHRAE 7-point scale thermal sensation vote (TSV), as shown in Fig. 2(a). The thermal acceptable thermal vote (ATV) was based on a direct assessment (acceptable and unacceptable), as shown in Fig. 2(b). The preference thermal vote (PTV) utilized the 3-point Mclntyre preference scale, as shown in Fig. 2(c). The respondents finished part A, after the investigators explained about each question. Part B collected demographic information such as gender, height, activity level