4 Architectural spatial design strategies for summer microclimate control in buildings

a comparative case study of Chinese vernacular and modern houses[2]

ABSTRACT The objective of this paper is to clarify the spatial design strategies used to control the microclimate of a Chinese vernacular house in summer by comparing the building with modern Chinese rural houses and presenting ideas for contemporary architectural design practice. For this goal the spatial configuration, the spatial boundary conditions, the vegetation in the space and the human activity in the space

2 This chapter is the original version which is published as: Du, X., Bokel, R., & van den Dobbelsteen, A. (2016). Architectural Spatial Design Strategies for Summer Microclimate Control in Buildings: A Comparative Case Study of Chinese Vernacular and Modern Houses. Journal of Asian Architecture and Building Engineering, 15(2), 327-334. doi: 10.3130/jaabe.15.327

were analysed for the vernacular house and for modern rural houses. Also, field measurements were conducted to evaluate the summer thermal environment in the vernacular and a modern house. The results show that the vernacular house has a diverse spatial design and a better building microclimate, making it easier to obtain thermal comfort than the modern houses. Therefore, spatial design strategies of Chinese vernacular houses are still of great value to modern house design, especially when the free-running thermal comfort theory is applied.

KEYWORDS spatial design strategies; building microclimate; Chinese vernacular house; adaptive thermal comfort

4.1 Introduction

It is broadly accepted that buildings worldwide account for 20-45% of the total energy consumption, and this number is still rising, especially in developing countries. This has caused designers to examine contemporary architectural design strategies and to reconsider and re-evaluate the passive design strategies used in vernacular buildings. The term vernacular architecture is used for architectural design that uses locally available resources to address local needs. Vernacular architecture has evolved over a long period of time in one location to suit the local climate, culture, economy and historical context of that period (Oliver, 1997). People have traditional lifestyles in vernacular buildings in virtually every climate in the world, from the arctic to the tropics, in temperatures from below zero to over 40 °C, and historically without the benefit of gas or electrically driven mechanized heating and cooling systems (Meir & Roaf, 2003). China, with a vast land area and a long history, has a rich heritage of various types of traditional vernacular houses in different climate regions. The importance of implementing passive design strategies used in Chinese vernacular buildings into modern architectural design can be seen by considering the rising Chinese energy use. China is already the largest energy consuming country in the world. In the year 2007 the Chinese building sector accounted for 23% of the total Chinese energy consumption (Liang, Li, Wu, & Yao, 2007). By the end of 2012, there were 169.9 air-conditioning units per 100 urban households and 28.9 units per 100 rural households in Chongqing (NBSC, 2018). To decrease the energy consumption for buildings, the authors investigated the passive design features for summer thermal comfort in a typical Chinese vernacular house from a new perspective, i.e. in terms of spatial design, to control the building microclimate. The objective of this paper is to clarify the spatial design strategies used to control the microclimate of the Chinese vernacular house in summer. These strategies are then compared with strategies in modern Chinese rural houses. Ideas for contemporary architectural design practice are presented as a result.

4.2 Methodology

The authors of this paper introduce the term building microclimate as “a type of microclimate which involves indoor spaces and spaces surrounding the indoor spaces in a particular building”. It is not just the microclimate around the building; it also includes the indoor climate.

Santamouris and Asimakopoulos (1996) defined the microclimate as follows: “within a particular region, deviations in the climate are experienced from place to place within a few kilometres distance, forming a small-scale pattern of climate, called the microclimate”. It is a flexible concept whose scale can be the region, city, neighbourhood or building. However, regardless of the scale, the author’s literature review showed that previous definitions considered the microclimate to be the microclimate outside the building. This new definition of building microclimate is very useful in relating the thermal comfort in the building to the microclimate in the indoor, semi-indoor and outdoor spaces of the building. Passive design, especially spatial design, can modify the building microclimate (Du, Bokel, & van den Dobbelsteen, 2014). In a particular building microclimate, the spatial configuration and the spatial boundary conditions are the major elements of spatial design. These elements can control the building microclimate by influencing the physical parameters: air temperature, humidity, solar radiation and wind velocity.

General information on vernacular and modern houses is given in section 4.3. Spatial design aspects such as the area, size, height, spatial configuration, spatial boundary conditions, vegetation and occupants’ activities of a vernacular house and of five modern rural houses are given in section 4.4. These spatial design aspects were obtained from a field survey and from interviews with the occupants.

In addition, field measurements were performed to evaluate the summer thermal environment in the vernacular house and in one of the investigated modern houses closest to the vernacular house. The measurements were performed in the summer period from 00:00 to 24:00 on August 28th 2012. In the vernacular house, the measured parameters were: air temperature, relative humidity, and wind velocity at key positions. The measurement points are shown in figure 4.1. In the modern house A, air temperature and relative humidity at different floors were measured. The measurement points are shown in figure 4.2. The measurement instruments were temperature loggers and temperature and humidity loggers recording data every five minutes. The accuracy of the temperature measurements is 0.2 °C, and the accuracy of the humidity measurements is 5%. The instruments were located at 1.2 m above the ground in the indoor and outdoor measuring points. The wind velocity was measured using a manual anemometer with a range of 0.1-30 m/s and an accuracy of 5% plus 0.05 m/s. During measurement periods, the vernacular house was free-running, i.e. without cooling and heating, the occupants of the modern house use fans for ventilation and cooling. The weather condition on the measured days was partly cloudy with occasional rain at night which is a typical summer weather condition in the Chongqing area. The measurement results, displayed in hourly averages are shown in section 5. Finally, lessons were learned from the vernacular house and discussed in section 6.

