AN EMPIRICAL STUDY ON OUTDOOR THERMAL ENVIRONMENT OF RESIDENTIAL DEVELOPMENTS AND STREET BLOCKS IN HONG KONG

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Summary

Majority of Hong Kong's population lives in high-rise high-density residential developments or mixed use street blocks. In such high-density living conditions, the provision of open space at neighborhood level is of vital importance to enable residents to enjoy better quality of life with the social, psychological and environmental benefits that open spaces can bring. However, when designing these public spaces, the effect of the overall build forms on the microclimate conditions need to be considered. Only when the conditions allow for human comfort would these spaces serve to promote sustainability. One significant factor having adverse effect on human comfort is heat stress. Heat stress in urban areas can be described by Urban Heat Island (UHI).

This study investigates the impact of design-related variables on outdoor micro level heat island effect in residential developments and mixed use street blocks in Hong Kong. It hypothesizes that a significant part of the differences in outdoor temperatures within and between the studied areas can be explained by the impact of design-related variables. The findings of the study will lead to specific environmental design guidelines to help practitioners to make design decisions at micro-urban and urban scales for more sustainable communities.

1. Introduction

Hong Kong has a population of 6.7 million, and a total land area of just 1,100 square kilometres, making it one of the most densely populated cities in the world. Due to the scarcity of available land (around 25% of the total area) for building in Hong Kong, most of the population lives in high-rise high-density residential blocks (privately developed or government subsidized) in urban areas, where the population density averages at around 26,000 persons per square kilometre and reaching 51,000 persons per square kilometer in the most densely populated area. The urban fabric is dominated by tall buildings with limited open space provision. (Figure 1a, b and c from left to right)

Figure 1a Large-scale residential developments with tower blocks of similar height and configurations

Figure 1b Sharp edged buildings of different height in urban street blocks

Figure 1c Newer taller developments form 'walls' surrounding older street block

It is well established that urban open spaces are vital to the well being of city dwellers. Urban spaces contribute to achieving sustainability and their importance for better quality of life is particularly crucial in high density cities such as Hong Kong. In light of the high density high rise environment of a compact city like Hong Kong, where the area of urban open space per inhabitant is only about 2.9 m^2 / inhabitant (Census and Statistics Department, 2001) as compared to the World Health Organization's recommendation of 10 m^2 / inhabitant, the importance of provision of high quality urban open spaces is further high-lighted.

Study by Lo et al (2003) on the analysis of attributes affecting urban open space design and their environmental implications concludes that microclimate is the most important criterion for urban open space users in Hong Kong. Research by S. B. A. Coorey (2008) on design of open spaces in public housing estates in Hong Kong also found that respondents' evaluation of physical environmental quality such as climatic comfort for open space scores comparatively high compared to other attributes such as crowding, privacy, safety and social interaction in achieving users' satisfaction of open space in high density contexts.

In light of these findings, microclimatic conditions are considered integral to the success of an urban open space, since they have significant influence on the level and satisfaction of use. The potential of urban open spaces in providing human comfort and promoting sustainability of urban living greatly depends on their thermal performance.

1.1 Background

Multiple and intensive land use is a sustainable approach in dealing with expanding metropolitan areas. Hong Kong has adopted the MILU model of development to cope with the increasing population and the economic need to expand the metropolitan area on very limited build-able land over the last five decades (Lau et al, 2005). The success of MILU model is evident in the development of Hong Kong into the metropolitan that it is at present, with many cities in China, such as Guangzhou and Shanghai following suite. However, the MILU model has also contributed to the adverse effect on microclimatic condition such as increased Urban Heat Island (UHI) in urban areas due to its typically high-rise high-density built form. The study of UHI in existing MILU developments would serve to inform other cities the possible adverse effects of adopting the MILU model and to make design decisions to avoid such effects.

