SENSITIVE ANALYSIS OF LANDSCAPING EFFECTS ON OUTDOOR THERMAL ENVIRONMENT IN A RESIDENTIAL COMMUNITY OF HOT-HUMID AREA IN CHINA

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Abstract

Landscaping design factors, like lakes and vegetations, have a large impact on microclimates and are considered an efficient mechanism for cooling communities. In order to evaluate different effects of landscaping design factors, a field measurement on outdoor environmental parameters were carried out in a residential community in Guangzhou, China. Meanwhile, a CFD software of microclimatic simulation, ENVI-met, was employed to simulate the conditions during the experiment days. After validating the models and simulation results with measured data, different landscaping design factors are sensitively analyzed.

Key words: Sensitive Analysis, Landscaping design, Outdoor thermal environment, Heat island

1. INTRODUCTION

Landscaping design factors, like lakes and vegetations, have a large impact on microclimates and are considered an efficient mechanism for cooling communities. In many urban settings, the loss of vegetation is an important factor contributing to urban heat islands. Neighborhoods with more trees or surrounded by lakes are annually cooler than those with fewer trees. Downtown areas of cities typically have the hottest temperatures as they are dominated by tall concrete buildings and rarely support much vegetation.

As the great increase in population, more and more forests were changed into cities. A lot of side effects appeared during the procedure of urbanization. Too high outdoor temperature caused larger number of death reported. Meanwhile, residents are setting higher standards for the outdoor environment quality in their communities. In summer, they need cool air outside with pleasure wind and shadows, while little or none big winds and as warm as it can in winter. All of these require architects and landscaping designers to develop their plans not only based on the level of safety and productivity but also thermal comfort. Indeed, through arrangement of buildings, landscape elements, planting materials and landforms, we can modify climate and optimize conditions to fall within the human comfort zone for outdoor activities.

This paper focuses on how the landscaping factors affect the outdoor environment qualities. Firstly, it describes the field measurements and their results in a residential community. Secondly, it discusses the calibration and sensitive analysis procedures through ENVI-met simulation. Finally, some conclusions and suggestions in landscaping design are developed.

2. FIELD EXPERIMENTS

2.1 Description of the site and experiment procedure

From July 19th to 24th in 2007, an integrated experimental investigation on outdoor thermal environment was carried out in a residential community in Guangzhou, China. This community has over 50 independent residential buildings with more than 5,000 families. Its footprint area is approximately 220,000 ㎡ with a total construction area of over 500,000 ㎡ (Fig. 1a).

In the experiment, several environmental parameters, including air temperature (T_a), relative humidity (RH), wind speed (v) and globe temperature (T_g), were measured in different spots (Fig. 1b) with various types of vegetation and pavement materials (table 1). Data loggers were set on the pedestrian level of 1.5m height to automatically monitor the air temperature, globe temperature and humidity from 10:00am to 5:00pm. Meanwhile, wind speed was measured manually in an interval of one hour with hot wire anemometers.

2.2 Experiment results and analysis

The results of on-site measurements are shown in Fig. 2. Meanwhile, observed data in the same days are obtained from the Guangzhou Meteorological Satellite Ground Station, which is located in rural part of Guangzhou and approximately 13 km away from the site. These data are considered to represent the macroclimatic conditions, while the measured stand for the site microclimate. When comparing these two data sets, slight

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differences (less than 1℃ in T_{air} and 8% in *RH*) are found, as shown in Fig. 2 a and b. The community has a higher temperature and lower humidity level in most of time. This is because the enclosed building distribution contributes to block the transportation heat from the busy traffic and commercial buildings outside of the community, while a low building density of 27.8% and high vegetation percentage of 32.1% can reduce anthropogenic heat from the apartments and solar radiation on the pedestrian level.

a. 

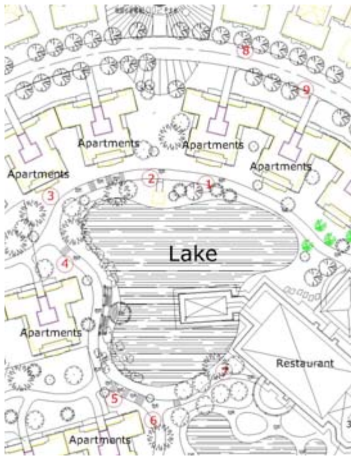
b. 

Fig. 1 Outlook of the residential community and measured spots

Table 1 Description of Spots in the measurement

Spot No.	Position	Height from ground	Shaded By Vegetations	Surface type
1	north to the lake	1.5m	entirely	bushes
2	north to the lake, next to pavilion	1.5m	partially	grass & bushes
3	northwest to the lake, joint of 3 paths	2.0m	entirely	normal bricks
4	northwest to the lake, joint of 3 paths	2.0m	none	normal bricks
5	southwest to the lake, joint of 3 paths	1.5m	none	concrete
6	joint of 3 paths, between lake and swimming pool	2.0m	none	grass
7	between lake and swimming pool	1.5m	entirely	grass & bushes
8	between two buildings, north to the lake	1.5m	none	pervious bricks
9	between two buildings, north to the lake	1.5m	entirely	grass & bushes

In general, spot No.5 has the highest air and globe temperature while lowest wind velocity, due to almost no shadows from vegetations, concrete pavements and poor natural ventilation conditions. It indicates the thermal environment in that nearby area is relatively bad and unable to benefit from the landscaping factors at all. Meanwhile, spots No. 1, 2, 3 and 7 with entirely or partially vegetation shading have lower temperature than the weather station, especially No. 1 which has the lowest temperature among all the spots during the whole period.

