A Study of Lingnan Garden's Adaptability to Hot and Humid Climate

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Abstract. Lingnan garden is one of the three major styles of Chinese classical garden. This paper is intended to analyze the construction methods used in the building of Lingnan gardens to minimize the influences of hot and humid climate, including ventilation, sunshade, heat insulation, temperature reduction, damp proofing, wind proofing and rain proofing, and to discuss its adaptability to climate. To conclude, in the context of ecology, sustainability and green construction, the 'passive ecology' strategy stated above has important implications to the building of public modern urban landscape and green spaces.

Keywords: Lingnan garden · Climate adaptability · Passive ecology

1 Introduction

Lingnan garden is one of the three major styles of Chinese classical garden. Having gone through the Nanyue reign in Western Han Dynasty and Southern Han period, it emerged unexpectedly since Qing Dynasty, centering on Pearl River Delta and covering Guangdong, Guangxi, Fujian, Taiwan and other provinces. Chinese private garden has experienced a long-term development, and resulted in a situation with three dominating styles: Northern garden, Jiangnan garden, and Lingnan garden. Lingnan garden is designed to fit in daily life activities, and the garden environment is a part of the architectural space; therefore, Lingnan garden is also called 'Lingnan courtyard' [1].

The adaptation of gardens to nature is specifically reflected in their adaptation to climate, to geography, to environment and to construction materials. Among all the elements, climate is very important in creating local characteristics, and different climates lead to different garden styles to a large extent. What is called 'passive ecology' is different from the current 'active ecology', which is accomplished by modern techniques; the passive ecology strategy aims to create relatively adaptable and healthy space at a very low cost. Undoubtedly, the 'natural' passive ecology model is the concept that should be referential to modern green construction modes. In the context of ecological sustainability and green construction, it has become an important subject to inherit and innovate the climate adaption and 'passive ecology' strategy of Lingnan garden, to master the regionalism of green construction, and furthermore to build a living environment adaptive to Lingnan climate.

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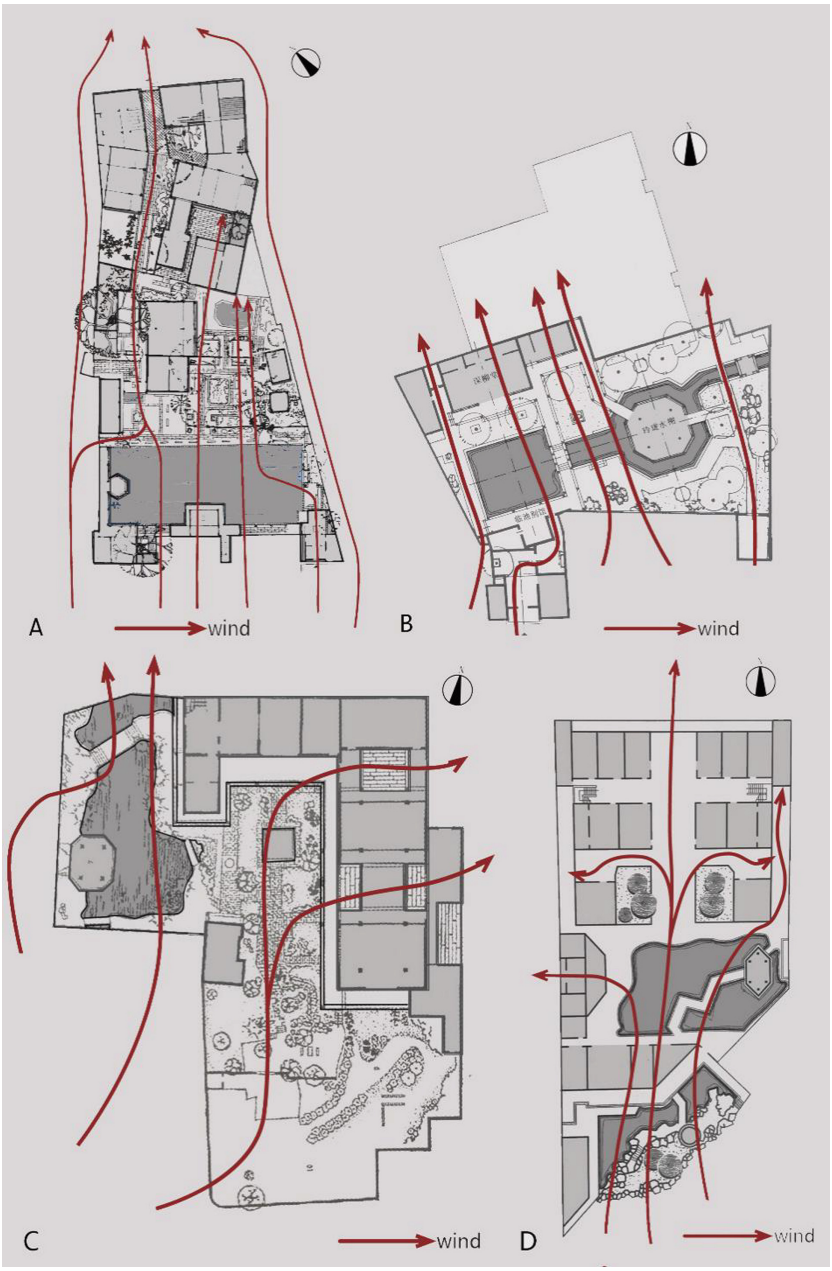

