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Cooling and humidifying effect of plant communities in subtropical urban parks

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ABSTRACT

Urban vegetation has been proved to play an important role in mitigating the heat island effect. However, it is not clear how independent small-scale plant communities affected the microclimate. In this paper, the effects of fifteen plant communities on temperature and relative humidity were investigated from November 2010 to October 2011 in urban parks in subtropical Shenzhen City, China. The canopy density, canopy area, tree height and the background climate conditions under plant communities were measured. The effects of small-scale plant communities on temperature and relative humidity were the most significant at 1400–1500 h during the day. The temperature reduction and relative humidity increase due to small-scale plant communities were higher in summer, followed by autumn, spring and winter. As compared to the control open sites, the temperature reduction due to plant communities ranged from 2.14 °C to 5.15 °C, and the relative humidity increase ranged from 6.21% to 8.30%. We found that multi-layer plant communities were the most effective in terms of their cooling and humidifying effect, while bamboo groves were the least effective. Regression results revealed that four factors, namely canopy density, canopy area, tree height and solar radiation, had significant influence on temperature reduction and relative humidity increase.

Introduction

With the rapid progress of urbanization, the urban heat island (UHI) is aggravated mainly because of the reduced density of the green vegetation and the loss of vegetative cover in the urban environment (Akbari et al., 1992; Antrop, 2000; Martinuzzi et al., 2007). Many studies have shown that trees can affect the air temperature and relative humidity through shading, transpiration and evaporative cooling (Hamada and Mikami, 1994; Rosenfeld et al., 1998; Dimoudi and Nikolopoulou, 2003; Georgi and Dimitriou, 2010). The importance of urban vegetation as a measure to mitigate heat island is well known (Oke, 1989; Chang et al., 2007; Shashua-Bar et al., 2010). It was reported, for example, that a 10% increase in vegetated surface reduced the temperature by 0.14–0.32 °C (Kuo, 2000).

Honjo and Takakura (1990) suggested that smaller green areas with sufficient intervals were preferable for effective cooling of microclimate to lumped larger green areas. Shashua-Bar and Hoffman (2000) reported that the cooling effect of small green areas (such as gardens and streets) was significant and developed the Green CTTC model to predict air temperature. Saito et al. (1990/1991) found that the air temperature distribution in an urban area was closely related to the distribution of green cover, and even a small green area of about 60 m × 40 m had the cooling effect. These studies clearly showed that it was important to investigate how the cooling and humidifying effect was affected by small plant communities.

Temperature reductions in urban green areas have been measured, particularly during summer (Shashua-Bar and Hoffman, 2002; Georgi and Zafiriadis, 2006; Potchter et al., 2006). Jauregui (1990/1991) measured the daily maximum and minimum temperature in Chapultepec Park (500 ha) in Mexico City, and found that daily minimum temperature was 3–4 °C cooler in the park. Measures made on clear nights showed that the effect of the park on air temperature was noticeable and its influence reached a distance about the same as its width (2 km). Chang et al. (2007) conducted a survey in 61 parks in Taipei city during the summer and winter. The results showed that air temperature in parks varied in different times and seasons, and the cooling effect of parks may be related to park characteristics, such as park size, trees and paved coverage. Shashua-Bar et al. (2009) found that the combination of shade trees over grass in a hot-arid region was the most effective landscape strategy, which can reduce air temperature by 2k. Bau-Show and Yann-Jou (2010) measured the microclimate conditions under ten tree species and two bamboo species, and found that tree foliage density, individual leaf thickness, leaf texture, and leaf color lightness had significant effect on cooling the shaded air.

The results from previous research on the cooling effect of urban green areas can support urban planning, urban design and the

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restoration of urban environments. However, to understand the cooling effect of urban green areas requires more data and long-term measurements, not limited to summer. Despite the fact that studies on the cooling effect of entire parks exist for some cities (Barradas, 1991; Upmanis et al., 1998; Yu and Wong, 2006; Hamada and Ohta, 2010), little work has been done on the microclimate of separate plant communities in subtropical areas. The present study seeks to evaluate the diurnal and seasonal variations in the cooling and humidifying effect of fifteen different small-scale plant communities (about 600 m^2) in subtropical city of Shenzhen, China. We analyzed the differences between fifteen plant community in terms of their cooling and humidifying effect, and studied the relation between plant community characteristics and cooling and humidifying effect throughout a year to provide guidelines and theoretical reference for urban greening in urban areas to maximize its ecological function in terms of impacts on the microclimate.