4.3 The studied houses and their local environment

The studied houses are located in the Shuangjiang town of Tonnan County, Chongqing, China. The vernacular house is a typical and traditional Chinese wall-enclosed courtyard house that is well preserved and therefore valuable as a case to study the Chinese traditional architectural design strategies. The symmetrical and axial wall-enclosed courtyard is the typical character of this type of dwelling. The whole building covers an area of 3,500 m^2 and the building area (S) is 1,768 m^2 (excluding gardens, courtyards and patios). Figure 4.1 shows the aerial view, the plan and the sections of the house. The vernacular house layout and spatial design are suitable for the traditional Chinese family that consisted of several subordinate families. Most of the rooms in Chinese courtyard dwellings, except the kitchen and the main hall, have flexible functions i.e. they could be bedroom, reading room or storeroom (Hu, 2008). Therefore, the vernacular house is neither a single building block nor a group of building blocks organized by the courtyards.

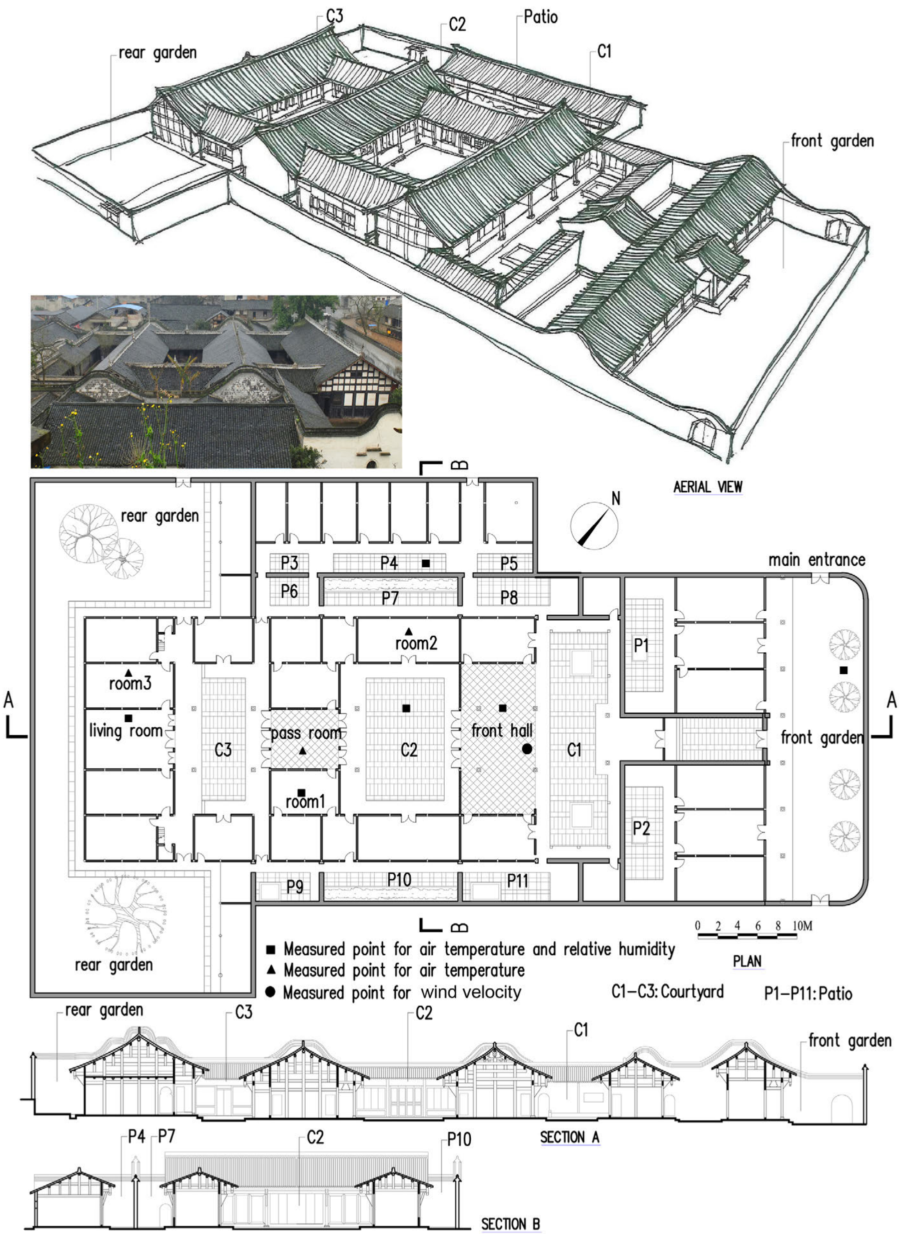

FIG. 4.1 The aerial view, plan and sections of the vernacular house and the measured points