Fig. 1. Temperature reduction by water surface in Lingnan garden: A. pond dug in front courtyard B. pond dug in back courtyard C. pond dug in side courtyard D. ponds dug in both front and back courtyards.

Lingnan is located in the south of the East Asian monsoon region, and has characteristics of tropical and subtropical monsoon and oceanic climates, with the Tropic of Cancer running through its middle part. Most parts of Lingnan have a humid subtropical monsoon climate, while Leizhou Peninsula, Hainan Island and South China Islands have a tropical climate. With a relatively large solar zenith angle, the summer can be longer than half a year in most parts, and stays all year around on South China Islands. Meanwhile, the climate is also characterized by distinct dry and wet seasons: the summer rainfall contributes 80% of the total annual precipitation, while it seldom rains in winter and spring; the distribution of precipitation reflects the monsoon climate features. Apart from northerly-wind cold waves, typhoons and strong storms, the region also has long wet seasons and flood periods. Thus, the Lingnan climate is mainly hot and humid with high temperature and rainfall. Climate conditions have two major influences on the building of gardens in Lingnan. On one hand, the solution to hot and humid climate mainly consists of ventilation, sunshade, heat insulation, temperature reduction, damp proofing, wind proofing and rain proofing. During the construction of a Lingnan garden, it is both important and necessary to consider the influences of hot and humid climate. On the other hand, with rich heat and waterfall, long summers and warm winters, and distinct dry and wet seasons, the evergreen plants reach growth spurt twice a year, and blossom twice or throughout the year. Rich plant resources lay a groundwork for the construction of Lingnan gardens. In the long history, the Lingnan people have followed the nature and improved the environment; they have learned lessons of climate adaptation and integrated gardens into architecture. Thus, a large number of gardens, which are proved to be successful in life and have great research values, have been created [2].

2 Temperature Reduction

In Lingnan gardens, the water surface is one of the important environmental factors to lower temperature, as well as a very effective measure to adjust the microclimate in the garden environment. People dug a pond as the 'water courtyard', or brought water into the garden: both measures help the exchange of hot and cool air and convection, thus resulting in natural ventilation and temperature reduction [3]. As shown in Fig. 1, the ponds are classified by their locations in the garden: they can be built in front courtyard, middle courtyard, back courtyard or side courtyard; some gardens have ponds in both front and back courtyards. For example, the building of Qinghui Garden in Shunde is characterized by its adaptability. In order to adapt to hot climate in the south, the garden was designed to be sparse and lower in the front and dense and higher in the back. The front yard faces south while the residential zone is in the north. A large water surface covers the front yard; the specific heat capacity of water is high, so when water

evaporates it can take away a lot of heat. The houses in the back yard have a compact layout, which is sparse but not empty, dense but not crowded. Most of the buildings were built against the prevailing wind in summer for good ventilation. In summer, the cool winds flow upon the large water surface in the front yard and blow endlessly to the residential zone in the back, making people feel fresh and relaxed.

