

Applicability research on passive design of residential buildings in hot summer and cold winter zone in China

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Abstract. Passive design has long been a concern as an effective way of building energy efficiency. However, different urban climate characteristics determine the time-effectiveness of passive design. According to the climate characteristics of hot summer and cold winter zone in China, this research chose five cities, Shanghai, Wuhan, Chongqing, Nanjing and Changsha, to analyze their residential building energy consumption and thermal environment conditions. Based on Weather Tool calculation and analysis, the purpose of this research is to put forward the concept of Suitable Degree (SD), namely the applicability of the passive design. In addition, five cities' SD of passive design technology had been analyzed from aspect of ventilation, temperature, solar radiation and envelope, then passive design strategies and methods of five cities' residential building were discussed.

1. Introduction

Recently, with the continuous improvement of people's living environment and comfort requirements, residential building energy consumption has increased year by year. As research shows, the national residential building energy consumption accounted for nearly 60% of the total energy consumption of buildings by 2015. For decades, the energy saving of residential buildings in cold regions of China has achieved remarkable results by reducing the ratio of window and wall, strengthening the heat preservation, central heating and optimizing control. In hot summer and cold winter Zone in China, the overall energy utilization efficiency is low and energy consumption of residential building is increasing year by year, due to the special climate characteristics and life characteristics of residents, residential building heating and air conditioning equipment is used locally intermittent.

To further improve residential building thermal environment and reduce building energy consumption in hot summer and cold winter zone, governments had set up a number of standards in China, such as Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone-JGJ134-2010, Design Standard for Residential Buildings of Low Energy Consumption-DB42T559-2013 and so on. Specification and guidance from the energy and thermal aspects of the equipment were also provided. In this regard, the relevant scholars did a lot of related research. On researching the influencing factors of residential buildings, Zhang Xu compared and analyzed the sensitivity of energy consumption of residential buildings in hot summer and cold winter zone, combining with external walls, windows and other energy-saving measures quantitative calculation [1]. Fu Heng used dynamic simulation analysis of the residential building coefficient and natural ventilation on residential building energy consumption impact [2][3][4]. Yu Jinghua researched the best insulation thickness of roof and exterior wall of residential building in hot summer and cold winter zone [5][6]. Research on energy saving potential, Jin Sike used Dest energy consumption to simulate the 65% of residential building energy-saving measures requirements [7]. Yang Zijiang put forward coping strategies in view of the existing residential building energy



efficiency in Hubei 50% transformation [8]. Yu Xiaoping proposed the technical route of low energy consumption residential building [9]. Research on passive energy saving in residential buildings, Zhang Hui discussed the technology of passive energy saving of residential buildings in hot summer cold winter regions [10]. For residential buildings, although Ministry of Housing and Construction of Hebei Province, introduced the institute of design standard for energy efficiency of passive low-energy residential buildings, they were mainly used in cold regions, however in hot summer and cold winter zone there were still some deviation.

With the popularization of green building theory and the continuous updating of energy saving technology, low-energy passive residential building has become one of the hot spots at home and abroad. In this research, by using the Weather Tool software analysis of the climate characteristics at different cities in hot summer and cold winter zone and the thermal comfort zone, we provided the ideas for passive energy saving of residential buildings in hot summer and cold winter zone, furthermore combined with analysis of the suitable degree of passive design strategies.

2. Influence of Residential buildings' Thermal environment In Hot Summer and Cold Winter zone

For a long time, the Yangtze River basin has been a region of rapid economical development in China, but it is also the unbalanced development of social and economic areas. The differences between economic level and the influence of history and culture, lead to the formation of the region's unique living phenomenon. From the climatic zoning, the vast area of the Yangtze River Basin is located in hot summer and cold winter zone in China, where summer persists high temperature and humidity, the temperature exceeding 34°C, while the temperature is less than 8°C in winter, the spring and autumn season is wet long period of transition, therefore there is a year in the residential heating, cooling, ventilation and desiccant and so on. Affected by climatic characteristics, living habits and economic conditions and other factors, in hot summer and cold winter zone residential building heating and cooling operation are mostly intermittently used for short-cycle. The use of such equipment is compares to the calculation ways of energy efficiency standards. There exists the use of cycles and operating conditions inconsistent, resulting in residential building energy efficiency indicators and the deviation of the actual energy consumption. To a certain extent, also affected the practical effect of residential building energy efficiency.