TOC

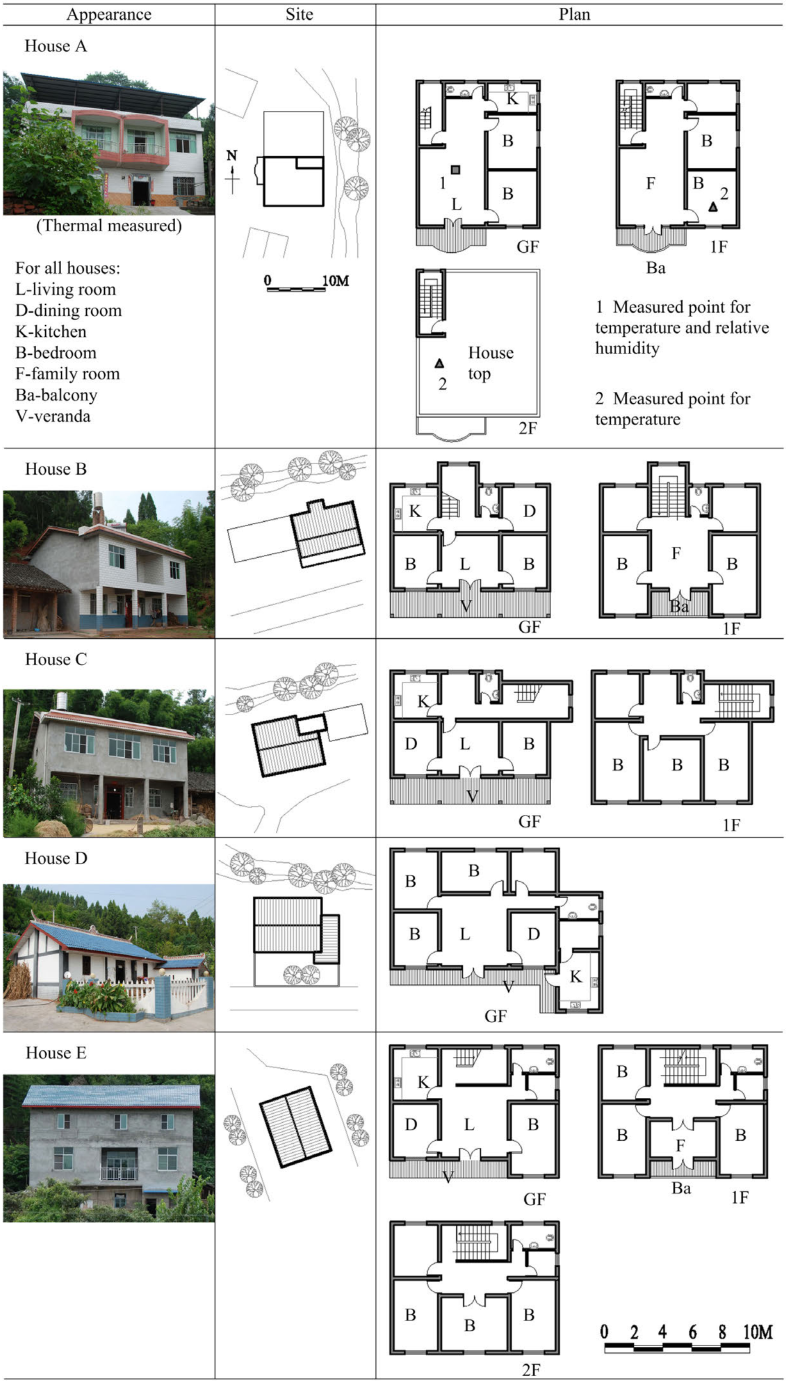

FIG. 4.2 The appearance, site and plan of the five investigated modern rural houses

TOC

Five modern houses near the vernacular house were also investigated. These are typical local rural detached houses built between 2008 and 2011 by the famers themselves. The total area of the houses is 95 m^2 to 270 m^2. The appearance, site and plan of the five houses are shown in figure 4.2. The lifestyle in the rural house is close to a modern lifestyle although the inhabitants have retained some rural traditions. Normally, a family consists of three to six people. The rooms have clear functions with the living room, bedroom, kitchen and toilet as the basic elements. The thermal aspects in one of the houses (house A) were measured. House A is located approximately 480 m from the vernacular house. It is a typical rural two-story newly built residential building. The whole building is oriented east-west, covering an area of approximately 85 m^2, approximately 10 m long from east to west and 8 m wide from south to north.

The studied houses are located in the south-west of China, Chongqing and belong to the hot summer and cold winter climate zone (GB50176-93, 1993). The annual average temperature is 16 to 18 °C, and the annual relative humidity is 70% to 80%. The most extreme high temperature is 41.9 °C and the most extreme cold temperature is -1.7 °C. In summer, the maximum average temperature reaches 28.1 °C in July and the relative humidity is between 75 and 80%, the prevailing wind comes from the northwest and the average wind velocity is 1.6 m/s (National Meteorological Information Center of China Meteorological Administration & Department of Building Technology Tsinghua University, 2005). The summer here is extremely hot, humid and uncomfortable.