The study of thermal environment of urban outdoor spaces requires understanding of urban morphology and climatology, both multi disciplinary study areas involving architectural design, planning considerations, building physics and atmospheric sciences. The local climate of an urban area can be greatly affected by the urban thermo-physical and geometrical characteristics and anthropogenic moisture and heat sources present in the area (H. Taha, 1997). In the high-density high-rise setting of Hong Kong, it can be anticipated that the adverse effect on the thermal conditions would be further aggravated since urban heat island intensity (UHI) rises with increased building density and canyon geometry (M. Santamouris, 2001). Hong Kong has one of the highest net urban densities in the world (Ganesan et al 2000). UHI is an outcome of modification brought into characteristic of land use in densely populated areas (Solecki et al 2005). In such scenario it is mandatory to integrate urban climotological elements (Abbate, 1997).

1.2 Hypothesis

This study investigates the impact of different form of open space configurations on outdoor micro level daytime and nocturnal heat island effect in residential and mixed use developments and street blocks in Hong Kong in order to understand the design implications involved in making comfortable outdoor open spaces for people's enjoyment. This paper hypothesizes that a significant part of the differences in outdoor temperatures within and between each studied site can be explained by the different typical open space configurations on the overall environment.

2. Methodology

The methodology used in this study is based on one that has been established by previous research on coastal UHI measurement in Hong Kong (Giridharan et al, 2004). The methodology has been improved by conducting simultaneous measurements at three different geographical zones for any given measurement period. 15 to 20 measurement points were chosen for each sample site, taking into account the maximum possible variations in design-related variables such as sky view factor, height to floor ratio and surface albedo.

Figure 2 Sky view images and photographs showing the variations in design-related variables

The data collection period was from 1300-2200, with hourly data collected at each measurement point. Data were collected simultaneously at 3 sites from different geographical zones for a period of 3 days.

In each of the studied site, 1 mini weather station measuring air temperature, relative humidity, wind speed and direction, and solar radiation was fixed at the most representative of the measurement points and 3 micro-loggers with sensors measuring air temperature, relative humidity and wind speed are fixed at other strategic measurement points, taking into account the variation in design descriptors of their location. Mobile measurement of air temperature, relative humidity and wind speed using an anemometer were carried out at all measurement points.

Figure 3 Photographs showing fieldwork equipment and measurement on site using fixed mini-weather station and mobile anemometer

2.1 Classification of Inner-city Areas

Inner city areas refer to the parts of Hong Kong Island, Kowloon Peninsula and the more urbanized parts of the New Territories which are not abutting the sea front, and are subject to minimal impact of the sea due to high density and height of buildings in the proximity. The characteristics of inner city residential developments and mixed use street blocks are identified as follows:

- Very dense construction and street blocks virtually walled by surrounding buildings;
- Construction materials used for vertical surfaces are of very high heat storage capacity;
- Very high degree of impervious horizontal surface (asphalt, concrete, cement stone paved);
- The block geometry generally traps radiation and creates air stagnation;
- Very tall and sharp edged buildings;
- Very low density of vegetation along the streets;
- Negligible extent of heat sinks due to small urban parks and lack of sizeable water bodies within the micro environment;
- High heat and waste release from residential and commercial space;
- High volume of traffic;
- High levels of commercial and street lightings;
- Canyon geometry ratio in the order of 3 to 6

