

RESEARCH BRIEF

2004/001

A Study of Urban Heat Island in Singapore

RESEARCH FINDINGS

The severity and impact of the Urban Heat Island (UHI) phenomenon have been explored through different methods in Singapore. The satellite image (Figure 1) shows the clear difference in temperature between the 'rural' and 'urban' areas. It indicates the occurrence of the UHI effect during the day in Singapore. The 'hot' spots are normally observed on exposed hard surfaces in the urban context, such as the industrial area, airport and Central Business District (CBD). The satellite image also shows some 'cool' spots which are mostly observed on the large parks, the landscape in between the housing estates and the catchment area.

In the historical analysis of long-term climatic data of Singapore, four meteorological stations were chosen from the National Weather Observational Network with data coverage of at least ten years. Yearly mean dry-bulb temperatures were analysed and found to be rising significantly in Changi (Figure 2).

The maximum difference of 4.01°C was observed between well-planted areas and the CBD area from the two mobile surveys (Figure 3). In addition, the mapping of temperature (Figure 4) has shown a clear variation of temperature from the southern 'urban' area to the northern 'rural' area. The survey routes near to large green areas experienced lower temperatures compared with other land uses like the industrial areas, the residential areas, CBD area and the airport. Both the lowest temperature and mean temperature, 24.3°C and 25.01°C respectively, were observed in a well-planted area – Lim Chu Kang. On the other hand, places with fewer plants always had higher temperatures. The CBD region, the high density and high-rise commercial area, had the highest temperature and mean temperature of 28.31°C and 28.08°C respectively. It can be concluded that large green areas definitely have a positive effect on mitigating the UHI effect in the city.

POTENTIAL MEASURES TO MITIGATE UHI

Urban greenery, 'cold' materials, and urban geometry are three main measures considered to mitigate the existing UHI effect in Singapore.

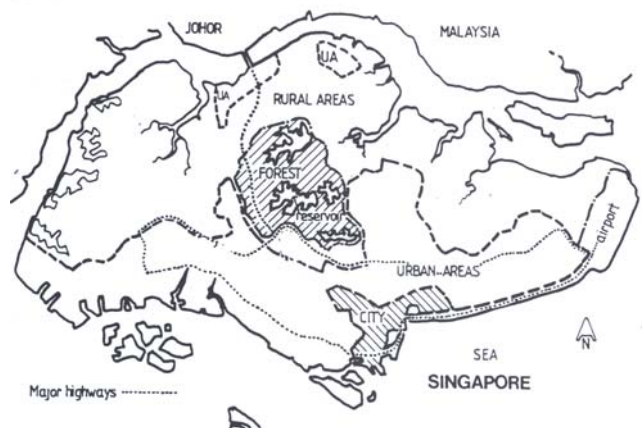
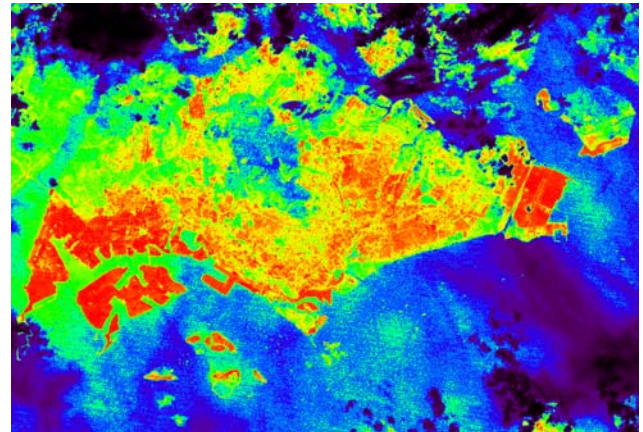


Figure 1. Relative temperature derived from thermal band of Landsat-7 ETM+acquired on 11 October 2002 and the 'urban' and 'rural' partition of Singapore.

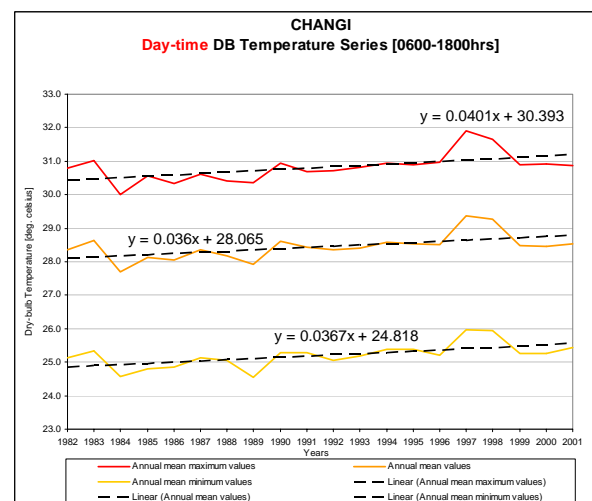


Figure 2. Analysis of long-term climatic data.

