A preliminary study on environmental performances of pocket parks in high-rise and high-density urban context in Hong Kong

Stephen Siuyu Lau, Pingying Lin* and Hao Qin
Department of Architecture, The University of Hong Kong, Hong Kong SAR, China

Abstract

This article reports the results of an empirical study on summertime environmental performances of a pocket park in Hong Kong. The results suggest that (i) wind condition has a critical impact on outdoor air temperature (Ta), especially in a tropical area like Hong Kong and (ii) building geometry is significantly related to outdoor Ta in Hong Kong. The shading effect from buildings may be more important than shading and evapotranspiration effect of greenery in the unique urban context of Hong Kong.

Keywords: pocket park; high rise and high density; urban geometry; greenery

*Corresponding author.
ilsa1008@hotmail.com

Received 6 December 2011; revised 2 March 2012; accepted 29 March 2012

1 INTRODUCTION

It is well known that Hong Kong is a high-rise and high-density city due to its unique geographical features and large population. The city is concentrated along the two sides of Victoria Harbor, as the densely built area accounts only <20% of the land. At the urban scale, Hong Kong, apparently as a compact city, has been acknowledged by some researchers as a sustainable urban form. The compact urban form leads to less energy consumption in urban infrastructure and transportation system, which accounts for a great part of urban total energy consumption [1]. However, the compact city has also been criticized for the drawbacks, for example, climate change and mental health of residents. Evidence of climate change in Hong Kong has suggested a generally warmer climate. According to the data from Hong Kong Observatory, there was an average rise of 0.12°C per decade from 1885 to 2009. The rate of increase in average temperature became faster in the latter half of the twentieth century [2], when Hong Kong went through a period of extensive urbanization.

Urban heat island (UHI), as an indicator of urban climate, has been investigated by local researchers. Giridharan [3] investigated 17 residential estates in Hong Kong and found that, during peak summer clear sky days, the mean maximum UHI within the estates and between the estates are 2.1 and 1.5°C, respectively. UHI can cause many negative impacts on the environment and people in the way as higher temperature resulting in higher cooling load in summer, serious air pollution and thermal discomfort etc [4]. Many factors contribute to such a climate phenomenon. Wong and Chen [5] summarized the most important factors based on previous research outcomes worldwide as follows: canyon geometry, building materials, greenhouse effect, anthropogenic heat source, evaporative cooling source and wind pattern. Apparently, modification of urban geometry and surface materials, land use characteristics and proper design of green area would be viable strategies to mitigate UHI intensity. Therefore, to find a way to lower the air temperature (Ta) and to increase air quality in Hong Kong, research on characteristics of the outdoor green area with surrounding buildings is required.

On the whole, only 23.7% of the land is developed in Hong Kong in 2010, apart from this, more than 65% is covered by vegetation [6]. Nonetheless, most of the green area is concentrated and not invading into densely built area. There is very limited open space for greenery in densely built area in Hong Kong due to the unique urban morphology featuring high rise and high density, which results in pocket parks scattered throughout the city and functioning as main green open space in downtown. The area of pocket parks can be as small as only about 300 m^2. Most of the research of pocket parks place great emphasis on the perspectives of esthetics, social needs and mental healing for residents [7].

The positive effectiveness of green area on microclimate has been testified by many researchers. Most of the research focused

doi:10.1093/ijlct/cts033 Advance Access Publication 30 May 2012

on the cooling influential intensity and range of green space on the surrounding built-up area. On the one hand, some of the research investigated the microclimate conditions of the individual green area. Large urban parks can extend a noticeable cooling influence beyond their limits over the surrounding area. Jauregui [8] reported that the influential range of a large urban park (~525 ha) in Mexico City reaches one park's width away from the park and the green area is 2–3°C cooler than outside the park. At the smaller scale, even a park as small as 60 × 40 m can lead to a Ta reduction of 3°C inside the park compared with the surrounding area [9]. However, the effect of pocket parks, much smaller than aforementioned parks and surrounded by high-rise high-density buildings, has not been investigated. On the other hand, some researchers also studied a series of parks with different sizes and forms. Shashua-Bar [10] observed the cooling effect of 11 wooded sites with various geometric configurations in Israel and developed an empirical model for predicting the cooling effect of green areas based on the observations. The areas range from 450 to 11 000 m^2. He concluded that the shading effect by tree canopy and the Ta of non-wooded surroundings were most important for the Ta variance inside the sites. In Chang *et al.*'s [11] research about 61 Taipei city parks (ranging from 0.1 ha to more than 20 ha), results showed that urban parks were on average cooler than their surroundings, except that about one-fifth of the parks were warmer than their neighborhood. It was found that, in regard to the park size, the larger parks are on average stronger cool islands than the smaller ones. The features of these previous research can be summarized as follows: (i) small parks only account for a small part of the study sites; (ii) more focused on the effect of large parks; (iii) without considering the combined effect of surrounding buildings and vegetation in park, which would be very important for small parks. Therefore, the following questions are still unknown: (i) whether small parks, as pocket parks in Hong Kong, can help to improve the microclimate in surrounding area? (ii) What are the most important characteristics of parks and surroundings relating with the park cooling effect? To answer these questions, a field measurement in a pocket park in Hong Kong was carried out to clarify the environmental performances from both morphological and greenery perspectives. This article is a preliminary study aiming at: (i) designing a method to detect and compare the different environmental performances of various pocket parks with varying morphological and greenery characteristics in Hong Kong; (ii) investigating whether there are relationships between climate parameters with morphological and greenery characteristics, in order to verify important design parameters for future research.

2 FIELD MEASUREMENT

2.1 Study site

The park, Sung Hing Lane (SHL) Children's Playground, is located in Central and Western District of Hong Kong (Figure 1). It belongs to the Leisure and Cultural Services Department, which is in charge of all the recreation and open spaces in Hong Kong. According to the Hong Kong Planning Standards and Guidelines [6], the open spaces are categorized into three grades: Regional Open Space (at least 5 ha in size), District Open Space (at least 1 ha in size) and Local Open Space (at least 500 m^2). SHL falls in the third category, with an area of about 560 m^2.

