ICUC 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* hour variation law of Yu Yin Shan Fang in typical days of four seasons and make an overview of the garden outdoor thermal environment quality in different seasons. Then, four representative typology garden spaces are chosen to focus on the analysis of space distribution characteristics of outdoor SET* at 12 o'clock and the effect 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: Lingnan Garden/the Climate Adaptability/Thermal comfort/Landscape Elements

Introduction
In recent years, as the climate problem worsens significantly, people gradually pay more attention to it. 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 garden's constant adaptation to climate also contributes to establishing their own characteristics. Usually, the worse the climate environment is, the more ingeniously designed techniques with great adaptation to climate is Lingnan garden in China is one of them. Following the principle of “set 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 characteristics 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 qualitative and quantitative analysis of the climate adaptation characteristics of 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
Yu Yin Shan Fang, as the research object, is located at Nan'an town Fangyuan area in Guangzhou city, Guangdong province. (23°11'44"N,113°12'32"E) and belongs to the hot and humid regions. It is also one of the best one of classical gardens preserved from Qing dynasty. As its name indicates, it is famous for its small space and exquisite art and is also a model of the Chinese landscape gardening system as it is as being as the research sample of traditional Lingnan garden. The functional pattern of Yu Yin Shan Fang is shown in Fig.1.

Methodology

a) ENVI-met Modeling
ENVI-met is a chain of software used for micro-climate simulation developed by Binsen and the University of Ghent, Belgium. Based on thermodynamics and fluid mechanics principles, the software employs three-dimensional numerical simulation method, with comprehensive consideration of climate factors, vegetation factors, etc., making it be capable of dynamic simulation of interaction between surface, air, vegetation and the city within small-scale scopes.

b) Obtaining the initial climate 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 Flanders Meteorological Data Source, Environment Analysis of Chinese Architecture and Bioclimatological Database for Chinese Architecture.

c) Choosing Thermal Evaluation Indicators
Standard Effective Temperature (SET*), Modified SET* (SET*) and the Thermoneutral Zone (TNZ) as outdoor thermal comfort index is introduced to make comprehensive description and analysis of the garden thermal comfort environment quality. The index's advantage lets it avoid the extra index of the indoor air temperature, relative humidity, the average radiation temperature of clothing, as well as the activity quant thy, and the index visually reflects human thermal sensation corresponding warm sensation and health status under different SET* are given by A. Cimini and D. H. M. Cobb, respectively, that SET* 10°C-30°C is the acceptable range for human, 20°C-25°C for human comfort range.

Results of Simulation

a) Comparative Analysis of Garden Thermal Environment in Four Seasons

The 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 SET* average value is characterized by high temperature in summer and lowest in winter. The highest SET* is the main factor denoting outdoor thermal environment, high outdoor SET* is mainly due to the high solar radiation intensity in the garden outdoor space. SET* is positively correlated with temperature. Thus, a lower space average SET* means a strongly positive correlation. By calculating garden SET* distribution differences at a certain moment, a longitudinal comparison of garden thermal environment differences at the same moment can be made. Yu Yin Shan Fang can see significant differences in the daytime among different places within the garden. Along with a rising, 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.

b) Climate-Adaptability Analysis of Four Typical Garden Spaces
With referring to Lingnan garden type spaces made by Y. L. Zhang, M. Y. Zou, X. X. Cheng and M. B. Dou, four spaces (Fig.5 Table 3) where outdoor activities occur with high frequency, are selected and the relationship between the Lingnan garden type spaces and the climate adaptability of outdoor space are discussed and compared.

Space Type A: Dulian Hall – Shenxi Hall and LinChibeiGuan
Space A is enclosed by them in the east part of the activity zone, which greatly allows to “breakthrough”. Pool space is in the center of Space A, whose surrounding is covered by sparse vegetation. Then the panga in front of Shenxi Hall and the front porch of LinChibeiGuan form a shade space with good exposure, so it is good for “breakthrough”.

In this space, the water level is heavily influenced by solar radiation. Therefore, all of the midday SET* values exceed the upper limit of comfort level except the sunshade areas. The space is further subdivided into different combination patterns of environmental elements to reveal the radiation environment (Fig.2). Because the healthy exposure to solar radiation is between 3°C-12°C lower than the non-shade with same underlying surface, for porch space is not in direct solar radiation, there is a small effect on human comfort level, in spring, summer and autumn. The area of the frame in Shenxi Hall and the front porch of LinChibeiGuan force the combined space for shade, and also is a suitable space to stay. SET* temperature difference between space A and B is nearly 3°C, which is 1.5°C at midday.

Space Type B: Grooming Pavilion and LinChibeiGuan
Grooming Pavilion is the main architecture of Space B, is a place where the master invade the garden to groom the flowers and enjoy the 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.4). However, its SET* value is still below 2°C lower than the maximum value of the same moment. Thus we can keep the hall cool and have a deep sleep when solar radiation reaches the strongest level. In addition, thus the vegetation effectively reduces the degree of solar radiation on the space, and in the meantime, water and vegetation make garden more comfortable by influencing the temperature and humidity. The vegetation is adapted to help reduce SET* in summer.

A Compass is made to study the adjusting roles of four combination patterns of vegetation in space A and B at 12 o'clock with solar radiation on the garden thermal environment. Significant adjustment of vegetation in autumn and winter and of water in spring. This space employs vegetation cover and water as underlying surface has the lowest SET* all the time than other combination patterns. Hence the combination of water and vegetation is more advantageous to the adjusting roles in the garden environment.

Space Type C: Bridge Pavilion – Gallery Lobby
Bridge Space D refers to the gallery bridge area located at the junction of space A and B. Over the center of the city is a garden space, which is priority to "breakthrough". In order to connect main function spaces in the garden. Its SET* peak in the daytime appears later than other three space types (Fig.5). The reason is as follows: on the one hand, gallery bridge area is 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 are different air densities, which further from hot pressing difference to promote air flow in a small environment when calm wind occurs outside. The SET* 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 Garden Pavilion – Front Yard of Wopito La
The main feature of Wopito La has a large pool, which combines with the sunlighting function of Wopito La and reduce light blockage. The average SET* value of space D at the midday is basically kept in the highest level among the four space types (Fig.6), all of which exceed the maximum limit of comfortability range with only water as an exception. Reasons are same as for space A. Moreover, the pool water in the garden is covered by red sandstone tiles, which have small thermal capacity with fast heat absorption and heating speed. Therefore, its SET* is often over the temperature scope of human comfort. The space is located near to 12 o'clock with solar radiation, so it is more suitable for outdoor activities, the space is right suitable for visitors to go sightseeing and for a nap after lunch sitting or lying in Wopito La. In cold winter, however, the space plays an excellent warming role and becomes a suitable place for enjoying outdoor warm in winter.

Conclusion
1. Surface solar radiation is one of the main reasons for outdoor SET* differences in four seasons. The maximum peak of garden SET* changes with a target temperature and is regular in the daytime. Garden SET* differences are significant in different spaces in the daytime; at night, its SET*turns on a stable state both in time and space.

2. There is a great difference between the climate factors and the outdoor thermal environment of the garden in the daytime. Water vegetation and architecture shade are all help to reduce SET* values in the garden, of which vegetation plays an obvious regulating role in summer and winter, water in spring and the combination of them plays the most significant regulating role.

3. The local microclimate of daytime garden created by four typical spaces are correlated with their spatial functions. The climate adaptability of these spatial functions, confirms the "pragmatic feature" of the Lingnan garden.

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