Measurement of Summer Outdoor Thermal Environment of Campus Open Space and Validation the Simulation Model

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ABSTRACT
A field measurement of outdoor thermal environment was carried out in different open space of campus located in the hot and humid zone in summer. From the measurement results of air temperature, humidity, wind velocity and globe temperature at the pedestrian-level, and the typical ground surface temperature, the main characteristics of summer outdoor thermal environment under different open space in hot and humid zone are obtained. Design method, underlying surface materials and sky view factor have a great influence on the outdoor thermal environment. The piloti, which design form adapts the climate in Guangzhou, can effectively improve the outdoor thermal comfort in hot summer. The measurement results are further used to verify the ENVI-met model. The results show that: the ENVI-met model reasonably reproduced the majority of the observed spatial and temporal characteristics of the 2-m temperature field over the simulation period, and the relative errors are within 11.2%, which proved that ENVI-met is a reliable model to simulate the different urban scenarios. Then, discrepancy between measurement and simulation was analyzed.

KEYWORDS
open space; outdoor thermal environment; measurement; simulation

INTRODUCTION
Due to under the control of the hot-wet climate all year, urban heat island effect is widespread in hot and humid areas (N Yamtraipat and J Khedari 2005). With the continuous improvement of living standards, how to reduce the urban heat island effect and improve the quality of urban thermal environment has become an urgent need for the people, and also the key problem of building science and technology.

Campus semi-open space can be divided into building external semi-open space and construction semi-open space. The outside of the building mainly refers to the semi-open space in the campus providing the exchange intermediary space for the

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teachers and students (Gong 2005). For example: square, foot path, lawn area, lakeside area, building of the around.

The quality of campus semi-open space’s thermal environment in the south hot summer caused the designers’ attention. Campus semi-open space quality directly relates to the students using the whole campus environment, and diversified environmental factors produce diversified outdoor thermal environment. In the campus planning and design, it cannot be ignored to realize the diversity of campus semi-open communication space, and realize the campus semi-open space thermal environment optimization design in the long summer (Peng 2004).

FIELD MEASUREMENT

Measurement of environment. The typical teaching buildings cluster (building 31-34), which located in north campus of SCUT, was the primary teaching buildings, as shown in Fig.1. The characteristics of subtropical climate and the design conditions of rooms without air conditioners had called higher requirements on ventilation and shading (Tang 2005). The layout of building groups had formed a wind channel naturally, and the southeast wind could blow from the east square, through the loggia then enter into the buildings. The teaching buildings cluster have employed piloti, loggia, square and water body properly to improve the microclimate, and the passive design helped reduce the energy consumption in buildings.

(1) There is a square with vegetation located in the front of building 31. Fig.1.
(2) Near the lake, there was piloti space of Building32, which could be used as bicycle parking as shown in Fig.2. It not only had appropriate functions, but also could bring the wind from the West Lake into the building groups. In summer, the square in front of building 31 could bring in the southeast wind. As shown in Fig. 2.
(3) All the stair halls and corridors should be open and spacious, as shown in Fig. 3, and there were loggias connected the building group, it could form effective communication space and keep the building from blocking wind.
(4) The West Lake was on the south of building groups; air cooled by the lake blow to the teaching buildings group and also reduces the air temperature in the teaching group. As shown in Fig 1.

![Fig.1 Master plan](image1)
![Fig.2 Piloti](image2)
![Fig.3 Open gallery](image3)

From the practical analysis, we know that the design of different type of open space was not isolated. Designing from an overall view could keep the integrity and continuity of people’s activity, and improve the local microclimate by space
assemblage.

**Measurement of points.** The selection of the measure points based on the research of the open space which as a representative.

![Fig. 4 Measurement points](image)

Total 5 points are set and distribution is showed in Fig. 4. The measurement points can be roughly distributed in five different areas, such as campus square (point 1), building of piloti (point 2), water district (point 3), patio (point 4), and lawn area (point 5). The measurement period was continuous 48 hours from 10p.m. July 4 to 10p.m. July 6 in 2010 which was a high temperature period. The average temperature was 32.155°C, the average RH 60.798%, and the average wind speed 1.864 (m/s). The main measure parameters were the 1.5m height air temperature, relative humidity, globe temperature and ground surface temperature.