SHL is a typical pocket park in Hong Kong. As in Figure 2, SHL is surrounded by buildings in all four directions, no direct connection with roads. Surrounding buildings are mostly six to seven floors high, except two adjacent high-rise buildings with around 25 floors in the Southeast and Northwest corner of the site. These buildings are mainly made of concrete frame and brick walls with light color painting or tiles on exterior walls. Inside the park, ground materials include dark red plastic on the east and light gray concrete tiles on the rest of the park. During the measurement period, there were usually less than 10 people in the park simultaneously. Considering most of the people were just sitting or slowly walking through the park, the heat gain from human body can be neglected compared with solar radiation (SR). It is worth to mention that several restaurants at the west side of park place the kitchens directly towards the park, which exhaust noticeable quantity of waste heat into the park.

Figure 3, including four adjacent building façades, shows that the park is enclosed by buildings to a high extent. Within such a block, the daily average sun path from June to September (hottest months in Hong Kong) is shown in Figure 4, and thus, the percentage of shaded hours engendering by adjacent buildings and the total SR condition are presented in Figure 5a and b. Queen's Road West lies to the south of the park, while Centre Street, Kwai Heung Street and Sung Hing Lane are to the west, east and north, respectively. Queen's Road West and Centre Street carry heavy traffic load, while the others not.

The street canyon ratio or aspect ratio, which can be generally understood as the ratio between the building height and the distance between buildings (height-to-width ratio), is usually applied to define the urban geometry characteristics. Giridharan states that most of the residential estates in Hong Kong have a high canyon geometry ratio in the order of 2–3 [3]. Actually, many streets in downtown areas have much higher street canyon ratios. Oke identified that a street aspect ratio (H/W) of 0.4 was an appropriate geometrical guideline for the design of mid-latitude cities regarding urban microclimate [12]. However, the optimum figure in low-latitude cities, such as Hong Kong, has not been researched. As for parks or the open spaces in the city, the aspect ratios generally tend to be lower. Figure 6 provides two sections of the study site, showing that the aspect ratios of two directions are 0.96 and 0.79, respectively.

2.2 Measurement methods

The field measurements were conducted on 27th, 28th May and 27th July 2011. The general background climatic

Figure 1. *Location of study site (source: Google map).*

Figure 2. *Bird views of the site model (left), site plan (middle) and site view from Northeast corner (right).*

information from Hong Kong Observatory is given in Table 1. The weather conditions in these 3 days are acceptable with clear sunny sky [13, 14].

By comparing the climate conditions of the first 2 days with typical climate in summer, it is found that they can still represent the summer condition. It is known that mean maximum Ta's from June to September are 30.2, 31.4, 31.1 and 30.1°C, respectively. From Table 1, it can be seen that the temperatures in 27 and 28 May are very close to the average value in summer.

The measurement period in each day is from 1 to 10 p.m. The field work included climatic measurement and site survey. Climatic measurement was conducted to collect the data of climatic parameters, while site survey was to collect the morphological and greenery data. The climatic measurement comprised stationary weather stations and mobile measurement both using HOBO weather station (see Table 2 for specification of instrumentation), while the site survey included measurement and taking sky view images using digital camera with fish eye lens.

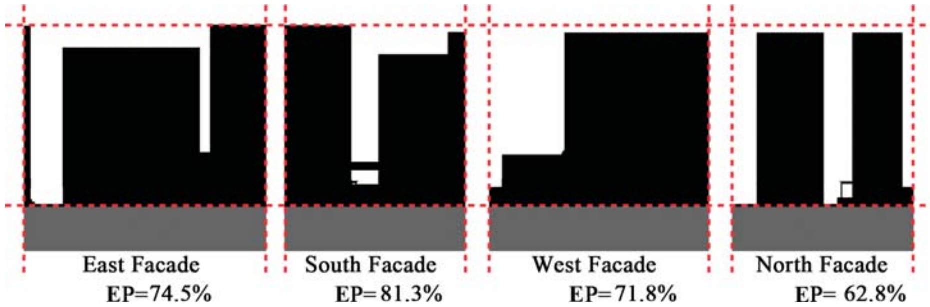

Figure 3. *Configuration and percentage of enclosure (EP) of four adjacent building façades.*

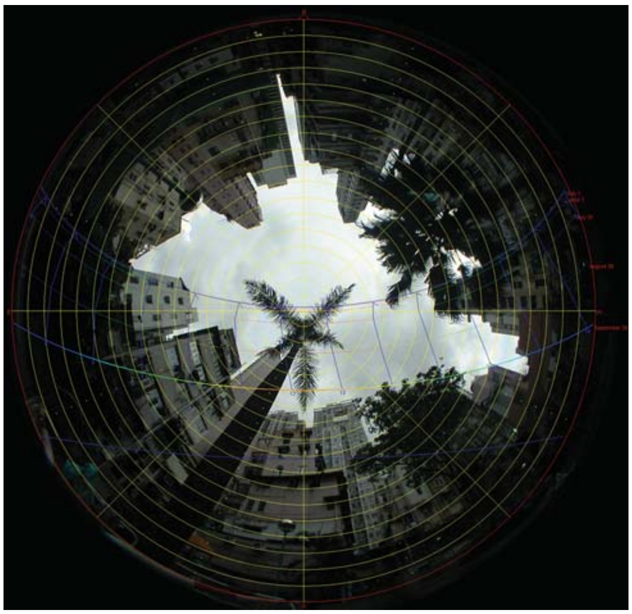

Figure 4. *Daily average sun path from June to September (generated by WinSCANOPY software).*

To investigate the local cooling effects of this pocket park, 'Local Cool-Island' is introduced into this research, with a definition of the temperature difference between the park interior and its nearby surroundings, where the general setting is similar. According to previous research, the influence range is hypothesized at about one park-width away from the park [10, 11], within which mobile measurements were conducted.