Methods

Research site

Studies were conducted in Shenzhen, China (22°27′–22°52′ N and 113°46′–114°37′ E), a city with a population of 1.04 million. Shenzhen has typical subtropical oceanic features of a hot summer and mild winter. The annual average air temperature and annual average precipitation are 22.5 °C and 1966.5 mm, respectively. The prevailing wind direction is NE, and mean wind speed was 2.0 m/s. According to Meteorological Bureau of Shenzhen Municipality, the minimum monthly mean air temperature is 12.0 °C in January, and the maximum was 29.5 °C in August. Precipitation was 802.5 from May to July 2011, which represented approximately 63.2% of the precipitation during our analysis period.

Lychee Park, Lotus Hill Park and Garden Expo Park, covering 28.8 ha, 60 ha and 66 ha, were chosen as the study sites (Fig. 1). All sites are surrounded by dense urban buildings and other structures. Lychee Park has approximately 600 litchi trees (*Litchi chinensis*) and other subtropical plants; about 38% of the total area is covered by water. Lotus Hill Park consists of mountains, lawns, lakes and fields, and the dominant species are king coconut (*Roystonea regia*) and coconut palm (*Cocos nucifera*). Garden Expo Park is a comprehensive park with 101 view spots and 236 plant species.

Fig. 1. Map of Shenzhen City and three urban parks used in the study. The spots indicate the positions of the parks and the dark gray lines indicate the boundary of parks.

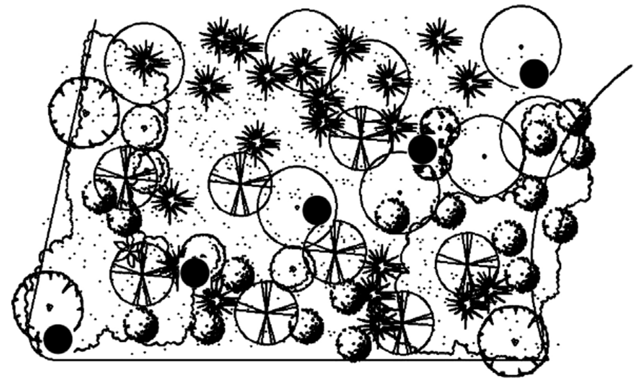

Fig. 2. Location map of measuring points. The solid circles represent the measurement points.

Fifteen typical small-scale plant communities with different combinations of trees, shrubs and grasses were chosen for the investigation (Table 1). The 15 plant communities were divided into four types according to their compositions and structures. Each plant community consisted of at least 5 species occupying 500–600 m^2 of land. The plant communities were far away from other plant groups, hills and water. Those plants were planted in 1990–1995, and consequently plant communities were in a stable state. In addition, unshaded paved space next to the experimental sites was selected as control.

Measurements

In order to assess the cooling and humidifying effect of 15 plant communities and compare the differences between these, measurements were taken under the canopies. Given this condition, the measurement points which were equidistant were fixed on the diagonal lines of plant communities at a height of 1.5 m above the ground based on ecological line-intercept method (Fig. 2). Five measurement points were selected for each plant community, and four measurements were made at each point. Temperature and relative humidity were measured with a portable weather station (Kestrel, NK4000, USA) when the wind speed slowed below 2.0 m s^{-1} (Chang et al., 2007). Solar radiation and canopy density were measured with an illumination meter (LI-COR, 250A, USA) and a plant canopy analyzer (LI-COR, LAI-2000, USA), respectively. The canopy area of each plant communities and tree height were examined by vertex altimeter (Haglof, VL400, Sweden). Canopy density was estimated by obtaining the leaf area index of trees and shrubs, while canopy area was estimates by the width of the tree crown.

