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Daytime urban heat island effect in high-rise and high-density residential developments in Hong Kong

R. Giridharan, S. Ganesan*, S.S.Y. Lau

Department of Architecture, University of Hong Kong, Hong Kong, China

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Abstract

Nearly 60% of electrical energy use in Hong Kong is for space conditioning during summer months. The paper investigates the impact of design-related variables on outdoor micro level daytime heat island effect in residential developments in Hong Kong. The paper hypothesizes that the differences in outdoor temperatures within and between residential developments can be explained by the impact of design-related variables on the overall environment. Case studies of three large housing estates reveal urban heat island effect (UHI) in the order of 1.5 °C within an estate, and 1.0 °C between estates. The results indicate that energy efficient designs can be achieved by manipulating surface albedo, sky view factor and total height to floor area ratio (building massing) while maximizing cross ventilation.

Keywords: Daytime urban heat island effect (UHI); Design variables; Open structure; Close structure; Residential development; Hong Kong

1. Introduction

In Hong Kong, most of the residential estates have high canyon geometry ratio of the order of 2–3. According to Oke [1], 70–80% of daytime radiant energy surplus within canyon is dissipated to air through turbulent transfer. The balance 30–20% is stored and released in the night. The sky view factor is very low in most of the residential developments in Hong Kong. This is largely due to high-rise and high-density environment (Fig. 1). In principle, low sky view factor should lower the nocturnal cooling of the environment but increase the daytime shadow effect [1–3]. But there has been no empirical research done to indicate the real impact of the low sky view factor on the outdoor environments in residential estates in Hong Kong.

Most of the residential developments have very low surface albedo. This is largely due to a high proportion of concrete or asphalt paving in the open areas. In recent times, this trend is changing. The outdoor surface is generally paved with cement bricks or tiles. Both cement bricks and tiles have relatively higher albedo than concrete surfaces and asphalt. The level of vegetation in most of the inner urban residential estates is very poor. Even when vegetation is present, it is generally of 1 m height and less denser. If the vegetation is less than 1 m in height, the albedo lies between 0.18 and 0.25 [1]. This will have negligible contribution on overall albedo level. Some of the urban residential estates do not have enough vegetation within its premises but there may be enough vegetation in close proximity. The Wah Fu residential estates are good examples (Figs. 4a and 5a).

The thermal performance of a residential development in an inner city is usually affected by land area, massing and surrounding buildings [4,5]. Most of the residential developments in Hong Kong Island and Kowloon fall under the inner city category. The compact urban form might be contributing to a lower thermal performance in Hong Kong. There has been only limited research interest in this field in Hong Kong, and there are no firm design guidelines for the creation of an energy efficient sustainable environment. On the other hand, globally, there is adequate research on relationship between energy consumption of individual buildings and natural forces, but very little research on urban scale thermal performance and energy consumption phenomena [5].

The paper will investigate the impact of design-related variables on outdoor micro level daytime heat island effect in residential developments in Hong Kong in order to understand the design implications. The paper hypothesizes that a significant part of the differences in outdoor temperatures within and between residential developments can be explained by the impact of design-related variables on the overall residential environment. The initial investigations are

* Corresponding author. Fax: +852-2559-6484.
E-mail address: sganesan@hkusua.hku.hk (S. Ganesan).

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Fig. 1. High-rise and high-density urban fabric of Hong Kong.

carried out on three large estates in Hong Kong, i.e. Belchers, Wah Fu 1 and Wah Fu 2. The Belchers is a new generation development while Wah Fu 1 and Wah Fu 2 belong to the first generation high-rise high-density developments of the 1960s. A detailed analysis of the Belchers is presented, as this scheme is more illustrative of the impact of urban design on outdoor thermal conditions.

2. Literature review

Rapid urbanization has replaced natural land with artificial surfaces in most cites around the world with undesirable thermal impacts. The effect of urbanization on local climate, especially on outdoor temperature, is alarming [1–3,6,7]. Such changes have altered the radiative, thermal, moisture and aerodynamic properties of the environment [8]. This has caused concentration of heat in urban areas, which is known as urban heat island (UHI). Strictly speaking, urban heat island intensity is the temperature difference between urban and cool rural area (Fig. 2). The height of the heat island is three to five times of the average building height [2]. In Hong Kong it could be in the order of 300–500 m above the canopy layer in residential zones. The exact extent of the UHI depends on time and space as a function of meteorological, locational and urban characteristics [11].

The heat island intensity is proportional to the degree of urbanization [1,3,7]. The UHI aggravates both indoor and outdoor thermal discomfort and increases the space conditioning energy consumption [2].

Heat island effect is influenced by the following *physical properties and phenomena in the urban environment* [1–3]:

- Canyon radiative geometry.
- Thermal properties of material.
- Anthropogenic heat.
- The urban green house effect.
- Reduction of albedo by canyon geometry.
- Reduction in evaporating surface.
- Reduced turbulence transfer.

Manmade factors or the *design variables* that contribute to the above physical properties and phenomena are [1–3,6,7]:

- Urban structure.
- Size of the city, population and density of built-up area.
- Ratio of building height to distance between them.
- Width of the streets.
- Building materials.
- Surface materials.
- Sky view factor.

Sky view factor is a good proxy for the population density. Strictly speaking sky view factor will be low where density is high. Oke's [1] study on UHI shows a weak

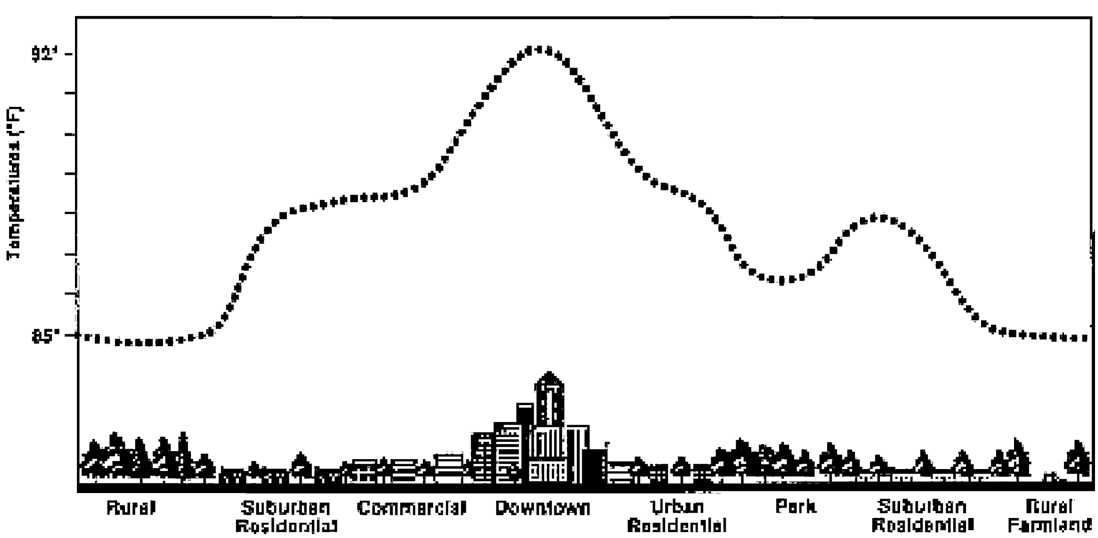

Fig. 2. A general urban heat island profile.