Appendix N

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Investigating the Effects of Greenery on Temperature and Thermal Comfort in Urban Parks

(Final Report)

By Dr C.K. Chau

Department of Building Services Engineering

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Investigating the effects of greenery on temperature and thermal comfort in urban parks PI:

Dr. Chi-kwan CHAU, Building Services Engineering, The Hong Kong Polytechnic University

Co-Is:

Prof. Edwin, H.W. CHAN, Dept. of Building and Real Estate, The Hong Kong Polytechnic University

Dr. Esther, H.K. YUNG, Dept. of Building and Real Estate, The Hong Kong Polytechnic University

Dr. Conrad PHILPP, School of Art, Architecture and Design, University of South Australia

Executive Summary

Nowadays, urban greening is a popular program with an ultimate objective of improving the environmental quality within urban areas including roadside environments. Urban greening can mitigate urban heat island (UHI) effect and improve thermal comfort by moderating micro-climatic conditions and provide shading. It can bring other benefits including the ability to attenuate noise levels, improve air quality and reduce urban storm water runoff. Accordingly, this study aims to reveal the cooling effect as well as the thermal comfort enhancement attributed by the characteristics and features of urban parks, e.g. greenery. In order to address these two objectives, a series of field measurements and questionnaire surveys have been performed within three urban parks in Hong Kong having different areas and aspect ratios. For determining the cooling intensity of the parks, the parks areas were divided into several zones to facilitate comparison of temperatures at different zones. Additional temperature measurement points were set up beyond the boundaries of the parks which radiated a certain distance from the center of parks (i.e. 50m and 150m). Our preliminary results show that the temperatures increase from the center to the boundary of the parks by 1°C. And the temperatures inside the parks were lower than the temperature outside, and increased with the distance away from the boundaries, the temperatures of the parks were lower than that at 150m away of the parks by 1-2°C. For thermal comfort, a mobile meteorological station, which contained sensors for measuring air temperatures, relative humidity, globe temperature, wind speed, and solar radiation, was assembled for recording the microclimate conditions. During the measurement campaigns, questionnaire surveys were also performed within the same parks. The collected 616 responses were subsequently used to reveal the multi-lateral relationships among factors. Thermal comfort and acceptability of the thermal environment were shown to be influenced by personal preception of people. In contrast, meteorological factors and visual of greenery only display weak relationships with thermal comfort and acceptability of thermal environment.

Research Project Title: **Investigating the effect of greenery on temperature and thermal comfort in urban parks**

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Introduction

Nowadays, urban greening is a popular program with an ultimate objective of improving the environmental quality within urban areas including roadside environments. Urban greening can mitigate the urban heat island (UHI) effect and improve thermal comfort by moderating micro-climatic conditions (Avissar, 1996; McPherson, 1992; Ng et al., 2012; Park et al., 2012; Shashua-Bar et al., 2009; Taha, 1997) and provide shading (Dimoudi and Nikolopoulou, 2003; Ali-Toudert and Mayer, 2007; Shahidan et al., 2012). It can bring other benefits including the ability to attenuate noise levels (Ozer et al., 2008; Islam et al., 2012; Van Renterghem et al., 2012), improve air quality (Akbari et al., 2001; Jim and Chen, 2008; Nowak et al., 2006) and reduce urban storm water runoff (Bartens et al., 2008; Armson et al., 2012).

The cooling effect beyond boundaries of parks and the thermal comfort inside parks are influenced by the physical setting of urban parks. In particular, the cooling effect provided by a park has been shown to be influenced by park area (Lin et al, 2015; Feyisa et al., 2013), park geometries (Kong et al., 2014), type of plant cover (Lin et al, 2015, Cheng et al, 2007), land-cover within a park (Feyisa et al., 2013), and proportion of vegetated surface versus paved surfaces (Feyisa et al., 2013). Large parks were on average cooler than the smaller ones, but this relationship was a non-linear one and parks with ⩾50% paved coverage and little tree- and shrub-cover were on average warmer than their surroundings (Chang et al, 2007). Fragmented greenspaces could also provide effective cooling (Kong et al., 2014). On the other hand, a park’s cooling effect usually extended beyond its boundary into the surrounding streets and buildings (Feyisa et al., 2013), and the extent of influence was also affected by the character of the area around each park despite being related in part to park size (Kong et al., 2014). Nevertheless, questions still remain on how the surrounding characteristics, e.g. shade of buildings and street canyons, influence the urban thermal environment, and whether quantitative relationships can be established among them for help prediction. Worst still, a substantial amount of evidence indicated that the findings on the cooling effect provided by greenery were not transferrable from one city to the other due to differences in climatic conditions and land topography (Kong et al., 2014).

In addition, greenery inside parks can improve the thermal comfort of park-users as well as people living in immediate vicinity. Of particular interest is how the park characteristics can help improve the thermal comfort or acceptability of thermal environment of park users. A number of factors have been identified to influence the thermal environment of urban parks. Physical settings like tree canopy layer (Klemm et al., 2015; Ng and Cheng, 2012; Shashua-Bar et al., 2010), shrubs, flower beds and grass area (Ng and Cheng, 2012; Shashua-Bar et al., 2010) and sky view factor (Lin, 2012), and meteorological factors like temperature (Zacharias et al., 2001; Katzschner, 2006; Nikolopoulou and Lykoudis, 2007; Lin, 2009; Kantor and Unger, 2010), wind speed (Katzschner, 2006; Eliasson et al., 2007) and solar radiation (Zacharias et al., 2001; Katzschner, 2006; Nikolopoulou and Lykoudis, 2007; Lin, 2009) have been found to influence thermal comfort in parks. Hitherto, there are few models being developed to predict the thermal comfort conditions in parks even though some models have been developed for predicting thermal comfort in indoor or outdoor environments. For example, the body heat balance thermal comfort model developed by Ole Fanger (1967), and the adaptive models developed by Brager and de Dear (1998). Although these two streams of models are good for predicting the thermal comfort conditions in indoor environments, they are not able to accurately predict the thermal comfort in outdoor environment whose unsteady conditions contradict with the basic assumption. Furthermore, there are some outdoor thermal comfort models such as Universal Thermal Climate Index (UTCI) as a function of air temperature, wind, radiation, and humidity and coupled with a state-of-the-art clothing model (Błażejczyk et al., 2010), and the models for predicting thermal sensation which was expressed in terms of air temperature, wind speed solar radiation and absolute humidity (Cheng et al., 2010). However, they cannot accurately predict the thermal comfort conditions in outdoor parks without the inclusion of individuals' physiological, psychological, behavioral and visual perception factors, which are believed to play a more active role in urban parks (Klemm et al., 2015; Lin et al., 2011; Niu et al., 2015; Yang et al., 2013). In addition, none of the quantitative models developed so far have successfully included urban park characteristics like sky view factor (SVF), shading and greenery (Georgi and Tzesouri, 2008; Lin et al., 2012) which are anticipated to exert considerable influences on thermal environment.