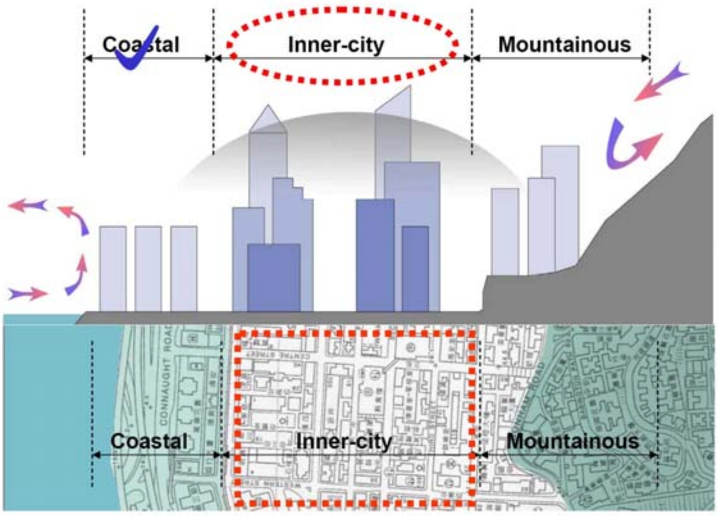

Figure 4 Conceptual section and plan of inner city classification

2.2 Surveyed Sites

A total of 18 sites, including public housing estates, private-sector residential developments and primarily residential mixed-use street blocks of similar scale were surveyed in this study. They are distributed in 6 different geographical zones. The samples are representative of the typical residential environment types in Hong Kong's most populated urban areas, chosen to incorporate the maximum possible variations in design-related descriptors. Attention is paid to select samples which have a larger variation in categories which have shown to make the most impact on UHI from previous study of coastal UHI in Hong Kong. Tower block residential developments as well as MILU street blocks were surveyed.

Figure 5 Location of surveyed sites in 6 different geographical zones in Northern part of Hong Kong Island and Central Kowloon Peninsula

In this paper, only one set of the 3 simultaneously surveyed sites will be discussed, the built form and urban fabric of the three sites are shown in the figures below:

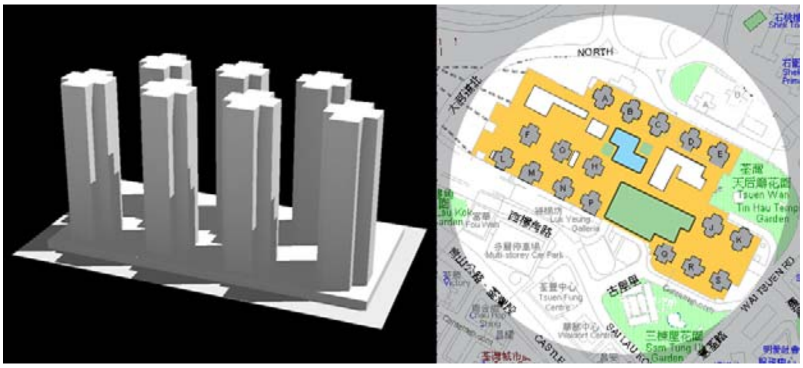

Figure 6 Site A -Towers on podium type configuration typical in residential developments

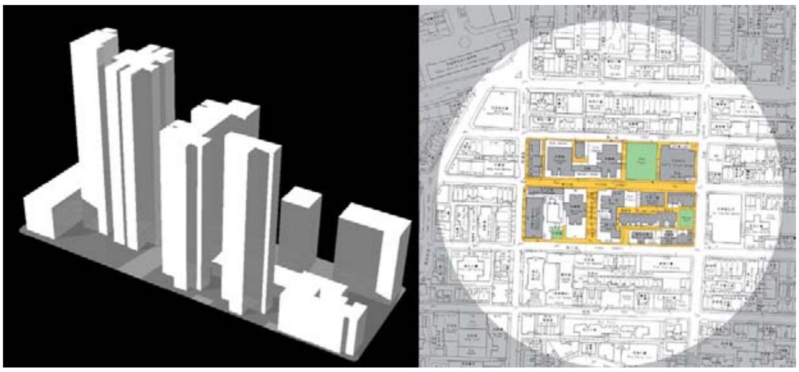

Figure 7 Site B - Mixed use / residential street block with small pocketed open spaces

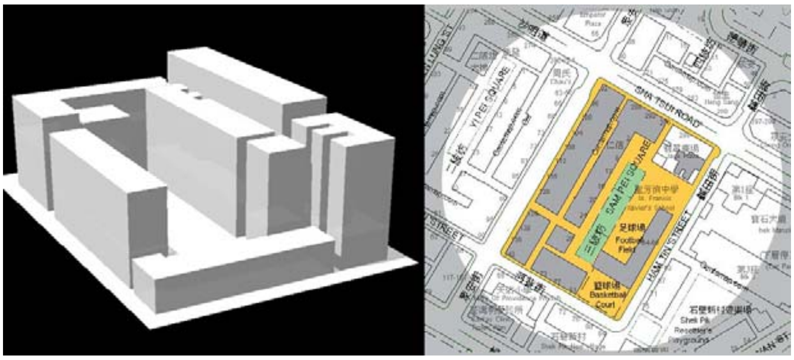

Figure 8 Site C - Mixed use / residential street block with courtyard type centralized open space

