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Evaluating the local climate zone classification in high-density heterogeneous urban environment using mobile measurement

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ABSTRACT

Urban heat island (UHI) has been identified as a threat to urban living quality in the context of climate change. As awareness of the impacts of urban expansion on local climate increases, urban planners/decision makers attempt to incorporate climatic considerations into the planning process. An increasingly-used urban climatic analysis scheme— Local Climate Zone (LCZ) classification— has been applied in Hong Kong, a high-density city with heterogeneous an urban environment. This study aims to evaluate the LCZ mapping in such a unique urban context using in-situ air temperature data. The fine-scale spatial variation of the daytime and nighttime screen-level air temperatures was investigated via mobile measurements during the summertime of 2016. The measured data were collated in Geographic Information System (GIS) based on the current LCZ maps. Statistically significant air temperature differences were observed between most LCZ classes, which confirm the veracity of LCZ in high-density heterogeneous urban contexts. Higher uncertainties in the site-averaged air temperature and considerable intra-LCZ air temperature differences in LCZs 1 to 6 were observed. It indicates that the current LCZ procedures of Hong Kong can be further refined for a better understanding of the climatic heterogeneity in densely built urban areas.

1. Introduction

Extreme weather events, such as heat waves, are becoming more frequent and intense amid climate change (IPCC 2014). Such trend will have a tremendous effect on health (McMichael, Woodruff, and Hales 2006, WHO 2003), particularly in highly urbanized and sprawling cities (Stone, Hess, and Frumkin 2010). Furthermore, due to the Urban Heat Island (UHI) phenomenon in highly urbanized areas, the impact of heat wave could be further intensified (Tan et al. 2010). As one of the densest and most populated cities in the world, Hong Kong is particularly susceptible to severe heat-related health consequences (Chan et al. 2012). Traditionally, the UHI intensity is described as the air temperature difference between the urban area and its surrounding rural areas (Rizwan, Dennis, and Liu 2008). However, under a heterogeneous urban context, this definition is inadequate to depict the intra-urban differences in air temperature between different districts in a large city (Chen et al. 2012, Stewart and Oke 2012, Oke 2004, Lowry 1977).

Urban form is closely related to the urban climate (Eliasson 1990). The forms of urban planning and development are influential

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to the local climatic conditions (Grimmond 2007) because the urban environment alters the wind flow, radiation balance, water and heat balances (Landsberg 1981). Urban expansion without appropriate planning control leads to substantial environmental degradation (Betanzo 2007). As awareness of the impacts of urban expansion on local climate grows, urban planners and decision makers have started to incorporate the climatic consideration into the planning process (Eliasson 2000).

To provide a better spatial understanding of local climate and help planners improve the urban form based on the climatic consideration, several classification schemes have been developed. They are the Urban Zones of Energy partitioning (UZE) (Loridan and Grimmond 2012, Loridan et al. 2013), Urban Climatic Map (UCMap) system (Ren, Ng, and Katzschner 2011), Urban Climate Zone (UCZ) scheme (Oke 2004, 2006) and Local Climate Zone (LCZ) scheme (Stewart and Oke 2012). The common theme of these different schemes is that all of them are established according to the information from urban indicators. These urban indicators include but are not limited to the land use/land cover (LU/LC) pattern, topographic, surface geometry and climatic spatial information. Based on this information, the above mentioned zoning systems/schemes can depict the effects of the spatially varied urban environment on local climate modifications. Urban form and function classification are standardized in the LCZ scheme, making it possible to provide a more detailed spatial understanding of the variability of intra-urban air temperature, rather than a simple description of urban-rural difference (Stewart and Oke 2012). The LCZ scheme was developed and serves as a global standard for depicting different urban morphologies (Stewart and Oke 2009). The scheme features 17 types of LCZ classes, including ten built types (LCZ 1 to LCZ 10), and seven land cover types (LCZ A to LCZ G). A full list of LCZ classes is shown in.