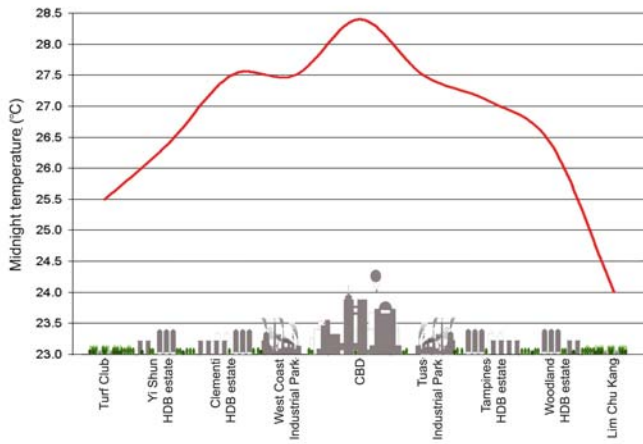


Figure 3. Urban Heat Island profile of Singapore.

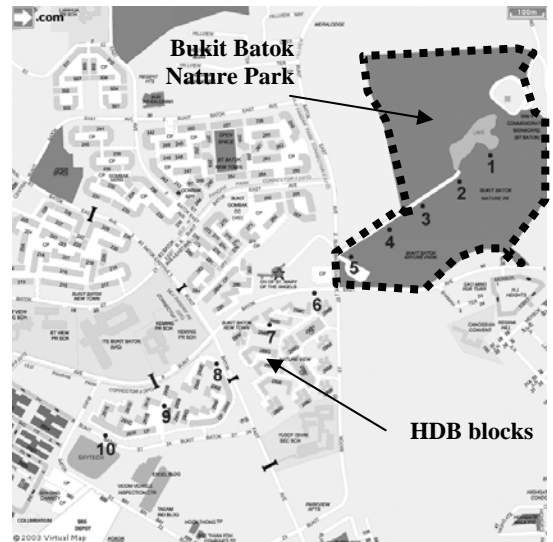
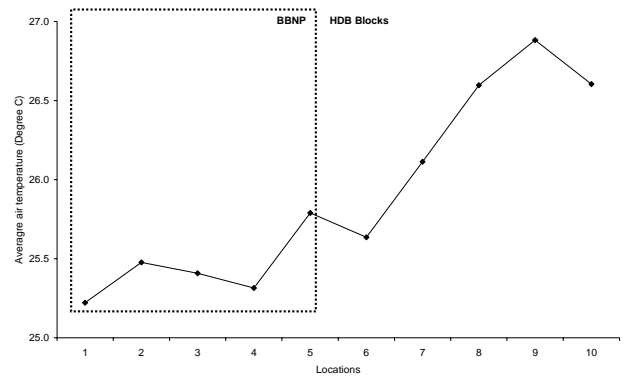


Figure 5. The impact of parks on the ambient temperature of the surrounding HDB blocks.

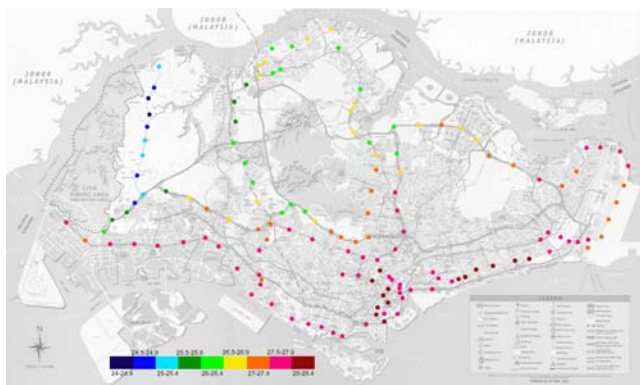


Figure 4. Temperature profile of the Singapore island.