4.4 Spatial design of the studied houses

4.4.1 Spatial configuration

Indoor space

In the vernacular house, there are fifty-one rooms varying in size from 15 m^2 to 55 m^2, surrounded by courtyards or patios. The total area of the indoor spaces is 1,123 m^2, which is approximately 63.5% of the total area of the building (S). The rooms that surround courtyard 2 and courtyard 3 are the major rooms (living room, bedroom, dining room etc.) for the homeowner (figure 4.3). Other rooms are service rooms. The height of the rooms without attics or ceilings is 5 m to 7 m and the height of the rooms with attics or ceilings is 3 m to 4 m. In the modern house, six to twelve indoor spaces are present in each of the five objects. The areas of the rooms are 7 m^2 to 25 m^2 and the heights are 2.8 m to 3.3 m (figure 4.2).

Semi-outdoor space

The semi-outdoor space is a type of space with a semi-enclosed wall or roof. It is also called “grey” space or “buffer” space in architectural design. A Semi-outdoor space is an important component in architectural spatial design because it can provide diverse spaces and can flexibly connect the indoor spaces and the outdoor spaces. Two types of semi-outdoor spaces were designed in the vernacular house. One type is the transitional space between the indoor space and the outdoor space. The outside corridor and veranda are examples of the transitional space type. Another type is the semi-enclosed room with large openings. There are two semi-enclosed rooms in the vernacular building: the pass room and the front hall (figure 4.3). The total area of the outside corridor is approximately 484 m^2, 24.7% of the total area of the building (S), and the area of the semi-outdoor rooms is around 161 m^2, 9.1% of the total area of the building (S). The depth of the outside corridor is 1.5 m to 3.0 m. The height of the semi-outdoor spaces is equal to the adjacent indoor spaces.

For the modern house, two types of semi-outdoor spaces were designed. One is an outside veranda, which was set at the entrance; another is a balcony, which was set at the first floor. The depth varied from 1.2 m to 1.8 m (figure 4.2). The total area of the veranda and balcony is between 6%-8% of the total area of the houses.

Outdoor space

Outdoor space here refers to the space around the building, without a roof, that is directly exposed to the natural environment. Courtyards, patios and gardens are the main components. In this article, a courtyard is identified as having a small height to width ratio, and a patio is identified as having a large height to width ratio. Garden refers to a large green area space not completely surrounded by rooms.
In this vernacular house an abundance of courtyards and patios were designed to provide natural light and ventilation for the numerous rooms. There are three main courtyards, eleven patios, one front garden and one rear garden in the house

(figure 4.3). The three main courtyards are located in the centre and on the axis of the building. The total area of the outdoor spaces is 1,732 m^2, which is 49% of the total covered area of the building. The size, area, height and aspect ratio of all of the courtyards and patios are listed in table 4.1. The three courtyards are surrounded by the outside verandas and the patios are surrounded by verandas and enclosed walls. There are no courtyards or patios in the modern houses.

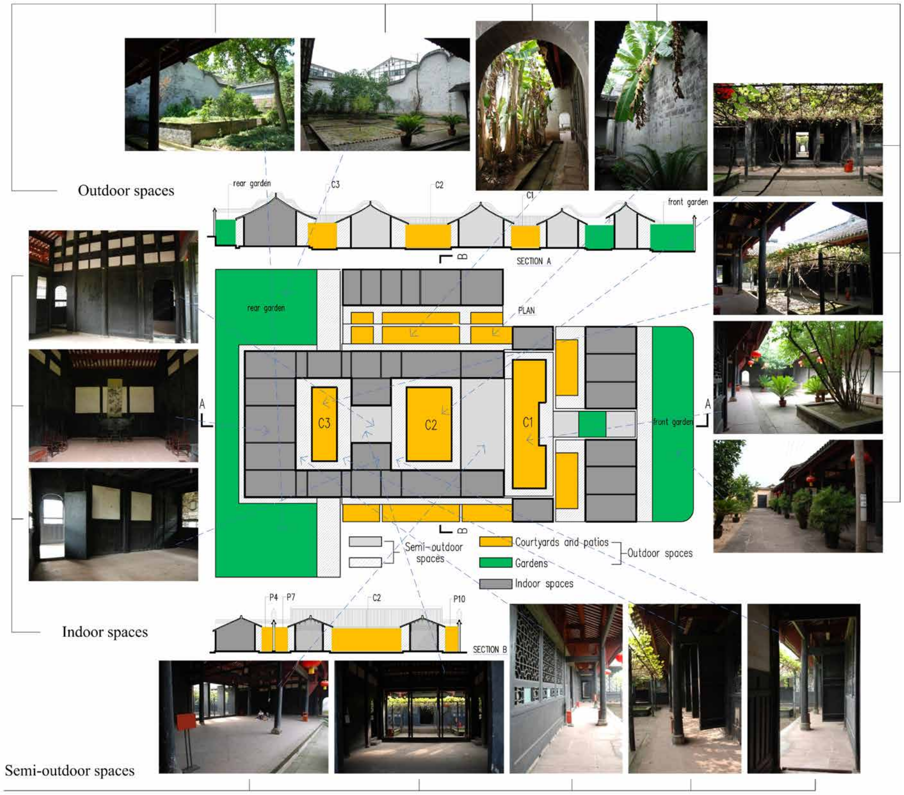

FIG. 4.3 The spatial configuration of the vernacular house

TABLE 4.1 Size of the courtyards and patios in the vernacular house

	Courtyards			Patios										
	C1	C2	C3	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
Width (m)	21.5	12.4	12.4	9.5	9.5	3.9	11.5	5.7	3.9	13.5	7.3	6.4	13.6	8.9
Depth (m)	5.8	7.9	4.4	4	4	2	2	2	2.9	2.9	2.9	2.9	2.9	2.9
Height (m)	5	5	5	6	6	6	6	6	6	6	6	6	6	6
Ratio (H/D)	0.86	0.63	1.24	1.5	1.5	3	3	3	2	2	2	2	2	2
Area (m^2)	125	98	55	38	38	7.8	23	11.4	11.3	39.2	21.2	18.6	39.4	25.8