Accordingly, it is the ultimate aim of the proposed study to formulate appropriate models to predict the cooling effect as well as the thermal comfort enhancement attributed by the characteristics, e.g. greenery, of urban parks in Hong Kong. After the formulation of these two models, it is the intention to apply them to predict the temperature changes and thermal comfort enhancement in Green Deck. The temperature changes due to the Green Deck predicted by GIS software will be used as inputs to the developed thermal comfort model for predicting the thermal comfort enhancement due to Green Deck. All in all, the findings can provide valuable insights on formulating park design guidelines in providing comfortable greening areas in compact urban cities, which should be a valuable asset for informing the design of Green Deck.

Objectives

I. to investigate the cooling effect provided by the greening area in urban parks;

II. to investigate the effect of greenery on thermal comfort inside urban parks;

III. to predict the cooling effect and thermal comfort enhancement provided by Green Deck

Research plan

The study aims to determine the effect of greenery in urban parks on the temperature change to the surroundings and the outdoor thermal comfort of park users (see Objectives I and II). To achieve these objectives, a series of field measurements and questionnaire surveys have been conducted near three existing urban parks in Hong Kong to provide data for constructing an outdoor thermal comfort model embracing micro-climatic, physical and physiological factors.

The successful formulation of models for predicting the adaptive outdoor thermal comfort inside parks and for predicting the temperature profiles surrounding greenery areas can provide insights on formulating park design guidelines in providing comfortable greening areas in urban cities. The study comprises two stages: *Stage I: Development of Thermal Comfort and Cooling Effect Prediction Models,* and *Stage II: Prediction of cooling effect and* *thermal comfort enhancement by Green Deck. The* methodology details are laid out as follows:

Methodology

<u>*Development of Thermal Comfort and Cooling Effect Prediction Models*</u>

<u>*Studied sites*</u>

Three urban parks (i.e. Shum Shui Po Park (SSPP), Yuet Wah Street playground (YWSP) and Kowloon Park (KP)) in Shum Shui Po, Kwun Tong and Tsim Sha Tsui were selected for conducting measurements and questionnaire surveys. These parks were surrounded by high rise buildings and medium trafficked roads. Figure 1 (a,b and c) shows the park locations with the major characteristics (see Table 1).

Figure 1a Shum Shui Po Park

Figure 1b Yuet Wah Street Playground

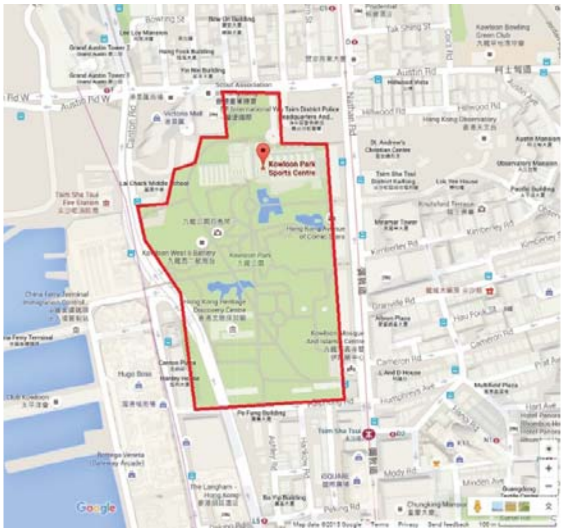


Figure 1c Kowloon Park

Figure 1 Location maps of the surveyed parks

Table 1 Characteristics of the surveyed parks

	Shum Shui Po Park (SSPP)	**Yuet Wah Street Playground (YWSP)**	**Kowloon Park (KP)**
Area	107.5m x 97.5m	51m x 200m	317m x 417m
Tree coverage inside park	60%	70%	90%
With water features in parks	No	No	Yes
Surrounding building	50m	30-80m	100-120m
Distance between the parks and building	20m	10m	30m
Aspect ratio of the surrounding buildings	2.5-3	3-8	2-3

Field measurement campaigns

A mobile meteorological station was assembled for recording the microclimate conditions (see Figure 2). The mobile station embraced sensors for measuring air temperature, globe temperature, wind speed, relative humidity and solar radiation. All instruments are compiled for the specification stated in WMO, No.8 (2008).

Figure 2 A mobile meteorological station

Air temperature and humidity were measured by HOBO U23 Prov2 Temperature/Relative Humidity Data Logger as well as the thermal sensor described in the previous section. U23 was a weatherproof data logger with temperature and relative humidity sensors. The operating range of the temperature sensors was -40^{o}C to 70^{o}C with a resolution of 0.02^{o}C at 25^{o}C, and an accuracy of ± 0.21^{o}C. The operating ranges of the relative humidity sensors were -40^{o}C to 70^{o}C and 0 to 100% RH with a resolution of 0.03^{o}C and an accuracy of ± 2.5^{o}C. Solar Radiation Shield was installed in the mobile station to protect the sensors from sunlight and rain. Proper shield was also needed when measuring air temperature and humidity in order to minimize radiative exchange between instrument and the surroundings, to maximize convection and to avoid warm air formation around the sensors (ISO 7726, 1998; WMO-No 8, 2008). Wind velocity was measured by Dantec low velocity flow analyzer with Robust temperature-compensated velocity probe (54T35). The operating ranges of the velocity sensors were -20^{o}C to 80^{o}C and the measurement range lie between 0.01 m/s and 30 m/s. For the globe temperature, it was recorded by globe thermometer which generally consisted of a 40mm grey table tennis ball and temperature sensor. Silicon Pyranometer was used for measuring the solar radiation. The operating ranges were -40^{o}C to 75^{o}C and with accuracy ± 5%. The measurement range was from 0 to 1280 W/m^2.

A series of measurement campaigns were carried out from 11:00 to 17:00 from December 2014 to March 2015, from June 2015 to August 2015 and from October 2015 to December 2015. Two measuring points inside the parks was located under trees and an additional one was located in the open space for Shum Shui Po Park, Yuet Wah Street Playground and Kowloon Park. For the measurement of cooling intensity of the park, Shum Shui Po Park and Yuet Wah Street Playground were selected for the measurement. Parks areas were divided into several zones in order to compare the temperatures in different parts of parks. There were totally 16 and 12 zones in Shum Shui Po Park and Yuet Wah Street Playground respectively. Data was collected at each measurement point in particular zone in a five minute interval. Additional measurement points for temperature readings were set up beyond the boundaries of the parks which radiated from the center of parks for certain distance. There are totally ten measurement points, which are five of them are located on the radiated boundaries 50 meters away from the center of parks, and another five measurement points on the radiated boundaries which were 150 meters away from center.

