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Research Paper

Effects of urban planning indicators on urban heat island: a case study of pocket parks in high-rise high-density environment

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ABSTRACT

Due to urbanization, the urban heat island (UHI) effect has become a modern endemic threat to human health and energy consumption, especially in compact urban areas with high population density. Pocket parks, as the major component of urban green space in high-rise high-density built area of Hong Kong, play important roles in shaping the city. By conducting in situ climate measurements and morphological analysis of 12 sites in Hong Kong, this study investigates the impact of pocket parks on UHI intensity, and the relationships between five urban planning indicators and UHI. Results show that pocket parks and their surrounding areas in Hong Kong have a moderate UHI intensity (0.1 °C) during the daytime but a very high nighttime UHI intensity (2.39 °C). Ten parks are cooler than their surrounding urban streets for both daytime and nighttime, which means that pocket parks in Hong Kong can help to alleviate UHI intensity at the micro scale. Floor Area Ratio (FAR), building density and Tree Cover Ratio (TCR) are found to be significantly and negatively related with daytime UHI. It indicates that higher FAR, building density and TCR in high-rise high-density urban environment may help to reduce daytime UHI intensity without increasing the early nighttime intensity. Planting trees is an effective measure to reduce the UHI intensity inside the parks for high-rise high-density urban environment. But a threshold for TCR (around 42%) shall be achieved to maximize its cooling effect.

1. Introduction

Due to rapid urbanization and population growth, the urban thermal environment has been substantially modified, especially in metropolitan cities. Researchers from worldwide have recorded that the air temperature in urban areas are higher than their surrounding countryside, which is generally known as urban heat island (UHI) effect (Landsberg, 1981; Oke, 1987). UHI effect in low and mid latitude cities could cause the increase of energy consumption for cooling and peak demand in summer (Radhi, Sharples, & Assem, 2015; Santamouris, 2014). UHI effect has also become a modern endemic threat to thermal comfort and human health. It has been proved that extreme hot weather conditions would cause the increase of mortality and hospital admissions. Chan, Goggins, Kim, and Griffiths (2012) indicated that an average increase of 1.8 °C in daily mean temperature above 28.28 °C is associated with an estimated increase of 1.8% in mortality. Yan (2000) uncovered a strong weather mortality relationship in a compact urban environment of Hong Kong and pointed out that the elderly (age > 65) were more vulnerable to weather stress. Therefore, addressing UHI effect is pressing for an aging society such as Hong Kong.

Urban environment and climate have been extensively investigated by scholars. It has been pointed out that UHI intensity is influenced by various factors including solar radiation intensity, sky condition, wind pattern, canyon geometry, building material, greenhouse effect, anthropogenic heat and evaporative cooling source (Oke, 1987; Santamouris, 2001; Wong & Chen, 2009). From the urban planning point of view, it is widely accepted that manipulation of urban land use intensity and increasing green area are important UHI mitigation strategies.

Urban planning indicators have been widely applied by urban planners to control the intensity of urban development at the early planning stage. Many studies have been conducted to investigate the relationship between urban planning indicators and urban climate. Satellite images were often used in larger scale urban studies to calculate the percentage of different land cover types, for example, percentage of water bodies, vegetated land, built-up area, etc. These indicators were then correlated with surface temperatures based on remote sensing technology (Lee, Kim, & Yun, 2016; Mathew,

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Khandelwal, & Kaul, 2016; Wu, Ye, Shi, & Clarke, 2014 ; Zhang et al., 2013). There are also some relatively smaller scale studies. Zhao, Fu, Liu, and Fu (2011) extract the values of floor area ratio, building density and green cover ratio, main urban planning indicators, from 11 sites with a size of 500 m in radius in China based on Google Earth images using stratified random sampling technique. They found that, these three indicators together could explain 99.49–99.69% of the variance of peak surface temperature. However, air temperature was less studied than surface temperature. In another study done in Florence, Petralli, Massetti, Brandani, and Orlandini (2014) calculated the indicators on nine circles of different size (r = 10–500 m) using geographically referenced data provided by the government. Results showed that summer minimum intra-urban temperature was positively related with street cover ratio, building cover ratio and building volume density and negatively related with green cover ratio, tree cover ratio and lawn cover ratio, and these relationships were stronger for circles of higher radius.