From the technical application level, in order to achieve the building itself energy saving, passive designing should take advantages of the building's natural ventilation, natural lighting, shading, building envelope thermal insulation, solar energy utilization and other design measures to adjust the building thermal comfort as much as possible. Passive design can provide a good basis for efficient utilization of active technology to achieve the reduction of equipment and the overall energy efficiency of the building. Song Yehao proposed the concept of bio climatic buffer layer in combination with the comfortable climate of human body and put forward the strategy and method of the passive design of ecological architecture from the macro and micro level [11]. This kind of strategy provided a good theoretical foundation for passive energy-saving design of buildings.

From the demand of living environment, the acceptable limit is 28°C in summer and it is 16°C in winter. From the comfort temperature change, the transition season in hot summer and cold winter region provides a good condition for the passive building energy saving. In the process of research, Shanghai, Wuhan, Chongqing, Nanjing, Changsha are chosen for thermal environment comparison. From the enthalpy diagram of different cities, five cities are in the same hot summer and cold winter zone, and results show that the urban climate has different impact on the buildings under the same thermal comfort requirements of residential buildings. (Figure 1) For the thermal comfort of residential buildings and building energy efficiency, although the same is heating, cooling, ventilation and dehumidification requirements, the specific design requirements also reflect a certain degree of difference at different times. Therefore, there are some differences on passive technology in the application of residential buildings between different cities, and it is very important.

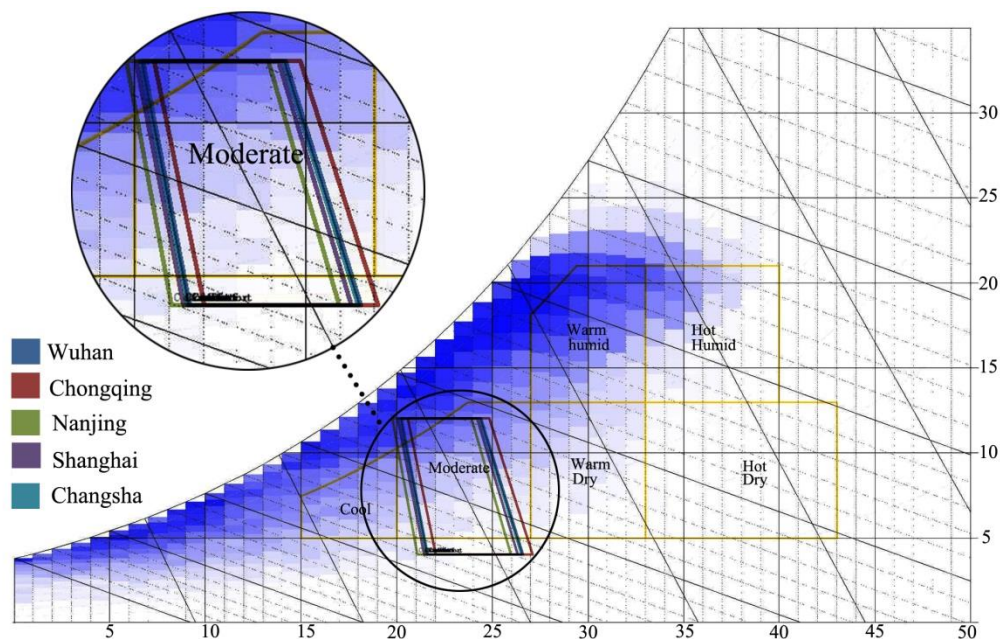


Figure 1. Enthalpy wet chart compares of thermal comfort range in five cities

3. Applicability passive technical analysis of residential buildings

Combined with Weather Tool calculation and analysis of climate analysis software, based on the passive technology of residential buildings in Shanghai, Wuhan, Chongqing, Nanjing, Changsha, the passive applicability is analysed. In this research, combined with ECOTECT quantitative data analysis results and proposed the concept of SD. It is the percentage improvement of the comfortable period after a certain type of passive technology is used, compared to the comfort period in the absence of any energy-saving technology. SD reflects the application of passive technology in buildings. In other words, the magnitude of the suitable degree reflects the amount of space available for passive technology.

3.1. Building ventilation influence

For residential buildings, building ventilation can be achieved through two ways, natural ventilation and night ventilation.

