A Position Paper

Urban Heat Island in Hong Kong

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Introduction

This is a summary report of a study to investigate Urban Heat Island (UHI) in Hong Kong. It is aimed at ‘decision makers’- planners, architects, urban designers, developers and public health care professionals and help them to take more consideration regarding to UHI in urban planning.

Hong Kong possesses oceanic sub-tropical climate. Hotness, humidity and thermal discomfort are main characteristics of the weather in most days of the year and in the context of global warming, Hong Kong experiences hotter climate than before. In a Hong Kong Observatory technical report, it is found that the annual mean temperature is increasing at a rate of 3.5 °C per year in the recent 20 years and the number of cold days is decreasing at a rate of 0.3 day per year in the recent 100 years. The UHI effect is one of the reasons accounting for such local climate change.

Hong Kong is particularly vulnerable to high summer temperatures – our homes, workplaces, public buildings, public realm and transportation vehicles are equipped with air conditioning, which contribute to the urban heat conditions. Hot weather places additional stress on the body, raising health risks for the vulnerable and increasing discomfort for everyone. Every 1 degree rise in outdoor temperature means at least 6% increase in energy costs. Hong Kong’s growth over the next decade needs to ensure that new development is located, designed and constructed to minimize, and if possible, reduce its contribution to Hong Kong’s urban heat island.
What is the Urban Heat Island?

Urbanization is the growth of the proportion of the population living in urban areas. The world is experiencing unprecedented urban growth. Only 3% of the world’s population lived in urban areas in 1800 and this figure increased to 14% and 47% in 1900 and 2000. The rapid urbanization and the emergence of many mega cities trigger a number of environmental issues. The Urban Heat Island is one of the effects of urbanization. The UHI refers to the phenomenon that the temperature in the urban place is always higher than that in surrounding rural areas, especially at calm and cloudless night. Figure 1 illustrates an idealized heat island profile for a city, showing temperatures rising from the rural fringe and peaking in the city centre. The profile also demonstrates how temperatures can vary across a city depending on the nature of the land cover, such that urban parks and lakes are cooler than adjacent areas covered by buildings.

According to Landsberg [1], Urban Heat Island, as the most obvious climatic manifestation of urbanization, can be observed in every town and city, such as New York, Washington, Tucson, Phoenix, Mexico City, Tokyo and Shanghai etc. The urban heat island is mainly caused by the storage of solar energy in the urban fabric during the day and release of the energy into the atmosphere at night. The process of urbanization and development alters the balance between the energy from the sun used for raising the air temperature (heating process) and that used for evaporation (cooling process).

The strength of the urban heat island is measured by the ‘urban heat island intensity’, which describes the maximum difference in temperature between urban and rural locations within a give time.
period. The highest values of the urban heat island intensity, in the region of 3-8 °C, are often reached between about 11 o’clock at night and 3 o’clock in the morning (Figure 2). This is why the urban heat island is often referred to as a nighttime phenomenon. UHI intensities are also greater in summer than winter because of contrasts in the amount of energy received from the sun, which is absorbed by the urban surface during the day and released at night. The urban heat island keeps Hong Kong warmer in winter. This could be one additional reason explaining the decreasing cold days within the whole year, besides the contextual greenhouse effect that the annual mean temperature is increasing. Besides, the UHI is found to have a relationship with the urban population, as shown in Figure 3.

The heat island effect is welcomed in short winter in Hong Kong will increase the city temperature, make the citizens comfortable and decrease the energy consumption for heating. Anyhow, Hong Kong lies in the sub-tropical region and
experiences a very long hot and humid summer so that in such case the heat island effect is a negative effect. The planners, architects, urban designers and developers should keep in mind that the urban heat island intensities should be mitigated and planning and construction should not deteriorate the heat condition.

Figure 2. The variation in UHI intensity for Hong Kong over 24 hours for Autumn 2006. The temperature taken from Hong Kong Observatory station is used as the urban temperature while that taken from Ta Kwu Ling station is used as the rural temperature. (courtesy HKO)

Figure 3. The UHI’s linear relationship with the urban population
Urban Heat Island Studies around the world:

Firstly discovered by Luck Howard [2], the UHI has attracted much attention of the researchers around the world.

