ICUC9 482:
Research on Outdoor Thermal Environment of Lingnan Garden in Hot-humid Region, China -Taking Yu Yin Shan Fang as an Example

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Abstract

This paper tries to seek a method to study how the traditional Lingnan garden spaces adapts to the local hot and humid climate. Firstly, numerical simulation method is used to study the outdoor average SET * hourly variation law of Yu Yin Shan Fang in typical days of four seasons and make an overall evaluation of garden outdoor thermal environment quality in different seasons. Then four representative typed garden spaces are chosen to focus on the analysis of space distribution characteristics of the outdoor SET* at 12 o'clock and of the impact of environmental factors (water, vegetation) on the garden thermal environment. Finally this paper expects to make relatively comprehensive description and analysis of climate adaptation characteristics of traditional Lingnan garden from time and space dimension respectively to make it a better inheritance in modern design.

Keywords: Linnan Gardens/the Climate Adaptability/Thermal comfort/Landscape Elements

Introduction

In recent years, as the climate problem worsens significantly, people gradually pay more attention to microclimate. As urban green space, gardens are of great significance to the improvement of the urban climate. Through the ages, climate and geographical features jointly affect the forms of gardens. Conversely, the gardens' constant adaptation to climate also contributes to establish their own characteristics. Usually, the worse the climatic environment is, the more ingeniously designed techniques with great adaptation to climate are created. Lingnan garden in China is one of them. Following the principle of "let nature take its course and improve the nature", wise Lingnan people creates the traditional courtyard style architecture which is a habitat merging home and garden. The style forms the unique local characteristic in Lingnan from aspects of the plane layout, space combination and so on, which skillfully responds to the hot and humid climate in Lingnan. Outdoor space experience is an extremely important part of Lingnan garden life. Therefore, outdoor space comfortability directly affects the quality of garden life. This paper, by means of the numerical simulation method, makes quantitative research on climate adaptation characteristics of the traditional Lingnan garden. The paper also analyzes the garden thermal environment in different seasons, and introduces standard effective temperature (SET *) as the evaluation standard of human body comfortability to comprehensively evaluate the garden outdoor thermal environment quality in each season and to explore the correlation between typical garden space types and thermal environment comfortability in each season.

Study Case

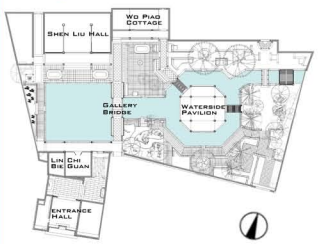

Fig.1 Functional Layout of YuYinShanFang

Yu Yin Shan Fang, as the research object, is located at Nacun town Panyu area in Guangzhou city, Guangdong province, China (23.13 ° N, 113.23 ° E) and belongs to the hot and humid regions. It is also the best one of four classical gardens preserved from Qing dynasty in Guangdong. It is famous for its small and exquisite trait and is also a mirror of Lingnan living environment, so as to be identified as the research sample of traditional Lingnan gardens. The functional layout of Yu Yin Shan Fang is shown in Fig.1.

Methodology

■ENVI - met Modeling

ENVI - met is a kind of software used for micro-climate simulation developed by Bruse and Fleer of the university of Bochum in Germany. Based on thermodynamics and fluid mechanics principles, the software employs three-dimensional non-hydrostatic model, with comprehensive consideration of climate factors and the interaction between factors, to be capable of dynamic simulation of interaction between surface, air and vegetation of the city within small-scale scopes.

ENVI - met modeling (Fig. 2) of Yu Yin Shan Fang is made according to the surveying and mapping data. In order to ensure the precision of the model, 1 m resolution is selected, with level modeling grid for 64 x 52, 5 nested grids, loam as the ground attribute and vertical grid for 24 is equidistant grids, and elevation difference is ignored because of the flat garden.

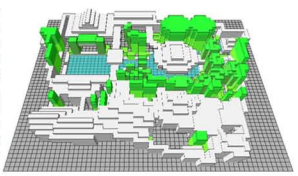

Fig.2 Envi-met Modeling of YuYinShanFang

■Obtaining the initial climatic conditions

Due to the randomness of meteorological environment, representative meteorological data are selected as the initial climatic conditions of the simulation(Table 1), based on Special Meteorological Data Set of Thermal Environment Analysis of Chinese Architecture and Standard Meteorological Database for Chinese Architecture.