The following four parameters are analyzed to quantify the effects of different landscaping factors on microclimate in the community.

1) Air temperature (Fig. 2 a).
    a) Evaporation of water body. The average temperature of spots along the lake (No. 1, 2) is 1.3 ℃ lower than the ones away from the lake (No. 8, 9). However, the max recorded temperature differences among these spots can be as high as 2.2℃ at noon. And the frequency of high temperature (>35℃) of the spots near the lake is averagely 25% less than the ones far away.
    b) Vegetation shadows. Through comparing temperature of various similar spots (2 vs. 1, 8 vs. 9 and 4 vs. 3), spots under shadows always are 0.6~0.8℃ lower and 20% less in high temperature (>35℃) frequency.
    c) Peak temperature. Comparing to the concrete pavement (spot No. 5), the time when peak temperature occurs during the day is 1.5 hours later for the spots with lake (No. 4, 5, 8) and over 2 hours for the spots under shadow (No. 1, 3, 9). However, all the values of peak temperature are similarly 3 ℃ lower.
2) Humidity (Fig. 2 b). The values of *RH* in spot 2 and 8 are close to each other. It indicates that large area of water body can only have limited benefits to the humidity level of the whole community.
3) Globe temperature (Fig. 2 c). Similar changing patterns of globe temperature in different spots (No.2, 5, 8) were found during all the experiment days. All the max values occurred at noon (12:00 or 13:00). However, the measured values differed largely between shaded spot No. 2 and the other spots. It indicates that shadows are critical to reduce solar radiation, and the surface types have little effects on the globe temperature.
4) Wind speed distribution (Fig. 2 d). Due to diversifications in wind speed and direction, we only measured the average speed in 30 seconds. According to the results, low-speed wind of less than 0.5 m/s, or so-called

breeze, occurred approximately 50% in the experiment period. It means that pedestrians are unable to feel any air movements at most of the time outdoor. However, wind of high speed over 2 m/s only happened 3% of the measured time, indicating a safe wind environment inside the community.

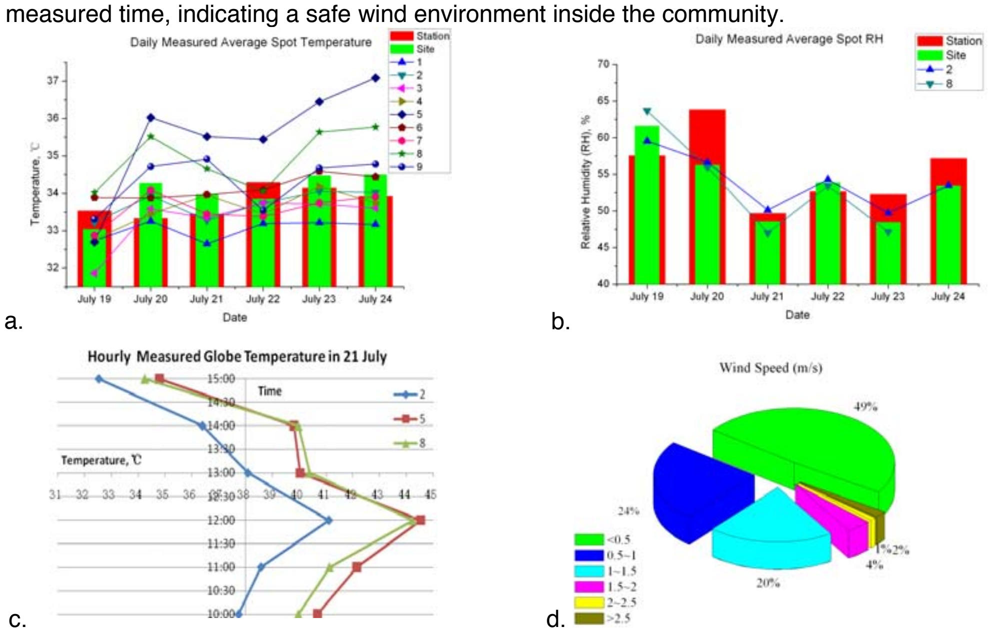


Fig. 2 Results in the field measurements

3. VALIDATION AND SENSITIVE ANALYSIS OF ENVI-MET SIMULATION

3.1. Validation assessment of ENVI-met simulations in hot-humid area of China

ENVI-met software is a three-dimensional non-hydrostatic model for the simulation of surface-plant-air interactions in urban environment. It has been widely used in the computer-aided design and evaluation of various urban planning cases. However, in order to make sure this software can be applied to the future sensitive analysis and other studies in the hot-humid climate, a validation assessment was carried out.