In Europe, various studies on the intensity of the UHI have been done for many cities. A daily upper docile limit of 3.1°C was reported by Chandler [3] in a comparison of Kensington and Wisley over a period of ten years. Lyall [4] observed the average magnitude of the nocturnal heat island effect was 2.5 °C in June and July in London. An average UHI intensity of around 7°C was found by Barring [5] during the winter and spring seasons in Malmö, Sweden and the UHI intensity observed in Essen, Germany by Swaid and Hoffman [6] was between 3 to 4 °C for both day and night time.

In North America, there are also lots of studies of UHI carrying on in many cities. In 1997, the Environmental Production Agency (EPA) instituted the “Heat Island Reduction Initiative” (HIRI) in the wake of the heat wave that struck Chicago in July 1995, resulting in a death toll of over 700 people [7]. As part of this initiative, the “Urban Heat Island Pilot Project” (UHIPP) was launched in 1998 to investigate the UHI effect, raise public awareness of the issue, and quantify the effects of mitigation measures [8]. Subsequently, five cities have been selected for inclusion: Baton Rouge, Chicago, Houston, Sacramento, Salt Lake City.
In Asia, numerous studies on the UHI have also been done in some countries. Chow [9] reported the magnitude of the urban heat island effect in Shanghai, China. A systematical study on UHI was carried in Singapore [10]. In many cities in Japan, such as Tokyo, Kobe, Osaki etc, studies on UHI were carried on as well. Strategies as well as guidelines that mitigate the UHI intensity were proposed. For example, network of water, green space and wind paths along the Meguro river in Shinagawa was proposed in order to mitigate the UHI effect, as illustrated in Figure 4.

Figure 4. Proposed measures to mitigate the UHI effect in Shinagawa (source http://www2.city.shinagawa.tokyo.jp/jigyo/05/bijyon_s.pdf)
What is the Evidence for Hong Kong’s Urban Heat Island?

According to the technical report of Hong Kong Observatory, due to the greenhouse effect, the world is getting warmer and warmer in the last century. In the context of global warming, Hong Kong experiences a higher temperature increase, i.e., the mean temperature of the Hong Kong has increased 1.8 °C while that of the entire earth has increased 0.6 °C through the last century [4], which could be illustrated in Figure 5. The UHI effect is thought to be the main reason causing the difference. However, studies of Hong Kong UHI were not so many that some data, for example, the spatial and temporal distribution of the UHI intensity is not clear, and the dominant factors, which result in the Hong Kong UHI, also need further research as the topography, climate and city structure is different with those cities studies before. Hence further detailed research about detection and characteristic of Hong Kong UHI is imperative. There are three prevailing approaches detecting the UHI. One is using the historical Hong Kong Observatory data.

The HKO stations record accurate temperature and other weather data, but there are only limited stations and they cannot provide the spatial distribution of the UHI over the whole city.

The second approach is to employ the remote sensing technology. According to J.A. Voogt and T.R. Oke [16], thermal remote sensors can observe the surface UHI since they ‘see’ the spatial patterns of upwelling thermal radiance. Studies that have applied thermal remote sensing to study of UHI have been well summarized by them. An example of such UHI image is shown in Figure 6. In Hong Kong, Prof J. Nichol et al. have utilized the ETM+ satellite images to investigate the UHI and proved this technology an useful technology to study the
UHI. Spatial distribution of the UHI and the effect of building structure and material could be derived from remote sensing image, as shown in Figure 7 [11].

Figure 5. Annual mean temperature anomalies globally and at Hong Kong Observatory Headquarters (courtesy HKO)

Figure 6. Relative temperature derived from thermal band of Landsat-7 ETM+ satellite (Singapore – courtesy N H Wong)
The third approach uses grounded-based measurements. Fixed weather stations or moving vehicles can provide usable data on the ground. By taken consideration of the neighbourhood conditions, such as the surface albedo, sky view factor, green area, wind condition etc, it is also possible to investigate the causing factors which result in the UHI in certain area [17].

Besides the UHI, another term named as Physiological Equivalent Temperature (PET) [12] is used to describe the effective temperature, which considers all the environmental factor, such as temperature, solar radiation, wind speed, humidity etc. It is an effective thermal index for the urban planners and architects to evaluate the environmental condition. An example of the PET distribution in Hong Kong with 1km*1km resolution is shown in Figure 8.

Figure 7. UHI distribution in Wan Chai, derived from the satellite remote sensing images. (courtesy J. Nichol)
Figure 8. Distribution of calculated PET in Hong Kong, in Jan (left) and July (right). (source: Prof A. Matzarakis)

Figure 9. Total daily deaths in London, by age group in 2003. The peak in deaths is coincided with the August heat wave
What are the Environmental & Socio-Economic Consequences of the Urban Heat Island?

