An evaluation of the effects of urban morphology on outdoor thermal perception in Hong Kong's subtropical summer using LCZ classification

Sum Ching Chung, The Chinese University of Hong Kong, New Territories, Hong Kong; and K. K. L. Lau

Abstract Text:

Thermal comfort is essential for people to enjoy the outdoor environment without being exposed to distress due to weather. Studies of outdoor thermal comfort have investigated the interplay between microclimatic elements and thermal perception. Climatic factors and the built environment, as well as memory, adaptation and expectations, were found to play a major role in determining thermal perception (Nikolopoulou and Steemers, 2003; Lin, 2009; Liu et al., 2017).

In subtropical summer outdoor comfort studies, mean radiant temperature is often seen as the most significant microclimatic factor in thermal sensation. As the subtropics receive the highest solar radiation in summer, it is essential to incorporate elements that reduce radiation fluxes in the development of comfortable outdoor built environments. The provision of artificial shelter and tree shade is widely found to be beneficial to thermal comfort and attract space visitors (Hirashima et al., 2016, Chan et al., 2017). On the scale of a city, urban geometry (e.g. building density and height) create differential obstruction to solar radiation and air flow, thus affecting mean radiant temperature and wind speed.

Despite growing efforts on climate responsive urban planning, there is a lack of studies which systematically evaluate the effects of aspects of urban morphology on thermal perception. The Local Climate Zone, a classification system developed by Steward and Oke (2012), is suggested to be a valuable tool to unravel this relationship as it categorizes areas based on factors including building geometry (e.g. sky view factor, mean building height), construction materials, land cover, tree density, and human activity (Villadiego and Velay-Dabat, 2014). There are 17 standard LCZs where "built types" (1-10) are areas of various mean building height and density and "land cover types" (A-G) are areas of different surface material (e.g. A-dense trees, E-Bare-rock or paved, G-Water).

This study aims to further develop the understanding of the impact of different building elements on outdoor thermal perception on a high density subtropical city of Hong Kong by employing LCZ classification. Hong Kong's urban geometry is remarkably diverse with the presence of 8 out of 10 main built-type LCZs (LCZ1-6,9-10). In addition, land-cover LCZs C,D and LCZs F,G are commonly found in areas with high greenery coverage and water sources respectively.

In this study, 13 locations covering 8 LCZs (1-6,D,F) were sampled using the simultaneous questionnaire survey and microclimatic measurement approach established in existing literature. Measurements of air temperature, globe temperature, wind speed and relative humidity were performed and around 2000 questionnaires were collected in summer 2017 (May-September). Physiological equivalent temperature (PET) was calculated for each questionnaire using microclimatic parameters measured during survey time and clothing and activity level

recorded on the questionnaires. For data analysis, average PET and average thermal sensation vote (TSV) in each LCZs were ranked and the distributions of TSV in LCZs were compared using ANOVA.

The PET at sample sites ranged from 29.1°C to 57.2°C and air temperature from 29.6°C to 39.1°C. This severity of heat stress in Hong Kong during its hot and humid summer meant that no neutral PET was found during our survey session as such conditions resulted in >30% subjective thermal sensation vote (TSV) of +3 (very hot) and >50% when combined with +2 TSV (hot), regardless of LCZ. In the ANOVA analysis of TSV, thermal sensation was found to be significantly different across LCZs and hence urban morphology has a significant influence in the determination of thermal comfort.

Notably, highest mean thermal sensations were recorded in LCZ1 (TSV_{mean}=2.13) and LCZ4 (TSV_{mean}=2.12), which respectively correspond to compact high-rise and open high-rise areas, despite having high sky view factor and the 2nd and 3rd lowest PET_{mean} recorded. Potential causes for lower thermal comfort in LCZ1 and 4 are obstructed ventilation pathways due to high-rise buildings and generally an absence of greenery.

Overall, average thermal sensation was lowest LCZD (TSV_{mean}=1.66), LCZ2(TSV_{mean}=1.71) and LCZF (TSV_{mean}=1.84). With the lowest average PET, LCZD (Hong Kong Park) outperformed all other sampled site in terms of thermal comfort. Average thermal perception in the compact mid-rise zone - LCZ2 was significantly better than other built-type LCZs. At our LCZ2 sample site, the combination of good ventilation and some shading effect from building might have provided a reasonably comfortable environment. However, the comparatively high average PET on this site suggests that other factors might be in place. In the largely open and unshaded LCZ F (Central Harbour Pier), high air velocity counteracted with high solar radiation due to low sky view factor, thus improving thermal comfort.

Our results suggest that microclimatic variables are not able to explain all variations in thermal perception between LCZs. High-rise morphology significantly increases thermal discomfort, and on the other hand, pleasant environments near greenery and blue space increases thermal tolerance. The effects of environmental perception need to be further evaluated in order to support our purposed explanation for the modified relationship between PET and thermal perception in various LCZs. Nevertheless, our results highlighted the high importance of aspects of built environment on outdoor thermal assessments. Hence, the diversity of built environment must be ensured when designing thermally comfortable urban space.

References

Chan,S.Y.,Chau,CK.,Leung,T.M.,2017. On the study of thermal comfort and perceptions of environmental features in urban parks: A structural equation modeling approach. Building and Environment,122,171–183.

Hirashima,S.Q.S.,de Assis,E.S.,Nikolopoulou,M., 2016. Daytime thermal comfort in urban spaces: A field study in Brazil. Building and Environment,107, 245–253.

Lin,T.P., Matzarakis,A,Hwang,R.L.,2010. Shading effect on long-term outdoor thermal comfort. Building and Environment, International Symposium on the Interaction between Human and Building Environment Special Issue Section, 45, 213–221.

Liu,W., Zhang,Y., Deng,Q.,2016. The effects of urban microclimate on outdoor thermal sensation and neutral temperature in hot-summer and cold-winter climate. Energy and Buildings, 128, 190–197.

Nikolopoulou,M.,Steemers,K.,2003. Thermal comfort and psychological adaptation as a guide for designing urban spaces. Energy and Buildings, Special issue on urban research, 35, 95–101.

Stewart,I.D.,Oke,T.R.,2012. Local Climate Zones for Urban Temperature Studies. Bull.Amer.Meteor.Soc. 93, 1879–1900.

Villadiego,K.,Velay-Dabat,M.A.,2014. Outdoor thermal comfort in a hot and humid climate of Colombia: A field study in Barranquilla. Building and Environment, 75, 142–152.