# Indoor thermal comfort of traditionally residential dwellings in southern Shaanxi of China

*This study makes a sampling investigation of the current construction and indoor thermal environment in the old street in the ancient town Qinmuchuan. Based on the statistic analysis of the practical measured data about indoor humidity and wind speed in summer and also climate adaptation of buildings by using Weather Tool 2011, it puts forward adaptable passive strategies for construction designs. In the later rebuilding of traditional residential dwellings, walls made of raw soil should be used to adjust the weather conditions in southern Shaanxi. Then, it suggests promoting new techniques and measures. Meanwhile, passive designs for construction should be fully used for the enhancement of indoor thermal comfort. Given suitable conditions, the technology of active architectural energy saving can be employed.*

*Keywords: Thermal environment indoor, adaptive thermal comfort zones, passive design strategy, traditional dwellings*

## 1. Introduction

It is widely acknowledged that buildings account for more than 30% of total final energy consumption in the world and are responsible for consuming 35%-40% in the developed countries[1,2], among which 30-60% are for improving indoor thermal environment in buildings[3]. In China, the building energy consumption has increased by 45% in two decades[4]. The proportion of building energy consumption was about 27.5% in 2001[5] and it was up to 36% (i.e. construction and operation) in 2014[6]. With China's prosperous economy and growing urbanization rate, the Chinese government has to, on the one hand, implement the total energy use control to limit the building energy consumption in operation under 1.1 billion tce (23%)[3], and on the other hand ensure a much healthy and comfortable indoor environment. China covers a vast territory with five climate zones for building thermal design purpose, southern Shaanxi belongs to 'Hot Summer Cold Winter'[7]. How to inherit the wisdom experience of traditional residential buildings in passive design? In the past decades, many researchers have conducted studies on indoor thermal environments and comfort in different regions in China and showed some useful and common knowledge. Previous research has shown that many researchers conducted studies on the correlation between indoor thermal environment and climate, such as, field survey of residential buildings in summer and winter covered nine cities from 1998 to 2004 conducted by Yoshino et al.[8] highlighted a great diversity in indoor thermal environments between the northern and southern China. Regarding the indoor environmental conditions of passive houses, however, there are also some negative findings. Langeretal[9]. evaluated the indoor environment in 20 new passive houses and 21 conventional houses and found that passive houses have significantly lower relative humidity. That was also reported in Austria[10], where measurements indicated extended periods below 30% relative humidity, giving rise to 30% of occupants complaining about the dry indoor air during winter. Local discomfort related to cold floor in winter was also found in PH post-occupancy evaluations[11,12]. This is because the heating demand of passive house is so low that traditional radiant heating system can be omitted and it can be heated simply by conditioning the supply air. Climate partition based on passive design strategy research, summarizes the content of each passive design strategies, design method and analysis method, using the relevant statistical software is verified, qualitative analysis, formed the passive design strategies of different climate zone is effective sorting and single design strategy in different climate zones for the sorting[13-15].

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## 2. Subjects

Actually, selected object is principally typical and representative, so the old street in the ancient town Qingmuchuan is selected as an investigated object for its intactness and present usability. Characterized by the courtyard type, large volume and complex structure, Rongshengchuang boathouse has a high research value.

### 2.1. Climate condition

Southern Shaanxi (33°N107°E) is one city of Shaanxi province located in the middle of China and belongs to the severe Hot Summer Cold Winter climate zone. The climate of southern Shaanxi is characterized by Lower temperature outdoor air in January. Some important weather characteristics are given as follows, the outdoor air temperature is −10°C on average, and the average daily highest/lowest outdoor temperatures are 0°C/3°C in January. Because it is located in the mountain environment, Qinba mountain traditional local-style dwelling houses built around the mountain, more open construction pattern, is mostly the character "-" or "L" two plane form, tile roof, cold stand soil (rammed earth wall) wood structure system, has good ecological performance. However, there is no reasonable heating facilities in residential construction, and the indoor comfort is poor. Especially in the severe cold weather in recent years, indoor comfort issues are more prominent and serious.