**MEASUREMENT RESULTS ANALYSIS**

**Air temperature of different points.** Fig. 5 showed air temperature in 1.5m height. The air temperature’s variation trends in each type open space are consistent. In all areas the peak temperature appears at around 15:00. The peak temperature difference between piloti area and square area is about 1.7°C. During 9:00 to 18:00, the temperature of piloti area is the lowest.

The piloti could obviously reduce the air temperature in 1.5m height in day, but its cooling effect is not obvious at night. The lawn cannot relieve a peak temperature during the day, but its cooling effect is obvious at night. In the daytime the order of air temperature in 1.5 m height of different underlying is the patio > the lawn > the square > the lake zone > the piloti area. At night the order is the patio > the square > the piloti area > the lake zone > the lawn.

The piloti can reduce air temperature as much as 2-3°C in summer, which is better than other underlying to reduce the air temperature in 1.5 m height. A wide range of green space and water in summer can also reduce the air temperature. Because the solar reflectivity of the trees and green space is big, the soil moisture content is much, the evaporation consumption is much, and the heat capacity of plants covering ground is large.

A 0.9°C temperature difference is observed between teaching building blocks and a grass surface square, revealing the influence of sky view factor and ground surface on temperature distribution at night-time.

More short-wave and long-wave reflections and long-wave radiations could be
received on a square, which should be paid attention to create a super hot outdoor thermal environment in campus clusters in summer. In Guangzhou, increasing the outdoor shading components on Square, reducing solar radiation can improve the outdoor thermal environment of square area.

**RH of air of different points.** Fig.6 showed RH of air in 1.5m height. During the day, the RH of air over lake is greater than the rest areas. From 12:00 to 18:00, the RH of air under the piloti and over the lake was higher just because the air temperature under piloti was lower and evaporation of water can increase air humidity separately. During the day, the RH of air under piloti and over the lake was basically the same. The RH of air over the lawn and the square are basically the same and lower than that under the piloti and over the lake. In the night, the RH of air under the piloti is slightly lower than other areas, but variation trends are consistent.

The maximum of RH appeared in the morning at all points. The minimum of RH maybe appear anytime during the time from 12:00 to 18:00, which was caused by transitive environments and local situations of each point.

**Global temperature of different points.** Fig.7 showed Global temperature excepte point 5. The Global temperature also called feeling temperature is an important index for human thermal comfort, which reflects thermal radiation condition of the environment. The Global temperature of point 2 and point 4 are much lower than that over square and patio. The Global temperature difference between under the piloti and over the square is about 10-20°C.

In summer, piloti is a suitable place for activity to people which has a more thermal comfort than square of without shading component.

**Ground surface temperature of different points.** Fig.8 showed ground surface temperature of different points. All points excepte 5 used the same ground surface materials which is shale brick pavement, point 5 is lawn. Ground surface temperature under the piloti changes gently, about 30.5°C. In the night, the lowest ground surface temperature is about 26°C at point 4. In the day, the highest ground surface temperature over square and the road besides lake are about 52°C.

The same surface material, but difference ground surface temperature. Compared to Shale brick pavage, the ground surface temperature of lawn was lower, but had the same tendency. A 6°C temperature difference was observed when temperature of them
was peak. There was an obvious effect that the lawn could reduce the ground surface temperature in the summer (Yang 2009). The ground surface temperature of point 2 was lower and changed a little all day. Though the same ground surface materials but thermal environment of piloti is better than other space, which showed that blocking out the sun radiation can improve thermal environment.

The characteristics of Shale brick pavage are hard, not bibulous, less water content and high thermal effusivity, absorbing more heat and cooling slowly when exposed in the sun. It makes the building façade and air around get hot. In summer, ground surface temperature gets higher and makes the outdoor thermal environment poorer when no shading component in the sun. So the hard impervious materials are not suit for the public space of outdoor.

**SIMULATION**

The new version of ENVI-met model (4.0) was used to simulate the microclimate of the experimental site. The actual environment and elements of the site, such as building, vegetation, soil and pavements, etc., were defined in an ENVI-met area input model (Fig. 9 and Fig. 10). More detail please look at their web site (Anon.).

