MICROCLIMATE IN A HIGH-RISE RESIDENTAL DEVELOPMENT IN SINGAPORE

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Abstract

Tropical Singapore is one of the most densely populated countries in the world and heavily urbanized. About 85% of the population lives in government-sponsored high-rise buildings, which have spread throughout the island. More housing developments are planned to accommodate a projected increase in population; urban planning and architectural design associated with these developments will benefit from measurements and models of the urban climate. This study focuses on obtaining a deeper understanding of climate conditions in a single housing development. A new estate is selected as representative of current practice in building height, orientation and density of land development. Measurements are made within the housing site, which in effect is an urban canyon, at a less-enclosed and developed location near the development and also at a vegetated, undeveloped location, providing a two-tier reference for the housing-development data. The measurement will start at the end of May 2009; data will include temperature, humidity, wind speed and direction, solar radiation, rainfall, pressure and surface temperature. Required site-specific inputs will be identified for simulations with the ENVI-met program, which accounts for the impact on simulated temperatures of buildings, vegetation and local airflow, and a comparison of measurements and simulation. Further our results will be compared with results of a reported investigation under similar conditions in Colombo, Sri Lanka.

Key words: ENVI-met, thermal comfort, microclimate, tropical urban climate, Singapore

1. INTRODUCTION

Singapore is located on a small island (682.7 km^2) at the southern end of the Malaysian Peninsula, 1.5 degrees north of the Equator. This city-state is heavily urbanized and it is the third most densely populated country in the world (6,750 persons/km^2). The population of Singapore will grow in the next 25 years (*Figure 1*) and more housing developments are planned to accommodate the projected increase. Presently about 85% of the residents live in government-sponsored high-rise buildings (HDB), which have spread throughout the island.

The changes in the spatial and structural configurations in HDB estates may modify their environmental significantly, especially their thermal regimes. The injurious effects of the densely built-up urban area are known well, these can be harmful to health, economy and thermal comfort.

Urban planning and architectural design associated with housing developments will benefit from measurements and models of the urban climate. This study focuses on obtaining a deeper understanding of climate conditions in a single housing development.

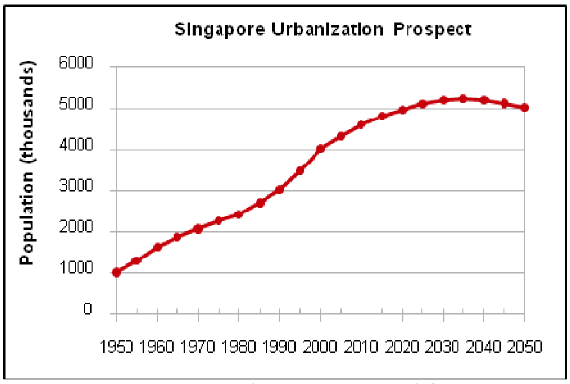

Figure 1 Prospect of Urbanization of Singapore
(Source: World Urbanization Prospects - 2009)

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2. OBJECTIVES

The objectives of this study are the followings:
- To investigate the difference of air temperature, relative humidity, wind speed and direction, solar radiation, rainfall, pressure and surface temperature between an open area and a chosen HDB block.
- To take a microclimatic survey of an HDB area; to investigate the microclimate in an HDB block; to study the change of temperature, relative humidity between the open area and the typical urban HDB block across the HDB area by transverse routes.
- To examine the validation of an ENVI-met microclimate model for tropical climate.

3. STUDY AREAS

According to Köppen's classification Singapore belongs to the climatic type Af, characterized by uniformly high annual temperature (27.5 ℃) and humidity (84 %) as well a s abundant precipitation (2190 mm/year) throughout the year. The climate of Singapore can be divided into two main seasons, the northeast monsoon and the southwest monsoon season, separated by two relatively short inter-monsoon periods.

The study areas are located at the eastern part of the island, which districts are called Punggol and Sengkang (*Figure 2*). An open area (as rural area) and a HDB area (as urban area) are chosen to compare their measured meteorological data (temperature, humidity, wind speed and direction, solar radiation, rainfall, pressure and surface temperature).

The suitable open area is signed by an orange point (on the top of map) on the *Figure 2*. This place is even, grassy, unshaded at the sufficient distance from the obstructions (*WMO, 2008*).

Punggol and Sengkang include the newest HDB areas in Singapore. The new estate is selected as representative of current practice in building height, orientation and density of land development. Presently Punggol and Sengkang are developing at a rapid pace, the greatest numbers of new houses are built here and these areas will be home for about 600,000 people.