Vegetation can improve the urban thermal environment at both the macro and micro level. At the macro-level, the temperatures observed in the parks are lower than those derived from their surrounding environment (Figure 5). For the surrounding built environment, closer to the park, a lower temperature was experienced. A difference of average temperature, 1.3°C , was observed at locations around the parks. The measurement conducted on a fair day indicated that housing estates with 22% vegetation coverage had lower ambient air temperatures as compared to the one with only 7% vegetation coverage (Figure 6). The maximum average temperature difference between the two sites is 2.32°C .

At the micro-level, vegetation strategically placed around roofs and walls can be considered as a complement of urban greens (Tables 1 and 2). It is found that, with the shading of plants, surface temperatures measured under different kinds of vegetation were much lower than those measured on the hard surface. The temperature measured under vegetation varied according to the density (LAI) of plants. Normally, lower temperatures were measured under thick foliage while higher temperatures were obtained under sparse foliage or only soil. The heat transfer through the bare roof was greater than that through planted roofs and roofs with only soil. Less solar heat reflected by the greenery and less long confirmed through comparisons of reflected solar radiation, global temperatures and Mean Radiant

Temperatures (MRTs) measured on-site.

The selection of material is significant for the thermal performance of building facades and the urban thermal environment. A material with high albedo can reduce the solar heat gain during the daytime. The surface temperature of the material is lower than that of a material with low albedo. Since the urban ambient temperature is associated with the surface

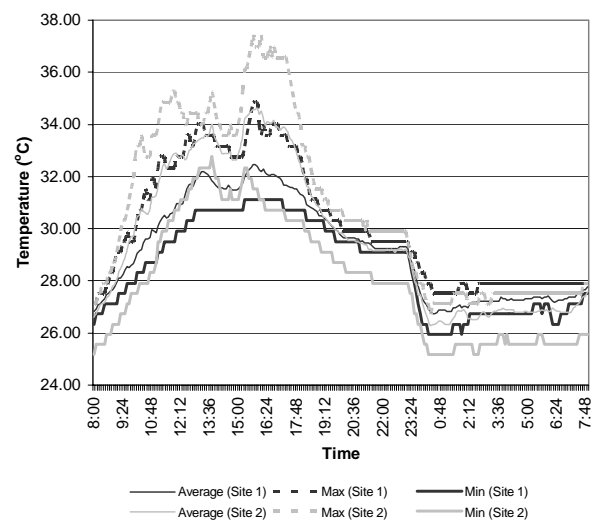


Figure 6. The comparison of temperatures between two sites (site 1: 22% greenery coverage; site 2: 7% greenery coverage).

Table 1. Summary of measured reductions caused by rooftop gardens in thermal parameters of building's roof

Thermal parameter		Range of reduction
Surface temperature of roof		0 – 31.0°C
Ambient temperature	at 300mm height	0 – 4.2°C
	at 1000mm height	0 – 1.5°C
Relative humidity		- 23.5% – 0%
Solar radiation (at 300mm height)		4.2 – 124.6W/m ²
MRT		0 – 4.6°C
Globe temperature		0 – 4.1°C
Heat flux transferred through surface		0.6 – 15.4W/m ²
Total heat gain over a day		395.0 – 466.3KJ/m ²

temperatures of the building façade, lower surface temperature can obviously help in decreasing the ambient air temperature and eventually contribute to better urban thermal environment. The results derived from the simulation revealed the variance of the surface temperatures of the building facades with different colours (Figure 7). The dark-coloured material can be up to around 7°C higher than the ambient air temperature while the light-coloured one is only around 2-3 °C higher than the air temperature.

In multi-storeyed buildings, façade plays a major role in governing the cooling load of the building while the roof has an important effect mainly on the top floor just below the roof. A simulation exercise revealed that the cooling load increased as the colour of the façade changed from lighter to darker (Figure 8). A reduction of 7.48% of cooling energy was achieved when the colour of the façade was changed from Alucobond Sparkling black to Alucobond pure white aluminum façade.

Modeling the CDB area using CFD simulations (Figure 9) have shown that facade materials and especially their colours play a very important role in the determination of the thermal environment inside the urban canyons. At higher wind speeds, the effect of materials on the air temperature was not much significant for wider canyons. However when low albedo materials were used, narrow canyons situated away from the inlet had higher temperatures even at higher inlet wind speeds. The temperature in the middle of such canyons was increased by 1°C. At very low inlet wind speeds, the effect of materials was found to be very significant and the temperature at the middle of the narrow canyon increased up to 2.52°C with the façade material having the lowest albedo (Figure 10). It was noted that the temperature at the middle of the wider canyons also increased up to 1.3°C. The rise in temperature inside the canyons can cause the peak electricity load to increase by up to 6.8% to 9%.