Due to the small area of pocket parks, only one fixed mini-weather station was stationed in the center of the park as Point 3 (control point inside the park; Figure 7). For the fixed-point measurement, a set of HOBO weather stations was housed there continuously collecting the climatic data from 1 to 10:30 p.m. For the mobile measurement, it was conducted at strategically designed points along the designated route showed in Figure 7, using a set of HOBO weather station carried by a trailer. Mobile measurement points cover nine points inside the park (Points 1–9, including fixed measurement point: P3) and nine points outside the park (Points 10–18). The mobile measurement was done once every 2 h, starting at 1 p.m., which led to five rounds a day. It took a few minutes at each point and the measurement at all points was completed within 2 h. The data collected at 1, 3 and 5 p.m. are for analysis of the daytime condition while 7 and 9 p.m. for the nighttime condition.

3 DATA ANALYSIS AND DISCUSSION

3.1 General descriptive statistics

Figure 8a, b and c presents the data of Ta, wind velocity (WV) and SR collected at control point (P3) in 27 May and 27 July. This figure was prepared using 5 s-interval monitored data. The data at this point in 28 May were lost due to the equipment problem. As can be seen from the first graph of the Ta pattern, the temperature in 27 July is much higher than 27 May, with a maximum difference of 4.9°C at around 2:20 p.m. This trend conforms to the SR pattern during that time. Wind speed in 27 July is higher than 27 May, which can partially balance the UHI effect on these 2 days.

Before data analysis, Ta's collected by mobile measurement were corrected to compensate for temporal temperature change within one round. As Ta at each point is obviously influenced by adjacent environment and the warming or cooling rates were different from point to point, the adjustment was conducted according to the changing rate of each point.

Table 3a and b provides the Ta data at all measurement points during both the daytime and the nighttime periods. P3 (marked with the line box) is the control point measured continuously by fixed weather station. In Table 3a, it can be seen that the mean Ta inside the park is higher than outside the park on all 3 days, and the difference is 0.2, 0.2 and 0.3°C, respectively, during the daytime period, while 0.1, 0.3 and 0.1°C in night time. The difference in temperature in daytime seems to be higher than in nighttime, which might be due to the difference of SR is much higher during daytime.

In 27 May, P1 and P4 are the highest in Ta during daytime, which are located inside the park and near the west façade. This may be explained by that there is much more heat released by the restaurants at the west of the park, comparing

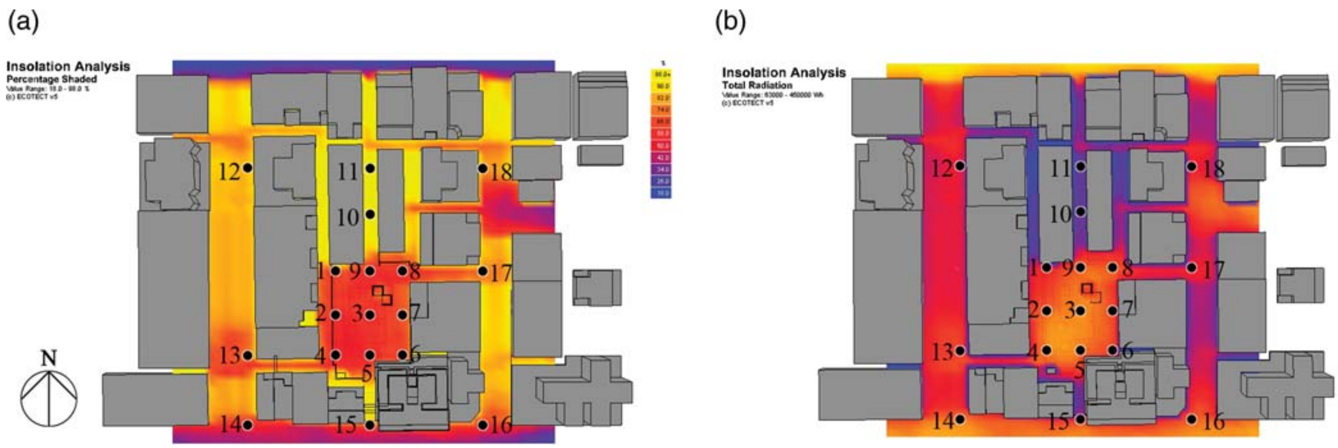

Figure 5. *(**a**) Daily average percentage of shaded hours engendering by adjacent buildings from June to September; (**b**) Daily average total solar radiation condition from June to September (generated by Ecotect software).*

Figure 6. *Two sections of the study site.*

Table 1. *Climatic parameters at Hong Kong observatory in measurement days.*

Date	Ta		S-Ta	RH		DoS	UV	
	Max	Min		Max	Min		Max	Mean
5.27	30.0	24.2	25.7	81	57	6.1	8	4
5.28	30.2	24.5	26.4	88	50	11	9	4
7.27	33.9	28.2	26.7	88	60	10.4	12	6

Ta, air temperature in °C; S-Ta, sea surface temperature in °C; RH, relative humidity in %; DoS, duration of sunshine in hours; UV, ultraviolet radiation index.

Ta and RH were recorded in Hong Kong Observatory; S-Ta was recorded in Waglan Island; Dos and UV were recorded by King's Park Observatory.

with the other three façades. The coolest points are P12 and P18, with a value of only 29.8°C. P18 is located near a big tree in the street to the east of the park, which is quite narrow with less sunshine.

It shows similar situation in 28 May and 27 July regarding the variation in Ta. The maximum Ta value is collected at P7 with a minimum value at P18. There appears to be a strong probability that it is due to the longer duration of sunshine in 28 May (11 h) and 27 July (10.4 h) than 27 May (6.1 h). Besides, according to Figure 8c, the SR in 27 July is much stronger than 27 May. Therefore, P7 and P8 at the east side of park get more sunshine and heat. The maximum difference is, up to 1.3°C, occurred between P 7 and P 18 in 27 July. In