Questionnaire Surveys

During the measurement campaigns, questionnaire surveys were also conducted within the same parks. The questionnaire form comprises five main sections. Section I aims to collect the park usage patterns and habit of the respondents. Section II aims at eliciting the subjective feelings on the microclimate conditions in parks. Perceived humidity level, wind speed, solar radiation, temperature and thermal environment were obtained and compared with the measurement data. These subjective feelings to the park environment were rated on a 7-point Likert scale (from -3 to 3 while '0' represents neutral, '-3' represents one extreme condition, and '+3' represents the other extreme). In addition, a six-point Likert-scale question was used for eliciting the levels of acceptance of respondents on thermal satisfaction (Graded '*Extremely Unacceptable*', '*Very Unacceptable*', '*Unacceptable*', '*Acceptable*', '*Very Acceptable*' and '*Extremely Acceptable*'). Section III includes questions which aim at evaluating the relationship between visual elements and the thermal sensation of the respondents. Questions were included to elicit from the respondents the perceived amount of different built environment elements could be seen in the parks. Respondents were requested to report to what degree trees, grassland, sky, water features (i.e. ponds or fountains) and shading facilities could be seen using the following five verbal responses: '*Nothing*', ‘*Extremely little*’, ‘*A Little*’, ‘*Moderate*’ or ‘*A lot*’ at the surveyed locations. Besides, respondents were asked to comment on whether those facilities were sufficient in the parks and whether they could bring benefits to the thermal environment of the parks. Section IV records some personal characteristics of the respondents e.g. clothing and activities levels, time spent in outdoor spaces, the immediate past activity and the purposes of park visit. Finally, Section V aims to collect the respondents’ socio-economic backgrounds including age, education level, salary, occupation, gender, health status, sensitivity towards heat. The responses collected from this session were used for analyzing the relationships among the objectively measured parameters, personal characteristics, thermal comfort and satisfaction level.

Geographic Thermal Environment Information

Thermal camera with a resolution of 320*240 pixels (Testo 875-1i) (see Figure 3) was used to measure the surface temperatures for different areas with the three selected parks by taking remote sensing images. The photos were then further analyzed by computer software IRSoft including input the emissivity, air temperature, relative humidity and wind velocity of the measured points. A series of measurement campaigns were carried out from 12:00 to 23:00 hourly for about ten days from October 2015 to November 2015. In addition, the geographic information of the parks such as the total park areas and the proportion of greenery areas was obtained from GIS-System (Holux M-241) (see Figure 4).

Figure 3 Thermal camera

Figure 4 GIS-System

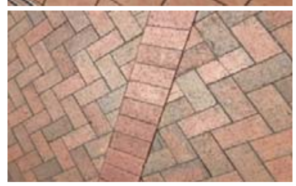
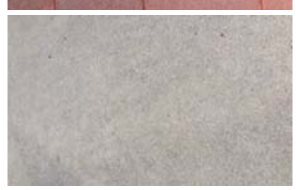
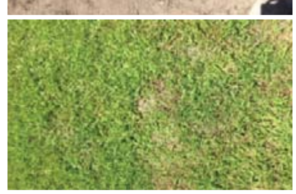
The Banyan tree located in the Banyan Court in Kowloon Park was chosen as the studied area because there was sufficient open area around the tree and the cooling effect of individual tree could be observed directly (see Figure 5 and 6). The ground temperatures for different orientations (north, west and south) and distances (2m, 4m, 6m and 8m) away from the center of Banyan tree were measured. The study did not involve the east orientation because buildings located nearby might influence the cooling effect on that side. The photos were taken hourly from 12:00 to 23:00 for ten different days to analyze the cooling effects of the individual tree on both day time and night time.

Figure 5 Location of the tree

Figure 6 Photos of the tree

Surface temperatures for the shaded and unshaded areas of nine different paved materials in Kowloon Park were recorded hourly from 12:00-23:00 hourly for ten days. Table 2 shows the paved materials and their respective emissivity. The values of the emissivity were extracted from Mills (1999) and the instruction manual of the thermal camera. Figure 7 shows the measurement route.

Table 2 **The paved materials that investigated**

	Materials	Emissivity	Photos of the materials
A	Clay	0.91	
B	Clay	0.91	
C	Brick	0.90	
D	Clay	0.91	
E	Rubber	0.89	
F	Concrete	0.91	
G	Concrete	0.91	
H	Sand	0.75	
I	Grass	0.92	

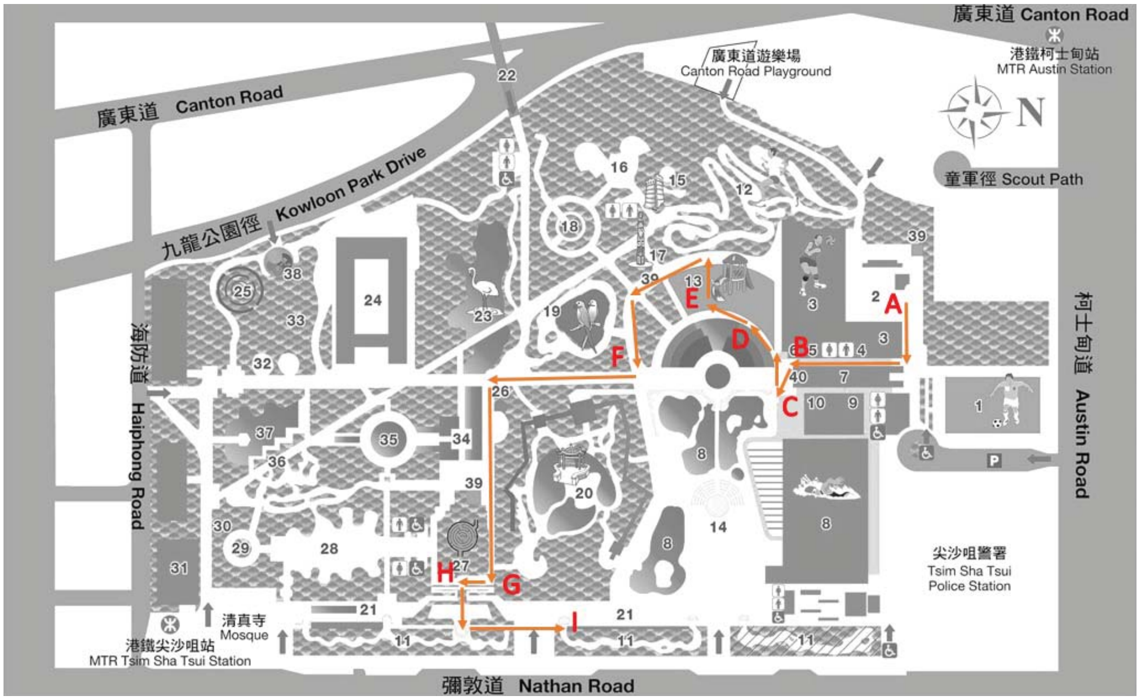
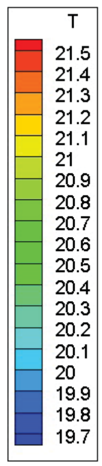


Figure 7 Measurement route

Results and discussions

Objective (I): To examine the cooling effect of proportion of greening area in urban parks

Parks areas were divided into a number of zones for facilitating comparison of temperatures in different parts of parks. Altogether, there were 16 and 12 zones in Shum Shui Po Park and Yuet Wah Street Playground respectively. Data was collected at each measurement point in particular zone in five-minute interval. Figures 8 and 9 show the contour maps of temperature patterns for Shum Shui Po Park and Yuet Wah Street Playground respectively.