For each measurement made under the plant communities, a corresponding measurement was made at the control sites. Fifteen plant communities were divided into three groups: only one group of measurements was made each day and each group was measured three days repeatedly. All measurements were made at 0800–0900 h, 1100–1200 h, 1400–1500 h and 1700–1800 h (LST = GMT + 8) on sunny days from November 2010 to October 2011.

Data analysis

Firstly, experimental data was compiled with Microsoft Excel (Microsoft, Excel 2007, USA). Subsequently one-way analysis of

Table 1
The structural characteristics of fifteen plant communities.

Code	Type	Structure	Canopy density (%)	Canopy area (m^2)	Tree height (m)
GEP1	Multilayer community	Tree layer (*Michelia alba*, *Callistemon hybridus* 'Golden Ball', *Terminalia mantaly*) + shrub layer (*Ixora chinensis*, *Duranta repens* 'Dwarf Yellow') + grass layer (*Zoysia japonica*)	65%	73.0	3.61
GEP2	Multilayer community	Tree layer (*Ceiba insignis*, *Ficus microcarpa*, *Delonix regia*, *Schefflera macorostachya*) + shrub layer (*Hibiscus rosa-sinensis*, *Jatropha integerrima*) + grass layer (*Nephrolepis cordifolia*, *Zoysia japonica*)	80%	82.5	7.50
GEP3	Tree-grass community	Tree layer (*Ficus microcarpa*, *Schefflera macorostachya*, *Livistona chinensis*) + grass layer (*Hymenocallis littoralis*, *Zoysia japonica*)	75%	92.5	5.63
GEP4	Multilayer community	Tree layer (*Bombax ceiba*, *Livistona chinensis*, *Cocos nucifera*) + shrub layer (*Thevetia peruviana*, *Ixora chinensis*) + grass layer (*Hymenocallis littoralis*, *Zoysia japonica*)	85%	70.5	2.88
GEP5	Bamboo grove	Tree layer (*Bambusa multiplex* 'Alphonse-Karr', *Heliconia humilis*) + grass layer (*Alpinia zerumbet*, *Zoysia japonica*)	70%	85.8	3.30
LHP1	Palm mixed community	Tree layer (*Roystonea regia*, *Phoenix sylvestris*, *Bismarckia nobilis*) + grass layer (*Axonopus compressus*, *Dianella ensifolia* 'Silvery Stripe')	50%	68.8	2.88
LHP2	Palm mixed community	Tree layer (*Ravenala madagascariensis*, *Cocos nucifera*, *Plumeria rubra* 'Acutifolia') + grass layer (*Axonopus compressus*)	75%	87.5	4.00
LHP3	Tree-grass community	Tree layer (*Ficus lyrata*, *Hyophorbe lagenicaulis*) + grass layer (*Axonopus compressus*)	70%	83.8	3.75
LHP4	Palm mixed community	Tree layer (*Livistona decipiens*, *Washingtonia filifera*, *Araucaria heterophylla*) + shrub layer (*Phoenix roebelenii*) + grass layer (*Axonopus compressus*)	55%	78.8	2.69
LHP5	Palm mixed community	Tree layer (*Elaeis guineensis*, *Bismarckia nobilis*, *Ravenala madagascariensis)* + shrub layer(*Phoenix roebelenii*, *Hibiscus rosa-sinensis*) + grass layer (*Axonopus compressus*)	75%	85.0	3.00
LP1	Multilayer community	Tree layer (*Araucaria heterophylla*, *Lagerstroemia speciosa*) + shrub layer (*Excoecaria cochinchinensis*) + grass layer (*Axonopus compressus*)	90%	87.5	4.63
LP2	Multilayer community	Tree layer (*Acacia confuse*, *Casuarina equisetifolia*) + shrub layer (*Pittosporum tobira*, *Brunfelsia latifolia*) + grass layer (*Axonopus compressus*)	80%	83.5	4.50
LP3	Multilayer community	Tree layer (*Litchi chinensis*, *Ficus benjamina* 'Golden Princess', *Terminalia mantaly*) + shrub layer (*Alocasia macrorrhiza*, *Stromanthe sanguine*) + grass layer (*Axonopus compressus*)	75%	83.8	4.01
LP4	Bamboo grove	Tree layer (*Bambusa textilis*, *Philodenron selloum*) + grass layer (*Wedelia chinensis*, *Axonopus compressus*)	85%	88.3	4.75
LP5	Tree-grass community	Tree layer (*Bauhinia blakeana*, *Araucaria heterophylla*, *Terminalia mantaly*) + grass layer (*Axonopus compressus*)	65%	75.0	3.00

