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# Urban heat island mitigation strategies: A state-of-the-art review on Kuala Lumpur, Singapore and Hong Kong

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ABSTRACT

Observing the rapid urban expansions and numerous infrastructure developments in the East-Asian context, many cities are suffering the urban heat island (UHI) effect and its associated environmental and social challenges. Moreover, the lack of sufficient attention to the application of effective heat mitigation strategies in current urban development in these cities can drastically intensify the eventual impacts of UHI. Therefore, many governmental sectors and policy makers have been implementing operative solutions for cooling cities. Nevertheless, this study argues that in Kuala Lumpur, despite the growing attention to this matter, there is still a need for more rigorous consideration by the architecture, engineering and construction (AEC) professionals as well as more scholarly studies to reflect sustainable solutions to the UHI effect. As a result, today, some of the dense urban areas in Kuala Lumpur are characterized with the use of thermally massive building materials, urban surfaces with low albedo, complex urban morphology, waste heat, and low density of vegetation. On the other hand, recent studies demonstrate that there has been a rapidly increasing interest in studies related to UHI in other East Asian regions such as Singapore and Hong Kong. Hence, this study develops a comparative analysis to provide a state-of-the-art review of the recent attempts towards mitigating the UHI effect in Kuala Lumpur, Singapore, and Hong Kong. Among several available UHI mitigation strategies, this study is limited to the analysis of the environmental impacts of urban vegetation (green roofs, green facades, vertical greeneries and green pavements). Findings reveal that in general, urban greening can significantly mitigate the UHI intensity, both directly and indirectly, resulting in the decrease of global air temperature and mean radiant temperature up to 4 °C and 4.5 °C respectively. Overall, the study develops new practical guidelines, discusses the public benefits and elaborates on the future directions of UHI studies.



## 1. Introduction

Urbanization is described as the process of land use change, whereby population becomes concentrated in towns and cities, representing economic and social modernization (Ren, Wang, Wang, & Liu, 2015; Wang et al., 2015). With regard to the considerable increase of economic growth and social development, substantial labor force tends to migrate from rural to urban-based industrial regions seeking new opportunities for a better life. United Nations Department of Economic and Social Affairs (UNDESA) recently revealed a record indicating a notable increase in the world urban population between the years of 1950, and 2014 (UNDESA/PD, 2014). In 1950, 30% of the world's population was urban, while by the end of 2014, this number has been increased to 54%. As a result of urbanization, the human settlement pattern has undergone significant changes, leading to the intensification of urban economic activities, and production of distinctive negative environmental effects, namely $CO_2$ emission (Al-mulali, Sab, & Fereidouni, 2012; Wang, Chen, & Kubota, 2016; Zhang, 2016). Additionally, forming 'islands' with higher temperatures in such contexts, central areas of metropolitan cities experience elevated temperatures compared to their rural surroundings (Radhi, Sharples, & Assem, 2015). This difference in temperature is what constitutes the urban heat island (UHI) effect.

In recent years, various studies continuously manifest that the increased ambient air temperature in cities caused by UHI phenomenon embraces enormous negative influences on social, environmental and

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economic dimensions of cities (Akbari et al., 2016). As a result, it is of high importance to adequately explore the essence of UHI with viewpoints to its causes and impacts and to study the strategies of UHI mitigation in sustainable ways. More importantly, due to the rapid urban growth and numerous ongoing infrastructure developments in the East-Asian cities, there is an imperative need for more extensive studies on UHI in this context. Many studies reveal that the largest impact of UHI is observed in winter and particularly during the night or early morning periods, nonetheless, the impact of UHI in summer and hot climates has its own specific importance particularly due to its consequential influence on urban thermal discomfort and air quality, air conditioning energy consumption, and heat-related human health issues (Sailor & Dietsch, 2007). Accordingly, this study is motivated to look at the current status and future direction of UHI phenomenon and its related scholarly studies in three cities of Kuala Lumpur, Singapore and Hong Kong.

## 2. Urban heat island (UHI)

### 2.1. The notion of UHI

UHI is a phenomenon closely associated with the development of cities and urban expansions (Mirzaei, 2015; Morris et al., 2015). The term 'heat island' generally describes the urbanized areas with higher temperatures compared to their neighboring non-urbanized areas (Arifwidodo & Chandrasiri, 2015; Fernández, Alvarez-Vázquez, García-Chan, Martínez, & Vázquez-Méndez, 2015; Kaloustian & Diab, 2015; Martin, Baudouin, & Gachon, 2014; Taleb & Abu-Hijleh, 2013; Tan & Li, 2015; Zhao, Zhou, & Liu, 2016). Urban centers typically have higher solar absorption, lower solar reflectivity (albedo) and greater thermal capacity/conductivity compared to the surrounding areas due to their darker and less vegetated surfaces (Kaloustian & Diab, 2015; Martin et al., 2014). Wanphen and Nagano (2009) reported that temperature difference between urban and rural areas can be as high as 5–15 °C. Akbari (2005) similarly characterized UHI as urban areas that are comparatively warmer in regards to solar radiation absorbed by surfaces of buildings and pavements and could not use the natural cooling effect of vegetation in compare with rural areas.

