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# The impact of environmental and human factors on urban heat and microclimate variability

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ABSTRACT

Urbanization is known to cause noticeable changes in the properties of local climate. Studies have shown that urban areas, compared to rural areas with less artificial surfaces, register higher local temperatures as a result of Urban Heat Islands (UHIs). Hong Kong is one of the most densely populated cities in the world and a high proportion of its population residing in densely built high-rise buildings are experiencing some degrees of thermal discomfort. This study selected Mong Kok and Causeway Bay, two typical urban communities in Hong Kong, to gather evidence of microclimate variation and sources of thermal discomfort. UHIs were estimated from 58 logging sensors placed at strategic locations to take temperature and humidity measurements over 17 consecutive days each in the summer/hot and winter/cool periods. By employing geographic information and global positioning systems, these measurements were geocoded and plotted over the built landscape to convey microclimate variation. The empirical data were further aligned with distinct environmental settings to associate possible factors contributing to UHIs. This study established the existence and extent of microclimate variation of UHI within urban communities of different environmental configuration and functional uses. The findings provided essential groundwork for further studies of UHI effects to inform sources of local thermal discomfort and better planning design to safeguard environmental health in public areas.



## 1. Introduction

The world has undergone rapid industrialization and urbanization in recent centuries. Rapid urban development modifies the natural surface and turns it into manmade structures and built landscapes. These changes have been known to raise local temperatures in urban areas and contribute to the formation of urban heat islands (UHIs). UHIs increase the risks of climatic and biophysical hazards in the urban environment, including heat stress and heightened exposure to air pollutants [1,2]. At the same time, an increased usage of air conditioning and refrigeration in hotter/humid summers incurs a corresponding increase in the energy consumption with negative impacts on the energy resources of a city [3].

Past UHI-related studies have focused primarily on North American and European countries located in the mid-latitudes. Less than 20 percent of these UHI-related studies was carried out in cities of subtropical climate [4]. Singh [5] estimated that 16 of the world's 24 megacities will be in Asia by 2015. These cities in tropical and subtropical regions have characteristically hot and humid summers with relatively weak winds and occasionally extreme continental climates [4]. The fairly stable and mild climates seemed to favor the rapid growth of population and urbanization [6], further exacerbating the heat island effect. Although UHI is about urban–rural differences, a large variation in climate from region to region makes it difficult to draw generalizations about UHI effects and quantify climate-sensitive urban design guidelines governing street dimensions and orientations for use by urban designers.

Microclimate UHI refers to the climate and UHI intensities of a small community or a cluster of developed areas. It is widely known that each city has its own local scale or microclimate that is uniquely different from regional and global climate patterns. Microclimates are influenced by topography, urban forms, and the presence of water bodies and vegetation [7–9]. The microclimate scale can be at the levels of community or neighborhood, building block, garden, and even down to the spacing between buildings,

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such as a street canyon [10,11]. Although more attention has been made in recent years on examining UHI effects at the microclimate level, the environmental performance of various causative UHI factors in an urban community has remained uncertain [12,13]. Much of the established microclimate results to date were based on simulated results conducted in wind tunnel facilities and through simulation by computational fluid dynamics [14,15]. Therefore, urban climate-related studies providing empirical evidence to quantify microclimate UHI effects is vital to understanding the impact of human activities and urban development on longer-term temperature change.

This study is an attempt to patch research gaps in microclimate UHI studies. It demonstrated the feasibility of low-cost sensors in undertaking continuous temperature measurements in a subtropical setting where UHI-related studies have been found inadequate. The integrative use of geographic information systems (GIS) technology in microclimate UHI studies also facilitated temporal and spatial examination of the UHI phenomenon. In addition, our study found key differences in the local environment (vis-à-vis urban morphological features and human activities) that collectively shape the microclimate. It showed that microclimate UHI is strongly affected by the existence of buildings and street canyon geometry amidst other meteorological factors and human activity patterns. The knowledge is essential to derive some parameters governing urban heat fluxes. The method of combining logging sensors and a GIS means that the UHI problem of a community can be examined spatially and effectively at little cost to result in better appreciation of subtle differences in the conditions prevailing over a given landscape. This knowledge can be incorporated into urban planning and design practice to maintain temperatures at a more pleasant level for human thermal comfort and less damaging to human health.