In horizontal direction, a mesh of 85×60 grids was allocated to the entire model area (170×120m), with a resolution of 2 m. For the reason of numerical stability, 3 nesting grids were set for the area surrounding the main model with loam surface by considering the high greening rate of the island. In vertical direction, the total number of vertical grids is 25, varying grid sizes were used as we focused on the near-ground microclimate in this study. For the space below 2 m, equidistant grids were used with a fine resolution of 0.2 m (dz) and, for the space above 2 m, telescoping grids were used with a telescoping factor of 20%.
The simulation ran for 48 h, starting at 06:00 on 4 July and ending at 06:00 on 6 July. Table 1 summarizes the major input parameters for the ENVImet simulation. The hourly meteorological data from the weather station and from the on-site observation were used to generate the forcing file for the simulation.

Table 1. Major input parameters for the ENVI-met simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>meteorological</td>
<td>wind speed: Hourly data from the meteorological station</td>
</tr>
<tr>
<td></td>
<td>temperature and relative air humidity: Hourly data from the meteorological station</td>
</tr>
<tr>
<td></td>
<td>Solar radiation: Hourly data from the meteorological station</td>
</tr>
<tr>
<td>vegetation</td>
<td>the height and the number of trees and the shrubs are obtained by visual estimation</td>
</tr>
<tr>
<td>building</td>
<td>Exterior wall $K=1.5 \left[\frac{W}{m^2 \cdot K}\right]$, reflectivity = 0.2</td>
</tr>
<tr>
<td></td>
<td>Roof $K=0.87\left[\frac{W}{m^2 \cdot K}\right]$, reflectivity = 0.3</td>
</tr>
<tr>
<td>initial temperature of soil</td>
<td>0-20(cm):305(K); 20-50(cm):307(K); Below50(cm):306(K)</td>
</tr>
</tbody>
</table>

The default leaf area density (LAD) values in ENVI-met were used for these plants. The thermal properties of the buildings envelope were derived from the local building design code (Anon.). The initial soil temperature profile was determined according to the measured front research (Yang 2013).

RESULT OF COMPISON AND DISCUSSION

Fig. 11 depicts the comparison between the observed and modeled air temperature at 1.5 m heights for the five points on July 4th.

![Comparison of modeled and observed air temperature at the points 1-5](image)

Fig. 11 Comparison of modeled and observed air temperature at the points 1-5

Compares the modeled and observed temperatures at the points 1-5 at the heights of 1.5 m. All points except point 4 the observed temperature lower than modeled air
temperature until 18:00. The observed temperature differences among those locations at 18:00 and 06:00 are well reproduced by the ENVI-met results. At 14:00, although relatively large errors between the predictions and the observations are observed at points 1 and 2, the general spatial distribution features of the observed temperature are reflected by the ENVI-met model. Both the modeled and observed data show that the temperature differences among these positions diminish with the increase of height. Table 2 showed the maximum error and the time of the day.

<table>
<thead>
<tr>
<th>Point 1</th>
<th>Point 2</th>
<th>Point 3</th>
<th>Point 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum error</td>
<td>7.08%</td>
<td>10%</td>
<td>11.20%</td>
</tr>
<tr>
<td>Time</td>
<td>11:00</td>
<td>12:00</td>
<td>9:00</td>
</tr>
</tbody>
</table>

The author explores the possible reasons for the error occurs: 1) simplify boundary conditions and physical processes (can not simulate climate background, clouds and natural wind effects); 2) There is a deviation between the actual state of the plant and input the ENVI-met Model, which the parameters according to the visual; 3) Measurement exists deviation; 4) The new function “full forcing” has been implemented in ENVI-met 4.0, which allows users to employ the measured meteorological data to force the model during the simulation. The wind environment simulation has a deviation between the actual state, because of “full forcing” file let the wind direction and velocity be changed every hour. Wind speed and air temperature has a direct negative correlation.

CONCLUSION AND IMPLICATIONS

Measurement results show thermal environment texture in different space. The lake and piloti can reduce the pedestrian air temperature, global temperature and surface temperature effectively at summer daytime. The piloti, which design form adapts the climate in Guangzhou, can effectively improve the outdoor thermal comfort in hot summer.

The measurement results are further used to verify the ENVI-met model. The results show that: the ENVI-met model reasonably reproduced the majority of the observed spatial and temporal characteristics of the 2-m temperature field over the simulation period, and the relative errors are within 11.2%, which proved that ENVI-met is a reliable model to simulate the different urban scenarios.

Just air temperature were compared between the the modeled and observed, next we should compared more parameters to validate the ENVI-met model.

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REFERENCES