### 2.2. Analysis and test of thermal environment in construction

The testing time is set on August 21 and 22, 2015. The continuous temperature test lasts 48h, and the ventilation test is 24h. The weather is sunny. Main test instruments are temperature and humidity used for testing temperature and collecting data, an infrared range finder for measuring size and area, an electronic breeze instrument for collecting wind speed data and the measuring tape. Because ventilation conditions are greatly influenced by the size of windows and doors, two testing points are respectively set close to a window (a door) and far from a window (a door). Point S is set in the outdoor patio (Fig. 1).

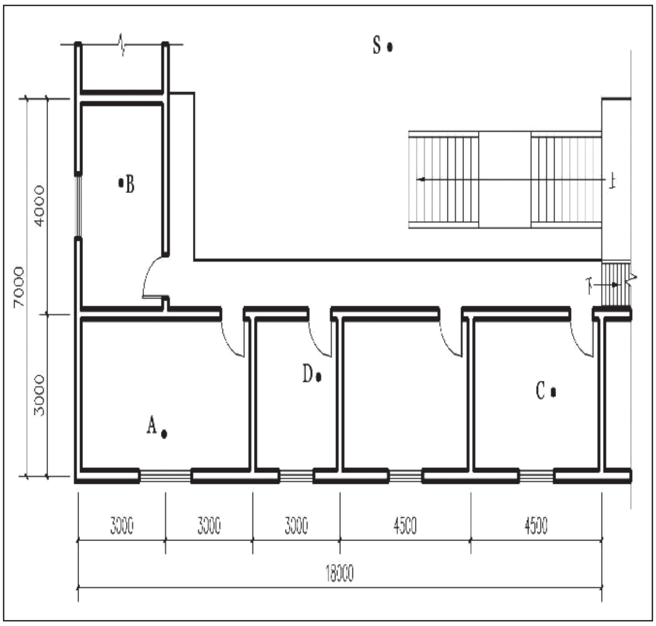


Fig. 1: Test point layout

### 2.3 Thermal environment testing

The testing results of the indoor and outdoor temperature are shown in Fig. 2. The average outdoor temperature was 33.46°C, the highest point reaching 34.45°C, the lowest point reaching 28.8°C. Temperature amplitude during the day time was 5.65°C. The temperature of guest rooms is generally higher, similar to that in the patio. Poor thermal protection shows that the mud wall does not display its better thermal insulation performance. There are two reasons as follows. Firstly, light partition walls reducing the ventilation effect are added to original buildings, secondly, previous window and doors have poor air tightness. The construction of envelopes does not make proper use of windows and doors possessing good performances, which results in the failure to reduce the heat exchange. Thirdly, house owners spontaneously add small green tiles laid on sloped roofs which are directly tied to wooden purlines and also use thin board ceilings. All of these decoration materials are light and their insulation performances are poor.