3 Ventilation

The effect of thermal pressure, also called 'stack effect', is often applied in the building of Lingnan gardens for ventilation and heat radiating. Since buildings are different in sizes and shapes, temperature differences in architectural spaces cause air infiltration between interior and exterior under the drive of thermal pressure. Therefore, the temperature differences in different spaces is necessary for thermal pressure effect. As shown in Fig. 2, the Ke Garden in Dongguan adopts an ordered layout, which is common in Lingnan, and its building complex of 'connected houses and high mansions' stands around the courtyard. There are totally one building, six towers, five pavilions, six terraces, five ponds, three bridges, nineteen halls and fifteen houses in the garden, including two staggered flat courtyard structure; high belvederes, slender but quiet buildings and open forecastles make up the main body of the whole garden. Courtyards, patios, doors, windows and halls are used as major vents, and various spaces are used as air passages, such as compound stairs, staired paths, walk stops and stair houses. As shown in Fig. 3, after the ground in courtyards or patios absorb solar radiation heat, its temperature increases, and long-wave radiation heat is emitted and the near-ground air is heated. Therefore, the hot air rises to the top opening of the courtyard or the patio and spreads in the sky. The air pressure at the bottom of courtyards or patios is low, while the pressure at the bottom of halls is high. Resulting from such a pressure difference, the air at the bottom of halls will flow to courtyards or patios to fill the empty space left by the rising air from bottom of courtyards or patios to top. Meanwhile, the temperature at the top of courtyards or patios is relatively low, which allows a large amount of fresh air flowing from under the eaves into halls. The fresh air can fill the empty space left by the original bottom air, thus the 'thermal pressure ventilation' effect is caused: the relatively hot air in the halls flows out at the bottom, and the relatively cold air flows in at the top, resulting in a heat convection.

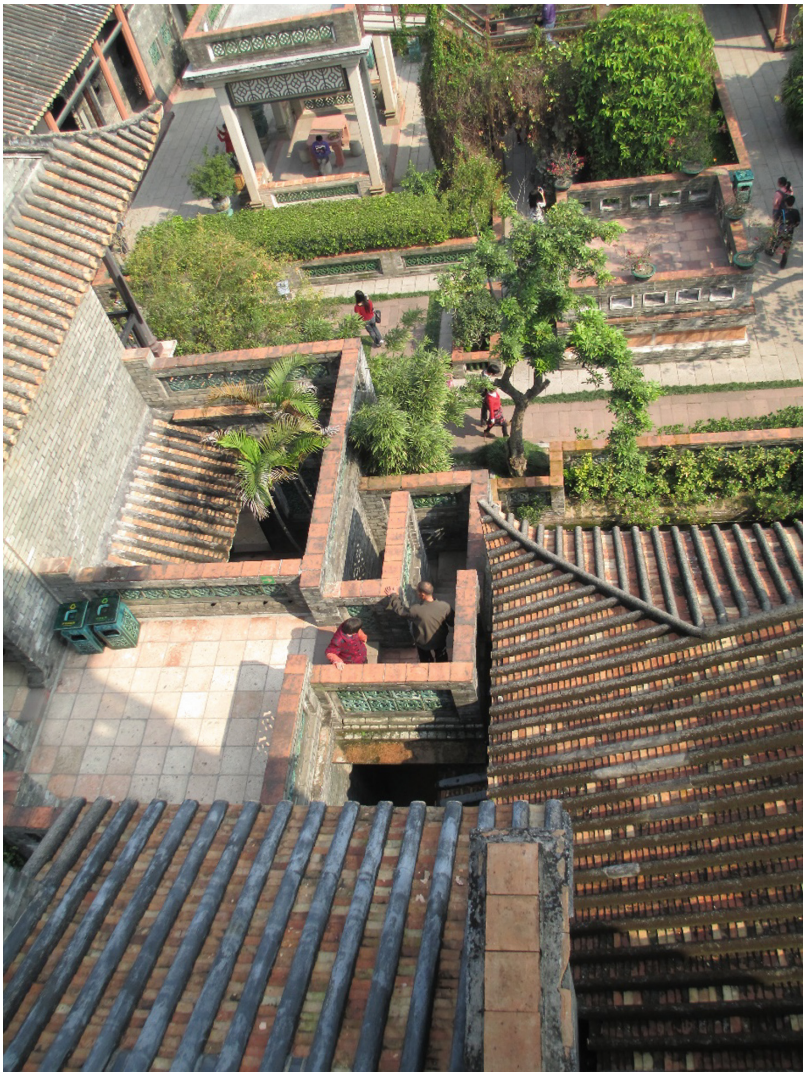

Fig. 2. The stairwell vent, the courtyard vent and the patio vent of the Ke Building in Ke Garden.

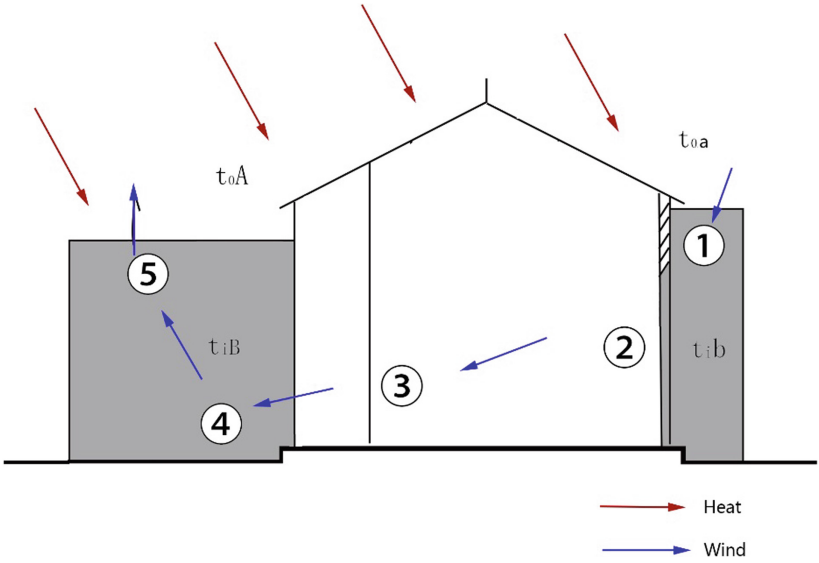

Fig. 3. The thermal pressure ventilation of courtyards and patios in summer

Note:

toA = air temperature in the upper portion of the big patio
tiB = air temperature in the lower portion of the big patio
toa = air temperature in the upper portion of the small patio
tob = air temperature in the lower portion of the small patio

In summer daytime: tiB > toa, tiB > tib, tib < toa, toA ≈ toa. Measured airflow: sky→①→②→③→④→sky

In summer nighttime: tiB < toA, tib > tiB, tib > toa, toa ≈ toA. Measured airflow: sky→④→③→②→①→sky

As shown in Fig. 4, the wind driven ventilation effect is that according to the fundamental of fluid mechanics, when a wind blows towards a building, the air flow against the wind is blocked, so the wind is forced to decelerate. The kinetic energy of the wind transforms into static pressure, and the pressure on the windward side becomes higher than atmospheric pressure, resulting in a positive pressure area [4]. When the wind is blocked by the windward side, it is forced to take a circular route quickly upon the building roof or around the building. The circle flow adds to wind speed, and the pressure on the top, the sides and the leeward side of the building is lower than atmospheric pressure, resulting in a negative pressure area. The so-called 'draught' refers to cross ventilation: when the positive pressure on the windward side and the negative pressure on the leeward side appear, and both sides have openings, a

short, straight and unobstructed air passage between the two openings can allow wind go through with little volume loss. The wind enters via the opening on the windward side, and leaves via the opening on the leeward side: such a wind driven ventilation is called 'draught'.

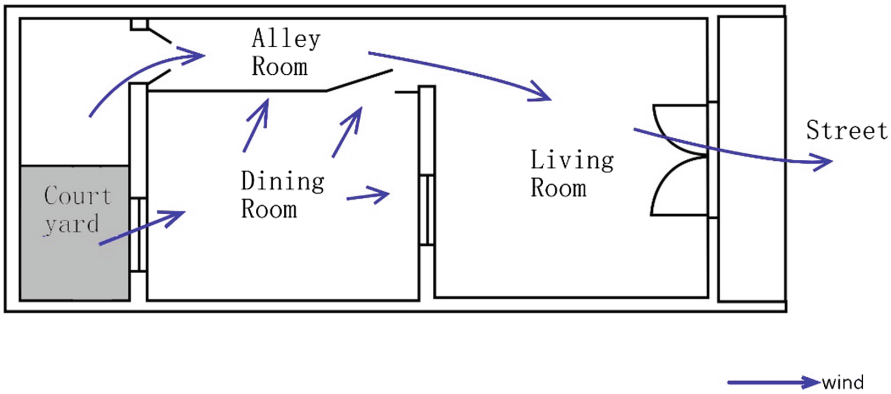

Fig. 4. A diagram of the wind driven ventilation of draughts.

The design of gates and windows in Lingnan gardens has a great influence on the cross-ventilation effect. In terms of gates, most entrances have a ventilated batten door outside, as well as a short batten door, which is commonly known as 'Tanglong'. The main functions of batten doors are ventilation, safeguard and privacy protection. Doors are often designed as mobile partition boards, and indoor screens are also mobile. Some doors have separate upper parts and lower parts; some are mobile at top half and a big gap at the bottom from the ground, allowing air flow freely from bottom to top; some are equipped with hollowed-out partition boards at top half and with ventilated short-wall partitions. All these varied styles of doors are beneficial for convection and ventilation [4]. As shown in Fig. 5, Manchuria window is also a common kind of window used in Lingnan gardens, and has various styles, including open will window, Manchuria window, side-axis window, center-axis window, removable window and wooden window. The windows can open by up-and-down sliding and upwards pushing, and both aim to form a larger windward surface, to create a larger windward angle and to accelerate air convection. On the second floor, the windows are replaced by ground partitions, whose lower half is equipped with ventilated and fixed wooden railings. Such a design can guarantee safety as well as double the wind volume.

Fig. 5. The center-axis Manchuria window designed by author in the expansion project of Qinghui Garden; the side-axis window in the Ke Garden.

4 Sunshade

Sunshade is one of the important measures to protect from heat and to lower temperature. Apart from cutting out direct sunlight and lowering temperature, sunshade can also increase shading surface and reduce radiant heat. Shading the opening parts on the wall can cause pressure difference and accelerate air flow to enhance ventilation. It is common for Lingnan gardens to adopt balcony sunshade, colonnade sunshade and overhanging eaves sunshade above doors and windows. An overhanging balcony can be used for sunshade, rain proofing and keeping cool; while the colonnade is available for passers-by, its sunshade can also help protect people from sun and raindrops, which can be found in the Yu Garden in Panyu. Besides, various kinds of overhanging eaves are common above doors and windows, including zig-zag brick eaves, corrugated brick eaves, polygonal brick eaves and overhanging brick eaves-bracket; in the Ke Garden of Dongguan and Li Garden of Kaiping, there were even wooden board overhanging shades and clamshell overhanging shades. In late Qing Dynasty and Minguo Period, under the influence of western architecture, gardens like Yuyin Hill House in Panyu began to adopt blinds. Meanwhile, the ground temperature will rise with the long-time sunshine casting on the ground, then the hot air will rise and pass into interior spaces easily. Therefore, preventing the ground's heat reflection caused by sunshine is a very important measure. It is common that Lingnan gardens adopt a dense layout. When the patio is big or the alleys are narrow and long, lattice walls or openwork windows are used to separate the big space, and the shades of lattice walls can decrease direct

sunlight on the ground. The grounds in Lingnan gardens are usually laid by granites or mosaic bricks. The granites are hard and smooth, and not prone to absorb radiant heat; they can absorb less heat and lose heat quickly, which helps reduce temperature. The mosaic bricks are hard with patterns in one-centimeter relief. The patterns in relief can not only help with skid proofing, prevent moss from growing high, and make the environment more delicate, but also add to shades effectively and reduce dazzling light reflection caused by direct sunlight. As presented in Fig. 6, in the Yuyin Hill House Garden, the Ke Garden in Dongguan and the new expansion of Qinghui Garden, the outdoor grounds are all laid by mosaic bricks. Besides, neat and crowded flower bases and flower stands are also common in Lingnan gardens, which can not only enrich the shading levels in space, but also help with sunshade. The flower bases and flower stands divide the surface into small squares to reduce the ground area exposing to sunlight. At the same time, the shadows cast by flower bases and flower stands can keep most parts of the garden stay in shade for most time of a day, which is also an important feature of Lingnan garden.