variance of SPSS software (SPSS Inc., Version 18.0, Chicago) was generated to examine the significance of cooling and humidifying effect of 15 plant communities. After that, a Duncan multiple comparison was conducted to separate the means ($p < 0.05$) of plant communities. We used correlation analysis and multiple regression analysis to analyze the relative contributions of canopy area, canopy density, tree height and solar radiation on temperature reduction (ΔT) and relative humidity increase (ΔH).

Results

Diurnal and seasonal variations of the microclimate

The average temperature under the plant communities and the control sites averaged 23.8 °C and 27.5 °C, respectively, while the average relative humidity was 56.4% respectively 49.1%. It was clear that plant communities were cooler and more humid than the open sites. The diurnal variations of temperature (Fig. 3) and relative humidity (Fig. 4) were described as V-shaped curves. More specifically, in summer, temperature and relative humidity under the plant communities at 0800–0900 h were 27.8 °C and 78.4%, which achieved minimum temperature and maximum humidity during a day. The maximum temperature was 31.8 °C at 1400–1500 h, and minimum relative humidity was 62.0% at the same time. At 1700–1800 h, the temperature and relative humidity of fifteen plant communities averaged 29.4 °C and 69.8%. In winter, the average temperature and relative humidity were the lowest in a year; and the maximum temperature and minimum relative humidity were 21.9 °C and 58.2% at 1400–1500 h during the day. However, the trend of diurnal variation in winter was reconciled with that in summer.

As mentioned above, plant communities had a noticeable cooling and humidifying effect. However, there were obvious seasonal variations of temperature reduction and relative humidity increase (Fig. 5). Plant communities reduced temperature by 4.6 °C in summer, and in autumn ΔT was 4.0 °C. Correspondingly, plant communities increased relative humidity by 8.1% in summer and 7.5% in autumn. Subsequently the values of temperature reduction and humidity increase gradually decreased to 2.9 °C and 7.3% in winter. It was concluded that plant communities had a stronger cooling and humidifying effect in summer than that in winter. The seasonal order of cooling and humidifying effect of plant communities was summer > autumn > spring > winter.

In comparison with the unshaded open sites, plant communities could effectively reduce solar radiation (Fig. 6). The solar radiation intensity under the plant communities in summer was only 6.0% of that at open sites and the values in spring, autumn and winter were 6.3%, 6.1% and 6.6%, respectively. It meant that plant communities could keep out 90% of solar radiation, which was favorable for the cooling and humidifying effect.

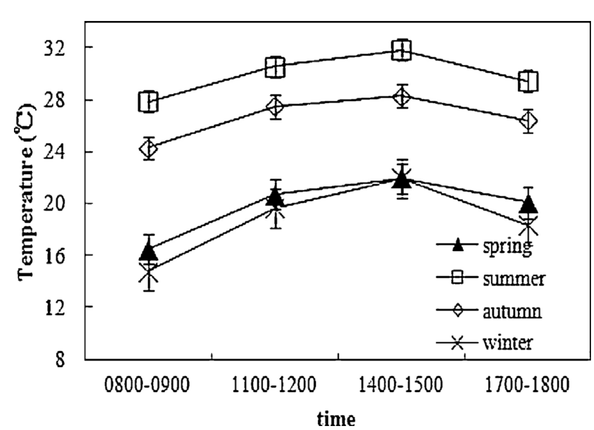

Fig. 3. Diurnal variations of temperature under plant communities in different seasons.

