

Microclimatic modeling of the urban thermal environment of Singapore to mitigate urban heat island

Rajagopalan Priyadarsini^{a,*}, Wong Nyuk Hien^b, Cheong Kok Wai David^b

^a *School of Architecture and Building, Deakin University, 1 Gheringhap Street, Geelong, Victoria 3217, Australia*

^b *Department of Building, National University of Singapore, Singapore*

Received 7 August 2007; received in revised form 28 November 2007; accepted 5 February 2008

Available online 6 March 2008

Communicated by: Associate Editor Matheos Santamouris

Abstract

This study investigates the urban heat island effect in Singapore and examines the key factors causing this effect. The possibilities of improving heat extraction rate by optimizing air flow in selected hot spots were explored. The effect of building geometry, façade materials and the location of air-conditioning condensers on the outdoor air temperature was explored using computational fluid dynamics (CFD) simulations. It was found that at very low wind speeds, the effect of façade materials and their colours was very significant and the temperature at the middle of a narrow canyon increased up to 2.5 °C with the façade material having lower albedo. It was also found that strategically placing a few high-rise towers will enhance the air flow inside the canyon thereby reducing the air temperature. Adopting an optimum *H/W* ratio for the canyons increased the velocity by up to 35% and reduced the corresponding temperature by up to 0.7 °C. © 2008 Elsevier Ltd. All rights reserved.

Keywords: Urban heat island; CFD; Geometry; Façade materials; Velocity; Temperature

1. Introduction

Increasing urbanization and industrialization has caused the urban environment to deteriorate. The urban climate and the environmental efficiency of buildings are influenced by the deficiencies in proper development control (Santamouris, 2001). As a consequence of changes in the heat balance, air temperatures in densely built urban areas are higher than the temperatures of the surrounding country. This phenomenon, known as Urban Heat Island (UHI), is a reflection of the totality of microclimatic changes brought about by man-made alterations of the urban surface (Landsberg, 1981). In high-latitude cities with cooler weather, heat islands can be an asset in reducing heating loads, but in mid and low-latitude cities, heat islands con-

tribute to the urban dweller's summer discomfort and significantly higher air-conditioning loads.

The effect of building is considered as one of the main reasons for urban heat island effect. Building masses increase the thermal capacity, which has a direct bearing on the city temperature. They reduce wind speed and radiate heat through the building fabric and also in the form of air-conditioning equipments. The heat that is absorbed during the day by the buildings, roads and other construction in an urban area is re-emitted after sunset, creating high temperature differences between urban and rural areas. The urban heat island phenomenon is due to many factors, the most important of which are summarized as follows (Oke et al., 1991):

- the canyon radiative geometry that contributes to the decrease in long-wave radiation loss from within the street canyon due to the complex exchange between buildings and the screening of the skyline;

* Corresponding author.

E-mail address: priya@deakin.edu.au (R. Priyadarsini).

Nomenclature

C_1, C_2	empirical constant in generation/destruction term of ε -equation	$\bar{\varepsilon}$	mean dissipation rate of \bar{k} (m^2/s^3)
C_3	empirical constant in buoyant term of ε -equation	θ	temperature rise above ambient
C_D	empirical constant for eddy viscosity	α	thermal diffusivity
g_i	gravitational constant in X_i -direction (m/s)	ν	kinematic molecular viscosity (m^2/s)
k	turbulent kinetic energy per unit mass (m^2/s^2)	ν_t	eddy viscosity (m^2/s)
\bar{k}	mean turbulent kinetic energy (m^2/s^2)	Π	total pressure (N/m^2); $\Pi = \bar{p} + ((2p\bar{k})/3)$
\bar{U}_i	mean velocity component in X_i -direction (m/s)	ρ	fluid density (kg/m^3)
\bar{U}_j	mean velocity component in X_j -direction (m/s)	μ_t	turbulent viscosity ($\text{kg}/\text{m}/\text{s}$)
X_i, X_j	distance in Cartesian coordinate (m)	σ_k	empirical constant of turbulent Prandtl number for k
<i>Greek letters</i>		σ_ε	empirical constant of turbulent Prandtl number for ε
β	volumetric expansion coefficient (K^{-1})	σ_θ	empirical constant of turbulent Prandtl number for θ
ε	turbulent dissipation rate (m^2/s^3)		

- the thermal properties of materials, which increase storage of sensible heat in the fabric of the city;
- the anthropogenic heat released from combustion of fuels and animal metabolism;
- the urban greenhouse, which contributes to the increase in the incoming long-wave radiation from the polluted and warmer urban atmosphere;
- the canyon radiative geometry, which decreases the effective albedo of the system because of the multiple reflection of short-wave radiation between the canyon surfaces;
- the reduction of evaporating surfaces in the city, which means that more energy is put into sensible heat and less into latent heat; and
- the reduced turbulent transfer of heat from within streets.

The urban canyon is a more useful city unit for investigation in the UHI study. It describes the conditions of a long street with tall buildings on both sides. The distribution of the ambient air in a canyon greatly influences the energy consumption of the buildings. The temperature in a canyon is influenced by the temperature of the canyon surfaces, because energy is transferred through convective process. Results from simultaneous measurements performed in three sets of canyon in Athens pointed out that the air temperature measured in the middle of the canyon is not influenced by the orientation of the street either during the day or during the night. This leads to the conclusion that air temperature in the canyon is not greatly influenced by the canyon configuration and is mainly controlled by the airflow process (Santamouris, 2001).

Many research works have been conducted in USA, Australia, Greece and Japan to study the UHI effect in many cities. But studies are relatively lacking in the low tropics, particularly with respect to quantitative evaluation. This study investigates the UHI effect and explores the

possibilities of improving the heat extraction rate by optimizing air flow in selected hot spots in Singapore.

2. Existence of UHI in Singapore

A combination of three methods is used to investigate the occurrence and severity of urban heat island effect in Singapore. They are:

- compare the temperatures at different locations by conducting simultaneous field measurements;
- mobile survey using car traverses through four different routes; and
- analyzing the satellite images.

Table 1 gives a summary of all the measurements mentioned in this paper.

2.1. Meteorological conditions

It is important to have an understanding about the climatic conditions of Singapore before analyzing the filed measurement results. Singapore is located at approximately $1^\circ 21''$ North, $103^\circ 54''$ East. The proximity of the island to

Table 1
Summary of all the measurements carried out

No.	Type of measurement	Date	Time
<i>Measurements to identify the existence of UHI</i>			
1	Field measurement 1	August 2002	9–11 am, 1–3 pm
2	Mobile traverse	August 2002	1.30–3.30 am
3	Satellite images	October 2002	10 am
<i>Measurements to validate the CFD model of the CBD area</i>			
4	Filed measurement 2	August 2003	8:40–9:40 am 14:40–15:40 pm 21:40–22:40 pm
5	Wind tunnel study	August 2003	

متن کامل مقاله

دریافت فوری ←

ISIArticles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات