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

1. 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.

2. Study Case

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.

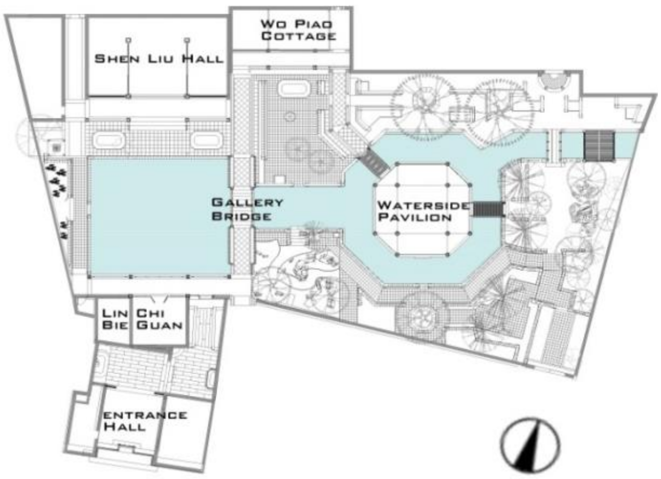

Fig. 1 Functional Layout of YuYinShanFang

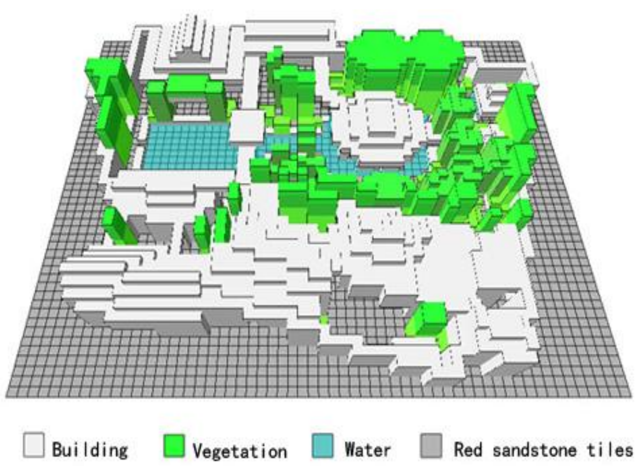

Fig. 2 Envi-met Modeling of YuYinShanFang

3. Methodology

3.1 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.

3.2 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* [1] and *Standard Meteorological Database for Chinese Architecture* [2].

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（m/s）		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

3.3 Choosing Thermal Environment Evaluation Index

Standard Effective Temperature (SET *, Standard Effective Temperature) [3] 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 [3] (Table 2). From this we can see that SET* 15 ~ 35 ℃ is the acceptable range for human, 20 ~ 30 ℃ for human comfort range.

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

SET* (℃)	Thermal Sensation		Health Status
	Sensatio	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

4. 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 [4], 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).

4.1 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. However, though horizontal monthly-average total solar radiation intensity in spring is lower than in autumn, the garden hourly average SET * in spring remains higher than in autumn. This shows that the garden outdoor thermal environment is also affected by other factors except the sun radiation. In addition, during most of the time in the day in spring and autumn, garden outdoor space is in a comfortable temperature range, and it is slightly uncomfortable after 20 o 'clock at night, but is basically still in the acceptable range. However, in summer it turns on the other way around. Finally in cold winter, it is in the acceptable range only from 10 o'clock to 16 o'clock.

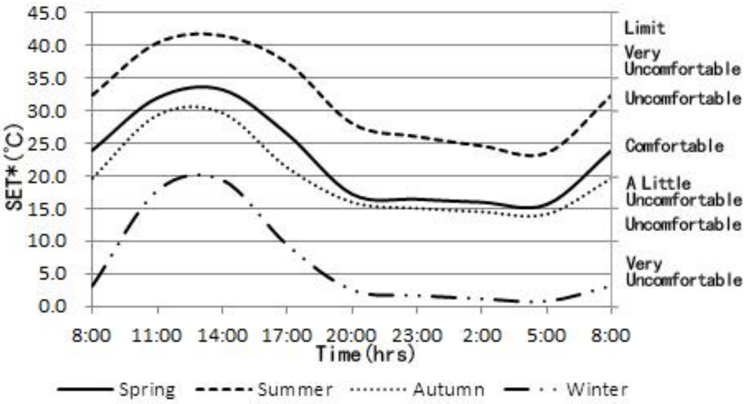

Fig.3 Hourly Average SET of Garden Outdoor Space in Typical Days of Four Seasons*

