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Quantitative effects of urban spatial characteristics on outdoor thermal comfort based on the LCZ scheme

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ABSTRACT

Based on the local climate zone (LCZ) scheme, nine typical urban areas in Shenzhen, China were chosen to conduct a field survey to quantitatively analyze the outdoor thermal comfort levels under different urban spatial characteristics. Four integrated indicators, F_1, F_2, F_3, and F_4, were defined based on the Fuzzy-AHP method by considering four different considerations for expressing nine different LCZs. Through physical meteorological measurements and simultaneous human responses on local environments, thermal "neutral" value ranges of three thermal comfort indicators (*TCI*) were obtained, varying from 27 °C to 29.5 °C in PET, from 21 °C to 24 °C in OUT-SET*, and from 28 °C to 29.5 °C in UTCI. Quantitative equations between F_i and *TCI* were expressed by applying Linear, Logarithmic and Cubic models to the calculated F_i and *TCI* values in the nine LCZs. Sampling experiments were conducted to generate near-random sampling F_i parameters from a four-dimensional distribution. By referring to thermal "neutral" *TCI* ranges, six optimal F_i combinations were determined and results show that the LCZ 1 B appears a preferable LCZ class for optimizing local-scale thermal comfort conditions in the high-temperature environments in subtropical regions of China. Additionally, the optimal F_i combinations provide quantitative theoretical guidance in sustainable urban design and planning.

1. Introduction

Rapid urbanization and dramatic increases in urban population have greatly changed the original natural underlying surface materials and spatial geometric forms across the world. Human activities then caused many climatic problems, including global climate warming and the urban heat island effects [1,2]. The changes in thermal environmental conditions in urban spaces also have great impacts on the building energy consumption and the outdoor thermal comfort levels of citizens [3–5]. When individuals experience more thermal stress, the resultant discomfort could negatively impact their health and their outdoor life in many ways [6]. Therefore, quantitative analysis of the outdoor thermal comfort is becoming an increasingly prominent issue for urban meteorologists, planners, and policy makers.

In recent scientific literature, a considerable amount of research has shown that urban spatial morphology (*e.g.*, spatial geometry features, urban surface materials, building or population density, anthropogenic heat amounts) has become a critical aspect in urban design for climate-sensitive areas influenced by local-scale meteorological variables [7,8]. During the past decade, several spatial factors have been identified for their effects on local climate, such as the H/W [9,10], SVF [11,12], vegetation or water body areas [13,14], as well as the albedo of ground materials [15]. However, for a practical project that requires habitability evaluation and further improvements, more comprehensive spatial factors of urban characteristics need advanced systematic evaluation of the integrated quantitative effects on local-scale urban thermal comfort. Better-founded underlying surface characteristics should be examined to conduct actual thermal comfort measurement studies. Then, based on these study results, quantitative urban spatial effects on local thermal comfort could be obtained as normative research guidance to assist urban designers or policy makers in building livable and comfortable urban spaces [16].

Conventional meteorological monitoring studies have mainly adopted limited selected measurements and usually failed to give