Table 2. *Specifications of HOBO weather station.*

Sensors	Model	Measurement Parameter	Accuracy	Measurement Range
Temp/RH smart sensor	S-THA-M002	Ta, RH	Ta: ±0.7 to +25°C; RH: ±3% over the range of 0 to +50°C; ±4% in condensing environments	Ta: −40 to +75°C; RH: 0−100% at −40 to75°C
Silicon pyranometer smart sensor	S-LIB-M003	SR	±10.0 W/m^2 or ±5%, whichever is greater in sunlight. Additional temperature induced error 0.38 W/m^2/°C from 25°C (0.21 W/m^2/°F from 77°F)	0−1280 W/m^2
Wind speed smart sensor	S-WSA-M003	WS	±1.1 m/s or 4% of reading whichever is greater	0−45 m/s
Wind speed and direction sensor	S-WCA-M003	WS,WD	WS: ±0.5 m/s, ±3% 17−30 m/s, ±4% 30−47 m/s; WD: ±5°	WS: 0−44 m/s; WD: 0−358°, 2° Dead Band

Ta, air temperature; RH, relative humidity; SR, solar radiation; WS, wind speed; WD, wind direction.
Source: http://www.microdaq.com/

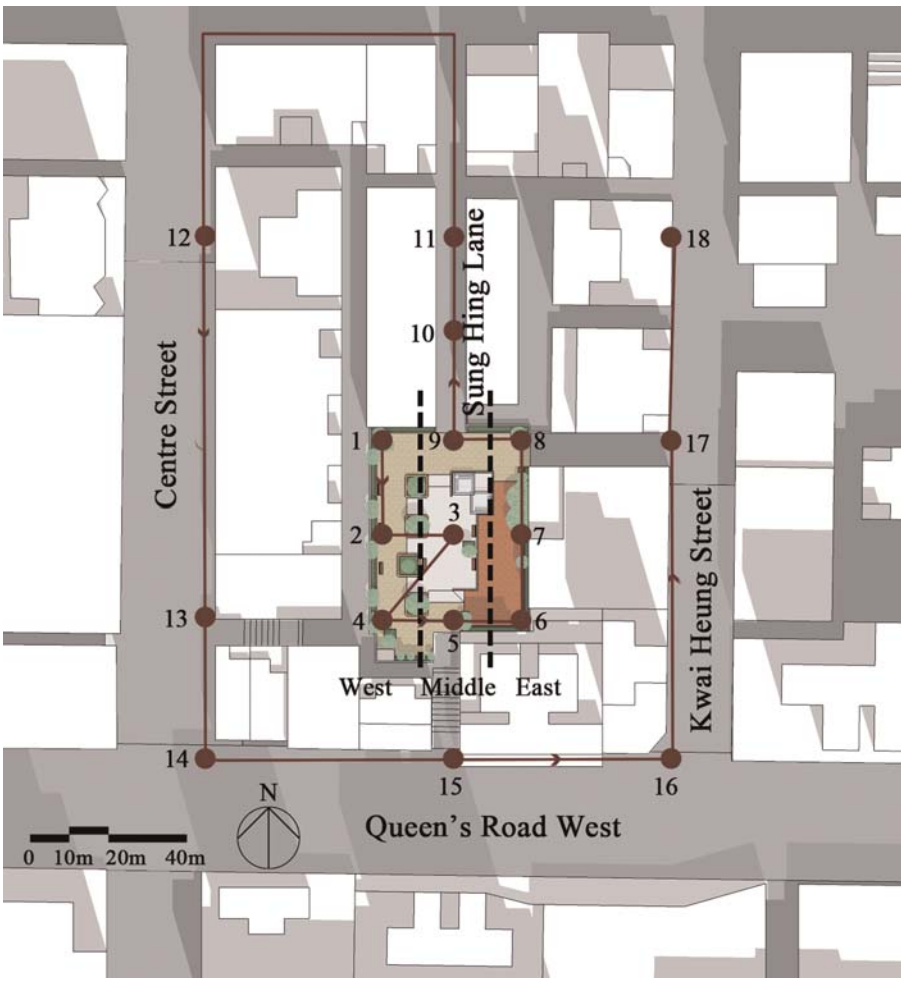

Figure 7. *Site plan with measurement points and route.*

Table 3b, it can be observed that there is no explicit pattern about the nighttime Ta distribution. Maybe it is because of too much anthropogenic heat during nighttime within this residential block, for example, heat released from cooking and air conditioners.

3.2 Comparison between inside and outside the park

Figure 9a, b and c illustrates the comparison of Ta, WV and SR between inside and outside the park. As is shown in Figure 9a, Ta inside the park is on average slightly higher than outside the park, although there is more vegetation inside the park than outside, which conflicts with common sense. From Figure 9b, it can be seen that wind speed outside the park is always larger than inside the park, which might partially explained the aforementioned Ta variation pattern, as natural ventilation is important for mitigating UHI intensity by accelerating the heat exchanges between urban surfaces [15]. In Figure 9c, the inside park receives more SR as it is more open than the surrounding streets. SR decreases sharply since 1:00 p.m., which is in accordance with the Ta pattern, except that Ta experiences a peak around 2:00–3:00 p.m. due to heat released from ground surfaces. This suggests that SR has a great impact on the Ta distribution.