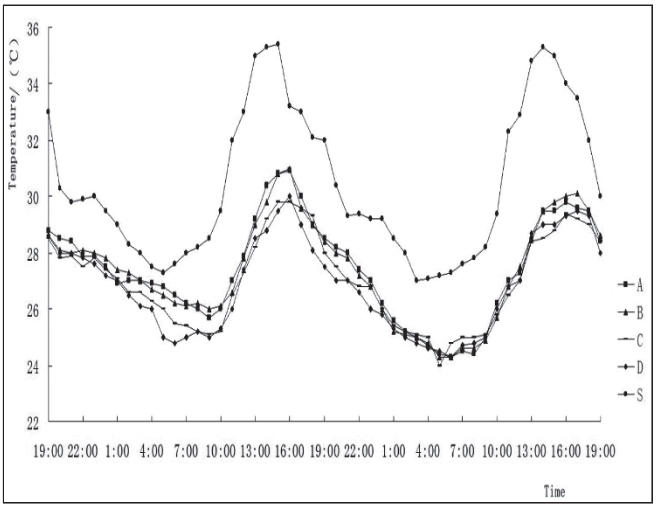


Fig. 2: Indoor and outdoor temperature curves

### 2.4 Natural ventilation and humidity testing

The testing results of indoor and outdoor wind speed are shown in Fig. 3. During the test, the average outdoor wind speed was 1.35m/s. The average wind speed close to Point A, B and C was 0.55m/s, 0.63m/s and 0.45m/s respectively. The wind speed close to Point D far from the window was 0.03m/s. After the renovation, the interiors of guest rooms are relatively sealed. There are no open windows to the inner courtyard. Also, doors and windows are not oppositely located. The above facts cause poor ventilation in the interiors of rooms. And it fails to make full use of the function of the inner patio to regulate the temperature. Although the attics are set up above guest rooms, the hot pressure ventilation cannot be formed because the wooden boards are used as ceilings for decoration and the attics are completely closed. It is known that Hanzhong is located in the high humidity and heat region. Here less chance of sunshine days, low static wind frequency and intense environment humidity attribute to the poor indoor comfort in hot summer.

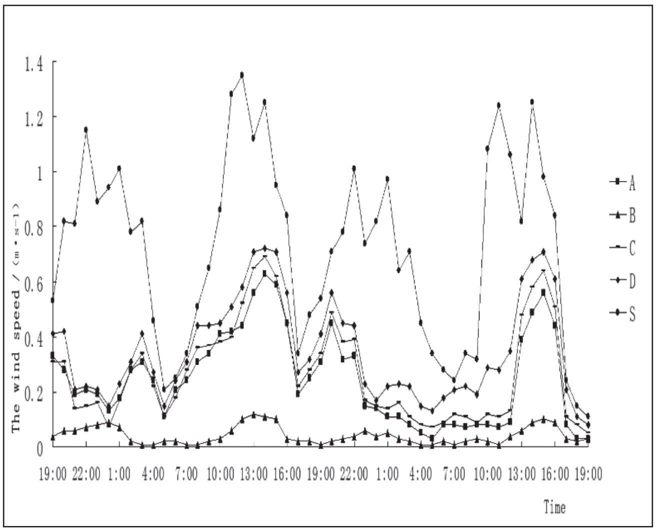


Fig. 3: Indoor and outdoor wind speed curves

## 3. Analysis of suitability passive building factors for regional and climatic characteristics

The Daba Mountains rise to the south of southern Shaanxi. To the north are the Qin Mountains. So this area has temperate and humid climate. The annually average temperature ranges from 12°C to 15°C with average lows about 0-3°C in the coldest month and average highs about 24-28°C in the hottest month in this region. The annually average precipitation ranges from 700mm to 900mm. The average humidity ranges from 60% to 80%. The average sunshine is about 1600-1800h. This study selects annually meteorological data in Hanzhong as a typical case, and carries out the analysis of climate adaptability with Weather Tool 2011.

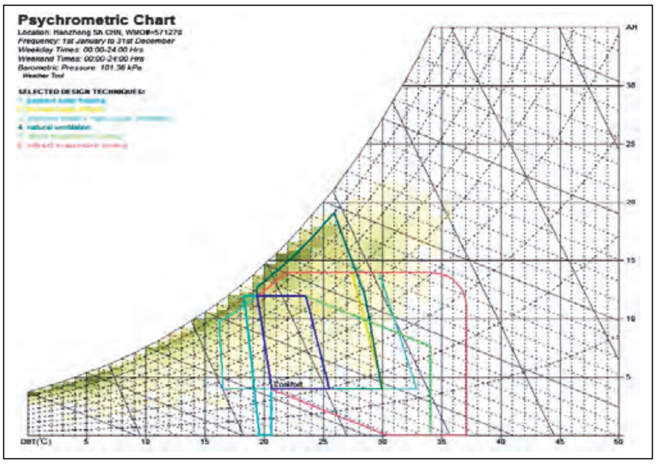


Fig. 4: The enthalpy of climate in Hanzhong dynasty

### 3.1. Passive strategy analysis of enthalpy

According to the characteristics of the selected area meteorological data, all kinds of passive strategies were analyzed and optimized in enthalpy. The use of passive strategies of the appropriate climate suitability not only can reduce the influences of constructions on the surroundings, but also reduce energy consumption caused by active measures.

(a) In the area, temperature is rather low throughout November, December, January and February, March, April, and October. It also happens during half of the time in May and September. Relative humidity mostly ranges from 50% to 75%. The most temperature is about below 10°C and the lowest temperature is below 0°C. So, this region is classified to be rather damp, for which it is significant to strengthen heat preservation.