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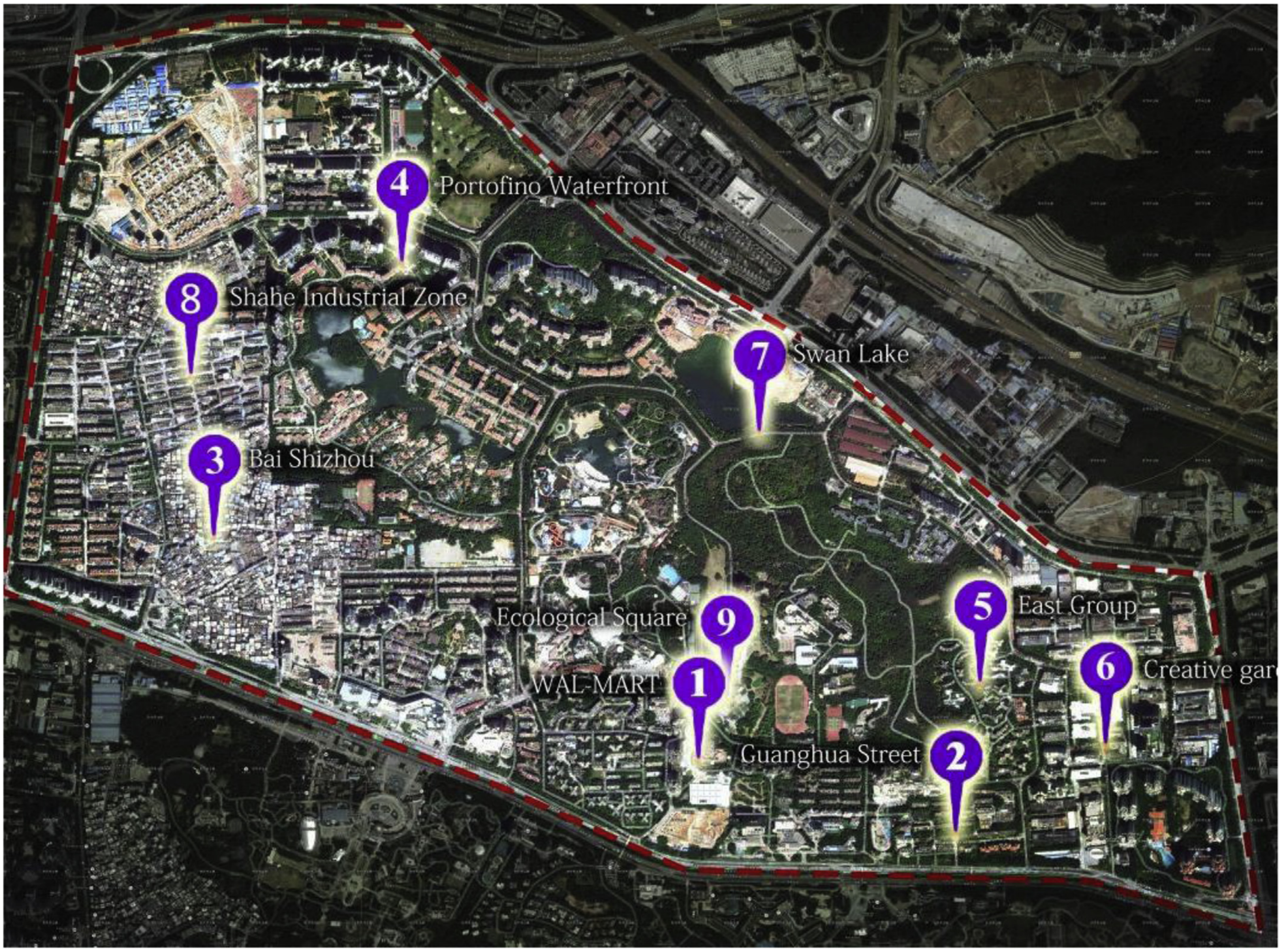

Fig. 1. The land use map of OCT and the locations of nine local areas.

comprehensive and quantitative metadata of site exposure or land cover [17,18]. Because systematic descriptions of local landscapes at measurement sites are lacking, quantitative influences on local climatic conditions and inter-site comparisons cannot be well conducted. Thus, a climate-based classification of diversified measurement sites named "local climate zones" (LCZ) was developed for local temperature studies by Stewart and Oke [19]. The classes of LCZ are local in scale, climatic in nature, and zonal in representation. The LCZs were defined as regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in horizontal scale. The landscape universe consists a total of 17 standard LCZs, including ten "built types" varying from LCZ 1 to LCZ 10 and seven "land cover types" from LCZ A to LCZ G. Each LCZ was individually named and defined according to the urban design expressions of fabric, texture and morphology. Stewart and Oke also suggested approximate value ranges for the related geometric properties, surface cover properties, thermal and radiative properties, and even metabolic properties. Consequently, many investigations on urban heat island and air temperature observations have applied the proposed LCZs when choosing the observation sites. Emmanuel and Krüger (2012) [20] observed temperatures in locations with different land cover characteristics by using the LCZ concept and evaluated the local climate change of Glasgow, UK. Leconte et al. (2014) [21] discussed the way urban fabric modifies urban climate through the utilization of 13 LCZs and investigated the screen-height air temperature distributions inside these LCZs in the Great Nancy Area of France. Middel et al. (2014) [22] designed five neighborhoods by reference to the LCZ classification scheme, and investigated the impact of urban form and landscaping type on the mid-afternoon microclimate in Phoenix, Arizona. Ojeh et al. (2016) [23] analyzed the hourly air temperature differences between an urban area (LCZ 2) and a rural area (LCZ B) in Lagos, Nigeria.

Although the LCZ scheme has been gradually applied in several studies, most of them still discuss the air temperature differences without further discussing the comprehensive spatial characteristics. Very few studies [24,25] have analyzed the relationships between diversified LCZs and local thermal comfort in detail. Since the thermal comfort levels in outdoor spaces noticeably influence human physical activity and human health, the quantitative relationships between LCZ-based urban spatial characteristics and human comfort should be discussed as an important issue through field thermal comfort measurements in humans. Then, the optimal urban space and preferable LCZ class should be expressed as theoretical guidance for urban planning.

To address these problems, we choose nine typical local areas with diversified LCZ classes as research areas in the hot and humid city of Shenzhen, China. Quantitative effects of different urban spatial characteristics on local thermal comfort are discussed from four main research aspects: 1) the differences in local human thermal comfort levels under different LCZ classes; 2) the generation of four integrated urban spatial indicators for quantifying urban spatial characteristics; 3) quantitative equations for expressing the relationships between integrated urban spatial indicators and local human thermal comfort levels; 4) sampling experiments for obtaining optimal integrated spatial