■Choosing Thermal Environment Evaluation Index

Standard Effective Temperature (SET*, Standard Effective Temperature) as outdoor thermal comfort index is introduced to make comprehensive evaluation of outdoor thermal environment quality. The index's advantage lies in combining the effects of the integrated air temperature, relative humidity, the average radiation temperature, wind speed and the clothing, as well as the activity quan tity, and the index visually reflects human thermal sensation. Corresponding warm sensation and health status under different SET* are given by ASHRAE (Table 2). From this we can see that SET* 15 ~ 35℃ is the acceptable range for human, 20 ~ 30℃ for human comfort range.

Table 1: Main Input Parameters

		Spring	Summer	Autumn	Winter
Typical Simulation Days		04/15	10/15	08/17	01/01
Initial Time		8:00	8:00	8:00	8:00
Total Simulation Time（h）		30	30	30	30
Wind speed up to 10 m High		2	2	2	1
Wind Direction（°）		135	45	180	22.5
The Surface Roughness		0.08	0.08	0.08	0.08
Initial Temperature（K）		294.7	296.2	302.7	281.9
2500m Moisture Content(g/kg)		14.1	12.0	19.9	4.9
2 Meter Relative Humidity (%)		86.0	63.9	74.0	69.0
Loam Temperature（K）	0-20cm	295.9	299.9	303.8	281.2
	20-50cm	296.9	300.9	304.2	282.2
	>50cm	297.9	301.9	304.7	283.2
Loam Humidity (%)	0-20cm	60	20	40	40
	20-50	70	30	60	50
	>50 cm	90	50	90	60

*Table 2: Corresponding Warm Sensation and Health Status under Different SET **

SET*（℃）	Thermal Sensation		Health Status
	Sensation	Comfortable	
40~45	limits	limits	Poor blood circulation
35~40	very hot	very uncomfortable	Unstable Pulse
30~35	warm	uncomfortable	Normal
25~30	neutral	comfortable	Normal
20~25	neutral	comfortable	Normal
15~20	cool	slight uncomfortable	Normal
10~15	cold	uncomfortable	Mucous membrane of the skin is dry
5~10	very cold	very uncomfortable	Poor blood circulation

Results of Simulation

Through ENVI - met simulation analysis, hourly meteorological data at various spaces within Yu Yin Shan Fang are obtained. Then, according to the fast computing web compiled by Architectural Environment Center of the University of California, Berkeley , garden SET* values are calculated space by space and hourly. Finally a comparative analysis is made between the values and thermal comfort standard of American ASHRAE (Table2).

■Comparative Analysis of Garden Thermal Environment in Four Seasons

Longitudinal comparison of average hourly SET* changes (Fig.3) of Yu Yin Shan Fang outdoor space in typical meteorological days of four seasons shows that outdoor average SET* is characterized by high temperature in summer and low in winter. Since solar radiation is the main factor deciding outdoor thermal environment, high solar radiation has a greater influence on the temperature rise of the garden outdoor space. SET* is positively correlated with temperature, thus outdoor space average SET* is relatively high and thermal environment condition is relatively poor in summer, when horizontal monthly average total solar radiation is relatively high. By this, we can see that time differences of garden thermal environment are directly related to horizontal solar radiation.

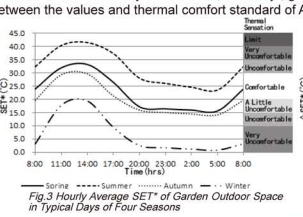

Fig.3 Hourly Average SET of Garden Outdoor Space in Typical Days of Four Seasons*

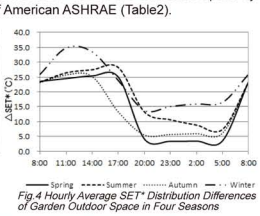

Fig.4 Hourly Average SET Distribution Differences of Garden Outdoor Space in Four Seasons*

By calculating garden SET* distribution differences at a certain moment, a lateral comparison of garden space thermal environment differences at the same moment can be made (Fig. 4). We can see significant differences in the daytime among different places within the garden. Along with sunset, the direct effect of solar radiation on outdoor thermal environment disappears.So garden SET* is uniformly distributed spatially and keeps a relatively stable state over time in the night, which is called the steady thermal environment at night.