4.4.2 Spatial boundary conditions

Openings in the spatial boundary

1 Window

The traditional Chinese wood lattice window is used in the vernacular house. Windows are approximately 30 to 40% of the external walls. The traditional window is latticed into small cells by small wooden frames. There are a few cells with glass, other cells are empty but have translucent fabric shading. All of the windows in the modern houses, studied for this paper, had aluminium alloy frames with single glass. The window size in the major rooms is 1.5 m x 1.5 m to 1.8 m x 1.8 m. The modern windows are sliding windows, of which only half the area can be opened.

2 Door

In the vernacular house, the doors are wooden with a solid panel at the bottom. The construction of the upper half of the door is similar to the windows, with lattices. The doors in the external walls are large, especially in the walls of the living room, pass room and front hall, which are located on the axis of the building. The doors can be completely opened.

The doors in the indoor walls of the modern houses are wooden doors without any openings. Their size is 0.9 m x 2 m. The doors in the external walls are made of steel without an opening. Their size is approximately 1.2 m x 2.1 m.

3 Opening

In the external walls of the vernacular house, in addition to windows and doors, there are openings high in the external walls for ventilation. These are always latticed into cells with a wooden frame similar to the style of the windows. Doors and windows are the only openings in the modern houses.

Material use of the spatial boundary elements

Wood, brick, tile and stone are the main materials used in this vernacular house. The structure of the vernacular house is a traditional Chinese timber framework structure with logwood columns and beams. Most of the external and internal walls are constructed with a timber frame. Walls can be constructed using more than one material. The bamboo-mud wall uses woven bamboo as either the structure or the reinforcement of the wall and mud as the filling and finish. Brick was used for the enclosed wall around the building. Sandstone was used for the outside area and on parts of the indoor floor. Some indoor floors were made of wood. Wood is also used as a structural material for the roof. Black tile was used as the top layer of the roof.

In the modern house the main construction material was reinforced concrete and brick. Brick was used for the external and internal walls. Concrete was used for the ground floor and reinforced concrete slabs were used for the roof and floors.

4.4.3 Vegetation in the different spaces

The vernacular house has abundant room for vegetation in the outdoor spaces: front garden, rear garden, courtyards and patios. The vegetation consists of trees, bushes, herbs and climbing plants. Trees are mostly applied in the garden; bushes and climbing plants are applied in the courtyards and herbs are applied in the patios (figure 4.3). There is no vegetation in the modern houses. However, in the rural environment, there are trees and woods at the back of the rural houses as can be seen in figure 4.2.

4.4.4 Human activity in the spaces

The vernacular house is a free-running building, i.e. without any mechanical cooling or heating. Human activity in the building adapts to this situation. The occupants of the vernacular house adjust their activities to the thermal environment present in the house and obtain thermal comfort by moving to a different area and by changing the boundary conditions. In the morning the temperature is low so that occupants can undertake any activity in every space. It shows that in summer the morning is the best time for activities. In the afternoon, as the indoor temperature rises, occupants prefer to open all the doors of the semi-enclosed rooms (pass room and front hall) and remain there. In the evening, after sunset, occupants prefer to stay on the veranda, in the semi-enclosed rooms or in the courtyards. At night, the occupants remain in the indoor space where they open all the windows. During extremely hot days, even at night, the occupants prefer to stay in the semi-enclosed rooms.

The modern houses are free-running for most of the summer period. During extremely hot days, the occupants use mechanical cooling such as a fan. As in the vernacular house, occupants in the modern houses have no preferred room in the morning. In the afternoon, they prefer to stay on the ground floor, as there is no other kind of semi-outdoor space available. In the evening, occupants open the door on the ground floor and stay there or move outside. At night, the occupants go to the first floor or remain on the ground floor.

4.5 Comparison of the thermal environments

Figure 4.4(a) shows the comparison of the measured air temperature in the vernacular house and the modern house. It was found that in the vernacular house, in the living room, room 1, room 2 or room 3, the indoor temperature remained at approximately the same level during the day. In the modern house, the temperature in the bedroom was much higher than in the living room because the living room is on the ground floor and therefore has a better thermal buffer than the bedroom on the first floor. In the vernacular house, there is a remarkable temperature difference in the different types of spaces (indoor space, semi-outdoor space and outdoor space). This difference is not present in the modern house during the day in summer.