(b) In this region, much hotter comfort happens in the part of the time in May, June, July, August, and September. Relative humidity ranges from 60% to 80% mostly. The temperature is always above 25°C with the high less than 31°C, which is relatively comfortable.

(c) Passive design measures are required to employ in the region. For example, strengthening natural ventilation, increasing thermal energy storage of the structure, and applying passive solar heating can greatly increase the time range of comfort.

### 3.2 Analysis of the effect of passive measures

Based on the analysis of climate enthalpy wet figure and passive construction measures, it can be concluded that passively ecological policies of climate can be effectively improved as follows when dwelling houses with indoor thermal comfort are built in the region.

*(a) Enhance the heat storage capacity of the envelope*

Enhancing thermal energy storage of envelopes can make even indoor temperature. It is effective in a transition seasons such as spring and autumn as well as summer, for which it is more suitable for the region (Fig. 5). Also, the annual time for indoor comfort will be increased by about 10% to 12% if thermal energy storage is reasonably adopted.

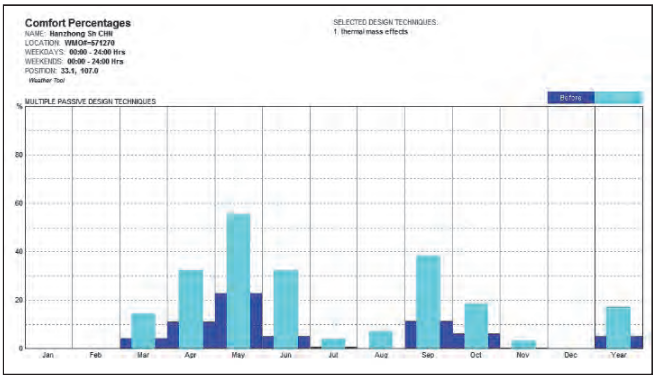


Fig. 5: Thermal mass effects

*(b) Increase shading and natural ventilation*

Due to the high humidity in summer, indoor air purification and humidification can be achieved by guiding indoor and outdoor air circulation (Fig. 6). Natural ventilation is very effective in improving indoor humidity in summer in the area. The time throughout the year for indoor comfort will increase by about 15% especially in June and August.

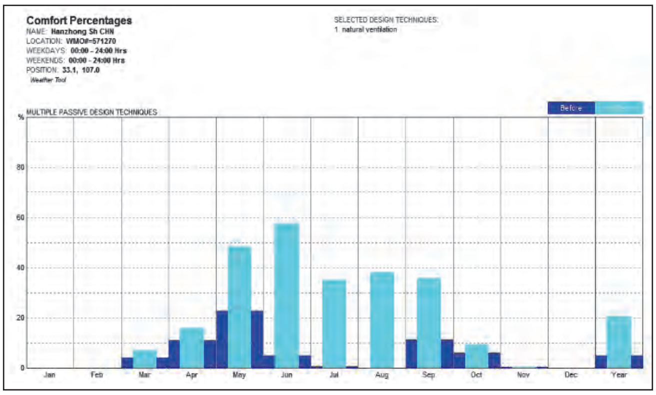


Fig. 6: Natural ventilation

*(c) Passive solar heating*

Passive solar heating is the mainly influential factor to get winter heating and also is an effective measure to improve indoor temperature in winter. Southern Shaanxi is classified to be V class area of light climate in our country. In this region, the sunshine condition is poor and the overall effect of passive solar heating is not obvious (Fig. 7). However, indoor comfort, with the increase by about 5% of a whole year, has been improved to some degree.