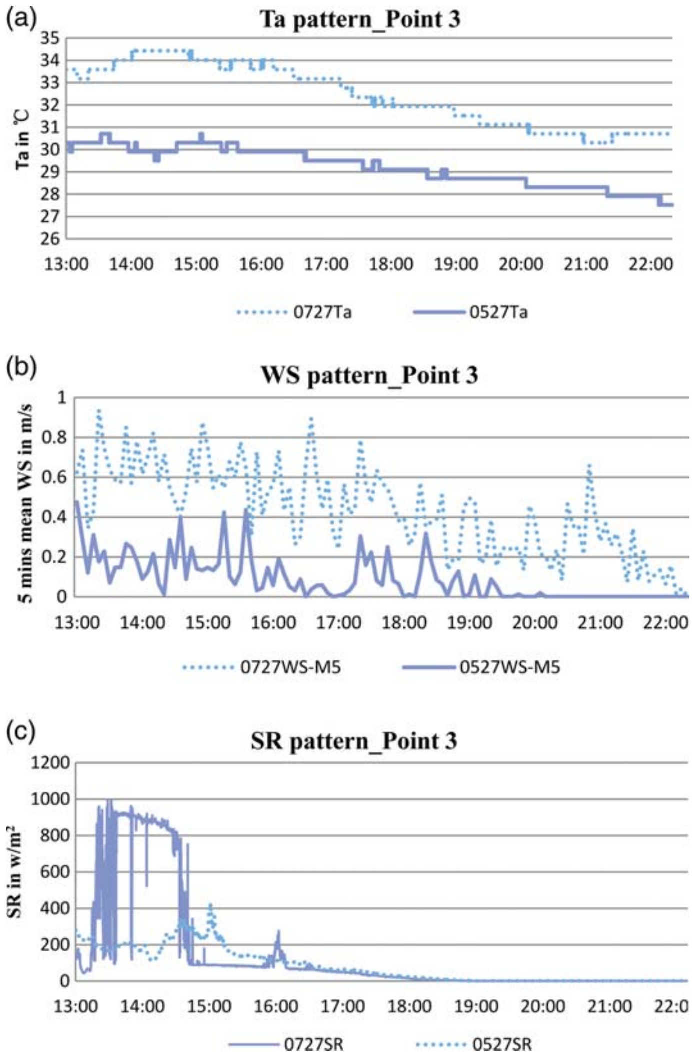

Figure 8. *(a) Temperature pattern; (b) wind speed pattern; (c) solar radiation pattern at control point (P3).*

Figure 10a and b compares Ta and WV between four streets surrounding the park to identify the relationship between the urban form and the Ta variation. It shows that Ta on Queen's Road West is the highest, which probably is due to the heat from heavy traffic and also that this street is the widest one among the four, receiving the most sunshine. Kwai Heung Street has the lowest Ta and relatively higher wind speed. Although it is wider than the Sung Hing Lane, it enjoys lower Ta, which may be cooled by better ventilation. This suggests that wind environment may be critical for lowering Ta in subtropical area.

To compare the Ta distribution, the park is divided into three parts along East-West direction, as west, east and middle of park. Figure 11a shows that west of the park experiences the lowest Ta in daytime but the highest Ta in nighttime. It is probably attributed to the fact that SR is the main heat source during daytime while anthropogenic heat during nighttime. Additionally, in daytime, west of the park suffers the lowest sunshine, while it is most impacted by the heat from the restaurants at nighttime. There seems to be no explicit pattern in wind speed variation between the three parts, except that they all show low wind speeds <0.4 m/s.

3.3 Regression analysis

Urban canyon geometry is used to define the variation of height, length and spacing of the buildings in an urban context. It has a significant impact on the energy exchanges, and thus, the temperatures of urban areas [16]. Sky-view factor

Table 3. *Mean Ta at all measurement points.*

Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Inside	Outside	Mean
(a) Mean daytime temperature at all measurement points																					
5.27	**30.6**	30.4	30.0	**30.6**	30.4	30.3	30.2	30.3	30.2	30.1	30.0	**29.8**	29.9	30.0	30.2	30.5	30.0	**29.8**	30.3	30.1	30.2
5.28	31.5	31.4	–	31.5	31.7	31.7	**32.0**	**32.0**	31.9	31.6	31.3	31.2	31.4	31.6	31.7	31.9	31.3	**31.1**	31.7	31.5	31.6
7.27	33.6	34.1	33.6	33.7	33.9	34.3	**34.6**	34.5	34.2	33.9	33.5	33.5	33.7	34.1	34.3	34.2	33.7	**33.3**	34.1	33.8	33.9
Mean	31.9	32.0	–	31.9	32.0	32.1	**32.3**	**32.3**	32.1	31.9	31.6	31.5	31.7	31.9	32.1	32.2	31.7	**31.4**	32.0	31.8	31.9
(b) Mean nighttime temperature at all measurement points																					
5.27	29.3	29.2	**28.5**	29.2	29.2	29.0	29.1	29.1	28.9	28.8	28.7	**28.5**	28.7	28.9	29.0	**31.0**	28.7	28.7	29.1	29.0	29.0
5.28	**30.9**	30.7	–	30.8	30.8	30.8	30.9	30.9	30.7	30.6	30.5	**30.3**	30.4	30.4	30.7	30.7	30.4	30.4	30.8	30.5	30.6
7.27	**30.9**	**32.4**	30.9	31.7	31.3	31.4	31.4	31.1	31.1	31.2	31.5	31.3	31.4	31.6	31.5	31.3	31.1	31.0	31.4	31.3	31.3
Mean	30.4	30.8	–	30.6	30.4	30.4	30.5	30.4	30.2	30.2	30.2	**30.0**	30.2	30.3	30.4	**31.0**	30.1	30.0	30.4	30.3	30.3

Note: P1–P9 are nine points inside the park, P10–P18 are nine points outside the park; In 28 May, the data at P3 (control point) were lost due to equipment problem; Bold numbers are the maximum and minimum values on each day.