At night, the indoor temperature (living room, room 1, room 2 and room 3) in the vernacular house remained at approximately (within 1 °C) the same level as the outdoor temperature (front garden), whereas the indoor temperature (living room-M and bedroom-M) in the modern house was higher (3 to 4 °C for the living room and 4 to 5 °C for the bedroom) than the outdoor temperature (house top-M). This indicates that when the outdoor temperature decreases, the heat in the vernacular house dissipates more easily than in the modern house. The indoor thermal environment in the vernacular house was better than in the modern house at night. This can significantly influence the occupants' sleeping quality. Because an investigation showed that 60 to 90% of local people complained that they were sleepless on summer nights due to the sweltering and sultry weather (Fu, 2002).

During the day, the indoor temperature (living room, room 1, room 2 and room 3) in the vernacular house was higher than the temperature on the ground floor of the modern house (living room-M) as the environmental temperature of the vernacular house was higher than the modern house. Nonetheless, the indoor temperature in the vernacular house (except for room 2) was lower than the temperature on the first floor (bedroom-M) of the modern house with a maximum difference of 1.5 °C. The temperature in the bedroom of the modern house (bedroom-M) remained at a high level throughout the entire day. In the vernacular building, the outdoor temperature (front garden) peaked at 36.5 °C around 14:30, while the indoor temperature (living room) peaked at 31 °C at 16:30. There is an obvious time delay, which is around two hours, between the peak temperatures. This time delay is not present in the modern house. The time delay helps the vernacular building to obtain a better thermal environment during the entire day.

Figure 4.4(b) shows the comparison of the measured relative humidity in the vernacular house and the modern house. Generally, the relative humidity of the measurement points in the vernacular house was lower than in the modern house which can obviously influence the occupants' thermal sensation in the hot and humid climate (Zhang & Yoshino, 2010). The only exception is that the relative humidity in the living room of the vernacular house was approximate 8%-10% higher than in the living room (living room-M) of the modern house during the night.

The measured wind velocity in the vernacular house is shown in figure 4.5. In figure 4.5, it can be seen that there is a continuous airflow in the front hall of the vernacular house during the day. The average wind velocity was 0.74 m/s. The occupants in the vernacular house reported that they can always feel an air flow, while in the modern house, the occupants complained there is not enough wind in summer.

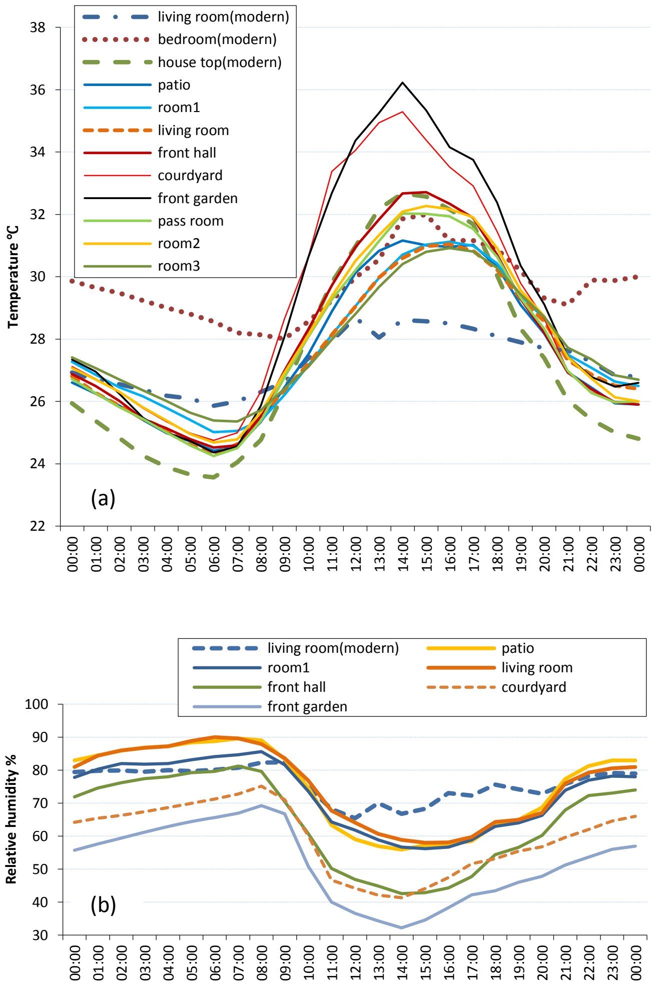

FIG. 4.4 (a) Measured air temperature in the vernacular and modern house (M) (b) Measured relative humidity in the vernacular and modern house. Hourly averages are displayed.

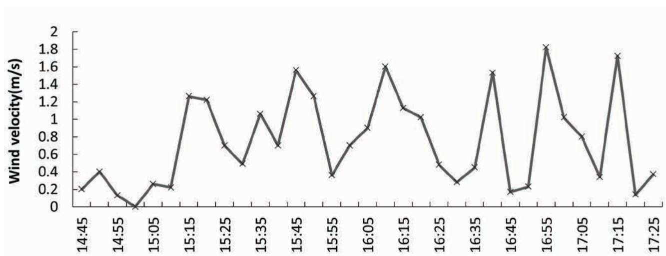

FIG. 4.5 Measured wind velocity in the front hall of the vernacular house

4.6 Strategies learned from the vernacular house

4.6.1 Diverse spaces

The biggest difference in spatial configuration between the vernacular house and the modern house is that the vernacular house is actually a combination of a group of houses, whereas the modern house is a single house. Therefore, the larger diversity in spatial design and spatial configuration of the vernacular house provides a good shading system and more natural ventilation. This potential can modify the building microclimate and adaptive spaces for occupants. As mentioned in section 4.1, in the vernacular building the total area of gardens, courtyards and patios is approximately 49% covered building area, and the area of semi-outdoor spaces is approximately 33.8% of the total area of the vernacular building, which is much larger than the percentage (6%-8%) of the modern houses. The high percentage of these spaces underlines the importance of these spaces for thermal comfort in summer.