## 2. Data and method

The study involved the deployment of multiple temperature sensors in two different urban communities of Hong Kong for internal consistency checks. To enable a structured understanding of microclimate differences, these sensors were mounted in locations with characteristically different environmental settings, including (1) areas traversed by a main road with heavy traffic; (2) areas bordering a secondary road with moderate traffic; (3) areas typified with heavy human activities; (4) open or park areas with greenery; and (5) semi-enclosed areas or tunnels.

### 2.1. Study area

Hong Kong, situated along the south east coast of China near the entrance of China's Pearl River Delta (22°15′ N, 114°10′ E), has an average attitude of 8 m above sea level. It is one of the most densely populated cities in the world with a high proportion of its 7 million people concentrating in 265 square kilometers of urban areas or 24 percent of the total land area (1108 square kilometers) [16]. The morphology of Hong Kong is a combination of mountainous terrain and widely scattered urban development with densely built high rises. The climate is a monsoon-influenced humid subtropical climate with hot and humid summers and mild winters according to the Köppen classification Cwa system [17]. Most summer days have characteristically high humidity with warm air coming from the southwest, creating zones of local thermal discomfort.

Mong Kok (MK) is located within the center of the Kowloon Peninsula and Causeway Bay (CWB) along the northern part of Hong Kong Island (Fig. 1). Both communities are densely populated and have mixed commercial and residential land uses [18]. They could both be classified as Compact High-Rise Zone (BCZ1) based on the local climate zone (LCZ) defined by Stewart and Oke [19]. MK is situated inland and away from the waterfront with pockets of green areas whereas Causeway Bay is bordering the Victoria Harbor and has a large urban park measuring over 19 ha [20]. According to a shopping survey conducted by the Hong Kong Planning Department [21], MK and CWB were respectively the first and second most popular shopping districts in Hong Kong as they were characterized by an interesting mix of street markets, street-side retail shops and food stalls, as well as medium-to large-scale shopping malls. They are believed to be two of the most representative urbanized areas with a high level of human activity that require an in-depth analysis of the effects of urbanization on microclimate.

The Mass Transit Railway (MTR)[2] is the most comprehensive transportation system in Hong Kong linking local districts and its exits are known to be core centers with high human activity. Due to ambiguity in identifying geographic boundaries for MK and CWB, radial buffers of 200 m and 400 m [22,23] were applied around all MTR exits at each site to embrace its activity areas (Fig. 2). Within the buffered areas, the urban morphologies of MK and CWB were characterized by rigid street networks interlaced with built structures. Both communities are facing a large number of urban issues of varying degrees, including crowded settlement, heavy traffic, infrastructure degradation, unfriendly pedestrian environment, and a lack of open space and urban greening (especially in the case of MK).

Fig. 2 shows the extent of the study areas in which the 200 m buffer zones delimit areas with a concentration of pedestrian flow, as well as commercial and retail activities. The peripheral zones from 200 m to 400 m represent areas with limited commercial activity to serve planned residential, convenience retail, recreational and other uses. These study areas outline the areal extent to mount temperature sensors to cover locations with the five characteristically different environmental settings explained earlier.

### 2.2. Instrument and data collection

Past research has shown that traffic emission and roadside activities are significant contributors to urban heat [24,25]. In accordance with standards set by the World Meteorological Organization [26], most of the official weather stations managed by the Hong Kong Observatory (HKO) are situated in park-like settings away from urban streets. This constraint, coupled with a sparse coverage of 43 automatic weather stations for the whole of Hong Kong [27], has prevented detailed examination of UHI in urban communities with well-developed road networks.

A total of 58 small and low-cost Thermochron iButton sensors (DS1923; Maxim/Dallas Semiconductor Corp., USA) [28] were each housed within a non-aspirated solar radiation shield (HOBO Onset RS-3) and mounted on a road-side street sign post with a hose clamp at 2.3 m above ground (Fig. 3) as stipulated by the Highways Department. The sensors took air temperature and relative humidity measurements at every 15-min interval for 17 consecutive days in the summer (15 September to 1 October 2012) and repeated again in the winter (18 January to 3 February 2013). The weather during these two periods of measurement was clear and calm with mean temperature readings ranging between 26 and 28.5 °C in the summer and 14.6 and 21.4 °C in the winter [27].

The survey locations (26 in MK and 32 in CWB) were decided strategically to include public transit access points (e.g., exits of the

[2] The Mass Transit Railway (MTR) is a light rail network and is the most convenient and a major means of public transportation in Hong Kong. The MTR exits are known as one of core locations of high human activity that collectively delimit the extent where population gathers for social and economic engagement.