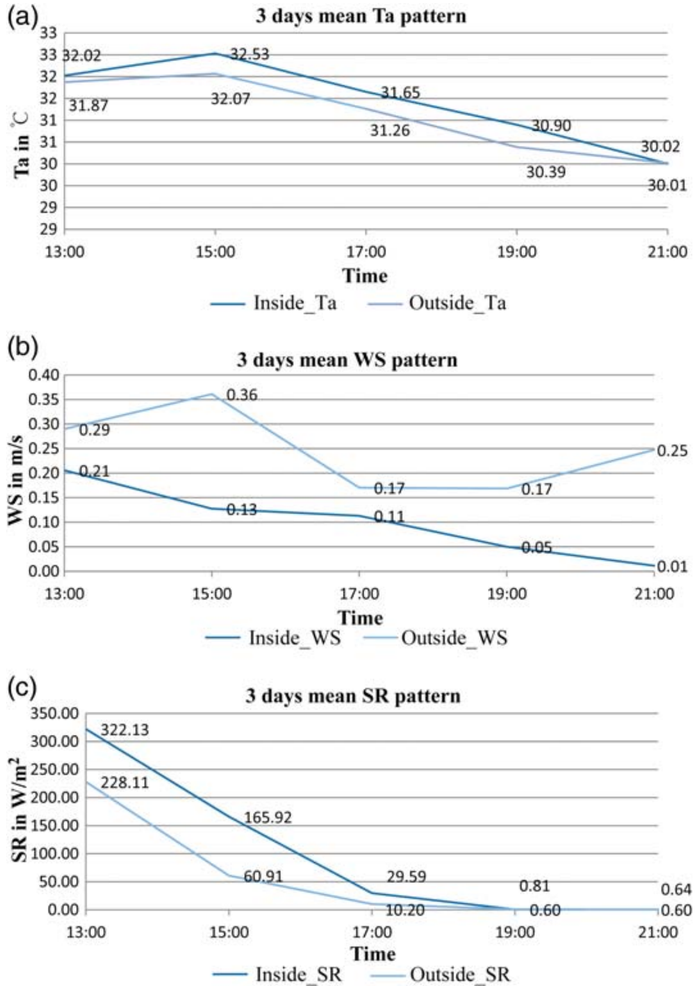

Figure 9. *(**a**) Three days mean Ta pattern; (**b**) 3 days mean WS pattern; (**c**) 3 days mean SR pattern.*

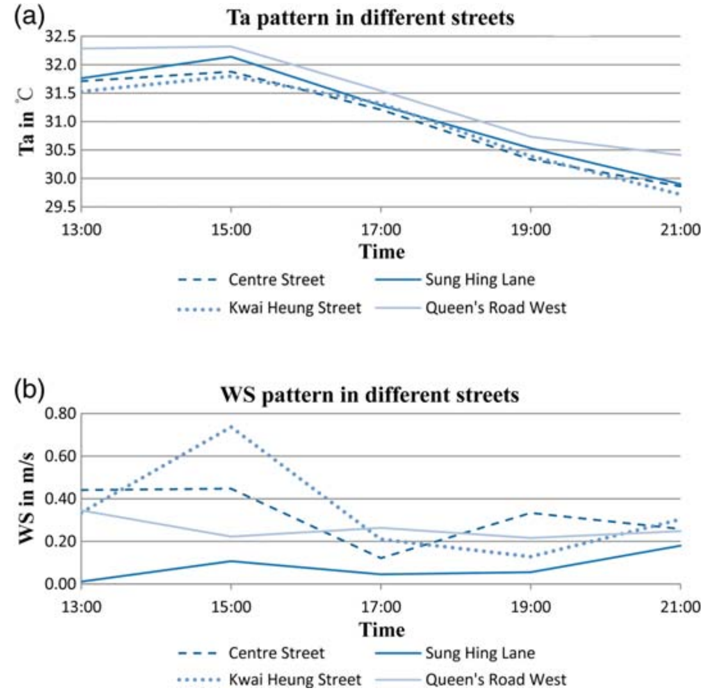

Figure 10. *(**a**) Ta pattern in different streets; (**b**) WS pattern in different streets. Note: Centre Street includes Points 12 and 13, Sung Hing Lane includes Points 10 and 11, Kwai Heung Street includes Points 17 and 18, Queen's Road West includes Points 14, 15 and 16.*

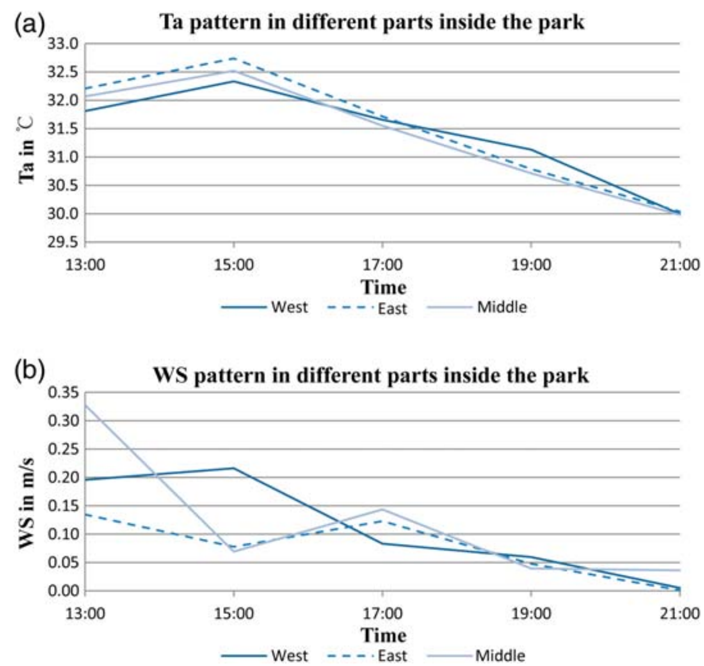

Figure 11. *(**a**) Ta pattern in different locations of the park; (**b**) WS pattern in different locations of the park. Note: West of the park includes Points 1, 2 and 4, east of the park includes Points 6, 7 and 8 and middle of the park includes Points 5 and 9.*

(SVF) is a universal factor applied by many urban climatologists to characterize the urban canyon geometry and to measure the fraction of the overlying hemisphere occupied by sky [17]. The reason to introduce SVF is that it is directly related with and can be used to quantify radiation exchanges within certain urban area. It was defined as 'geometric ratio which expresses the portion of the radiation output from one surface that is intercepted by another surface' [18]. In the subtropical area, lower SVF generally leads to a smaller proportion of sky that admits less SR during daytime, which helps to lower the temperature. However, it also traps more long-wave radiation within the urban area in nighttime, which ends up more heat stored in the system and thus higher temperature. Therefore, it cannot be determined that whether lower SVF is better for mitigating UHI intensity. Ta daytime and nighttime should be correlated with SVF separately and then the conclusion could be made based on comprehensive impact.