Fig. 6. The mosaic bricks adding to shades in the Ke Garden of Dongguan; the flower base and flower stand presented in a dense layout.

5 Rain Proofing

As there is no lagoon in Lingnan area, the rivers flow into sea directly, and tides will hold up river water or even enter into riverways. Such happens a lot especially in springs and summers, when intensive storms cause water puddles and fill pools and

rivers, and floods may outbreak. Therefore, the layout of riverside towns in Lingnan is principally based on water directions, and the 'comb layout' has become an important feature of Lingnan residences. The structure of comb layout is characterized by neat and ordered buildings, which align in north-south lines just like combs, and the alleys between two lines of buildings are named 'Li' and work as major traffic passages. Most of the Lingnan riverside towns have a small square, a semicircular pond or an elliptical pond in the front, and ancestral shrines are mostly located by water; almost all the houses were designed based on the principles that buildings should face waterbody directly, and alleys should be normal to the waterbody. Such a design is beneficial to quick rainwater drainage, and thus most of the Lingnan gardens follow this usual practice. For example, as shown in Fig. 7, the layout of Yuyin Hill House Garden in Panyu is very ordered: the Wugong Shrine Alley is normal to both the pond and the riverway outside the gate, and the pond is used for water storage, fish farming, drainage and flood control; the Hall of Deep Willows, the Cottage of Laid Ladle, the Waterside Pavilion and other main buildings, as well as alleys, are all normal to the square water surface, which, to the east, connects to the water network outside the garden by circular riverways. In the Liang Garden in Foshan, the Ancestral Shrine of Liang Family and alleys are all normal to the original Chen's Pond, and the Fenjiang Thatched Cottage, the Wuxiaduo House, the Qunxing Thatched Cottage, the Twelve-Stone House and other main buildings are also normal to the curled lake surface: the stagnant water are altogether drained into the urban river on the west.

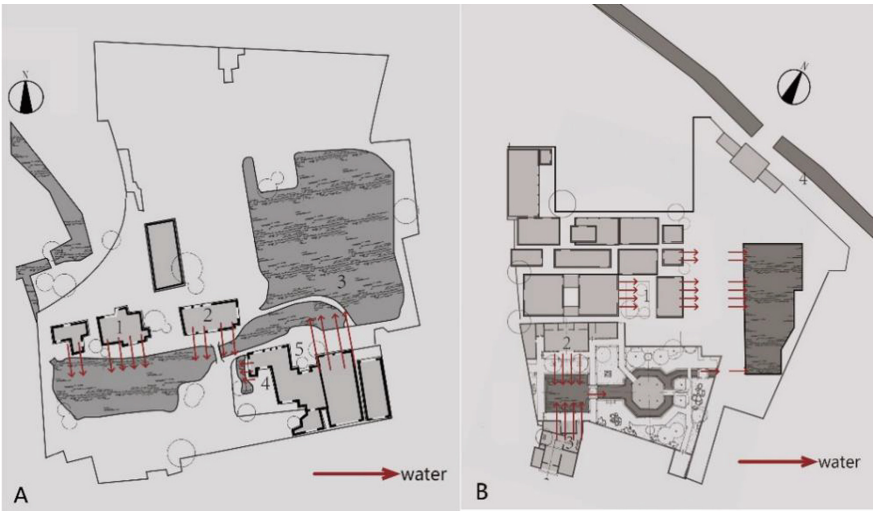

Fig. 7. The drainage normal to waterbody:

A. Liang Garden 1. Fenjiang Thatched Cottage 2. Wuxiaduo House 3. Ancestral Shrine 4. Qunxing Thatched Cottage 5. Sewer at the garden gate

B. Yuyin Hill House in Panyu 1. Wugong Shrine of Good Words 2. Hall of Deep Willows and the Cottage of Laid Ladle 3. Waterside Pavilion