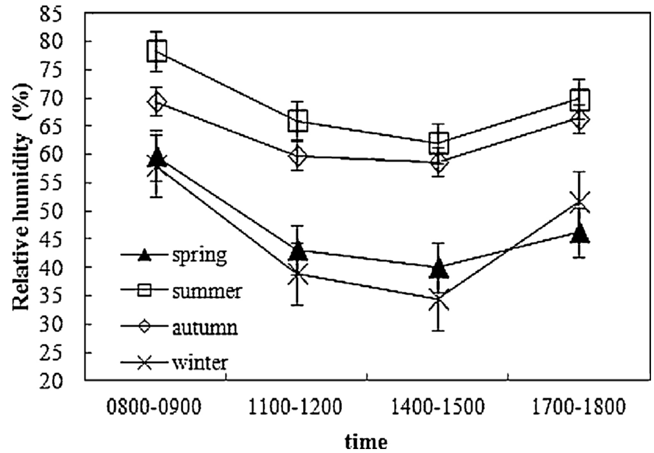

Fig. 4. Diurnal variations of relative humidity under plant communities in different seasons.

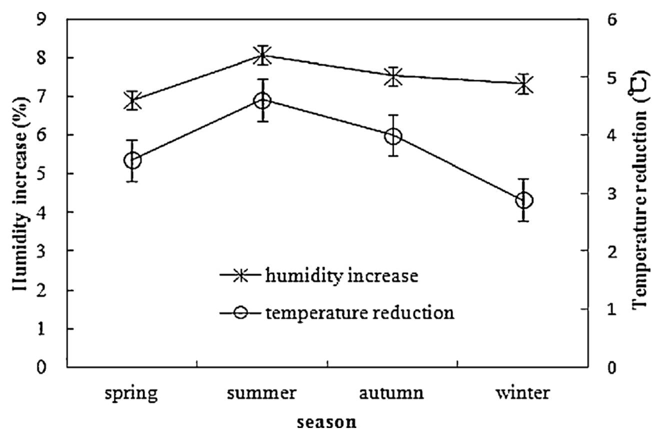

Fig. 5. Seasonal variations of temperature reduction and relative humidity increase under plant communities.

Differences in the cooling and humidifying effect of 15 plant communities

Among the 15 plant communities there were significant differences in cooling and humidifying effect according to multiple comparisons. The temperature reduction ranged from 2.14 °C to 5.15 °C in different plant communities (Table 2). The fifteen plant communities were separated into seven groups based on the degrees of temperature reduction by Duncan test ($p < 0.05$). LP1, GEP4 and LP2 were the most effective, while LHP1 was the least effective. Eleven other plant communities were divided into five groups with some overlapping.

The relative humidity increase ranged from 6.21% to 8.30%, which also had significant quantitative differences in fifteen plant communities. Again, the plant communities were grouped into seven groups. However, the order of effectiveness of plant communities in humidifying was different from that in cooling (Table 2). LP1, GEP2, LP2 and GEP3 were the most effective followed by GEP4 and LP3, while LHP4 and GEP5 were the least effective. Seven other groups were divided into four groups.

The results of analysis of variance revealed that four types of plant communities had significant differences in temperature reduction (Table 3) and relative humidity increase (Table 4) at $p < 0.001$. Multilayer plant communities (e.g. GEP2 and LP1) were the most effective, with an average temperature reduction of 4.7 °C. Palm mixed plant communities and tree-grass plant communities reduced temperature by 3.07 °C and 3.56 °C, respectively. Bamboo groves were the least effective on cooling effect, and the temperature reduction was 2.7 °C (Fig. 7).