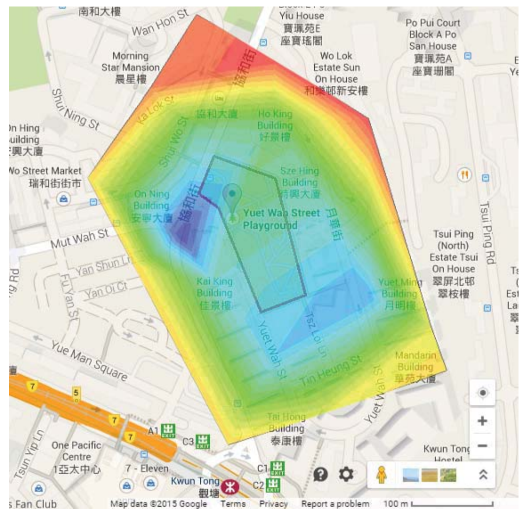


Figure 8

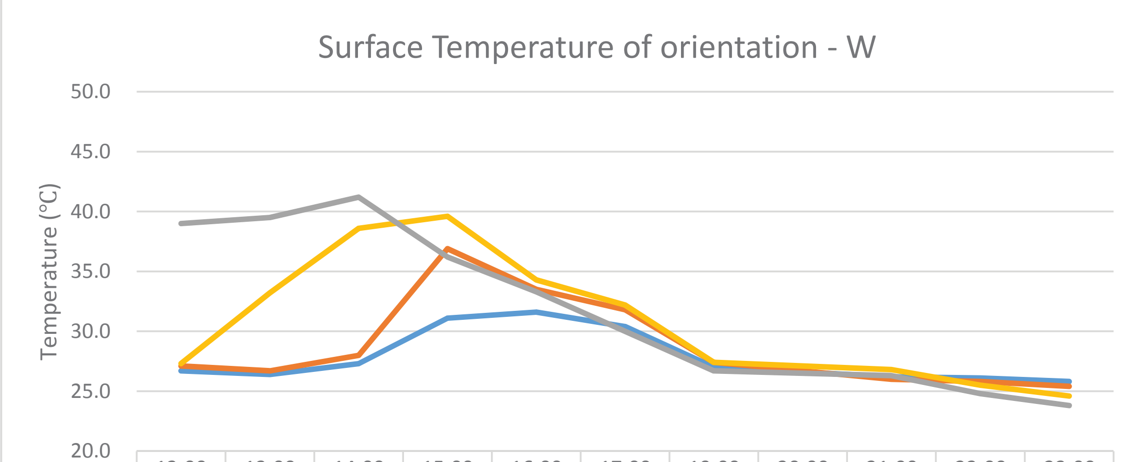
Contour map showing the temperature patterns in Shum Shui Po Park

Figure 9

Contour maps showing the temperature patterns in Yuet Wah Street Playground

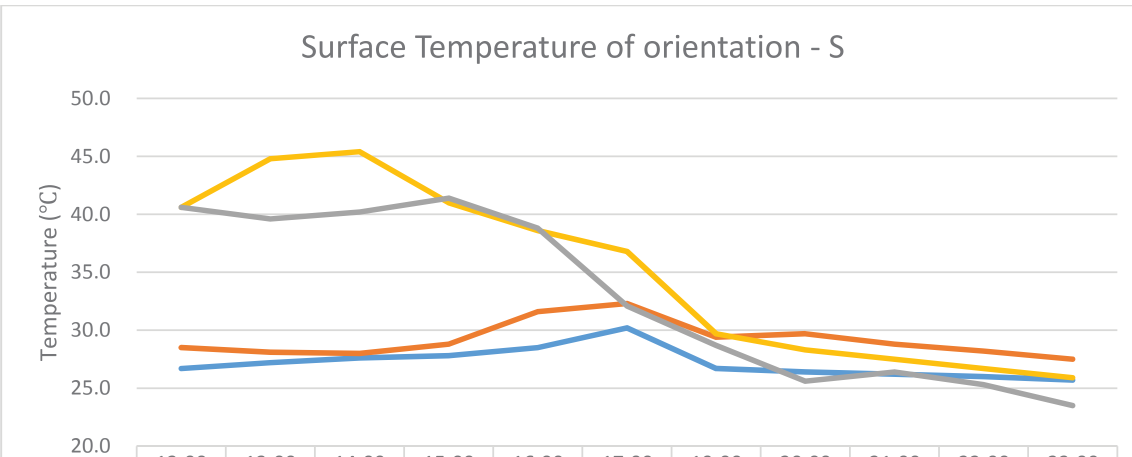
The results show that the temperatures increased by 1°C from the center to the boundary of the parks. And the temperatures inside the parks were lower than the outside temperature, and increased with the distance away from the boundaries, the temperatures of the parks were lower than those at 150m away by 1-2°C.

The ground surface temperatures at different orientations (north, west and south) and distances (2m, 4m, 6m and 8m) away from the center of the Banyan tree were measured. Locations 1 and 2 (2m and 4m away from the center of the tree) were mostly shaded by the tree while locations 3 and 4 (6m and 8m away from the center of the tree) were the unshaded areas.



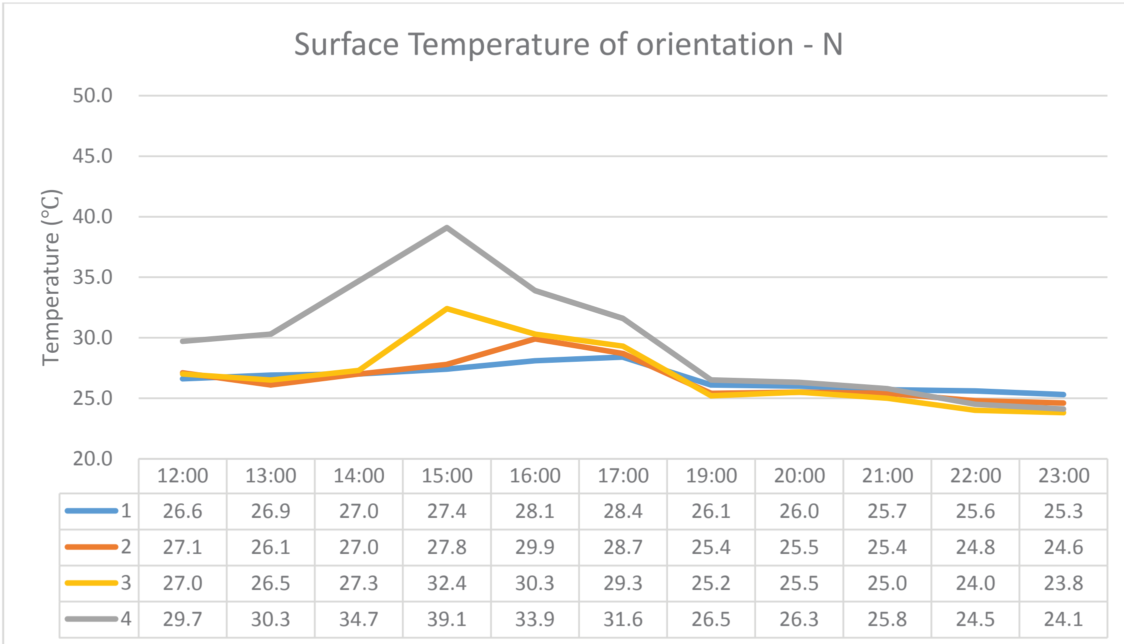
	12:00	13:00	14:00	15:00	16:00	17:00	19:00	20:00	21:00	22:00	23:00
1	26.7	26.4	27.3	31.1	31.6	30.4	27.0	26.6	26.2	26.1	25.8
2	27.1	26.7	28.0	36.9	33.5	31.8	27.4	26.7	26.0	25.8	25.4
3	27.3	33.2	38.6	39.6	34.3	32.2	27.4	27.1	26.8	25.5	24.6
4	39.0	39.5	41.2	36.2	33.3	30.0	26.7	26.5	26.3	24.8	23.8