3. Findings and Observations

The initial findings show that the majority of urban open spaces in Site A, B and C do not have the ability to improve the urban microclimate and mitigate the heat island effect by reducing summer air temperatures in dense urban areas by 3-4 ºC as suggested by simulation studies (Dimoudi and Nikolopoulou, 2003). The maximum intra-site temperature differences for both daytime and nocturnal measurements were found in Site C at only 1.8 ºC and 1.1 ºC respectively, which are significantly lower than the reduction suggested by simulation studies.

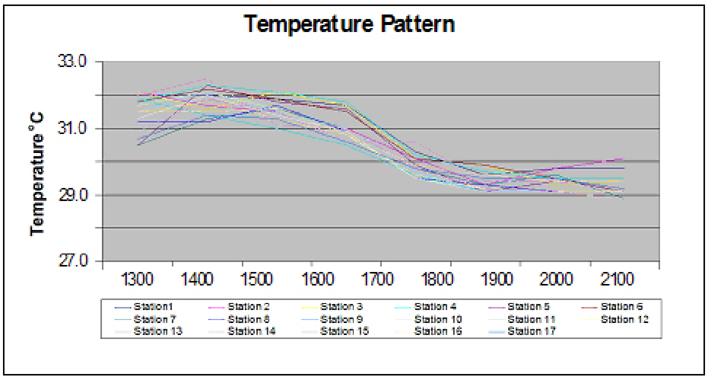

Figure 10 Temperature patterns of all measurement stations of Site C

The lowest temperatures were recorded at the 'central courtyard' type open space and the highest temperatures were recorded at the stations most exposed to heavy vehicular traffic. The lowered temperature measurements were only recorded at the measurement points within the boundaries of the open space, but have minimal effect on mitigating the UHI effect in the surrounding areas. This is probably due to the low level of vegetation present at these urban open spaces and also the low albedo material used in paving these spaces and in the vertical surfaces.

The reduction of the cooling effect can also be explained by the different urban morphology. The cooling effect is more evident in samples where the surrounding building configuration allows for sufficient air ventilation to pass through the open space. The size of the open spaces and their proximity to anthropogenic heat sources such as road traffic also has effect on their thermal performance. Figure 11 shows the comparison of temperature pattern for the main open space of Site A, B and C.

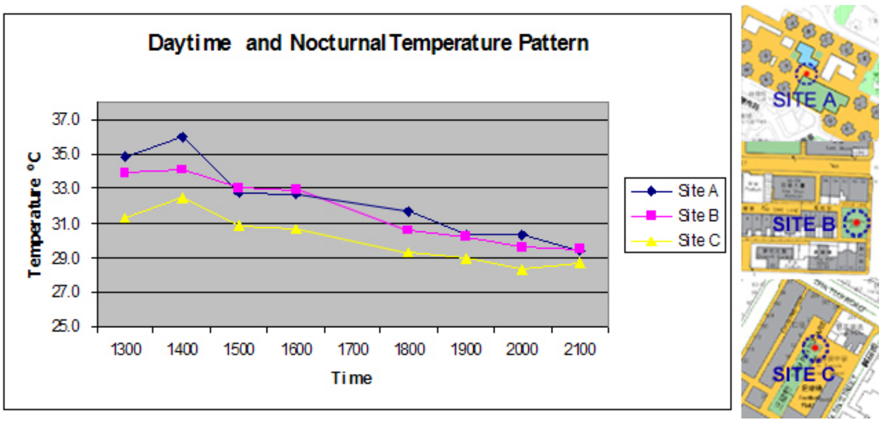

Figure 11 Temperature Pattern of Main Open Space of Site A, B & C

The comparison shows that Site A (podium type open space) and Site B (small pocket open space) has similar temperature pattern, with Site A having a slightly higher mean temperature. Site C ('central courtyard' type open space) has the lowest temperature. The mean daytime and nocturnal temperature difference between Site A and C is 2.7ºC and 1.6ºC respectively.