Similarly, Fig. 8 shows that multilayer plant communities increased relative humidity by 8.0% at a greater magnitude than other types. Meanwhile, palm mixed plant communities and bamboo groves could increase the relative humidity by almost 6.5%. It could be derived that multilayer plant community had the most significant effect on temperature reduction and relative humidity

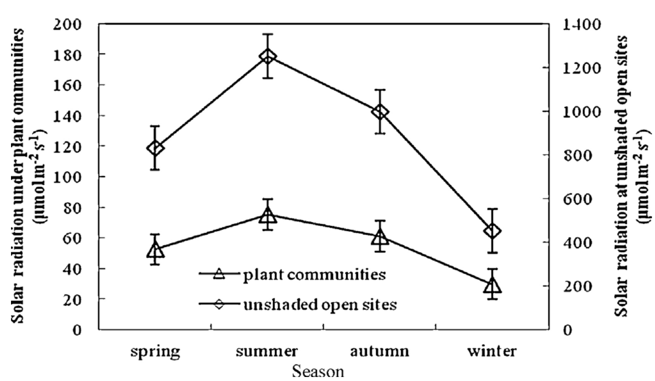

Fig. 6. Seasonal variations of solar radiation under plant communities and open sites.

Table 2
Temperature reductions and relative humidity increases of fifteen plant communities.

Plant communities	$\Delta\bar{T}$ (°C)[a]	Plant communities	$\Delta\bar{H}$ (%)[a]
LP1	5.15 a[b]	LP1	8.30 a
GEP4	5.10 a	GEP2	8.22 a
LP2	5.08 a	LP2	8.18 a
GEP2	4.49 b	GEP3	8.10 a,b
LP3	4.32 b	GEP4	7.98 b
GEP3	4.19 b	LP3	7.78 b,c
GEP1	3.82 b,c	GEP1	7.69 c
LHP2	3.63 c	LHP2	7.43 d
LHP5	3.47 c,d	LHP3	7. 39 d,e
LP5	3.41 d	LHP5	7.19 e
LHP3	3.22 d,e	LP4	6.78 f
LHP4	3.03 e	LHP1	6.59 f
LP4	2.78 f	LP5	6.50 f
GEP5	2.68 f	LHP4	6.30 g
LHP1	2.14 g	GEP5	6.21 g
Average	3.77		7.38
F	120.452		60.366
Significance	0.000		0.000

[a] $\Delta\bar{T}$ = mean temperature reduction; $\Delta\bar{H}$ = mean relative humidity increase.
[b] Column means with disparate letter in the same column are significantly different by Duncan test, $p < 0.05$.

Table 3
ANOVA of temperature reductions of fifteen plant communities.

	Sum of squares	df	Mean square	*F*	Sig.
Between groups	37.542	3	12.514	13.784	0.000
Within groups	50.840	56	0.908		
Total	88.383	59			

Table 4
ANOVA of relative humidity increases of fifteen plant communities.

	Sum of squares	df	Mean square	*F*	Sig.
Between groups	19.830	3	6.610	11.382	0.000
Within groups	32.521	56	0.581		
Total	52.351	59			

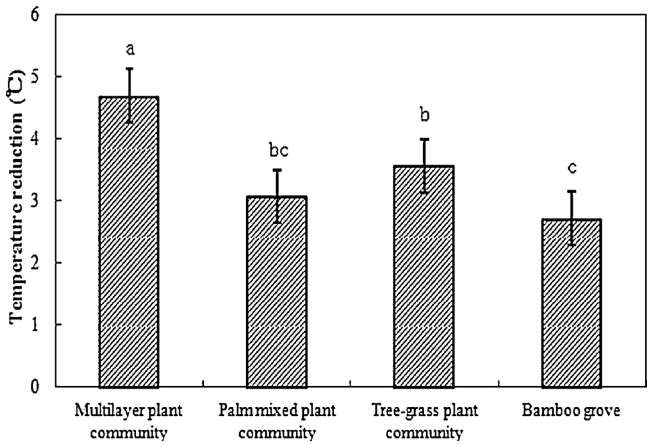

Fig. 7. Temperature reduction effects of four types of plant communities.