The properties of each LCZ class can be differentiated by metadata of urban land use and morphological factors (Stewart and Oke 2012). LCZs generated following the highly standardized scheme can help examine the UHI phenomenon in different cities. The advantage of the LCZ scheme over tradition land-use classification methods is that it also takes urban morphological details into consideration, which advances urban climatic research. Therefore, LCZ has been used in many different cities around the world for mapping (Bechtel et al. 2015). Moreover, to generate an internationally standardized LCZ classification database, a new project —World Urban Database and Access Portal Tools (WUDAPT)— was initiated in 2012 (Mills et al. 2015). It aims to develop LCZ maps for cities where detailed urban morphological data are not available using open-source remote sensing data. The performance of WUDAPT data in urban climatic analysis and the subsequent urban planning processes, in terms of accuracy and relevance, therefore requires comprehensive assessment (Stewart, Oke, and Krayenhoff 2014).

In Hong Kong, a prior study has classified 17 weather stations in the weather monitoring network of the Hong Kong Observatory (HKO) into LCZ scheme for UHI quantification (Siu and Hart 2012). After that, to develop climate-adapted urban planning and design strategies for the local practice, another study has further developed an LCZ classification map (with a spatial resolution of 300 m) for Hong Kong—a high-density large city with a highly heterogeneous urban environment (Zheng et al., 2018). The study's mapping method was GIS-based and it was possible because sufficient and detailed data of urban indicators are available in Hong Kong from the local planning department (PlanD). A set of LCZ maps with a finer spatial resolution of 100 m (a WUDAPT level 0 product) was also developed using the WUDAPT method to align the LCZ map of Hong Kong with worldwide research (Ren et al. 2016). The mapping accuracy of both of the above studies was evaluated in the study of Wang et al. (2018). The spatial pattern of the resultant LCZ maps showed a high consistency with the previous UCMaps system of Hong Kong. However, intra-LCZ site variations of urban indicators were also detected in the built-up LCZ classes (particularly LCZ1-6, see.

Table 1 and Fig. 1) of the resultant maps. It confirms the necessity of validation using measured air temperature data. The above also indicates the potential of further optimization of the LCZ classification procedure in a high-density urban scenario.

Mobile measurement using moving vehicles has been regarded a cost-effective method to investigate intra-urban environmental variability (Peters, Van Poppel, and Theunis 2012, Peppler 1929). It fills the monitoring gaps of the sparsely distributed fixed monitoring locations by providing more spatial information. This method has been increasingly adopted and continuously improved

Table 1
Criteria for GIS-based classification of LCZs in Hong Kong. Values for LCZs 1 to 9 are from Stewart and Oke (2012). Criteria for LCZs 10 to G are adapted from local urban planning datasets of Hong Kong (Wang et al., 2018).

LCZ Classes	Criteria of Classification
LCZ 1-Compact High-rise	$0.4 < \lambda_b < 0.6$ and $Z_h > 25$
LCZ 2-Compact Mid-rise	$0.4 < \lambda_b < 0.7$ and $10 < Z_h < 25$
LCZ 3-Compact Low-rise	$0.4 < \lambda_b < 0.7$ and $3 < Z_h < 10$
LCZ 4-Open High-rise	$0.2 < \lambda_b < 0.4$ and $Z_h > 25$
LCZ 5-Open Mid-rise	$0.2 < \lambda_b < 0.4$ and $10 < Z_h < 25$
LCZ 6-Open Low-rise	$0.2 < \lambda_b < 0.4$, $3 < Z_h < 10$
LCZ 7-Lightweight Low-rise	$0.6 < \lambda_b < 0.9$, $2 < Z_h < 4$, $0.2 < \Psi_{svf} < 0.5$
LCZ 8-Large Low-rise	$0.3 < \lambda_b < 0.5$, $3 < Z_h < 10$, $\Psi_{svf} > 0.7$
LCZ 9-Sparsely Built	$0.1 < \lambda_b < 0.2$, $3 < Z_h < 10$, $\Psi_{svf} > 0.8$
LCZ 10-Heavy Industry	LU/LC = Industrial Land
LCZ A-Dense Trees	LU/LC = Woodland
LCZ B-Scattered Trees	(LCZ A/B were combined due to the lack of information on wood species.)
LCZ C-Bush, Scrub	LU/LC = Shrub Land
LCZ D-Low Plants	LU/LC = Agricultural Land
LCZ *E*-Bare Rock or Paved	LU/LC = Roads, Railway, Airport, Quarries, Rocky Shore
LCZ F-Bare Soil or Sand	LU/LC = Badland, Vacant Development Land/Construction in Progress
LCZ G-Water	LU/LC = Reservoirs, Streams and Nullahs