The study about the urban geometry revealed that a few high rise towers strategically placed above the low rise buildings could actually help to enhance the velocity within the canyon (Figure 11). This was true when the wind flow was parallel as well as perpendicular to the canyon. For parallel flow, the velocity has been increased by up to 90% and the temperature has been reduced by up to 1°C with the

Table 2. The thermal performance of the plants with different LAIs (without air-con).

LAI	Range of surface temperature under shading (°C)	Range of indoor ambient air temperature (°C)
5.47	26.4-29.2	27.9-31.4
3	26.2-29.4	28.3-32.5
1.47	25.8-32.6	28.50-32.0
0 (soil)	24.4-56.7	28.9-33.5
0 (concrete surface)	25.4-51.3	26.9-40.5

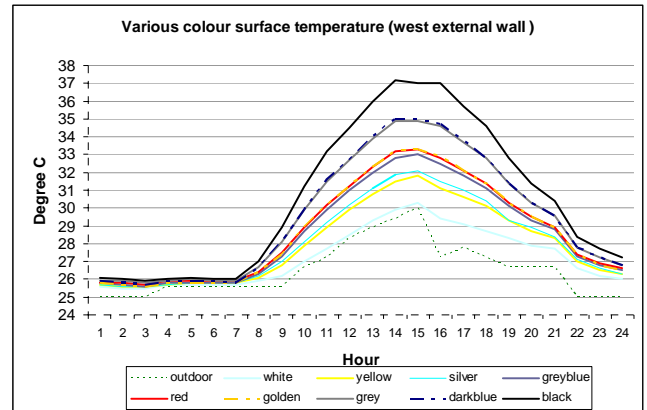


Figure 7. Effect of façade colour on surface temperature (aluminum panels).

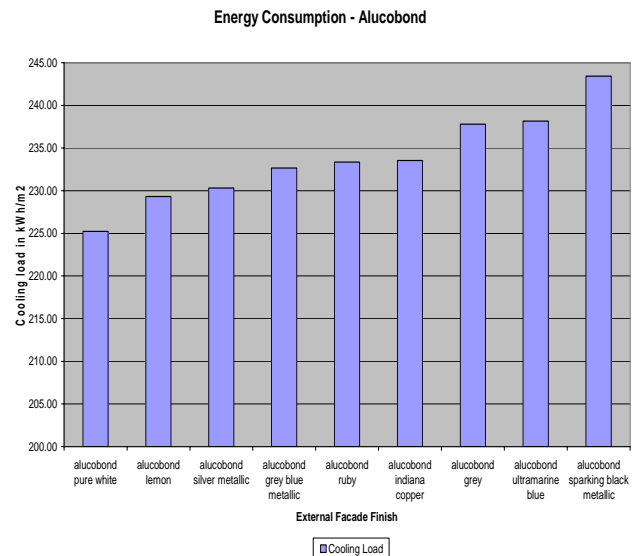


Figure 8. Annual energy consumption for a series of aluminum facades.

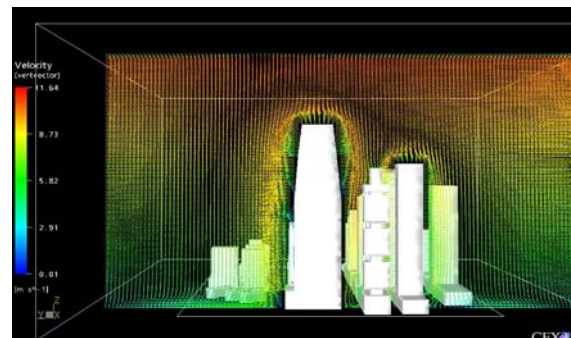


Figure 9. Modelling of the ventilation in the urban area.