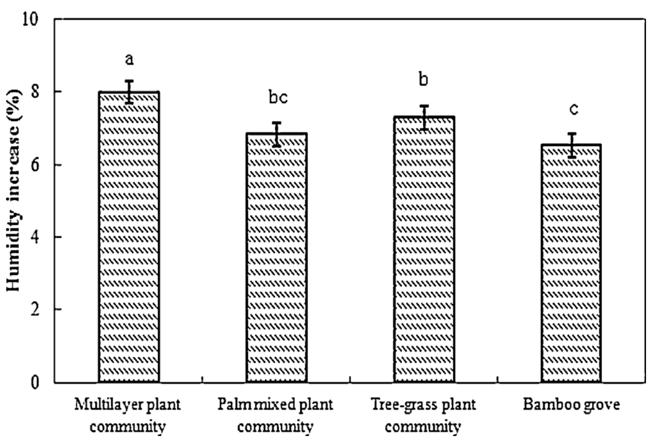

Fig. 8. Humidity increase effects of four types of plant communities.

increase, followed by tree-grass plant community, palm mixed plant community and bamboo grove.

Relationship between plant community characteristics and cooling and humidifying effect

To clarify the cooling and humidifying effect of plant communities, correlation analysis was undertaken to examine influencing factors of temperature and relative humidity of plant communities (Table 5). It was clearly shown that the correlation between temperature and characteristics of plant communities was higher. Temperature and relative humidity of multilayer community had a high correlation with canopy density and canopy area, but the correlation between temperature and relative humidity of the palm mixed community and canopy density and tree height was low. In short, there were correlations between temperature and relative humidity and characteristics of plant communities. Therefore, it was necessary to study the relationship between plant community characteristics and cooling and humidifying effect.

The results of regression analysis of air temperature reduction and relative humidity increase revealed that canopy density, canopy area and tree height had an important impact on the cooling effect (Table 6) as well as the humidifying effect (Table 7). Canopy density and canopy area had a positive effect, whereas tree height had negative effect on temperature reduction. Conversely, tree height had a positive effect on relative humidity as well as the canopy density and canopy area.

The order of relative contributions of plant community characteristics to temperature reduction was canopy density > canopy area > tree height. The order of relative contributions to relative humidity increase was canopy area > canopy density > tree height.

In addition, background climate conditions such as solar radiation and wind speed have been found earlier to have an influence on the cooling and humidifying effect (Shashua-Bar et al., 2009; Bau-Show and Yann-Jou, 2010). Regression results revealed that solar radiation had a significant positive effect on the temperature reduction (Table 6) and relative humidity increase (Table 7). However, according to real tested data, there was no relationship between wind speed and the cooling and humidifying effect, which may result from the areas of study sites and the wind directions.

Table 6
Regression model of temperature reduction effects of plant communities.

Model	*B* coefficient	Standardized coefficient	*t*
Constant	−2.973		−3.026*
Canopy density	0.041	0.481	5.094**
Canopy area	0.032	0.424	2.645*
Tree height	−0.025	−0.127	−0.896*
Solar radiation	0.027	0.291	3.572**

* Significant at $p < 0.05$.
** Significant at $p < 0.001$.

Table 7
Regression model of relative humidity increases effects of plant communities.

Model	*B* coefficient	Standardized coefficient	*t*
Constant	1.786		2.455*
Canopy area	0.026	0.462	3.518**
Canopy density	0.025	0.400	2.442*
Tree height	0.047	0.322	2.208*
Solar radiation	0.014	0. 379	3.692**

* Significant at $p < 0.05$.
** Significant at $p < 0.001$.

Table 5
Pearson correlation coefficients between temperature and relative humidity and characteristics of plant communities.

Type	Item	Canopy density (%)	Canopy area (m^2)	Tree height (m)	Solar radiation ($\mu mol\ m^{-2}\ s^{-1}$)
Multilayer community	Temperature	0.909**	0.919*	0.728*	0.695*
	Relative humidity	0.600*	0.702**	0.702*	0.633*
Palm-mixed community	Temperature	0.774*	0.834*	0.467	0.647**
	Relative humidity	0.597	0.774*	0.672*	0.638*
Tree-grass community	Temperature	0.944**	0.942*	0.996*	0.758*
	Relative humidity	0.655*	0.758*	0.638*	0.652*
Bamboo grove	Temperature	0.963**	0.874**	0.724*	0.853**
	Relative humidity	0.756*	0.716*	0.672*	0.650*

* Significant at $p < 0.05$.
** Significant at $p < 0.001$.