The UHI mitigation effect and thermal comfort improvement achieved by green area and vegetation had also attracted the attention of many researchers. Ca, Asaeda, and Abu (1998) conducted measurements inside a park and its surrounding area in Tokyo and it was reported that the grass surface was 19 °C cooler than asphalt surface and 15 °C cooler than concrete surface. Although vegetation cover can reduce surface temperature (Bonan, 2000; Ca et al., 1998; Lin, Ho, & Huang, 2007) and building energy load (Donovan & Butry, 2009) to a great extent, its effect on urban air temperature is not as significant (Hamada & Ohta, 2010; Takebayashi & Moriyama, 2009) (Table 1). Bowler, Buyung-Ali, Knight, & Pullin (2010) reviewed numerous research on green spaces of varying sizes and reported that on average a park was cooler than the surrounding urban environment by 0.94 °C in the day. Some researchers pointed out that the cooling effect increases with park size (Chang, Li, & Chang, 2007; Erell, Pearlmutter, & Williamson, 2010). But, there is no consensus on the threshold of green space size to produce an observable difference between parks and their surroundings. In a research conducted by Baris, Sahin, & Yazgan (2009), temperature and humidity values were collected in green areas located within residential areas. The results indicated that the climate is more related to the amount of vegetated area and the plant materials than the size of green area. In order to enlarge vegetation coverage, green cover ratio, tree cover ratio and lawn cover ratio have been employed globally in planning policies (Hamada & Ohta, 2010; Petralli et al., 2014; Wong et al., 2011). However, it is worth noting that the effect of vegetation can be affected by multiple factors, including urban texture, tree species, water availability, and weather condition, etc. A microclimate monitoring study conducted in a garden at the city center of Athens concluded that there was no significant temperature difference between the green space and its immediate surroundings (Zoulia, Santamouris, & Dimoudi, 2009).

It is found that most of the urban green areas investigated were relatively in large scale (Table 1), and most of the previous urban climate studies were conducted in cities with temperate climates and low rises or low density urban environments. This research focuses on higher density urban environments such as Hong Kong which has not yet been fully investigated in previous studies. As a mountainous territory, Hong Kong has preserved a large area of greenery, which is mainly concentrated in the land center, while the urban constructions are organized along the seashore. Within the high-rise high-density urban built area of Hong Kong, there are very limited open spaces available. According to the data from the Leisure and Cultural Services Department, there are 26 large parks and 2199 small parks (gardens, sitting-out areas, children's playgrounds) in built area of Hong Kong. A pilot survey of the parks in the Central and Western District conducted by the authors found that among 28 parks in this area, most parks are small with the size less than 3000 m^2. Small parks are the main green open space in high-rise high-density urban environment of Hong Kong. In this research, these small parks located on scattered pieces of land

Table 1
Literature on the effect of green space on urban air temperature.

Research	City	climate	Measurement month	Green space and reference area	Size of green space	Air temperature reduction
(Jauregui, 1990)	Mexico City, Mexico	subtropical highland climate	Whole year	Chapultepec Park and its surrounding area	~500 ha	4 °C at the end of dry season and 1 °C in wet months
(Spronken-Smith & Oke, 1998)	Vancouver, BC, Sacramento, CA	Oceanic climate (Vancouver), Mediterranean climate (Sacramento)	Jul, Aug	Ten parks in Vancouver and ten parks in Sacramento, compared with maximum urban temperature	2–53 ha	1–2 °C in Vancouver and 5–7 °C in Sacramento
(Oliveira, Andrade, & Vaz, 2011)	Lisbon, Portugal	Subtropical-Mediterranean climate (mild winters and warm to hot summers)	Summer	A small green space and its surrounding area	0.24 ha	6.9 °C (highest)
(Cohen, Potchter, & Matzarakis, 2012)	Tel Aviv, Israel	Mediterranean climate (mild, rainy winters and hot, dry summers)	Jan, Jun, Jul	Various urban parks and their surroundings	2000 m^2–28000 m^2	3.8 °C in summer and 2 °C in winter (in a park with dense canopy of trees)
(Zoulia et al., 2009)	Athens, Greece	Subtropical-Mediterranean climate (Hot-dry summer)	Summer	The National garden and its immediate surrounding	15.5 ha	−1.14–2.97 °C (Mean maximum)
(Chow, Pope, Martin, & Brazel, 2011)	Phoenix, Arizona	Subtropical desert climate (extremely hot summers and warm winters)	Oct	A park and its surrounding area	3 ha	0.7-3.6 °C
(Bencheikh & Rchid, 2012)	Ghardaia, Algeria	Hot desert climate	Summer	4 urban sites in old town and one reference point in open area	NA	4.5 °C
(Chen & Wong, 2006)	Singapore	Tropical rainforest climate (hot and humid)	Jan, Feb, Jun, Jul	Two big city green areas and their surrounding area	36 ha and 12 ha	1.3 °C (maximum)

Note: Climates are classified by the Köppen climate classification.