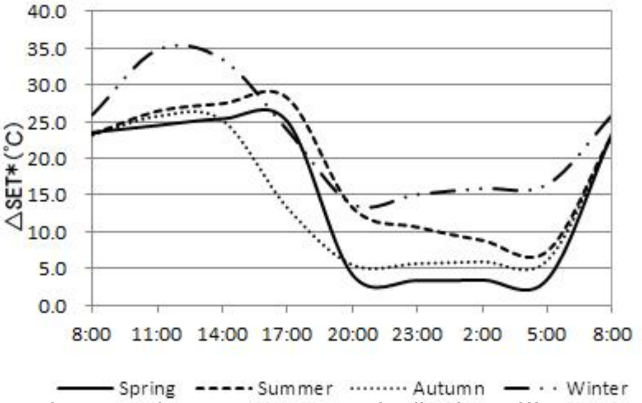

Fig.4 Hourly Average SET Distribution Differences of Garden Outdoor Space in Four Seasons*

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). By this, we can see significant differences in the daytime among different places within the garden. They are especially so in winter and change significantly over time, with SET* spatial distribution difference rising up to 35 ℃ 12 o'clock at noon. This indicates that the layout within garden at noon in winter has the greatest influence on garden thermal environment throughout the year. SET* distribution differences curves of garden space during four seasons level off at night (Fig. 4) and hourly average SET* curves change slowly (Fig. 3). This is because the direct effect of solar radiation on outdoor thermal environment disappears along with sunset. At night, garden SET* is uniformly distributed spatially and keeps a relatively stable state over time, which is called the steady thermal environment at night. To put it another way, the night garden environment layout becomes weak in its control of comfortability. Besides outdoor activities decrease at night, so this paper focuses only on garden comfort conditions in the daytime.

4.2 Climate Adaptability Analysis of Four Typed Garden Spaces

With reference to Lingnan garden typed spaces made by architecture master Xia Changshi and Mo Bozhi [5], 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.

An overall analysis of the hourly average SET* of four types of space in different seasons (Fig. 6) shows that the four curves are leveled off and the numerical value is close at night in four seasons, which again verifies the stability of thermal environment of the outdoor garden at night. The average SET* differences of four types of space are greatest near 12 o'clock at noon when the solar radiation intensity is the strongest. Thus we can see that different environment layouts have the most significant effect in adjusting garden outdoor thermal environment near the midday period of time. Therefore, this paper emphatically analyzes thermal environment conditions of all kinds of garden spaces in this time range.

Fig.5 Diagram of Four Typed Garden Spaces

Space Type A: Duichao Hall – Shenliu Hall and LinChiBieGuan

Shenliu Hall is usually used for guest reception, and LinChiBieGuan as master's study. 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 ". There is no vegetation cover in most of the space area, thus the water level is heavily influenced by solar radiation. Therefore, all of the midday SET* values in spring, summer and autumn exceed the upper limit of comfortability (Fig. 6). However, due to great differences of the space internal environment, the space is further subdivided into different combination patterns of environmental elements to make comparisons (Fig. 7). At the midday, except in winter, space above non-shelter hard floor exceeds acceptable range for human body. This pattern belongs to passing-through space and is not suitable to stay for a long time; Because of the large specific heat of water, the heating speed of surrounding air temperature slows. Moreover, 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

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 [5]	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