Hong Kong lies at the latitude of 22°17'N and has sub-tropical oceanic climate. The temperature in most days of the year is higher than the human thermal comfortable temperature. The UHI additionally increases the urban temperature. UHI in winter, is a welcome effect in some extent, however inversion layers may form due to the UHI effect. Ascending warm air current created from warm urban areas are trapped under inversion layer that exacerbate air pollution [18]. Higher urban temperature make the people feel uncomfortable and boost demand in more energy consumption for air conditioning. Increasing of the urban temperature by 1 °C may result in 2% to 3% in increase of energy consumption. During the last 40 years, it can be assumed that 3% to 8% of the current urban electricity demand is used to compensate for the heat-island effect alone [19]. Recent research conducted by National Aeronautics and Space Administration (NASA) also reveals that the UHI will also lead to increasing of the rain fall around the cities [20].

In addition, the UHI will also have significant socio-economic consequences. The UHI deteriorate the urban temperature in extreme hot weather conditions and may lead to increase of mortality. A case example is that during the summer of 1999, a heat wave occurred in the mid-western and eastern United States. This period of hot and humid weather persisted from July 12 through August 1, 1999, and caused or contributed to 22 deaths among persons residing in Cincinnati (18 deaths) and Dayton (4 deaths) [21]. Another example is the sudden increase of mortality in London in Summer, 2003, when in which time the heat wave occurs. Especially the elder people are much more vulnerable to the extreme heat condition. As shown in Figure 9, the sudden increase of mortality, especially the elder mortality, coincides with the heat wave in 2003. Taken consideration of all the impacts mentioned above, it can be concluded that the UHI is a negative effect more than a positive effect in Hong Kong.
What is the Principal Causes of the Urban Heat Island?

The UHI is an ‘inadvertent’ modification of the climate, caused by changes to the form and composition of the land surface and atmosphere. When a land cover of buildings and roads replaces green space, the thermal, radiative, moisture and aerodynamic properties of the surface and the atmosphere are altered. This is because urban construction materials have different thermal (heat capacity and thermal conductivity) and radiative (reflectivity and emissivity) properties compared to surrounding rural areas, which results in more of the sun’s energy being absorbed and stored in urban compared to rural surfaces. In addition, the height of buildings and the way in which they are arranged affects the rate of escape at night of the sun’s energy absorbed during the day by building materials. The result is that urban areas cool at a much slower rate than rural areas at night, thus maintaining comparatively higher air temperatures. Urban areas also tend to be drier than their rural counterparts because of the lack of green space, a predominance of impervious surfaces and urban drainage systems, which quickly remove water from the urban surface. This combination of effects alters the energy balance of the urban environment. Consequently in urban compared to rural areas, more of the sun’s energy absorbed at the surface goes into heating the atmosphere and thus raising the air temperature than into evapotranspiration (water uptake and loss by plants), which is a cooling process.
According to Oke et al [22], those important factors influencing the UHI include:

- Canyon radiative geometry decreases the long-wave radiation loss from street canyons since the complex exchange between buildings and the screening of the skyline. It could be graphically illustrated in Figure 10. Owing to this reason, the UHI intensity is correlated with the geometry of the urban canyon, as expressed by the relationship between the building’s height (H) and the distance between them (Width), namely the ratio: (H/W) [14]:

\[ dT_{\text{max}} = 7.45 + 3.97 \ln(H/W) \]

Figure 10. Schematic distribution of the impinging solar radiation in open-flat country, built-up area with H/W ratio of about 1 and high-density urban area with H/W ratio of about 4, revealing that more reflected radiation energy is stored within the canopy layer for higher H/W ratio case.

Figure 11. Typical Hong Kong buildings with high stores and high H/W ratio
or alternatively, the urban hemispheric height-to distance ration, as seen from a given point, can be expressed by the “sky view factor”:

\[ dT_{\text{max}} = 15.27 - 13.88 \times \text{SVF} \]

We believe this is the main reason for the UHI in Hong Kong. Typical buildings in Hong Kong possess high stories and the width between buildings is narrow, i.e., the buildings have high H/W ratio, as illustrated in Figure 11. On one side, this kind of geometry stores more heat in the day time than the buildings with low H/W ratio. On the other side, such wind-blocking buildings will block the prevailing wind, reduce the wind speed and deteriorate the urban air ventilation. This is why the Planning Department of Hong Kong initiates the project on “Air Ventilation Assessment in Hong Kong”, which is coordinated by Prof E. Ng [23].