Figure 10 Surface temperatures for the West orientation



	12:00	13:00	14:00	15:00	16:00	17:00	19:00	20:00	21:00	22:00	23:00
1	26.7	27.2	27.6	27.8	28.5	30.2	26.7	26.4	26.2	26.0	25.7
2	28.5	28.1	28.0	28.8	31.6	32.3	29.4	29.7	28.8	28.2	27.5
3	40.6	44.8	45.4	41.0	38.6	36.8	29.7	28.3	27.5	26.7	25.9
4	40.6	39.6	40.2	41.4	38.8	32.1	28.7	25.6	26.4	25.3	23.5

Figure 11 Surface temperatures for the South orientation



	12:00	13:00	14:00	15:00	16:00	17:00	19:00	20:00	21:00	22:00	23:00
1	26.6	26.9	27.0	27.4	28.1	28.4	26.1	26.0	25.7	25.6	25.3
2	27.1	26.1	27.0	27.8	29.9	28.7	25.4	25.5	25.4	24.8	24.6
3	27.0	26.5	27.3	32.4	30.3	29.3	25.2	25.5	25.0	24.0	23.8
4	29.7	30.3	34.7	39.1	33.9	31.6	26.5	26.3	25.8	24.5	24.1

Figure 12 Surface temperatures for the North orientation

Figures 10, 11 and 12 show the surface temperatures for different orientations at different distances away from the center of the tree at different time periods. These 3 figures show that the temperatures at Locations 1 and 2, which were shaded by the tree, were generally lower than the corresponding unshaded counterparts (Locations 3 and 4). Shading could lower the surface temperatures by at least 15°C during afternoon periods.

Furthermore, surface temperatures for shaded and unshaded areas of nine different paved materials (Table 2) in Kowloon Park were recorded hourly from 12:00-23:00 for ten days. Figures 13 and 14 show the surface temperatures for nine different paved materials at different time periods. Rubber (Material *E*) had the highest surface temperature under both shaded and unshaded conditions during afternoon periods. The surface temperatures of all the materials show a decreasing trend with time under both conditions. For the same materials placed under shaded and unshaded conditions, the surface temperatures were mostly the same after sunset. However, the results showed that rates of temperature drops under shaded condition were larger than those under unshaded condition. This suggested that shading could help substantially lower the surface temperatures. The decreasing trends of surface temperature for all the ground paving materials slowed down and became stable at night time.

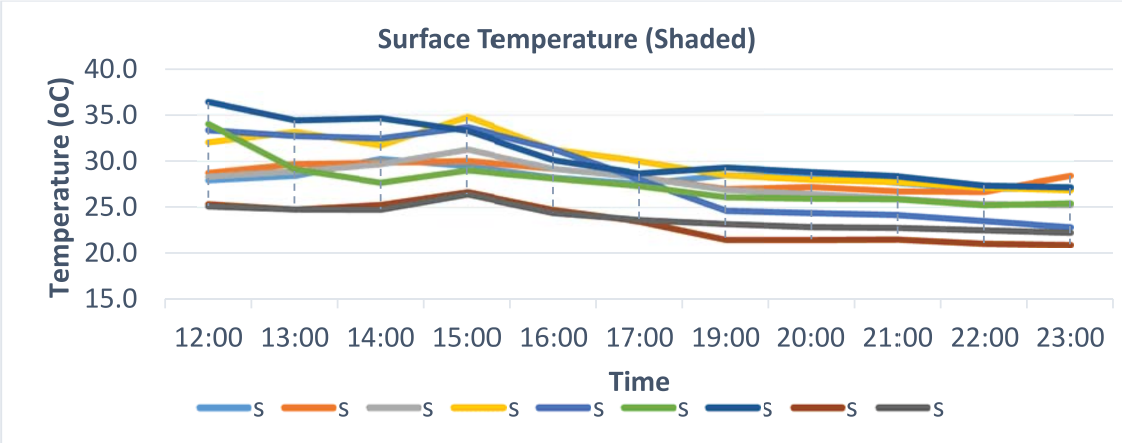


Figure 13 **Surface temperatures for nine different paved materials located in shaded areas**

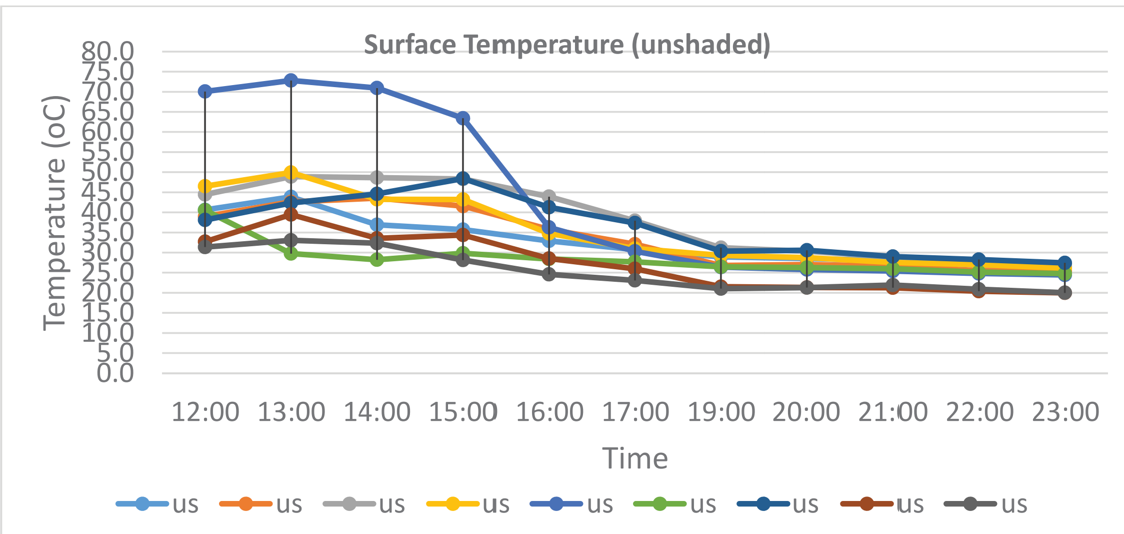


Figure 14 **Surface temperatures for nine different paved materials located in unshaded areas**

Objective (II): to examine the effect of greenery on thermal comfort in urban parks

Table 2 summarizes the personal characteristics of 710 survey respondents. About 60% of them were males and more than half were over 40 years old. More than 70% had only received elementary or high school education. One third of them were working, one third were retirees while the remaining were either students or housewives. More than half had an individual monthly income level of less than HK$20,000. This was reasonable as two of the examined parks were located in relatively deprived areas. Table 3 also shows a breakdown in the demographic characteristics including gender, age, education level, occupation and individual income by percentage for three parks.

