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# Urban heat island and wind flow characteristics of a tropical city

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**Abstract**

Urban Heat Island (UHI) has become a growing concern to the quality of densely built urban environments, particularly in tropical cities. Wind speed has widely been reported to have decreased the intensity of heat island effect in urban areas. The cooling effect of the wind helps to mitigate the adverse effects of heat island on the micro climate and human thermal comfort. This paper investigates the existence of heat island in Muar, one of the fast growing cities in southern part of Malaysia and its possible causes, and then examines the effects of different urban geometry on the wind flow. The results of this study indicate that the chaotic development in Muar has caused reduced ventilation in urban canyons. The heat island intensity in the city center was recorded as 4 °C during the day and 3.2 °C during the night. Investigation of various urban geometry modifications showed that step up configuration was the most effective geometry as it can distribute the wind evenly allowing the wind to reach even the leeward side of each building.


*Keywords:* UHI; Wind speed; Thermal comfort; Geometry modification; Tropical

## 1. Introduction

Over 61% of the world's population is projected to live in urban areas by 2030 (Economic and Division, 2012). The rapid urbanization has turned the cities into densely populated urban areas with less greenery and more impervious surfaces. Loss of vegetation increases the heat storage in the ground layer and building fabrics and contributes to the higher level of air and surface temperature in urban areas compared to their rural surrounding areas (Oke, 1982). This phenomenon which is known as "Urban Heat Island" (UHI) has become a rising concern to the quality of densely built urban environments (Wong and Yu, 2005). According to Landsberg (1981), UHI is a reflection of total microclimate changes caused by urban surfaces alterations. Akbari et al. (2001) described UHI as the areas that tend to have higher air temperatures that their rural surrounding areas due to the gradual surface modifications and replacement of natural vegetation by buildings and roads. Synnefa et al. (2007) defined UHI as the increased ambient temperature of urban areas due to warmer surfaces. Another definition of UHI indicates that urban heat island is a product of micro-climatic variations due to "man-made" interventions and modifications to the natural environment (Kolokotroni et al., 2006).

UHI occurs both during the day and night, but according to Oke (1987), the maximum intensity of heat island occurs 3–5 h after sunset. This is because cities retain much of its heat in roads, buildings, and other structures that prevents them from cooling down. The phenomenon has been well documented since the beginning of last century (Schmauss, 1925) and detailed research have been carried out for 60 years (Chandler, 1961; Oke and East, 1971; Lee, 1975; Lyall, 1977; Landsberg, 1981). Short term and long term measurements were conducted to investigate

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the heat island effect by various methodologies in cities with different size and climatic characteristics (Arnfield, 2003; Santamouris, 2007; Santamouris and Georgakis, 2003; Santamouris et al., 2001). Urban heat island may be considered as an asset in high-latitude cities, due to its role in reducing the energy needed for heating purposes, but many tropics, where all year round, wet or wet–dry seasons prevail, are subjected to heat- related illnesses and high level of energy consumption. In tropics, heat island causes further reliability on air conditioning and thus higher energy use. Application of air conditioning itself will increase the outdoor temperatures through emitting the excess heat to the urban air and more cooling will be required (de Schiller and Evans, 1998; Baker et al., 2002). It is found that for the city of Athens, where the mean heat island intensity exceeds 10 °C, the cooling load of urban buildings may be doubled, the peak electricity load for cooling purposes may be tripled especially for higher set point temperatures, while the minimum COP value of air conditioners may be decreased up to 25% because of the higher ambient temperatures (Santamouris et al., 2001). Factors generating UHI are believed to be the mutual response of over eleven manmade and natural factors (Rizwan et al., 2008; Memon et al., 2010). Che-Ani et al. (2009) summarized the factors generating and defining the intensity of heat island into two broad categories; first is the meteorological factors such as the air temperature, wind speed and direction, level of humidity and cloud cover and second is the urban design parameters, such as density of urban areas, percentage of built up ratios, aspect ratio of urban canyons, sky view factor, building construction materials and urban form.