- Thermal properties of materials increase sensible heat gain during the daytime and release it back into urban environment at night. These materials also replace soils or plants which are naturally cooling means in cities.
- The loss of evaporating surfaces transfers more energy into sensible heat rather than latent heat in cities.
- Anthropogenic heat released from vehicles, stationary sources or animal metabolism increases ambient air temperatures in cities.
- The urban greenhouse effect incurs more incoming long-wave radiation gain from the polluted urban environment.
- Reduced turbulent transfer of heat from within streets.
What are the Options for Managing the Urban Heat Island?

Policies designed to mitigate the UHI may need to balance the need to manage heat at the building, neighbourhood and city scales, taking into account the nature of development (new versus existing) and be conscious of what is achievable in reality. Furthermore, the climate of Hong Kong is changing because of alteration to global-scale climate processes. This has implications for the planning and design and current and future urban developments from the local to city scale. Urban designers and planners need to acknowledge this, and in doing so base design criteria on data that describes the current and projected future climate of Hong Kong, and be especially aware of the critical importance of minimum temperature for human thermal comfort, health and patterns of energy consumption.

As mentioned in the previous section, the principal causes of the UHI are the storage by day of solar energy in the urban fabric and release of this energy into the atmosphere at night, and the fact that the process of urbanization alters the balance between the energy from the sun used for raising the air temperature and that used for evaporation. The urban buildings’ geometry, construction material (which affects the effective albedo, thermal capacity and conductivity), decrease of plants and vegetation are account for this effect. In addition, anthropogenic heat could become an important future contribution of energy for the development of the UHI, depending on energy consumed in air conditioning/heating for example. The future construction and planning strategies that will mitigate the UHI should consider every aspect according to the main causes of the UHI.
In developing mitigation strategies for Hong Kong’s UHI, it must be kept in mind that the UHI is a city scale phenomenon and the outcome of the combination of the vast range of microclimates that exist across Hong Kong. Further, as the built components of the urban system occur at different scales (e.g., individual building to industrial park to major industrial zone) any physical alteration of these will have climate impacts at different scales. Consequently the link between UHI management policy and urban climate scale needs to be acknowledged. To manage Hong Kong’s UHI form and intensity would require the alteration of existing land cover characteristics for large areas of central Hong Kong. From a practical point of view this is not possible. However there are opportunities to change microclimates and therefore manage climates at the street canyon to neighborhood scale. Over time the cumulative effects on UHI form and intensity of a staged programme of local scale climate modification could be significant. Effective strategies that can be implemented within the context of the existing urban structure and have impacts at the local and near local scale include cool roofs, green roofs, planting trees and vegetation and cool pavements.

Cool roofs & walls: Roofs and walls in color (the albedo of which are usually lower than that of light color materials) and will probably reach temperature of 50-60 °C on hot sunny days. The stored energy will be released to the urban atmosphere and is the major resource contribution to the UHI. The higher the temperature of these roofs and walls is, the higher the UHI intensity will be. The heat of the buildings’ surface will also transfer into inside of the building, causing higher energy consumption for air conditioning. In addition, higher temperature of roofs and walls will also accelerate the deterioration of the construction materials. In contrast, roofs and walls built with materials with light color, high reflectance/albedo and low heat capacity in future building
construction are welcome. They will strategically change the effective albedo of the whole city.

**Cool Pavements:** Like many of Hong Kong’s roofs, the streets and to a lesser extent, the pavements of Hong Kong are typified by dark surfaces. The employment of ‘cool pavements’ comprised of material with high solar reflectivity and good water permeability is potentially a very effective way of mitigating high urban temperatures through decreasing absorption of solar energy and encouraging water storage in the urban surface and thus evaporative cooling. The high albedo roads and pavements may have benefits for nighttime street lighting. For Hong Kong, discernible climate impacts of cool pavements could be achieved for large parking areas, terminal facilities, air ports and urban roadways with large expanses of paved surfaces when re-surfacing or new surfacing is planned.