Through the validation assessment, both of the iterative and grid convergence were tested. Then, the ENVI-met results were compared to the experimental data described above. It showed that, within the uncertainties of experimental data (±0.7℃ in air temperature, ±5% in RH), the simulation results can meet the measured data of most spots.

3.2. Sensitive analysis of landscaping factors

In order to outline the effects of different landscaping factors on outdoor thermal environments, the validated ENVI-met model was employed to do sensitive analysis. All the converged simulation results are listed in Fig 3.–5.

1) Surface types (Fig. 3). Five types of surface were simulated. It indicates that surfaces with different material have various surface temperature but similar air temperature. As expected, the asphalt road with large volumetric heat capacity and low heat conductivity has the highest surface temperature.
2) Water depth (Fig. 4). Five kinds of lakes with various depths from 0m to 1.75m were simulated. According to the results, the water depth has little effects on the air temperature.
3) Vegetation types (Fig. 5). Three kinds of vegetation were simulated. Comparing with the bare sandy soil, grass only changes very little in both of air and surface temperature. However, 10m-tall trees with dense crown can reduce temperature significantly.

4. CONCLUSIONS

1) Humidity conditions of microclimate in the hot-humid area of China can not benefit too much from the evaporation from lakes and transpiration from vegetation. However, both of these effects can significantly reduce average and peak temperature, and thus improve the quality of thermal environment.
2) Additional attention should be paid when choosing the tree types and plant positions. Big trees with crowns, especially the evergreen ones with large leaf area density (LAD), can block the cross wind around buildings if not properly planted.

However, further studies on the optimization procedure of landscaping design are still required, especially the outdoor human comfort and rating systems on overall urban designs.

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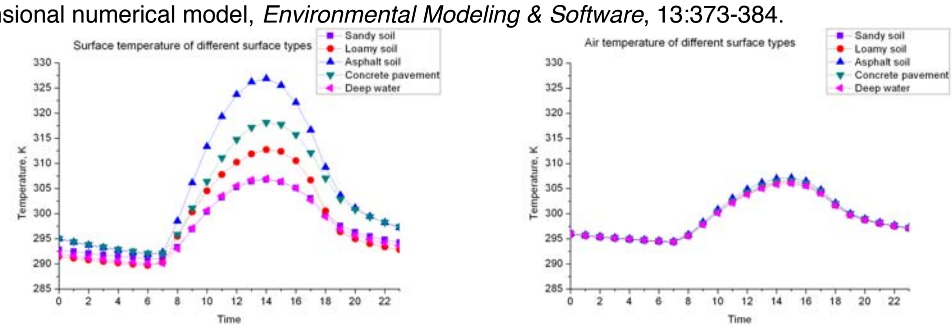

Fig. 3 Sensitive analysis of surface types

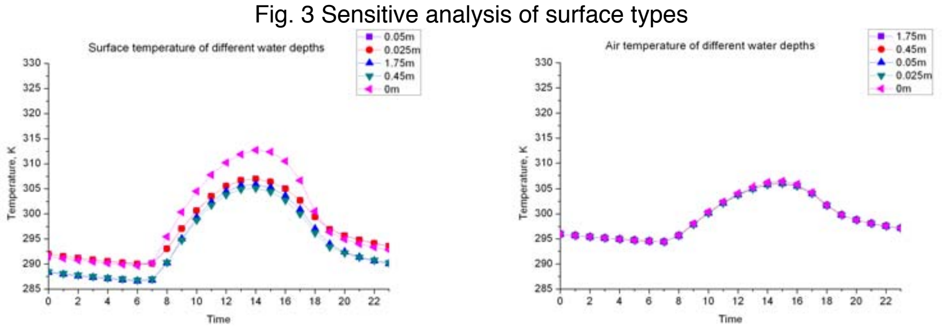

Fig. 4 Sensitive analysis of water depths

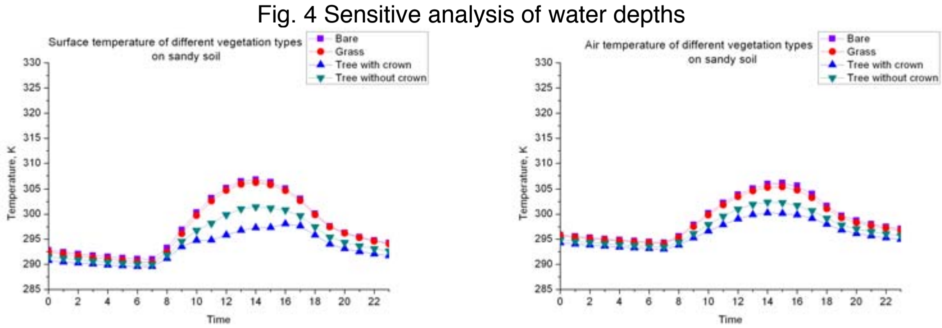

Fig. 5 Sensitive analysis of vegetation types on sandy soil