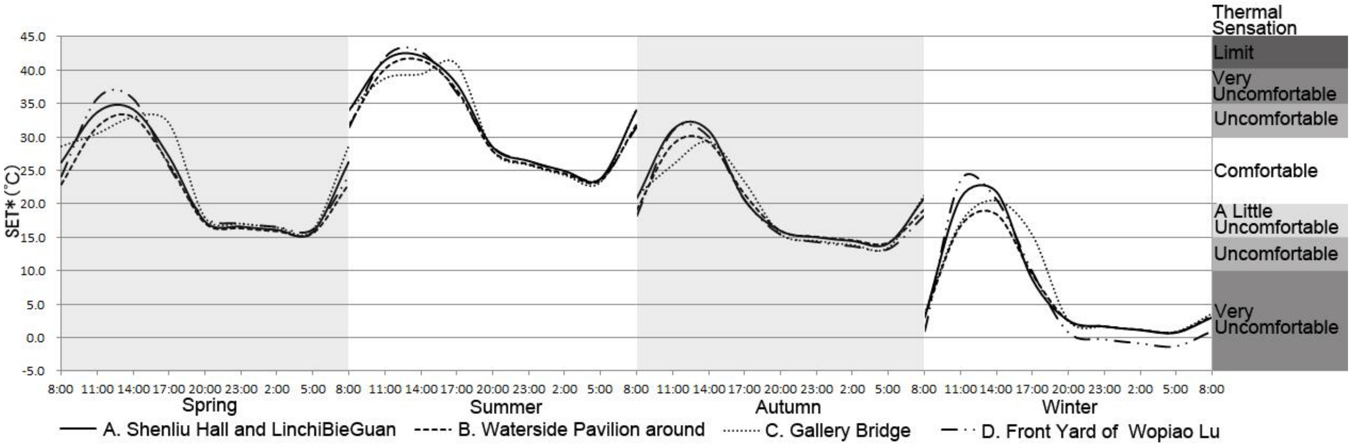

*Fig.6 Comparisons of the Hourly Average SET * of Four Types of Space*

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℃, close to the non-shelter space, which creates a warm and comfortable space for the cold winter and is also a suitable space to stay.

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 pavilion enjoys good exposure and pool water winds around octagonal pavilion. The pool side is surrounded by lush vegetation in great variety, which displays different landscape styles.

Except in summer, midday SET* of space B is in the acceptable temperature range all year round (Fig. 6). The extremely hot state appears at midday of typical days in summer. 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.

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

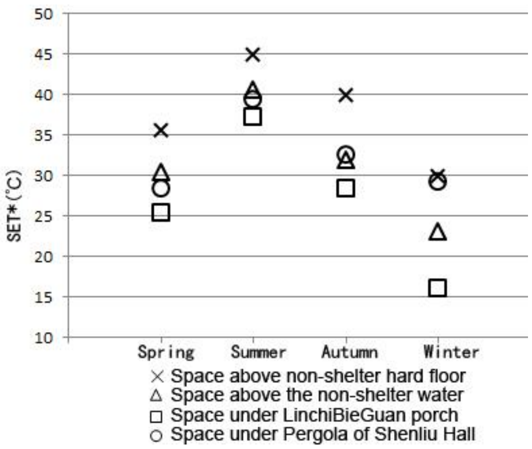

*Fig. 7 Comparisons of SET * at 12o'clock under Different Combination*

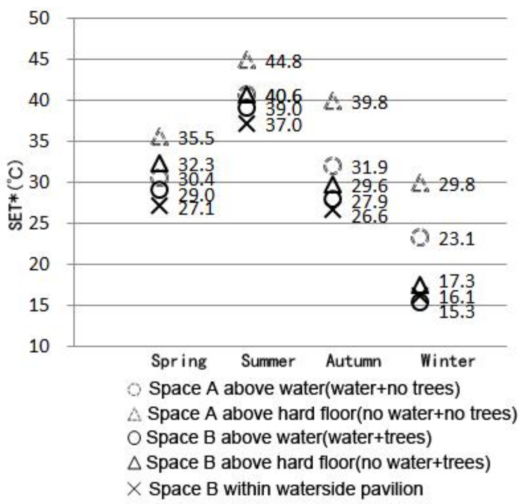

Fig.8 SET Comparison of Different Combination Patterns of Environmental Elements at 12 o'clock between Space A and B*