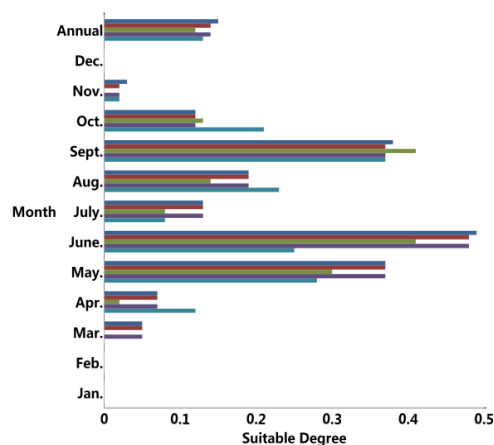


Figure 2. Comparison of natural ventilation

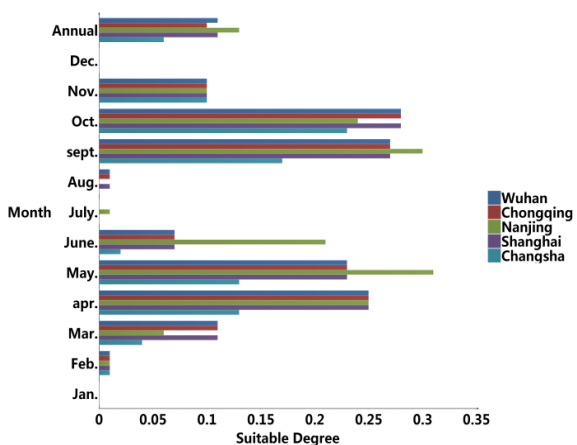


Figure 3. Night ventilation

From the comparative results, natural ventilation is an effective passive measures in Shanghai, Wuhan, Chongqing, Nanjing, Changsha, it can be used from April to October, concentrating in May, June and September. The suitable degree of Shanghai and Chongqing in May, June, September reached 0.37, 0.48, 0.37, SD of Wuhan reached 0.37, 0.49, 0.38. SD of Nanjing reached 0.30, 0.41, 0.41. SD of Changsha reached 0.28, 0.25, 0.37. Five cities in August were relatively high in temperature, but the applicability of natural ventilation was still large. Shanghai, Wuhan and Chongqing were 0.19, Nanjing was 0.14 and Changsha was 0.23.

Although the night ventilation has certain requirements on the temperature difference between day and night, It is of great help in the local time for the improvement of building thermal comfort. From the comparative results, night ventilation is concentrated in April, May, September and October. Shanghai, Wuhan, Chongqing four months of suitable degree reached 0.25, 0.23, 0.27, 0.28. The SD of four months reached 0.25, 0.31, 0.30, 0.24 in Nanjing. The SD of four months reached 0.13, 0.13, 0.17, 0.23 in Changsha. In other months, the local area of the application of night ventilation is also relatively high. For example, it reached 0.21 in June of Nanjing.

3.2. Evaporative cooling

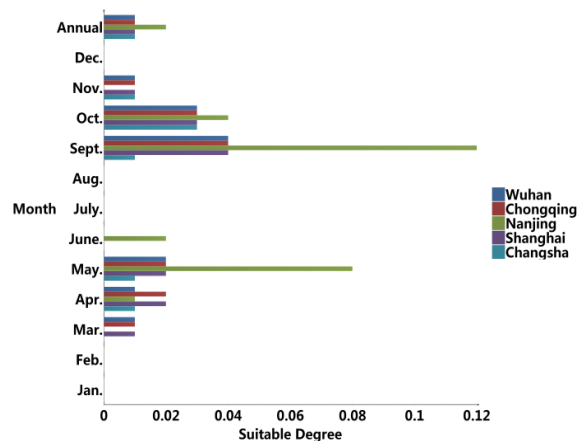


Figure 4. Direct evaporative cooling

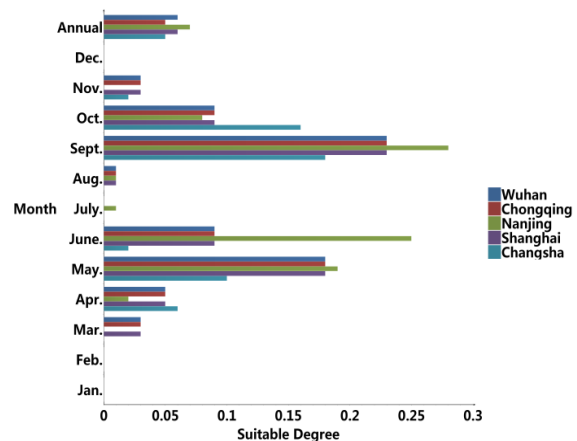


Figure 5. Indirect evaporative cooling

Evaporative cooling is a kind of economical and efficient cooling method, which uses the temperature difference between wet and dry bulb in the natural environment and the heat-moisture exchange. Building evaporative cooling can be realized by direct evaporation cooling and indirect evaporative cooling in two ways. From the analysis of the results, direct evaporative cooling effect of five cities in general, in addition to Nanjing in May, September for the degree of 0.08, 0.12, the remaining four cities have not exceeded 0.05.