Finally, equations of linear regression for temperature reduction (ΔT) and relative humidity increase (ΔH) were established through multiple regression analysis:

$$\begin{aligned}\Delta T = & -2.973 + 0.041 \ \text{canopy density} \ (\%) \\ & + 0.032 \ \text{canopy area} \ (\mathrm{m}^2) - 0.025 \ \text{tree height} \ (\mathrm{m}) \\ & + 0.027 \ \text{solar radiation} \ (\mu\mathrm{mol\ m}^{-2}\,\mathrm{s}^{-1})\end{aligned}$$

$$\begin{aligned}\Delta H = & \ 1.786 + 0.026 \ \text{canopy area} \ (\mathrm{m}^2) \\ & + 0.025 \ \text{canopy density} \ (\%) + 0.047 \ \text{tree height} \ (\mathrm{m}) \\ & + 0.014 \ \text{solar radiation} \ (\mu\mathrm{mol\ m}^{-2}\,\mathrm{s}^{-1})\end{aligned}$$

Discussion

In this study, we present empirical findings on the cooling and humidifying effect of 15 small-scale plant communities in urban parks. The plant communities had obvious cooling and humidifying effects during the entire year, although the effect varied in different times and different seasons. The effects of plant communities on temperature and relative humidity were the most significant at 1400–1500 h during the day. The temperature reduction and relative humidity increase were large in summer and small in winter, which further supported the conclusion that the higher the temperature, the stronger cooling effect (Shashua-Bar and Hoffman, 2002; Bau-Show and Yann-Jou, 2010). It was shown that the seasonal variations of temperature reduction and relative humidity increase were related to air temperature, to a certain extent. The temperature reduction and relative humidity increase due to small-scale plant communities were higher in summer, followed by autumn, spring and winter, something which is in line with the conclusion of Hamada and Ohta (2010).

As compared to the control sites, the temperature reduction of plant communities ranged from 2.14 °C to 5.15 °C, and the relative humidity increase ranged from 6.21% to 8.30%. We found that multilayer plant communities were the most effective regarding cooling and humidifying effect. This type of plant communities had diversified structures and abundant species. Moreover, the leaf area of multilayer plant community was larger, and consequently the plant communities may reflex more direct solar radiation than other plant communities. The cooling and humidifying effect of tree-grass plant communities was similar to that of palm mixed plant communities. It is speculated that this may result from similar leaf shape of trees and structure of plant communities. Bamboo groves were the least effective, which was due to less canopy areas. Considering the reasons above, it is suggested that planners should pay attention to the structures of plant communities and the amount of shading. In small-scale plant landscapes, conifer and broadleaf trees should be combined in optimal ways, and the combinations of trees, shrubs and grass should be designed to maximize the cooling and humidifying effect of microclimate.

Regression results for factors affecting the cooling and humidifying effect revealed that four elements, namely canopy density, canopy area, tree height and solar radiation, had significant influence on the temperature reduction and relative humidity increase. The canopy density was the most effective in cooling effect than other factors; however, it ranked second in importance of plant community characteristics regarding humidifying effect. Canopy density and canopy area were correlated with the shading. Shashua-Bar and Hoffman (2000) found that on average about 80% of the cooling effect in hot and humid climate regions could be contributed to tree shading. It was also considered that shading mainly affected the magnitude of temperature reduction and relative humidity increase in subtropical areas.

Equations were derived for temperature reduction (ΔT) and relative humidity increase (ΔH) of plant communities, which not only can be used as quantitative analysis tool to estimate ecological benefits of plant communities in temperature and relative humidity, but also to predict the cooling and humidifying effect of quasi-plant communities in the process of urban greening.

This study identified four factors that influence the effects of temperature reduction and relative humidity increase. However, other elements such as tree shapes, evapotranspiration, plant positions, and so on, require further study in order to gain further insight into the quantitative relations of plant communities. The research found that the ecological functions of small-scale plant communities were similar to those large green areas, since both of them have obvious cooling and humidifying effects on the urban microclimate. Results may be useful to estimate the cooling and humidifying effect of plant communities in urban residential areas and streets – something which was not done in this study.

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