of water in spring. The space where enjoys vegetation cover and water as underlying surface (Space B above the water) has a lower SET* all the time than three other combination patterns. In contrast, the space without vegetation cover and with hard floor as underlying surface (Space A above hard floor) has a higher SET* all the time than other combination patterns. The smallest difference between Space A and B appears in summer, still as high as 5.8℃. Hence the combination of water and vegetation is more advantageous to the adjustment of garden thermal environment.

In addition, a comparison is made to study three combination patterns of different environmental elements (Fig. 8). The results show that SET* within waterside pavilion remains the lowest value in space B at the midday in spring, summer and autumn. Even in winter, it is also close to the minimum limit of acceptable temperature range. The reason is that architectures and plants form effective shade, reducing shortwave radiation received by the water level and long wave radiation in the environment; moreover, the water surrounding waterside pavilion inhibits the heating speed of the surrounding air temperature and also evaporates to cool waterside pavilion at the same time, which indirectly plays a cooling role on it. Additive effects of three elements make the thermal environment of the space basically remain comfortable. Therefore, the space type, especially the space within waterside pavilion, is a preference to enjoy the cool at noon for people of Guangzhou area where midday high temperature occurs throughout most time of the year.

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), and the peak value is also slightly lower than sparsely sheltered Space A and D. 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 door. The biggest temperature difference between space A and B appears at the midday, so high speed wind occurs in space C located at the interface between space A and B. The SET* value of space C is thus decreased, which makes space C a comfortable environment and also a suitable space for people to go for a walk and sightseeing in the afternoon.

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

Wopiao Lu is a place of rest with simple display. The window design is novel, the shutter in the north side has the function of ventilation and lighting, and the blue glass Manchuria window in south side producing overlapping effect and the effect of different seasons when watching the scenery outside the window through it. 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 in four seasons 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 beyond the temperature scope for human body to bear at 12 o'clock when solar radiation reaches the strongest level in spring, summer and autumn. 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.

5. Discussion

Based on the above research, conclusions are drawn as follows:

1. The garden thermal environment throughout the daytime in spring and autumn is basically in acceptable temperature range; while in summer it goes beyond the acceptable limit in most of daytime; and it remains in the acceptable range only in a small percentage of daytime in winter. Therefore, 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, and especially significant in winter, and change evidently over time, with SET * spatial distribution difference reaching as high as 35 ℃ at noon. Yet at night, garden environment layout's influence upon comfortability weakens and 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. Hence, in contemporary garden design, rational allocation of environmental factors can be made to improve the garden outdoor thermal environment, and especially to relieve the discomfort of the high temperature in summer.
4. The local microclimate of daytime garden created by four typed spaces are correlated with their spatial functions. With open center and galleries on both sides, space A is suitable for relatively static activities under the galleries,

which give priority to "appreciation". Then space B, basically without shelter, is suitable for outdoor activities only in winter, and suitable to enjoy sightseeing within windows and have a nap after lunch sitting or lying in Wopiao Lu in other seasons. Space C is a linear space with shelter above, which combines its own shading effect with the air flow caused by the temperature difference between adjacent spaces, to make itself comfortable in the daytime all year round, and is suitable for both dynamic and static activities. Finally, flourishing vegetation and enclosing water space make space D a place to enjoy shade and cool air in summer. The climate adaptability of these typed space, confirms the "pragmatic" feature of the Lingnan gardening.

The adaptation strategy of Lingnan garden reveals the traditional architectural wisdom. The life within garden is closely related to the micro-climates created by its spaces. Further quantitative analysis of the correlation between various environmental factors and garden space thermal environment, helps to extract universal typed climate adaptation space pattern, providing the basis for evaluation of garden comfortability, and combining the garden space filled with traditional Lingnan wisdom with modern life to better inherit its climate adaptability features.

Acknowledgements

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