On the other hand, tree-view factor (TVF) is also introduced into this study to quantify the impact by tree canopy. It is defined as the fractions of the overlying hemisphere as

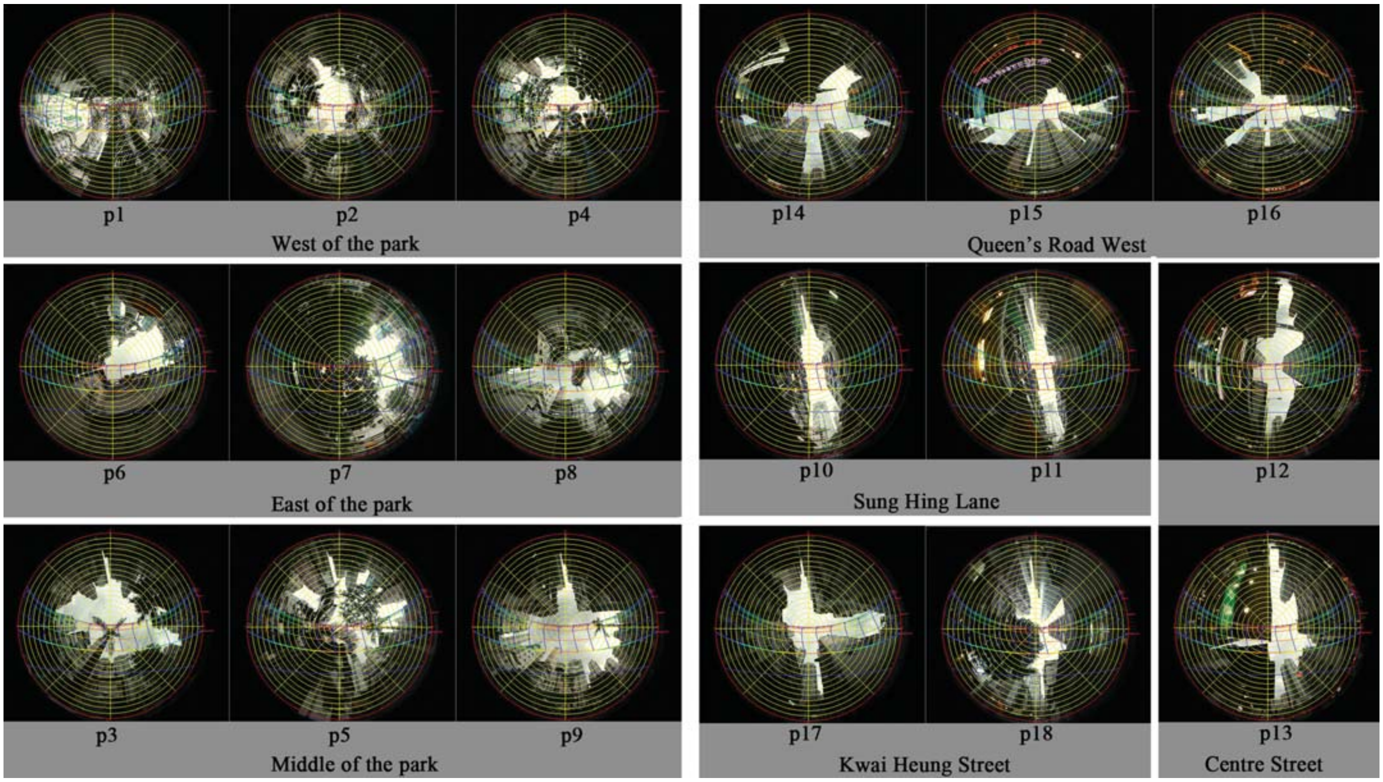

Figure 12. (**a**) *and* (***b***) *Hemispherical sky view images of all measurement points.*

shown in the sky view images occupied by vegetation canopy [14]. Normally, vegetation would help to lower the temperature through their unique function of shading, evapotranspiration and photosynthesis [5]. However, more vegetation does not necessarily lead to lower temperature, as it can also block the wind flux and thus impact the heat exchange process, which could be a major strategy to mitigate UHI intensity in tropic climate area. The optimum amount of greenery and strategically design of spatial arrangement should be holistically investigated.

In the present study, SVF and TVF are determined using photographic methods. Hemispheric photos at all measurement points were taken by a digital camera with a fisheye lens (Figure 12). Then SVF and TVF values were acquired by analyzing the photos with WinSCANOPY software.

As is shown in Table 4a, regression analysis results suggest that the correlation between Ta-day and SVF (marked with the line box) is relatively higher (Figure 13). Although the value of R^2 is only 0.254, representing that 25.4% of the Ta-day variation can be explained by SVF, it can still indicate the important role of SVF in influencing Ta. The results also present that there is no significant correlation between Ta-night and SVF. It may be due to the impact of anthropogenic heat from home cooking and air conditioning etc. As the park is quite small and highly enclosed, it is probably that it could be substantially influenced by the immediate building walls. Moreover, the results suggest that TVF has no important impact on both Ta-day and Ta-night.

Table 4. *Summary of regression models.*

Model No.	R^2	F Statistic	Significance	Variables
(a) Summary of Ta-day regression models.				
1	0.254	5.117	0.039	Building SVF
2	0.195	3.633	0.076	TVF
(b) Summary of Ta-night regression models				
3	0.114	1.936	0.184	Building SVF
4	0.174	3.153	0.096	TVF

Note: R^2: the proportion of variability in Ta-day that is explained by the model.

It seems that compared with greenery, the shading effect from surrounding buildings may be more important for lowering Ta within small open spaces. This is also confirmed by the fact that the points located in the narrower streets with almost no greenery but better ventilation are cooler than the points in the park with more greenery. Additionally, natural ventilation mainly depends on the building configuration, such as the orientation of opening, combination of different building heights, building height to street width ratio etc. Thus, to identify the optimum pattern of parks for high-rise and high-density context, further investigation on urban configuration and the mutual interaction between building and greenery would be needed. These implications would significantly impact the following site selection, which could make sure the most variation on important parameters.