4. Conclusion

Urban Heat Island (UHI) varies with geographical, latitudinal and urban density and population changes (Oke, 1988). To understand this UHI profile and further derive planning and design strategies for mitigating summertime UHI will greatly benefit the urban thermal environment and improve comfort of users.

This study focuses on potential alleviating function of urban open spaces in high rise high density residential and mixed use developments and street blocks. The initial findings show that different urban morphologies alter the thermal performance of the urban open space. A previous study (Giridharan, Lau et al, 2007) suggested that with the same amount of tree cover in high rise high density coastal building area, the open space in the form of pocket parks comes with lower air temperature of about 0.5 -1.0 °C compared to a landscaped courtyard. While the present study indicates the opposite in inner city area, with temperature of the central courtyard significantly lower than those of the podium and pocket park (Figure 11). The shift of temperature pattern between inner city and coastal area could be due to the influence of sky view factor. Further, as ventilation potential is greatly undermined by surrounding buildings, the pocket park and podium may not enjoy better advection cooling although they are more open than the courtyard space.

Further analysis is needed to determine to how, and to what extent these urban morphologies (building, form, fabric and configuration), and site specifics (volumetric composition, and orientation) constitute to a more sustainable urban environment by providing thermally desirable open spaces for social use.

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References

Abbate, G. 1997, Heat island study in the area of Rome by Integrated use of ERS-SAR and Landsat TM data. 3rd ERS Symposium on Space at the service of our Environment, held in Florence, Italy, 14-21 March, 1997. Complied by T.-D. Guyenne and D. Danesy. European Space Agency, p.305

Coorey, S. B. A. 2008, Design of Open Spaces in High Density Zones: Case Study of Public Housing Estates in Hong Kong, PhD Thesis, University of Hong Kong.

Census and Statistics Department, 2001, Hong Kong 2001, HKSAR Printing Department, Hong Kong

Dimoudi, A, and Nikolopoulou. M. 2003, Vegetation in the urban environment: microclimatic analysis and benefits. Energy and Buildings 35 (1):69-76.

Ganesan, S. and Lau, S. S. Y. 2000, Urban Challenges in Hong Kong: Future directions for design, Urban Design International 5 (1): p3-12.

Giridharan, R., Ganesan, S. and Lau, S. S. Y. 2004, Daytime urban heat island effect in high-rise and high-density residential developments in Hong Kong. Energy and Buildings 36 (6):525-534.

Giridharan, R., Lau, S.S.Y., Ganesan, S. and Givoni, B. 2007, Lowering the outdoor temperature in high-rise high-density residential developments of coastal Hong Kong: The vegetation influence. Building and Environment, doi:10.1016/j.buildenv.2007.10.003

Lau, S. S. Y., Giridharan, R. and S. Ganesan. 2005, Multiple and intensive land use: case studies in Hong Kong. Habitat International 29 (3):527-546.

Lo, S. M, C. Y. Yiu and Lo, A. 2003, An Analysis of attributes affecting urban open space design and their environmental implications, Management of Environmental Quality: An international Journal, 14 no.5:604-614

Oke, T.R. 1987, Boundary layer climates, Methuen, USA.

Santamouris, M., ed. 2001, Energy and Climate in the Urban Built Environment. James & James, London, UK.

Solecki, W. D., Rosenzweig, D., Parshall, L., Pope, G., Clark, M., Cox, J., and Wiencke, M. 2005, Mitigation of the heat island effect in urban New Jersey. Global Environmental Change Part B: Environmental Hazards 6 (1):39-49.

Taha, H. 1997, Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. Energy and Buildings 25 (2):99-103.