■Climate Adaptability Analysis of Four Typed Garden Spaces

With reference to Lingnan garden typed spaces made by architecture master Xia Chang and Mo Bozhi, four spaces (Fig. 5/Table 3) where outdoor activities occur with high frequency, are selected to analyze and discuss the relationship between Lingnan garden typed space and the climate adaptability design strategy.

Space Type A: Duichao Hall – Shenliu Hall and LinChiBieGuan

Space A enclosed by them is located in the quiet part of the garden activity zoning, which gives priority to "appreciation". Square pool is in the center of Space A, whose surrounding is covered by sparse vegetation. Then the pergola in front of Shenliu Hall and the front porch of LinChiBieGuan form a shade space with good exposure, as a good place for "appreciation ".

In this space, the water level is heavily influenced by solar radiation. Therefore, all of the midday SET* values exceed the upper limit of comfortability except winter (Fig. 6). The space is further subdivided into different combination patterns of environmental elements to make comparisons (Fig. 7). Because water let the heating speed of surrounding air temperature slow. And water evaporation takes away part of the heat, which plays a cooling effect on the space air near the ground. Therefore, the SET* above the non-shelter water is 4-8℃ lower, compared with non-shelter hard floor; In the north side, the SET* of LinChiBieGuan porch space is 7℃-13℃ lower than the non-shelter space with same underlying surface, for porch space is not affected by the sun in the morning; owing to the shading effect of the flower stands, in spring, summer and autumn, midday SET* of the space in front of Shenliu Hall in the south side is lower than the non-shelter space with lowering amplitude slightly less than north space; because of the small sun altitude angle at noon in Guangzhou wintertime, the flower in the south side cannot exert shading effect and thus the SET* under flower stands in front of Shenliu Hall is about 29℃, which creates a warm and comfortable space for the cold winter and is also a suitable space to stay.

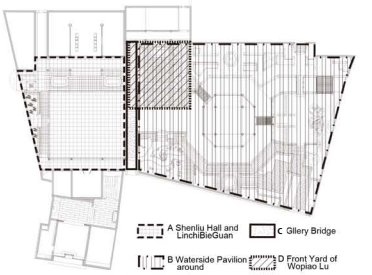

Fig.5 Diagram of Four Typed Garden Spaces

Table 3 An Introduction to Four Types of Space

Space Type	Type A Shenliu Hall and LinchiBieGuan	Type B Waterside Pavilion around	Type C Gallery Bridge	Type D Front Yard of Wopiao Lu
Garden Architecture Type	Duichao Hall	Water Atrium Pavilion	Bridge pavilion	Flat Gallery Garden
Environment Description	Water in the center sparse vegetation	Water around architecture Flourishing vegetation	Water under bridge sparse vegetation	No water, hard sandstone tiles, sparse vegetation
Function description	guest reception, study	Composing poem and restaurant	Enjoying cool air, sightseeing	Nap, Sightseeing

Space Type B: Water Atrium Pavilion - Waterside Pavilion around

Waterside Pavilion, the main architecture of Space B, is a place where the master invites refined scholars of letters to compose poem and enjoy wine. The pool water winds around octagonal pavilion. The pool side is surrounded by lush vegetation.The extremely hot state appears at midday of typical days in summer(Fig. 6). However, it's SET* value is still about 2℃ lower than the maximum value of the garden at the same moment.Thus we can see that tall and dense vegetation effectively reduces the role of solar radiation on the space, and in the meantime, water and the evaporative cooling of plants also help to reduce SET* of the space.