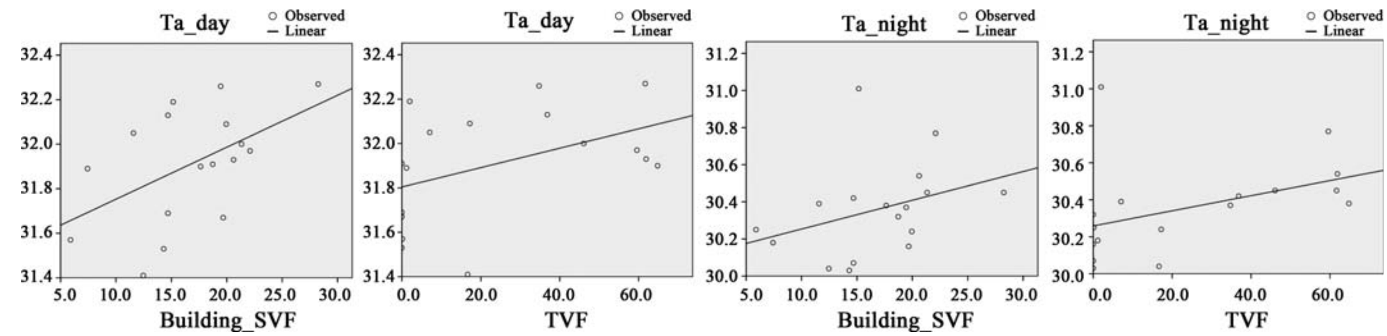

Figure 13. *Four regression models.*

4 CONCLUSIONS

This article reports the results of an empirical study on summertime environmental performance of a pocket park in Hong Kong. Climatic parameters of different measurement points all compared and correlated with morphological and greenery characteristics; regression analysis is conducted to testify the impact of building geometry and vegetation on outdoor Ta. The results suggest that: (i) wind condition has a critical impact on outdoor Ta, especially at tropical climate area like Hong Kong; (ii) building geometry is significantly related to outdoor Ta in Hong Kong. The shading effect from buildings may be more important than shading and evapotranspiration effects of greenery. However, this does not mean that the greenery is not necessary in outdoor open space of Hong Kong. The positive effect of greenery should be explored based on the combination function with surrounding buildings. To conclude, these findings hopefully will contribute to further research in the following ways: (i) clarifying the research methods; (ii) helping to identify the possible important variables in the research context of Hong Kong; (iii) helping to select more study sites that have the most variation on important research parameters.

There is some limitation of this study due to its small sample size, which limited the number of variables could be included in the regression analysis. Moreover, only one site could result in selection bias and thus influence the results. In future, more pocket parks would be selected and investigated. More impact parameters could be identified, for example, land use characteristics, building height to park width ratio or other morphological parameter that can define the shading effect according to sun path in Hong Kong etc. Specifically, more attention would be put on improving the accuracy of the measurement method in future study in order to correctly reflect the influence of urban design on climate variation. First, there are quite much anthropogenic heat generated by human activities might affect microclimate, such as air conditioning, walking, vehicles etc. Apart from air conditioning which cannot be removed, influence from other activities should be taken into account and avoided in the greatest extend. Secondly, as wind can change all the time, ideally climate monitor should be constant that wind condition could be more accurately captured. But, in present study, it cannot be realized due to instrumentation and manpower limitation.

The present study has provided much useful information for conducting more valid research for future study by refining research methods. It is hopeful that based on the implication from further study in future, a design guideline for policy-makers, urban planners, urban designers and architectures can be formed to create a more energy conscious and comfortable urban environment.

ACKNOWLEDGEMENTS

The authors acknowledge support from the University of Hong Kong UDF 11420-00600050-91430-14300-171-01 and HKU Seed Fund for Applied Research Project No. 10400769.06080.01100.301.01.

REFERENCES

[1] Ng E (ed). *Designing High-Density Cities for Social and Environmental Sustainability.* Earthscan, 2010;13–15,293–308.
[2] Hong Kong Observaroty. http://www.hko.gov.hk/contentc.htm (August 2011, date last accessed).
[3] Giridharan R. *Urban Design Factors Influencing Outdoor Temperature in High-Rise High-Density Residential Developments in the Coastal Zone of Hong Kong*. University of Hong Kong, 2005.
[4] Gartland L. *Heat Islands: Understanding and Mitigating Heat in Urban Areas*. Earthscan, 2008.
[5] Wong NH, Chen Y. *Tropical Urban Heat Islands: Climate, Buildings, and Greenery.* Taylor & Francis Group, 2009.
[6] Planning Department. http://www.pland.gov.hk/pland_en/info_serv/statistic/landu.html (August 2011, date last accessed).
[7] Seymour WN (ed). *Small Urban Spaces: The Philosophy, Design, Sociology, and Politics of Vest-Pocket Parks and Other Small Urban Open Spaces.* New York University Press, 1969.
[8] Jauregui E. Influence of a large urban park on temperature and convective precipitation in a tropical city. *Energ Build* 1990;**15**:457–63.
[9] Saito I, Ishihara O, Katayama T. Study of the effect of green areas on the thermal environment in an urban area. *Energ Build* 1990;**15**:493–8.

[10] Shashua-Bar L, Hoffman ME. Vegetation as a climatic component in the design of an urban street: an empirical model for predicting the cooling effect of urban green areas with trees. *Energ Build* 2000;**31**: 221–35.

[11] Chang C-R, Li M-H, Chang S-D. A preliminary study on the local cool-island intensity of Taipei city parks. *Landsc Urban Plan* 2007;**80**:386–95.

[12] Oke TR. Street design and urban canopy layer climate. *Energ Build* 1988;**11**:103–13.

[13] Giridharan R, Ganesan S, Lau SSY. Daytime urban heat island effect in high-rise and high-density residential developments in Hong Kong. *Energ Build* 2004;**36**:525–34.

[14] Yang F. *The effect of urban design factors on the summertime heat islands in high-rise residential quarters in inner-city Shanghai*. The University of Hong Kong, 2009.

[15] Santamouris M (ed). *Energy and Climate in the Urban Built Environment*. James & James, 2001.

[16] Grimmond CSB, Potter SK, Zutter HN, *et al*. Rapid methods to estimate sky-view factors applied to urban areas. *Int J Climatol* 2001;**21**:903–13.

[17] Oke TR. Canyon geometry and the nocturnal urban heat island: comparison of scale model and field observations. *J Climatol* 1981;**1**:237–54.

[18] Oke TR. *Boundary Layer Climates*, 2nd edn. Methuen, 1987.