**Planting Trees and Vegetation:** ‘Urban Greening’ would be the most cost-effective way of ameliorating harsh urban climates at the individual building to neighborhood scale. Trees and vegetations are good climate modifier due to the following three reasons: 1They provide shade, which reduces the temperature by 5-20 °C, compared to the places with solar radiation and provide better outdoor thermal comfort environment. Trees planted along the roads will have significant impact reducing the temperature of road, as mentioned in the last paragraph, which is a big factor causing the UHI. 2 Water is easier to be kept at the vegetated places while it is always drained away at concreted places. The trees and grass etc will convert the water beneath the vegetation surface into water vapor and release to the atmosphere. Thus much part of the solar radiant energy transferred to latent heat, instead of sensible heat (which raises the air temperature and causes human discomfort). It is estimated that
Evapotranspiration can result in reduction of the micro-scale temperature by 1-5 °C.

3 The trees and vegetations consume large amounts of solar radiant energy through the process of photosynthesis. Apart from that mentioned above, there are a lot of additional benefits arising from urban trees and plants. They can act as carbon store, reduce urban flooding, concrete the groundsill, filter air pollutants and CO₂, and contribute to quality of life. So the urban greening is a very important and cost-effective way to modulate the UHI, as well as the urban micro-climate. Policies should be made regarding to the urban greening.

In addition to the cool roofs and walls, green roofs and walls, which consist of a growing medium planted over the roofs or along the walls, can have a marked impact on the climate of the upper floors of buildings and their immediate environs, as illustrated in Figure 12. With their cooling effect as a result of the evapotranspiration, the plants have lower temperature compared with the bare concrete surface and could serve as a insulator layer.

Figure 12. some examples of buildings adopting the green roofs and walls
Urban Geometry: The urban geometry, such as the SVF, H/W ratio etc, has great influence on the formation of the UHI. But it is yet unknown that how different urban radiative geometries explicitly cause change of the air temperature and this issue needs further research. Fortunately it is found by previous study (named as AVA project) [24] that optimizing the natural ventilation inside the city could be an effective method to improve the heat extraction rate and to provide more thermal comfort (Please refer to [24] for detailed information about the AVA project). The UHI is always observed at calm, clear nights or days and disappear when there is wind [13,14,19]. The speed of wind is significantly reduced inside the city, which is known as the canyon effect, referring to the Figure 13. The higher the H/W, the urban wind is one that can be dominated and modified by urban design. The main urban design elements which can modify the wind conditions are the overall density of urban area, size and height of the individual buildings, existence of high-rise buildings and the orientation and width of the streets [8].

Figure 13. Different urban geometry and the corresponding airflow scenarios. (Oke, 1987)
**Reduction of anthropogenic heat release:** Anthropogenic heat, although not a very important factor causing the UHI, it could play significant role in certain condition. It is found that impact of anthropogenic heat may be important in urban centers but negligible in residential and commercial areas [24]. Besides, anthropogenic heat due to, for example the energy consumed for air conditioning, could be reduced by human habit, i.e, by adjusting the air conditioner to comfortable temperature instead of to very low temperature. These kinds of actions not only reduce the anthropogenic heat release to some extent, more importantly, they also have important meaning in saving the energy.
What More Needs to be Known about Hong Kong’s UHI?

Although there are studies focusing on the urban heat island of Hong Kong, the information that is available about Hong Kong’s UHI is not complete. Compared with the other major cities, such as London and Tokyo, our understanding of the causative factors, the form and intensity, the socio-economic and environmental impacts of Hong Kong’s UHI, and the guideline to mitigate Hong Kong’s UHI remains rudimentary.

The following subjects require further research on Hong Kong’s UHI:

1) Detection and characteristic of UHI – Develop a network of weather stations across Hong Kong to record critical climate variables, such as short and long-wave radiation, temperature, humidity, wind speed and direction. Utilize the fine resolution image by satellite remote sensing to detect and characterize the spatial and temporal distribution of the UHI intensity.

2) Use the gathered climate data to build an urban energy balance model for Hong Kong that can be applied at a variety of spatial scales.

3) Develop a decision support tool for planners, urban designers and architects to help identify and prioritize ‘anti-UHI’ interventions, such as targeted urban greening, urban geometry and cool material programmes.

4) Assess the contribution of the UHI to heat related excess deaths, and use evidence to inform the local heat wave plan.

5) Collect data on Hong Kong’s anthropogenic heat emissions and model future heat emissions to determine how to manage this potential extra source of heat.

6) Implement a range of anti-UHI demonstration projects that apply a number of UHI mitigation and collect requisite climate data to assess efficacy.
Urban Heat Island in Hong Kong

References:

Acknowledgement:

“Urban Heat Island in London” is referred.


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