Compared with direct evaporative, indirect evaporative cooling effect is obvious. Shanghai, Wuhan and Chongqing cities are concentrated in May and September, the SD was 0.18, 0.23. Nanjing concentrated in May, June and September, the SD was 0.19, 0.25, 0.28. Changsha concentrated in May, September and October, and the SD was 0.1, 0.18, 0.16. According to the analysis of SD, it could be seen that indirect evaporative cooling can be used to regulate thermal environmental conditions of residential buildings in some period.

3.3. Solar radiation influence

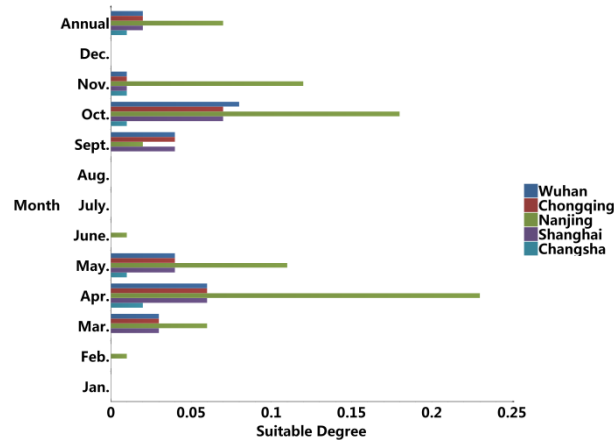


Figure 6. Passive solar house

Solar radiation directly affects the light and heat of residential buildings. From the passive use of speaking, the passive solar house is one of the common form. However, the data from the comparative analysis, five cities in June, July and August are not suitable for use. Relatively concentrated in March, April, May, September, October and November, the suitable degree was not high. Shanghai, Wuhan, Chongqing and Changsha suitable degree were below 0.05. However, there were some differences in Nanjing. April, May, October, November suitable degree were 0.23, 0.11, 0.18 and 0.12.

3.4. Envelope influence

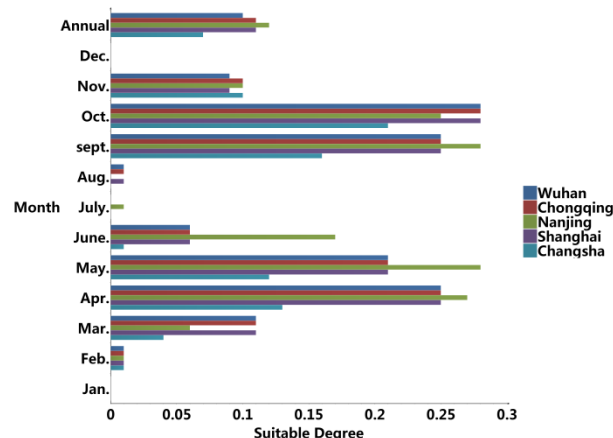


Figure 7. High melt materials

In residential buildings, the thermal performance of the envelope directly determines the thermal environment within the building, especially in extreme weather conditions in summer and winter. In the transitional season of hot summer and cold winter zone, the heat storage capacity of the envelope reflects the thermodynamic properties of the building to adjust the indoor thermal conditions. From the comparison results, the five cities in the envelope structure with high fusible materials to adjust the building comfort, more concentrated in April, May, September and October. In these four months, Shanghai, Wuhan, and Chongqing's SD respectively were 0.25, 0.21, 0.25, 0.28. The SD of Nanjing were 0.27, 0.28, 0.28, 0.25. The SD of Changsha were 0.13, 0.12, 0.16, 0.21.

4. Discussion

(1) From SD analysis passive technology it could be seen that the size of SD are all within 0.5. Combined with the comparative analysis of related studies on passive design technology, passive

technology embodied in many aspects, such as orientation, sunshade, envelope thermal performance, etc. And it usually focused on the building thermal physical demand, such as ventilation, lighting, power consumption, radiation, and so on. From above SD analysis, applicability order for passive technology was ventilation, envelope, evaporative cooling and solar radiation in hot summer and cold winter zone in China.