Table 3 Summary of personal characteristics of the respondents

Description	Number (Percentage)			
	SSPP	YWSP	KP	Total
Gender				
Male	164 (56.0)	198 (61.3)	36 (38.3)	398 (56.1)
Female	129 (44.0)	125 (38.7)	58 (61.7)	312 (43.9)
Age				
≤ 17	19 (6.5)	9 (2.8)	0 (0.0)	28 (3.9)
18 – 25	32 (10.9)	16 (5.0)	5 (5.3)	53 (7.5)
26 – 30	12 (4.1)	7 (2.2)	7 (7.4)	26 (3.7)
31 – 35	22 (7.5)	10 (3.1)	14 (14.9)	46 (6.5)
36 – 40	17 (5.8)	20 (6.2)	15 (16.0)	52 (7.3)
41 – 45	36 (12.3)	36 (11.1)	10 (10.6)	82 (11.5)
46 – 50	23 (7.8)	20 (6.2)	4 (4.3)	47 (6.6)
≥ 51	132 (45.1)	205 (63.5)	39 (41.5)	376 (53.0)
Education Level [a]				
Elementary	97 (33.1)	174 (53.8)	11 (11.7)	282 (38.6)
High school	142 (48.5)	110 (34.1)	48 (51.1)	300 (42.3)
Undergraduate degrees	50 (17.1)	36 (11.1)	31 (33.0)	117 (19.5)
Post-graduate or above	4 (1.4)	3 (0.9)	2 (2.1)	9 (1.3)
Occupation				
Self-employed	8 (2.7)	9 (2.8)	10 (10.6)	27 (3.7)
Employed	73 (24.9)	68 (21.1)	27 (28.7)	168 (23.7)
Students	44 (15.0)	19 (5.9)	5 (5.3)	68 (9.6)
Homemakers	48 (16.4)	35 (10.8)	20 (21.3)	103 (14.5)
Retired	120 (40.9)	192 (59.4)	30 (31.9)	339 (47.7)
Personal income per month (HKD) [a]				
≤5,000	51 (17.4)	123 (38.3)	39 (41.5)	213 (55.7)
5,001 - 10,000	18 (6.1)	16 (5.0)	10 (10.6)	44 (11.5)
10,001 - 15,000	16 (5.5)	17 (5.3)	3 (3.2)	36 (9.4)
15,001 - 20,000	12 (4.1)	13 (4.0)	3 (3.2)	28 (7.3)
20,001-25,000	9 (3.1)	13 (4.0)	2 (2.1)	23 (6.0)
25,001 - 30,000	6 (2.0)	5 (1.5)	6 (6.4)	17 (4.4)
≥30,001	5 (1.7)	8 (2.5)	8 (3.2)	21 (5.5)
Total	293	323	94	710

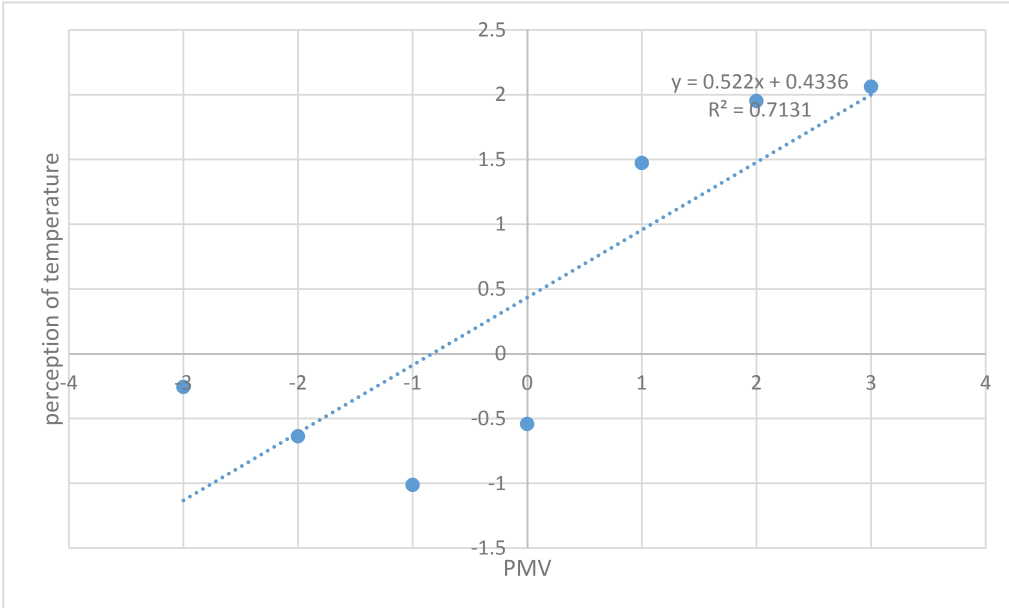
(a) Total does not sum up to 100% as some respondents refused to reveal their education level and individual income level.

One of the objectives was to identify the factors that affect thermal comfort and acceptability of the thermal environment (thermal acceptability). Thermal comfort originally rated using a six-point verbal scale were dichotomized into either 'comfort' and 'discomfort', while thermal acceptability originally rated on a six-point verbal scale was dichotomized into either '*Acceptable*' and '*Unacceptable*' in the final model development (see Table 4). '*Comfort*' includes the responses of '*Comfortable*', '*Very Comfortable*' and '*Extremely Comfortable*' while '*Discomfort*' includes the responses of '*Extremely Uncomfortable*', '*Very Uncomfortable*' and '*Uncomfortable*'. '*Acceptable*' includes the responses of '*Acceptable*', '*Very Acceptable*' and '*Extremely Acceptable*' while '*Unacceptable*' includes responses of '*Extremely Unacceptable*', '*Very Unacceptable'* and '*Unacceptable*'. With such dichotomization groupings, comparable total numbers of responses fell into two groups for thermal comfort and thermal acceptability.

Table 4 A summary statistics of responses in relation to thermal comfort and thermal acceptability

Description	**Number (Percentage)**			
	SSPP	**YWSP**	**KP**	**Total**
Thermal comfort				
Extremely uncomfortable	1 (0.3)	2 (0.6)	1 (1.1)	4 (0.6)
Very uncomfortable	4 (1.4)	7 (2.2)	1 (1.1)	12 (1.7)
Uncomfortable	57 (19.5)	70 (21.7)	14 (14.9)	141 (19.9)
Comfortable	214 (73.0)	216 (66.6)	61 (64.9)	491 (69.2)
Very comfortable	17 (5.8)	27 (8.4)	16 (17.0)	60 (8.5)
Extremely comfortable	0 (0.0)	1 (0.3)	1 (1.1)	2 (0.3)
Thermal Acceptability				
Extremely unacceptable	0 (0.0)	2 (0.6)	1 (1.1)	3 (0.4)
Very unacceptable	0 (0.0)	3 (0.9)	2 (2.1)	5 (0.7)
Unacceptable	33 (11.3)	47 (14.6)	11 (11.7)	91 (12.8)
Acceptable	246 (84.0)	246 (76.2)	61 (64.9)	553 (77.9)
Very acceptable	14 (4.8)	25 (7.7)	17 (18.1)	56 (7.9)
Extremely acceptable	0 (0.0)	0 (0.0)	2 (2.1)	2 (0.3)
	293	323	94	710

Predicted mean vote (PMV), which is a thermal index developed by Fanger (1972), was used to estimate the mean value of thermal sensation votes. Figure 15 shows that perception of temperatures was highly correlated with PMV (with a correlation value of 0.71).