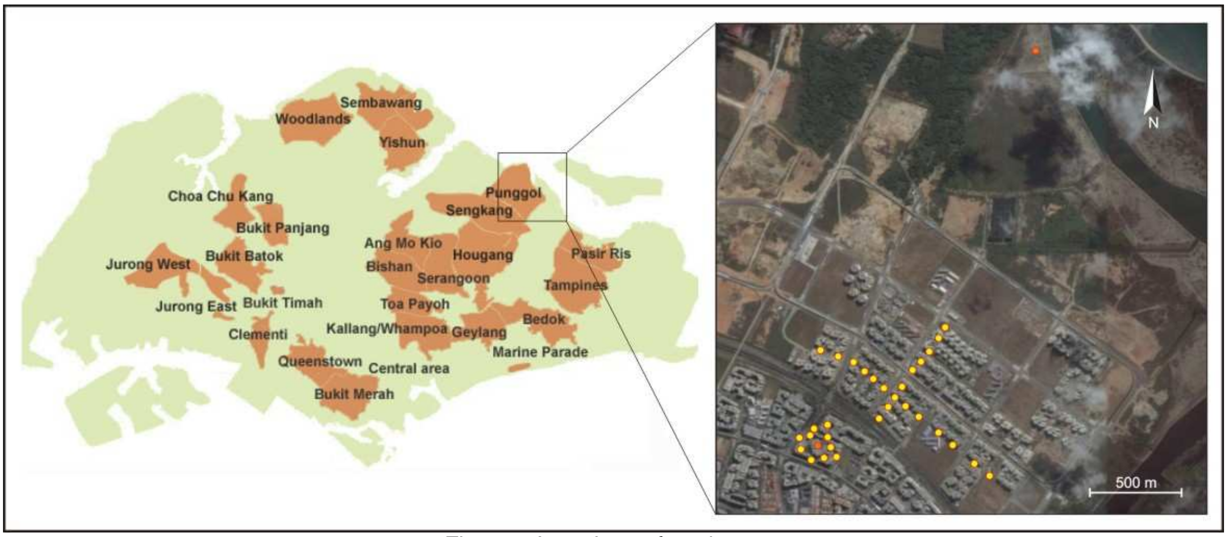

Figure 2 Locations of study areas
(Source: Housing and Development Board InfoWEB and Google Earth - 2009)

4. METHODS

4.1. Instrumentation

Before making the real measurements in the city a comparison of instruments was carried out under different weather conditions to select the most suitable sensors for the investigation. This comparative measurement was carried out 3-month long period at an unshaded, grassy and level location.

Temperature data were measured by six sensors: 2 units 'Vaisala HMP45', 2 units 'Campbell ASPTC' (one with fan off, one with fan on) and 2 units 'Onset HOBO'. The difference amongst the sensors increases as temperature rises, the smallest difference is found at sunrise (at 7 am). In the urban canopy layer ventilation is especially recommended, on this basis the 'ASPTC fan on' can serve as a reference to enable comparison amongst the sensors. (The ASPTC fan on would have been a good choice, but the disadvantage of this sensor is that the fan uses a lot of energy and hence requires frequent battery changes, furthermore several accessories are needed as a data logger, a safe enclosure, some batteries, etc.)

The relative humidity was measured by 4 sensors: 2 units Vaisala HMP45, 2 units Onset HOBO, as well as some spot measurements were taken by an aspiration-psychrometer to decide which type of sensor is more reliable.

In both temperature and relative humidity comparative measurements the Onset HOBO sensors proved the most reliable. This is a 'wireless' datalogger, the accuracy of its temperature sensor is ±0.2ºC with resolution 0.02ºC. The accuracy of its relative humidity sensor is ±2.5% with resolution 0.03%. The installation of this small sensor (10 cm) with radiation shield (20 cm x 23 cm) is really easy.

The 41 HOBO sensors purchased for the investigation were tested in closed space as well as under different weather conditions. The latter test measurement was during 5 days at the same place, where the comparative measurement was previously. Temperature and relative humidity were measured every minute. *Figures 3a* and *3b* show the differences of each sensor compared to the hourly average of all sensors. For example the Sensor No9 is one of the most reliable amongst the 41 HOBO sensors: its temperature values are between 0.07 ℃ and - 0.10 ℃, its difference from the average of all sensor is just -0.002 ℃ (*Figure 3a*); its relative humidity values are between 0.67 % and -0.17 %, its difference from the average of all sensor is only 0.20 % (*Figure 3b*). With the exception of some cases the temperature differences of sensors are less than the HOBO's accuracy (±0.2 ℃), while in cas e of relative humidity all differences are within this interval (±2.5%).