Several studies have been undertaken to document the UHI of cities in temperate regions (Chandler, 1965; Oke and Maxwell, 1975; Ackerman, 1985; Magee et al., 1999; Runnalls and Oke, 2000), but similar information is scarce for tropical cities (Sham, 1973; Padmanabhamurty, 1979; Jauregui 1986, 1997; Deosthali, 2000; Chow and Roth, 2006). In Malaysia heat island studies were pioneered by Sham, since 1972 (Sani, 1972, 1990; Sham, 1986). Sham investigated the impact of Kuala Lumpur growth on night-time temperature pattern during 1972, 1975 and 1980. The study indicated that the intensity of the heat island had increased considerably followed by increasingly larger areas representing higher temperatures. Sani (1972) conducted comprehensive research regarding UHI in Kuala Lumpur. The study analysed both air temperature distribution and air pollution levels in the city and observed urban–rural temperature difference of 4.4–5 °C. Mobile surveys were carried out in the city of Johor Bahru, Malaysia in March (rainy season) and September (dry season) 2008. The nocturnal urban–rural temperature difference recorded only 2 °C in the rainy day, but it reached a maximum of 4 °C in the sunny day (Kubota and Ossen, 2009). Many Malaysian towns are subjected to rapid population growth, a process in which land use, urban form, and ground cover changes (Johansson and Emmanuel, 2006). On the other hand, urbanization is very fast in tropics, and design issues related to urban climate are normally neglected. Muar is one of the fast growing cities in southern part of Malaysia. Unplanned and rapid urban development in Muar can alter the microclimate of this tropical town, thus changing the air temperature and wind pattern. Furthermore, wind speed has widely been reported to have lessened the intensity of heat island effect in urban areas (Morris et al., 2001; Kim and Baik, 2002; Memon et al., 2010). Therefore, this paper aims to identify the existence of heat island in Muar, one of the fast growing cities in southern part of Malaysia and its possible causes, and then examines the effects of different urban geometry on the wind flow pattern.

## 2. UHI and wind flow

The factors affecting the occurrence and intensity of heat island can be broadly classified into two categories. First category is the meteorological factors including wind speed and direction, humidity and cloud cover. The second category is basically the product of city design, such as density of built up areas, aspect ratio, sky view factor (SVF) and construction materials. This paper deals with heat island effects caused by city configuration and it investigates the impact of urban layout on the wind velocity. Several studies discussed the role of urban geometry on micro climate. Shashua-Bar et al. (2004) investigated the effect of urban geometry on the micro-climate. Their findings show that areas with shallow open spaces and wider spacing recorded temperatures 4.7 °C higher than baseline measurements taken from a meteorological reference. Other research used field measurements to study how urban form may affect the microclimate in different areas in Dubai (Thapar and Yannas, 2007). Comfort surveys showed that higher relative humidity levels are more acceptable by people when there is substantially more airflow. However, the increase in airflow does not necessarily increase the acceptance of higher temperature levels (Ahmed, 2003). Bourbia and Boucheriba (2010) investigated street design and its impact on urban microclimate in semi-arid climate and they found that the higher the aspect ratio, lower the temperature. They suggested that the SVF should be incorporated in urban geometry design as it plays a key role in mitigating the effect of urban heat islands. In a research investigating the relationship between thermal performance and urban morphology and linking them to climatic responses, Golany (1996) stated that the configuration of a city can assist wind circulation and affects wind velocity which in turn influences the temperature variations. He pointed out that city morphology directly affects the movement of the wind within it, depending on its design, shape, and orientation of the roads within it. Morris et al. (2001) investigated the association between urban heat island intensity and wind speed and cloud cover from a network of monitoring stations in and around the large city of Melbourne, Australia. Their main findings showed that calm winds and