For PMV,	-3	=	Cold		
	-2	=	Cool		
	-1	=	Slightly cool		
	0	=	Neutral		
	1	=	Slightly warm		
	2	=	Warm		
	3	=	Hot		
For perception of temperature,			0	=	Neutral
			Positive	=	Warm to hot
			Negative	=	Cool to cold

Figure 15 Relationship between perception of temperature and PMV

In addition, path analysis was used to reveal the multi-lateral relationships among factors in the collected results. Path analysis, which is considered as a special case of Structural Equation Modelling (SEM), can be used to reveal casual relationships among dependent variables and between dependent and independent variables (Hardy and Bryman, 2004).

Three major assumptions were made in this study before formulating the path model (see Figure 16). First, thermal comfort evaluation exerted an influence on an individual's acceptability of the thermal environment. Second, perceived meteorological conditions were affected by both objective thermal parameters and individual's visual perception of the park. Finally, both thermal comfort and thermal acceptability were affected by objective thermal parameters as well as individuals' perception of meteorological conditions, and visual perception of the park.

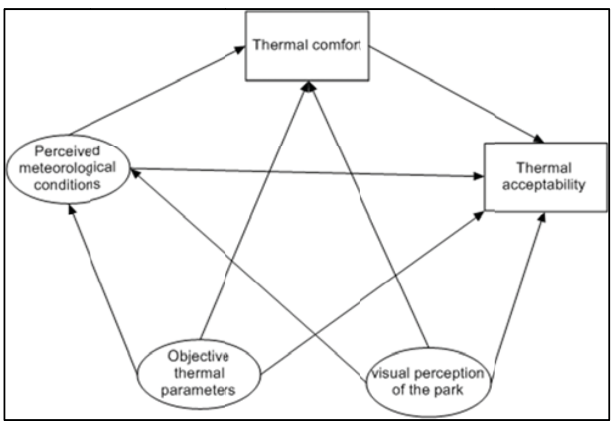


Figure 16 The proposed path model

The collected 710 responses were subsequently analyzed to reveal the multi-lateral relationships among factors. Figure 17 shows all the paths in the model together with their estimated correlation values. Factors determined to be statistically significant ($P < 0.05$) were subsequently used as input variables for the path model. A high coefficient value indicates a strong causal relationship between the dependent and independent variables, while a low coefficient value indicates a weak relationship. A positive coefficient sign implies the value of the independent variable increases with the value of the dependent variable. Conversely, a negative coefficient implies the value of the independent variable increases as the value of the dependent variable decreases.

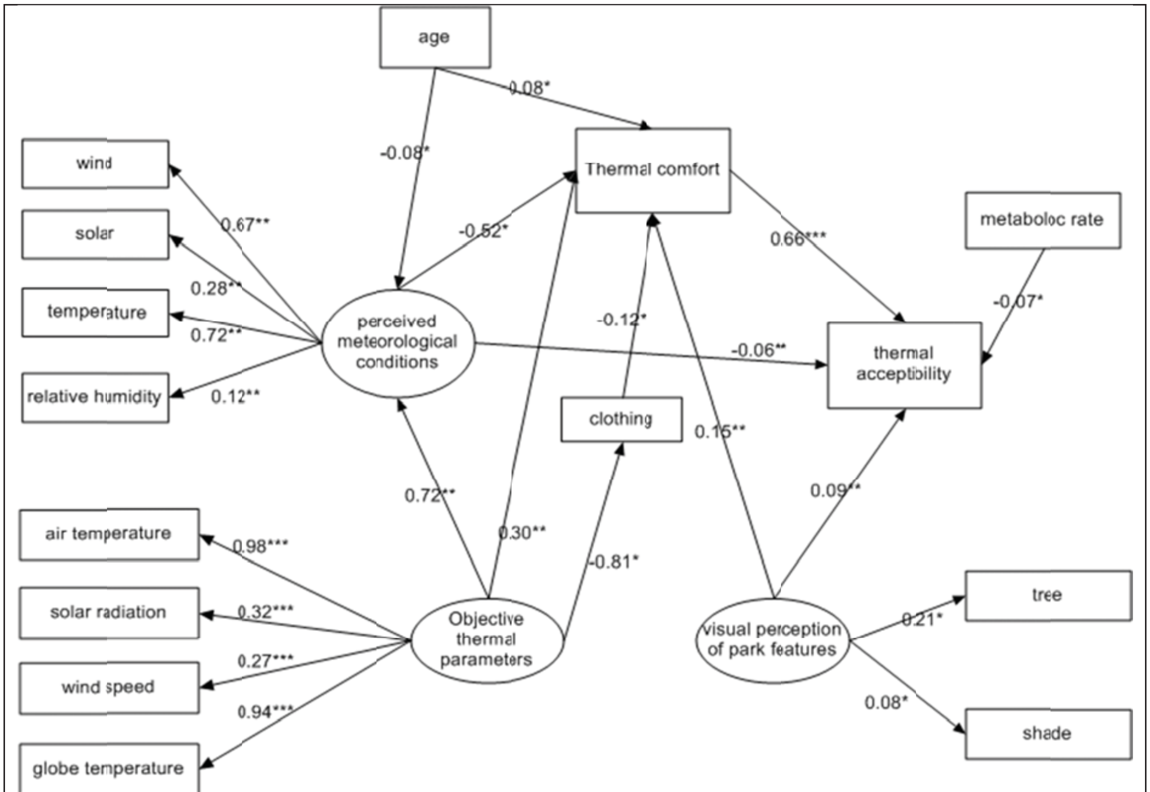
The path model shows the inter-relationships among thermal comfort evaluation, acceptability of the thermal environment, objective thermal parameters, visual perception of the park, perceived meteorological conditions and etc. The formulated path model is considered to be a reasonably good representation of the interrelationships as its goodness of fit meets with the requirements laid down for χ^2/df and the root mean square error of approximation (RMSEA) commonly upheld for evaluating the goodness of fit for path models (i.e., the model value of χ^2/df is 4.98, which is $2 < \chi^2/df < 5$ and the model value of RMSEA is $0.08 \leq 0.08$).

Our results basically confirmed our hypothesis that thermal comfort evaluation exerted an influence on an individual's acceptability of the thermal environment (r = 0.66). Thermal comfort was influenced by perceived meteorological conditions, objective thermal parameters and visual perception of the park (r = -0.52, 0.30, and 0.15 respectively). On the contrary, thermal acceptability was influenced by perceived meteorological conditions and visual perception of the park (r = -0.06 and 0.09 respectively), however, the results suggested that an individual's acceptability of the thermal environment was not influenced by the objective thermal parameters. Also, the results show that perceived meteorological conditions was affected by objective thermal parameters (r = 0.72). However, the results show that no influence of visual perception of the park on meteorological conditions perceived by park visitors.

The latent variable 'objective thermal parameters' was formed by grouping four factors including globe temperature, air temperature, solar radiation and wind speed together. These four factors showed positive relationship and exert strong influence with objective thermal parameters. Among those factors, air temperature exerted the strongest influence with objective thermal parameters while wind speed exerted the weakest (r = 0.98 for globe temperature and r = 0.27 for wind speed).