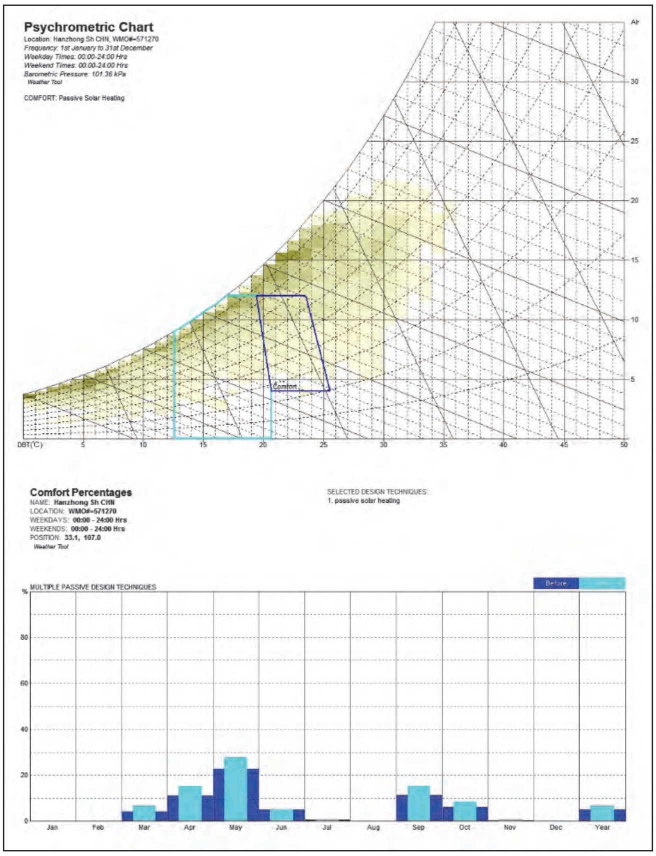


Fig. 7: Passive solar heating

*(d) Comprehensive use of passive measures*

Indoor comfort can be realized only depending on one single passive measure which will not be used generally. So, composite overlay of passive measures can be employed frequently (Fig. 8). For example, if these three measures are superposed, the indoor comfort in a year will be obviously increased by about about 20% - 23%. As shown in the figure, the indoor comfort cannot be achieved only by taking passive measure in the coldest December, January and February. Indoor auxiliary heating is still employed to meet the requirement for comfort. This does not mean the uselessness of passive construction measures but the consumptive savings of auxiliary heating by taking these measures.

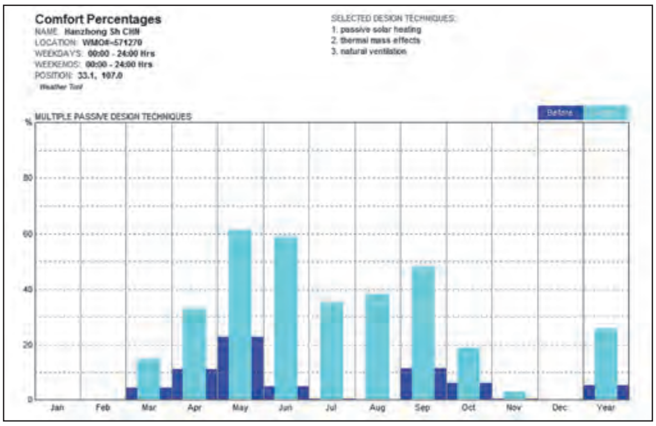


Fig. 8: Comprehensive effect analysis of passive measures in Hanzhong.

Shown as the above diagram, heat preservation in winter is the main difficulty in the construction design for climate in southern Shaanxi. Strategy A and C with auxiliary heating for winter and Strategy A and B for summer can meet the demand for climate adaptation and then achieve the goal of conserving ecological energy.

## 4. Conclusion

In response to the climate characteristics in Southern Shaanxi province, constructions in the region are mainly to meet the requirements for heat preservation in winter and heat insulation in summer. Based on the analysis of passive measures, it can be seen that enhancing thermal energy storage is essential for increasing thermal comfort by 10%-20%. In the process of rebuilding and newly establishing constructions, new rammed earth materials can be employed with the edge of being raw soil. In the south of Shaanxi province, the summer is rainy and the air humidity is high, so enhancing natural ventilation and taking shading measures are beneficial to perfect indoor heat and humidity and also extend the comfortable time by 15%. Meanwhile, deep overhangs of traditional dwellings can be used for references for the constructional designs. There are two main reasons. On one hand, transitional space can be formed; on the other hand, full shade can be created in summer so that less hot air goes into the rooms. In this way, taking appropriate measures will meet the requirement for climate adaptation and achieve energy conservation.


## Acknowledgements

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