Courtyards determine the arrangement of functional rooms, creating a good outdoor environment with vegetation and playing an important role in cross-ventilation and lighting. All the major rooms in the vernacular house are centred by three courtyards. Cross-ventilation is possible as the wind-assisted air can easily flow into the rooms through the one courtyard and flow out through the other courtyard. The wind velocity measured in the front hall proved that the average wind velocity was 0.74 m/s.

The patios are also indispensable for the vernacular house, as they have a major role in natural ventilation and solar control. A patio is clearly an important element in the architectural design because eleven patios were designed for this building. A patio is a tall, narrow and richly vegetated space with a height to depth ratio of 1.5 to 3, and its original purpose is to improve daylight access into the large and deep buildings. Such a narrow and richly vegetated space makes it difficult for the sunlight to reach the bottom of the patio and the adjacent indoor spaces. As a consequence, the measured peak temperature in the patio was 5 °C lower than the outdoor temperature (front garden) (figure 4.4(a)). The temperature difference between the top and bottom of the patio makes stack ventilation possible.

As mentioned in section 4.4.1, two types of semi-outdoor spaces were designed in the vernacular house: the one type being the verandas and the outside corridors and another type the semi-enclosed rooms. The outside verandas surrounding the courtyards and patios are a buffer space between indoor and outdoor spaces. With their great depth, the verandas shade the envelope of the indoor spaces well. Thus, they can create a transitional area with a lower air temperature. Due to their openness, the, occupants in the semi-outdoor spaces can catch the wind from various directions and the thermal sensation of the occupants is therefore much better than in the enclosed indoor environment (Szokolay, 2000). The lower relative humidity in the semi-enclosed spaces also contributes to a more comfortable thermal sensation. Having semi-outdoor spaces provides a wider choice of living spaces for the occupants, so that the occupants can choose their preferred thermal environment in summer.

According to the adaptive thermal comfort theory, “if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort” (Humphreys & Nicol, 1998). Moving to a thermally more comfortable location in the house, including the semi-outdoor spaces is one of the possible adaptive reactions of the occupants.

The indoor spaces of the vernacular building are relatively simple, but they have a remarkable characteristic: the sloping roof as the principal form, with a large height. As mentioned in section 4.4.1, the height of the rooms in the vernacular house is much higher than the height of the rooms in the modern house. The rooms in the vernacular house also have a larger volume. In the large space, air can move more easily and remain fresher and occupants will feel more comfortable.

The spatial configuration in the modern house is relatively simple; most of the spaces are single indoor spaces. An independent microclimate cannot be created in the modern building because of its simple spatial design. Thus, the modern house cannot create enough shading to prevent heat gains and cannot obtain enough natural ventilation. Occupants have few choices to move to a different space to adapt to the thermal environment in the modern building due to the limited availability of semi-outdoor spaces.

4.6.2 Adaptive boundary conditions

The total area of openings (window, door and opening) took a large percentage of the envelope of the vernacular house, as mentioned in section 4.4.1. The most important design characteristic of the windows and the openings are that they consist of empty lattices without glass. This ensures that the heat in the indoor spaces can easily dissipate at night. It is one of the reasons why the temperature in the indoor spaces is close to the outdoor temperature at night. In the modern houses, the aluminium window is completely covered with glass and cannot open completely (maximum 50 %). Therefore, the indoor temperature remained at a high level at night.

The large door area in the envelope of the vernacular house, especially in the semi-enclosed rooms (pass room and front hall), can be completely opened. This adaptive design ensures that the doors can be closed in winter to limit the heat loss and can be opened in summer to dissipate heat at night and obtain more cross-ventilation during the day.

4.6.3 Heavy and light materials

Both lightweight and heavyweight materials are used in the vernacular house. As mentioned in section 4.4.2, lightweight material (timber) was used in the main external walls and partitions, with a U-value of around 3.2-3.6 (W/m^2K). In contrast, heavyweight material (sandstone, tile and hollow brick) was used in the floors, roofs, enclosed walls and part of the gable walls, with the U-value of 1.2-1.5 (W/m^2K). A major benefit of using lightweight materials in the walls is that the indoor spaces can be cooled down quickly after sunset, i.e., the indoor heat can dissipate quickly at night. The measured indoor temperature was close to the outdoor temperature at night, which proves the benefit of using lightweight materials. The heavyweight materials can store the heat at night and delay the peak temperature in daytime. The heavy roof has a very good insulating function. In the modern building, brick and concrete slab are used, which is common in this area of China. The insulation of the modern walls and roofs (U-values of 1.5-2.0 W/m^2K) is better than the timber wall used in the vernacular house. However, better insulation is not good for heat dissipation at night. This difference in insulation can explain why at night the indoor temperature was much higher than the outdoor temperature in the modern building. The indoor thermal environment of the modern house at night in summer is therefore not as good as in the vernacular house.