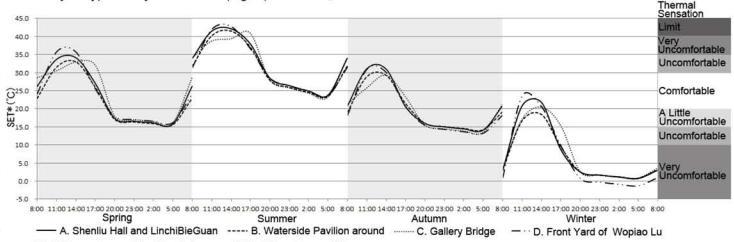

Fig.6 Comparisons of the Hourly Average SET of Four Types of Space*

A Comparison is made to study the adjusting roles of four combination patterns of water and vegetation in space A and B at 12 o'clock sharp noon on the garden thermal environment (Fig. 8). Results show that water and vegetation play a certain adjusting role on the garden outdoor thermal environment, with significant adjustment of vegetation in autumn and winter and of water in spring. The space where enjoys vegetation cover and water as underlying surface has the lowest SET* all the time than three other combination patterns. Hence the combination of water and vegetation is more advantageous to the adjustment of garden thermal environment.

Space Type C: Bridge Pavilion – Gallery Bridge

Space C refers to the gallery bridge area located at the junction of space A and B. Over the center of the bridge is a pavilion over water, which gives priority to "strolling" and is convenient to connect major function spaces in the garden. Its SET* peak in the daytime appears later than other three space types (Fig. 6). Reasons are as follows: on the one hand, gallery bridge itself has the shading capacity; on the other hand, a certain temperature difference is formed by the great difference of vegetation distribution between Space A and B, between them there are also different air densities, which further form hot pressing difference to promote air flow in a small environment when calm wind occurs outside. The biggest temperature difference between space A and B appears at the midday, so high speed wind occurs in space C. It makes space C a comfortable environment and also a suitable space for people to go for a walk in the afternoon.

Space Type D: Flat Gallery Garden - Front Yard of Wopiao Lu

The front yard of Wopiao Lu has sparse vegetation, which coincides with the sightseeing function of Wopiao Lu and reduce sight blockage. The average SET* values of space type D at the midday are basically in the highest level among the four space types (Fig. 6), all of which exceed the maximum limit of comfortability range with only winter as an exception. Reasons are same as for space A. Moreover, the underlying surface of space D is covered by red sandstone tiles, which have small thermal capacity with fast heat absorption and heating speed. Therefore, its SET* is often beyond the temperature scope for human body to bear at 12 o'clock when solar radiation reaches the strongest level. In addition, though unsuitable for outdoor activities, the space is right suitable for visitors to go sightseeing and for a nap after lunch sitting or lying in Wopiao Lu. In cold winter, however, the space plays an excellent warming role and becomes one of the few places suitable for enjoying outdoor warm sun in winter.

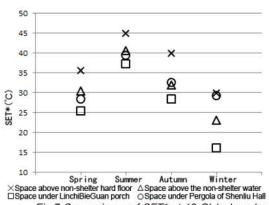

Fig.7 Comparisons of SET at 12 O'clock under Different Combination*

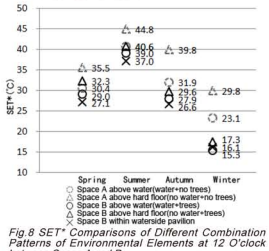

Fig.8 SET Comparisons of Different Combination Patterns of Environmental Elements at 12 O'clock between Space A and B*

Conclusion

1. Surface solar radiation is one of the main reasons for outdoor SET* differences in four seasons.
2. The average garden SET* changes over time with a large amplitude and is regular in the daytime. Garden space SET* differences are significant in different spaces in the daytime; at night, it's SET*turns on a stable state both in time and space.
3. Different combination patterns of environmental factors have great influence on the outdoor thermal environment of the garden in the daytime. Water, vegetation and architecture shade are all helpful to reduce SET* values in the garden, of which vegetation plays an obvious regulating role in autumn and winter, water in spring and the combination of them plays the most significant regulating role.
4. The local microclimate of daytime garden created by four typed spaces are correlated with their spatial functions. The climate adaptability of these typed space, confirms the "pragmatic" feature of the Lingnan gardening.

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