Personal perception of solar radiation, temperature, relative humidity and wind exhibited strong and positive relationships with personal perception of temperature and perceived meteorological conditions (r = 0.72). However, only a weak relationship was found between perceived relative humidity and perceived meteorological conditions (r = 0.12). Visibility of trees and shade showed a direct correlation with visual perception of park features, with correlation values of 0.21 and 0.08 respectively.

On the other hand, the results showed that clothing value and age exert influences on thermal comfort (r = -0.12 and 0.08), while metabolic rate exert influence on thermal acceptability (r = -0.07).



Insignificant paths are shown in dotted lines;
*** Significant at a 99.9999% confidence level;
** Significant at a 99% confidence level;
* Significant at a 95% confidence level
Model fit index: χ^2/df = 4.98, RMSEA = 0.080

Figure 17 The path model with standardized path coefficients

In this study, the formulated path model can help reveal the interrelationships among thermal comfort and thermal acceptability of the parks and determine the influences of different factors relating to thermal comfort and thermal acceptability. Factors can be compared in a holistic manner so as to identify the factors that deserving much attention in providing comfortable environment in urban parks. Above all, this study provides valuable insights for the provision of a comfortable thermal environment in urban parks. Firstly, the results showed that there were interrelationships between thermal comfort and acceptability which is in line with the findings arising from the study conducted by Zhang and Zhao (2006).

Secondly, the results suggested objective thermal parameters exerted a weaker direct influence on thermal comfort than perceived meteorological conditions, which are in contradictory with some earlier findings that only the objectively measured parameters like air temperature, relative humidity, wind speed affected thermal comfort assessment (Błażejczyk et al., 2010; Cheng et al., 2010). Our results revealed that perceived meteorological conditions was one of the important factors affecting an individual's thermal comfort assessment. Thirdly, clothing value only exhibited a weak correlation with thermal comfort, and metabolic rate did not correlate with thermal comfort. Lastly, the results showed that thermal comfort and thermal acceptability were influenced by an individual's visual perception of park features.

Objective (III): To predict the cooling effect and thermal comfort enhancement provided by Green Deck

Given that the Green Deck has not been built yet, we need to rely on the findings on the relationships between the inner and outer temperatures of the three surveyed parks to predict the cooling effect of the Green Deck. The prediction results have been translated into a contour map for portraying the temperature profiles for the Green Deck (see Figure 18).

It can be seen that temperatures would be increased from the center to the boundary of Green Deck by 1°C. The temperatures inside the parks were lower than the outside temperature, and increased with the distance away from the boundaries, the temperatures of Green Deck were lower than that at 150m away of the parks by 1-2°C.

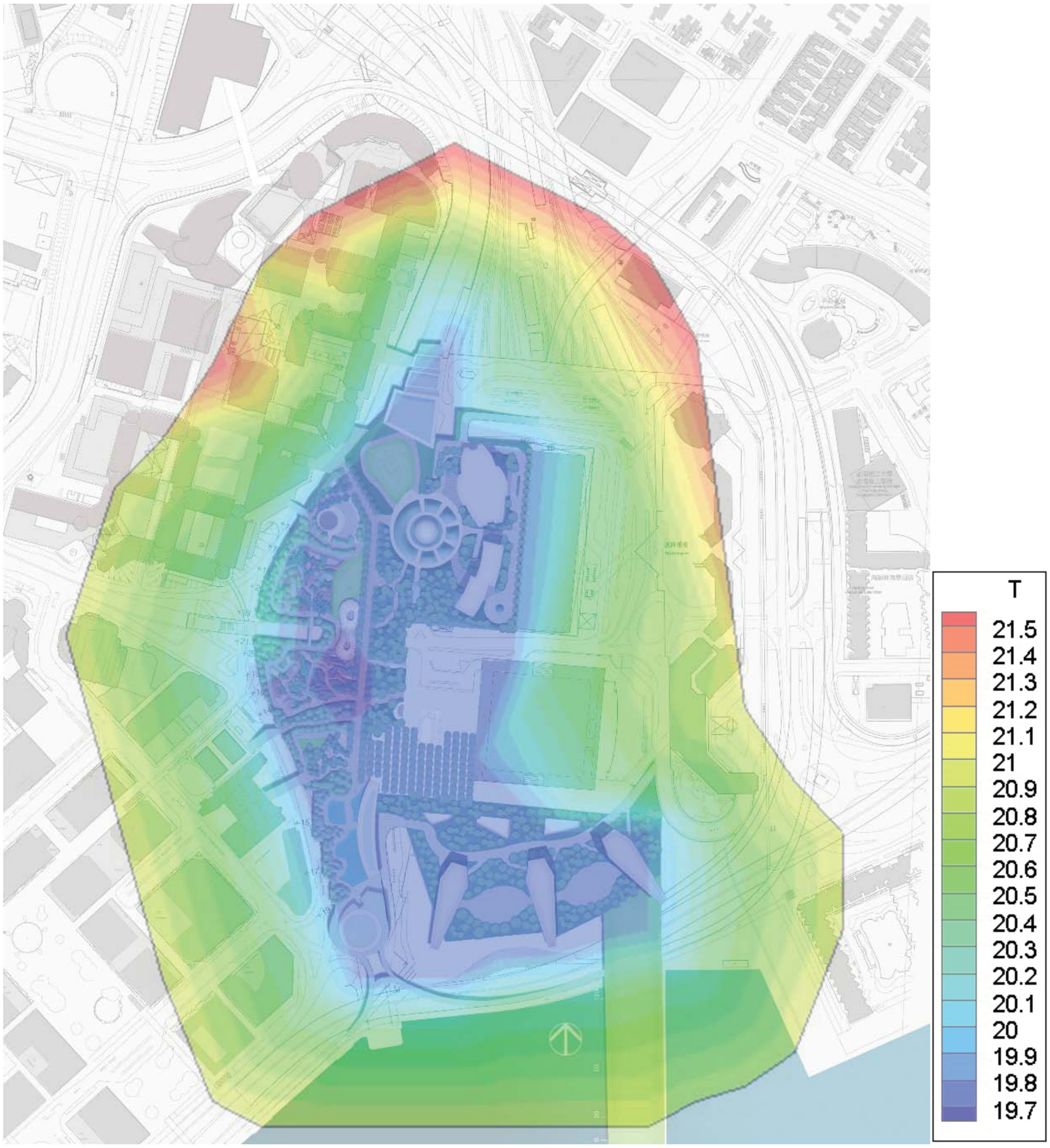


Figure 18 A contour map of green deck

Conclusion

In this study, the cooling effect and thermal comfort enhancement provided by Green Deck were predicted with aid of the findings revealed from three surveyed parks in Kowloon. The contour maps showing temperature profiles inside the parks, the ground surface temperatures at different orientations and distances away from the center of the tree as well as the surface temperatures of nine different paved materials in shaded and unshaded areas were revealed. It was predicted that the greenery in Green Deck could lower the air temperatures in surroundings by 1-2^oC and the shading provided by trees could lower the ground surface temperatures up to 20^oC. In addition, a path model was formulated to help reveal the interrelationships among thermal comfort and thermal acceptability of the parks and determine the influences of different factors which related to thermal comfort and thermal acceptability. In particular, it was found that thermal comfort and the acceptability of the thermal environment inside parks could be improved by the visual perception of trees.

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