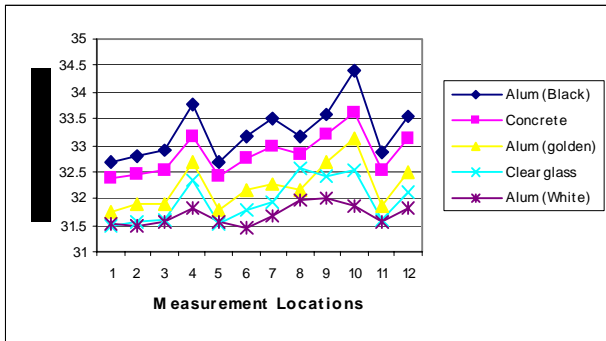


Figure 10. Comparison of temperatures for different materials.

introduction of a few high rise towers. For perpendicular flow, the velocity has been increased up to 10 times and the temperature has been reduced by 1.1°C. The velocities as well as temperatures of the lower zone were highly influenced by the high temperature of the road surface. The temperatures near the ground were influenced by the road having high surface temperature. But when the airflow was perpendicular, the introduction of high rise towers caused strong airflow at the lower zone, thus decreasing the temperature. The channelling effect observed for larger H/W ratio in the absence of the high rise towers continued to stay even for smaller H/W ratio with the introduction of high rise towers. Varying the geometry of the existing CBD area resulted in an increase in velocity of up to 35% and reduced the corresponding temperature by up to 0.7°C. Modifying the neighbouring street geometry enhanced the wind speed and lowered the temperature of narrow lanes. Reducing the height of the few existing high rise towers placed above the continuous row of low rise buildings reduced the wind speed at most of the locations and also resulted in higher temperatures.

OVERALL FINDINGS

Through a series of studies, some general guidelines related to mitigating the UHI effect in Singapore are generated. They are:

- Through the satellite image, the 'hot' spots are normally observed on exposed hard surfaces in the urban context during the daytime. It is suggested that these exposed hard surfaces should be strategically shaded by greenery or artificial sun-shading devices.
- Historical analysis of the long-term climatic data of Singapore indicates the rise of temperature is associated with the land uses. It is believed that implementing greening of Singapore and minimizing the release of anthropogenic heat can mitigate the UHI effect at the macro level.
- Temperature mapping surveys show the temperatures of the developed areas are associated with the greenery coverage within the sites. The well planted areas have the lower temperatures while locations with less greenery incur the higher temperatures.
- The further exploration on the greenery indicates

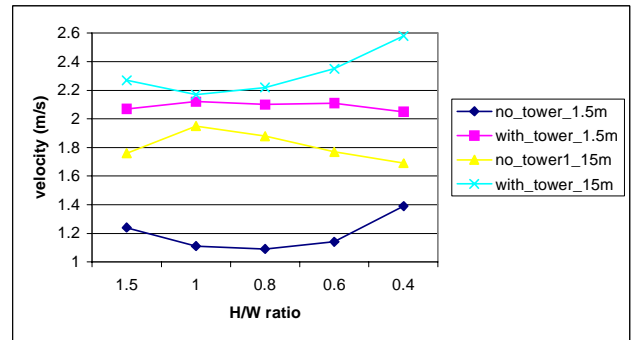


Figure 11. Velocities with and without high rise towers (wind flow parallel).

the positive impacts of plants on mitigating the UHI effect in Singapore. It is strongly recommended that plants can not only be introduced into a developed site as a cooling buffer but also be introduced into buildings as an insulating layer. The greenery can be introduced into the built environment in the forms of parks, rooftop gardens and vertical landscaping.

- Through the lab testing and simulations, it was indicated that the colours of building materials had significant impacts on surface temperatures which subsequently influenced ambient temperatures. It is suggested that more light-coloured materials should be employed to save cooling energy and mitigate the UHI effect.
- It was found that the heat from the asphalt road surface contributes much to the temperature increase inside the canyons. The high rise towers randomly placed above the continuous canyons in fact enhance the airflow and help to reduce the temperature inside the canyons.
- Façade materials and especially their colours play a very important role in the formulation of the thermal environment inside urban canyons. At very low wind speeds, the effect of materials was found to be significant and the temperature at the middle of the narrow canyon increases significantly with the façade material having low albedo.
- Air-conditioning condenser units spaced widely apart do not contribute much to the heat build up inside a canyon as long as there is some wind flow. Only the immediate surroundings next to the condenser units were affected. Arranging the condensing units vertically shows a significant change in the thermal environment especially when the wind flows perpendicular to the canyon. The effect of traffic is not found to be very significant.

CONTACT DETAILS

Dr WONG Nyuk Hien

Department of Building
School of Design and Environment
National University of Singapore
4 Architecture Drive
Singapore 117566

Tel: (65) 6874 3423; Fax: (65) 6775 5502

E-mail: bdgwnh@nus.edu.sg