### 2.2. Origins of UHI

The term Urban Heat Island (UHI) appeared for the first time in the *English-language meteorological literature* in a study by Gordon Manley in 1958 (Landsberg, 1981). However, the first discovery of UHI can be named after Luke Howard in 1820 (Priyadarsini, 2009), when he recognized the existence of a thermal difference between nights and days in London, as nights were 3.7 °F warmer and days were 0.34 °F cooler in the city compared to the surroundings (Priyadarsini, 2009). Several causes can be further attributed to the occurrence of UHI in urban contexts as shown in Table 1. The foremost reason for thermal difference in nighttime warmth is laid upon the fact that the thermal masses (e.g. buildings) in the urban areas absorb and store the shortwave radiations received throughout the day and release the absorbed energy during the nighttime through longwave radiations (Fernández et al., 2015). In high-latitude cities with cooler climates, heat islands can be an asset in reducing heating loads, but in mid- and low-latitude cities, heat islands contribute to urban dwellers' summer discomfort and significantly higher air-conditioning loads (Priyadarsini, 2009). Additionally, utilization of materials capable of storing shortwave radiations in the urban landscapes, and lack of evapotranspiration (e.g. shortage of vegetated areas) are also contributed to the appearance of UHI (Chen, Ooka, Huang, & Tsuchiya, 2009; O'Malley, Piroozfar, Farr, & Pomponi, 2015; Schrijvers, Jonker, Kenjereš, & de Roode, 2015; Smith & Levermore, 2008). Reduction of green spaces in urban landscapes can result in dissipating the shades and cooling effect of trees as well as increasing the $CO_2$ emissions. Materials that are being commonly utilized in constructing pavements and roofs, namely concrete and asphalt have significantly different thermal bulk properties (including heat capacity and thermal conductivity), and surface radiative properties (albedo and emissivity) compared to the ambient rural areas. Consideration of geometric features of urban landscapes is also another important factor influencing the UHI. The existence of tall buildings in big cities can potentially offer multiple surfaces for the reflection and absorption of solar radiations as well as increasing the possibility to proliferate the heat within urban areas (Fernández et al., 2015). Moreover, location of the buildings in the context of urban landscape can potentially influence the wind circulation throughout the urban inner spaces through blocking the wind, and preventing the cooling process by convection.

**Table 1**
Occurrence of UHI in urban context by several causes.

| Causes | References |
|---|---|
| Anthropogenic heat emissions | Fernández et al. (2015), O'Malley et al. (2015), Santamouris, Synnefa, and Karlessi (2011), Schrijvers et al. (2015) |
| Pollution and energy consumption within a city | Arifwidodo & Chandrasiri (2015), Fernández et al. (2015), O'Malley et al. (2015), Santamouris et al. (2011) |
| Reduced evaporation | O'Malley et al. (2015), Schrijvers et al. (2015) |
| Intensive land use and high density in urban areas combined with buildings with high thermal masses and heat retaining properties | Harlan & Ruddell (2011), Mavrogianni et al. (2011) |
| Urban street canyons effects resulting in lower rates of long-wave radiation loss during the night | Santamouris et al. (2011), Smith & Levermore (2008) |
| Reduced speed of wind caused by design and layout of the built environment | Fernández et al. (2015), Santamouris et al. (2011)) |
| Trapping the long wave radiation | Schrijvers et al. (2015) |
| Lack of green areas and presence of materials with reduced permeability | Chen et al. (2009), Smith & Levermore (2008) |
| Presence of low-albedo materials on buildings external façades and road surfaces | Santamouris et al. (2011) |

### 2.3. Adverse impacts of UHI

Negative impacts arising from the development of UHI is generally classified into people and (micro) climates (Dhalluin & Bozonnet, 2015; O'Malley et al., 2015). The increase of UHI intensity can negatively affect the citizens' well-being in various ways such as thermoregulatory system damages caused by heat stress appearing in the form of heat syncope, cardiovascular stress, thermal exhaustion, heart stroke and cardiorespiratory diseases (Kleerekoper, van Esch, & Salcedo, 2012; Rydin et al., 2012). Strong heat waves, often concomitant with intense UHI, can elevate the demands for air conditioning in buildings, especially among people who are more sensitive to heat (namely elderlies and children) (Dhalluin & Bozonnet, 2015). Therefore, increased energy consumption as a result of overutilization of mechanical air conditioning systems to cater for accelerated development of UHIs is a major concern. The resultant increase of air temperature can have a detrimental impact on the 'micro-climates' within cities compared to rural areas (O'Malley et al., 2015; Radhi et al., 2015), by formation of ground level ozone (Kleerekoper et al., 2012), change of local micro-and macro-climates (i.e. wind patterns, humidity alterations, storms, floods, and change in local ecosystems) (O'Malley et al., 2015). It is also a key player in worsening global warming conditions (Kolokotroni, Ren, Davies, & Mavrogianni, 2012).

## 3. UHI mitigation strategies

### 3.1. Introducing UHI mitigation strategies in the East Asian countries

City planners increasingly adopt sustainable solutions (e.g. innovative urban landscape planning and infrastructure design) as active