4.6.4 Vegetation

As mentioned in section 4.3, the vernacular house has a lot of vegetation whereas there is hardly any vegetation in the modern house. Various plants are planted in the outdoor spaces, i.e., courtyards, patios and gardens, of the vernacular house. The lush vegetation in the courtyards and patios provide enough shading to prevent direct solar radiation on both the envelope and the floor of the building. The measurements show that the air temperature in the courtyards and patios is lower than the temperature in the outdoor space (front garden). Especially in one of the patios (measured), the temperature was close to the indoor temperature, with a maximum temperature difference with the outdoor temperature (front garden) of 5 °C (figure 4.4(a)). Vegetation seems a very effective strategy in modifying the microclimate of the vernacular building in this study.

Santamouris and Asimakopoulos (1996) also stated that apart from the decorative function of vegetation, the vegetation also modifies the microclimate and the energy use of buildings by lowering the temperature of the air and of the surfaces. Vegetation increases the relative humidity of the air, functioning as shading devices and channelling the wind flow.

4.7 Conclusions

Various passive cooling strategies have been adopted in the vernacular house to cool the space in summer. The spatial design improved the microclimate in the house. An optimum solar control system and a good natural ventilation system have achieved a good building microclimate in the vernacular house. The diversity in spatial configuration also provided different spaces for the occupants from which to choose their preferred thermal environment. The adaptive boundary design (doors and windows) between the spaces makes it possible to transform the spaces easily from an indoor to a semi-outdoor space.

The modern rural houses have a “modern” spatial design which is adapted to “modern” life, and “modern” materials are used in the construction. However, the measurements showed that the modern design does not achieve a satisfactory summer thermal environment for occupants under free-running conditions. The modern house has lost the local bioclimatic technologies, i.e. the low-tech and energy saving measures but, at the same time, high-tech technologies are not utilized to obtain thermal comfort because of the poor financial situation of the rural occupants[3].

This study shows that the spatial design strategies of Chinese vernacular houses are still of great value to modern house design, especially for free-running building design. Obviously, the occupants' life style in the vernacular house and modern houses is different, which influences the architectural spatial design. Design issues such as privacy, safety and finances also influenced the spatial design of the modern house to achieve diverse spaces. However, without using the vernacular spatial design strategies, a good thermal comfort without mechanical cooling cannot be obtained in a modern house.

3 It should be noted that some of designs in the modern rural house have their advantages. For example, the two floors design made the living room in the ground floor of the modern house is cooler than other rooms because the shading and insulation through the first floor.

References

Du, X., Bokel, R., & van den Dobbelsteen, A. (2014). Building microclimate and summer thermal comfort in free-running buildings with diverse spaces: A Chinese vernacular house case. *Building and Environment, 82*, 215-227. doi: 10.1016/j.buildenv.2014.08.022

Fu, X. (2002). *Building energy saving technology in hot summer and cold winter region*. Beijing: China Architecture and Building Press.

GB50176-93. (1993). Thermal Design Code for Civil Building. Beijing: China Planning Press.

Hu, X. (2008). Boundaries and openings: spatial strategies in the Chinese dwelling. *Journal of Housing and the Built Environment, 23*(4), 353-366. doi: 10.1007/s10901-008-9123-z

Humphreys, M. A., & Nicol, J. F. (1998). Understanding the adaptive approach to thermal comfort *ASHRAE Transactions, 104*(1), 991-1004.

Liang, J., Li, B., Wu, Y., & Yao, R. (2007). An investigation of the existing situation and trends in building energy efficiency management in China. *Energy and Buildings, 39*(10), 1098-1106. doi: 10.1016/j.enbuild.2006.12.002

Meir, I., & Roaf, S. (2003). *Between Scylla and Charibdis: In search of the suatainable design paradigm between vernacular and high-tech.* Paper presented at the PLEA, Santiago, Chile.

National Meteorological Information Center of China Meteorological Administration, & Department of Building Technology Tsinghua University. (2005). Chinese meteorological dataset for built thermal environment. Beijing: China Architecture & Building Press.

NBSC. (2018). Annual report (Publication no. http://data.stats.gov.cn/english/easyquery.htm?cn=C01). Available from National Bureau of Statistics of China National database, from National Bureau of Statistics of China

Oliver, P. (1997). *Encyclopedia of Vernacular Architecture of the World.* New York: Cambridge University Press.

Santamouris, M., & Asimakopoulos, D. (1996). *Passive cooling of buildings*. London: James and James

Szokolay, S. V. (2000). *Dilemmas of warm humid climate house design.* Paper presented at the Proceedings of PLEA 2000 Architecture, City, Environment, Cambridge,England.

Zhang, H., & Yoshino, H. (2010). Analysis of indoor humidity environment in Chinese residential buildings. *Building and Environment, 45*(10), 2132-2140. doi: 10.1016/j.buildenv.2010.03.011