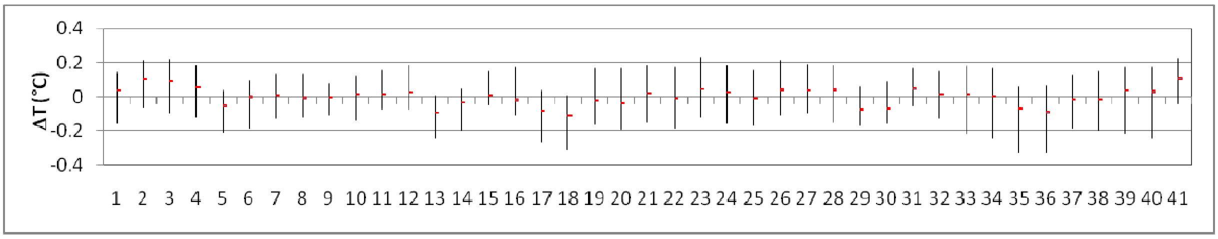

Figure 3a Temperature differences of each sensor compared to the hourly average of all sensors

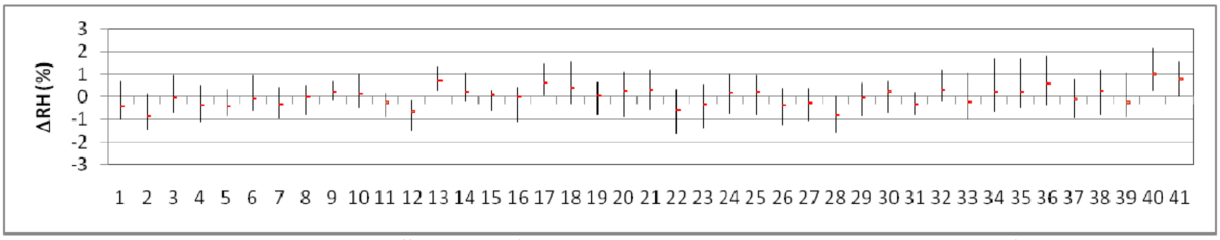

Figure 3b Relative humidity differences of each sensor compared to the hourly average of all sensors

4.2. Measurements

The duration of the investigation in Sengkang and Punggol will be one-year long from May 2009. The object of the first part of investigation is to take a general microclimatic surveying in the chosen HDB area. The following parts of the investigation depend on the results of first part. Questions of interest can be the effect of vegetation, the street direction, the width and depth of the street canyon, the role of shaded places, etc.

The measuring points are illustrated in *Figure 2*. The measurements will be taken at 32 points in the HDB area and at one point in the open area.

In *Figure 2* the points denoted in yellow will be measured by HOBO Pro v2 temperature and relative humidity sensors. The sensor with radiation shield will mount at a height of 2 m to lampposts (*Oke, 2006*). To avoid the direct thermal effect of lamp post the sensor will installed 40 cm far away from the lampposts. The measuring time interval will be 10 minutes.

These points are situated along two transverse routes and inside a typical urban HDB block. By the measuring points on the transverse routes it is possible to study the change of temperature, relative humidity between the open area and the HDB block across the HDB area. By the several measuring points inside the typical urban HDB block it is simple to understand deeper its climate conditions.

Two points denoted in orange on the *Figure 2*. One is situated in the center of HDB block, the other is on the open area. At these points temperature, humidity, wind speed and direction, solar radiation, rainfall, pressure and surface temperature will be measured on a tripod and a mast respectively.

4.3. Modeling

As mentioned, one of the objectives is to examine the validation of ENVI-met microclimate model for tropical climate. Urban microclimate models vary widely, based on their physical basis and spatial/temporal resolution. The ENVI-met is one of the most popular models at the micro scale.

Required site-specific inputs will be identified for simulations with the ENVI-met program. This is a three dimensional non-hydrostatic model for the simulation of surface-plant-air interactions, especially within the urban canopy layer. It is suitable for analyzing the thermal comfort regime within the street canyon at fine resolutions (down to 0.5 × 0.5 m) (*Bruse and Fleer, 1998*). ENVI-met will provide the following outputs (*ENVI-met, 2009*):

- Short-wave and long-wave radiation fluxes with respect to shading, reflection and re-radiation from building systems and the vegetation;
- Transpiration, evaporation and sensible heat flux from the vegetation into the air, including full simulation of all plant physical parameters (e.g. photosynthesis rate);
- Surface and wall temperature for each grid point and wall;
- Ground surface and wall temperature for each grid point and wall;
- Water- and heat-exchange within the soil system;
- Calculation of bio-meteorological parameters.

5. RESULTS

The measurement will start at the end of May 2009, for this reason results are not yet available. Our results will be compared with results of a reported investigation under similar conditions in Colombo, Sri Lanka (*Emmanuel et al, 2007*).

Acknowledgements

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