6 Damp Proofing

The humidity is high in most of the buildings in Lingnan area, and will cause great harm to people who live for long periods. Ji Kang of Jin Dynasty had recorded in his Essay on Nourishing Life: 'A residence should be built on dry and cool high grounds to prevent the harm of dampness and miasma.' His essay indicates the importance of damp proof when building gardens. The humidity in buildings has three main sources. First, the water vapor in the air may pass into interior spaces, especially in springs when the relative humidity outdoors can be higher than 95% or even reach 100%. When water vapor comes indoors, the humidity and pressure will rise, making people feeling unfit. Second, when the construction quality is low, there can be leaks on the exterior protection, and the interior spaces will be humid. Third, the groundwater can also rise and permeate, which increases indoor humidity. Therefore, most of the Lingnan gardens use rock foundations. One choice is to build up firm dados, which can be as high as 1.5 m, as the groundwater can also rise for approximately 1.5 m. The dados can be built by laying bricks or stones. Another choice is to build stone pillars and pillar bases, which can prevent groundwater from permeating along bases and pillars. The stone pillar base is usually as high as the diameter of the pillar, and the biggest one can be 1 m high. The interior grounds and galleries are built by big red step bricks without any decoration, which are commonly known as 'termite bricks'. As shown in Fig. 8, the termite brick was a common kind of flooring material in Lingnan and was still in use until 1960s. The termite brick is square, and its size is 33 cm × 33 cm × 7 cm. The ground needs to be leveled with dry sands by 3 to 5 cm, then the bricks are laid, after which the joints should be filled by cement plaster. Such a practice is cheap and labor-saving; the bricks can absorb water, reduce dampness and prevent termite infestations. In the open air in Lingnan gardens, the grounds are often laid by mosaic bricks of Shiwan and local red sandstones, and grass belts are planted along the brick gaps. The mosaic brick is ivory with patterns cut in relief; it is not enameled and can absorb much humidity. The big step bricks, mosaic bricks and grass belts are all permeable materials, and are also very fit for the current 'sponge city' conception. The permeable materials, as stated above, are quite 'elastic' when adapting to environment changes and different natural conditions. When the weather is rainy or damp, the mosaic brick can absorb and permeate water, which is suitable for natural precipitation, surface water and groundwater. When it turns sunny, the brick, which is also hard and wear resistant, will turn dry and pale again.

Fig. 8. The permeable materials of Ke Garden in Dongguan: big step bricks indoors and mosaic bricks, red sandstones and grass belts outdoors. (Color figure online)

7 Wind Proofing

Lingnan is a typhoon-prone area. In summers and autumns, 50% of the typhoons in south China make their landfall in Lingnan, which makes the most serious natural disaster in the area. Therefore, in addition to good ventilation, the typhoon-proof measures were also taken into consideration when building Lingnan gardens [2]. Most of the Lingnan gardens are relatively small-sized and connected with residential buildings. Dense layout and multi-layer layout are very common. A garden with dense layout depends on closeness of buildings to enhance its wind resistant capability, and one with multi-layer layout always faces directly against the prevailing wind or typhoon around the year. It is measured that in a garden compound with four or five layers, the courtyard in the last layer will only receive less than 20% of the wind force. In terms of garden plants, those with deep roots and strong trunks were preferable for their wind resistant capability; local species such as camphor trees, Chinese banyan, palm trees, mango trees, longan trees and lychee trees are also common, while shallow-rooted plants like poplars, paulownia trees and southern magnolia are relatively rare. From the perspective of species, diverse kinds of plants grow in dots and clusters in Lingnan gardens. Trees with different forms and structures are chosen according to different environments or planting areas. Large arbors and small trees are planted together, with bushes and grass growing under them. From the perspective of arrangement, the designs often aim to enrich shadings and enlarge vertical greening area, in order to reach the whole contour's free flowing. A proper proportion of tall trees and density can help the plants' beauty as well as their wind resistant capability.

8 Conclusion

To conclude, in order to deal with hot and humid climate, measures such as ventilation, sunshade, heat insulation, temperature reduction, damp proofing, wind proofing and rain proofing were often used in the building of Lingnan gardens for their climate adaptability. Making rational use of sunshine, wind, temperature, humidity and other natural resources can help reduce our dependence on conventional energy; such a strategy is named 'passive ecology' by academy, which is different from 'active ecology'. Therefore, the study of Lingnan garden's climate adaption has become a global focus in the field of ecology and sustainability design. In the context that Chinese local features are gradually disappearing, the study has important implications to the building of public modern urban landscape and green spaces, as well as the guarantee of urban health and sustainable development.

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