(2) According to indoor thermal environment changes of residential buildings impacted by annual climate characteristics in hot summer and cold winter zone, it could be roughly divided into five periods, such as heating period, ventilation period, dehumidifying period, cooling dehumidifying period and ventilation period from January To December. From SD analysis of passive design in five cities, it could be seen that application period of passive technology was different in different location. In order to meet the requirements of indoor thermal comfort of residential building, it could be adjusted by heating equipment in heating period, and by refrigeration equipment in cooling dehumidifying period, by ventilation equipment in dehumidifying period. And natural ventilation technology could be used in ventilation period. The application period of five cities could be compared in Figure 8, which combined with SD analysis and China building thermal design of typical meteorological reference data.

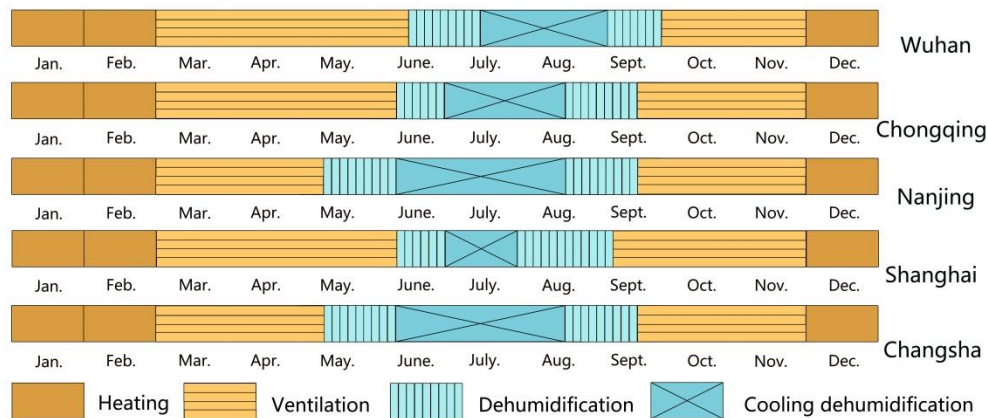


Figure 8. Diagram of passive adaptive technology comparative analysis

From Figure 8, it could be seen that deviation of heating period is small in five cities. However, the cycle length was different in wind period, dehumidifying period and cooling dehumidifying period. Cooling dehumidifying period of five cities were all in July, August and September. It could reach 688 hours in Wuhan, 479 hours in Nanjing, 458 hours in Changsha, 465 hours in Chongqing, and 251 hours in Shanghai. It could be affected by the marine climate in sometime in Shanghai, therefore, the cooling dehumidifying period was relatively short and the dehumidifying period was long. From the contrast of ventilation period in Fig.6, it could be seen that cycle length was Shanghai > Wuhan > Chongqing > Nanjing > Changsha, which directly affected the efficiency of natural ventilation.

(3) From the five cities comparative analysis of passive technology, It could be seen from that natural ventilation is an effective passive way to promote building energy efficiency in hot summer and cold winter zone in China, which could be accounted for over 40% of annual session. And natural ventilation could adjust the internal environment of residential buildings, when the outdoor temperature is less than 30°C, relative humidity is not more than 85% in summer [12]. When the outdoor temperature changes greatly, it could be adjusted by natural ventilation or intermittent ventilation cooling at night. Furthermore, comfort could be regulated by the combination of initiative and passive hybrid ventilation mode during dehumidifying period and cooling dehumidifying period.

(4) As an important factor, solar radiation should be paid attention for affecting the thermal environment of the building in hot-summer and cold-winter zone. Shading is an effective passive technology to regulate thermal radiation effects, and it could effective improve the thermal

environment, reduce air conditioning usage cycle, from the Angle of the roof, wall and window shade combined with different cities high angle change.

In addition, it should consider to pay attention to comprehensive utilization of sunshade and natural ventilation, combined with residential building demand. In summer, it could improve comfort by sunshade and natural ventilation during day and by night ventilation in night. In winter, it should consider the use of natural light and heat by passive solar house.

(5) It is a great significance to use reasonable energy storage palisade structure for improving the thermal comfort of indoor environment and realizing building energy efficiency. In part of residential building palisade structure of hot summer and cold winter zone, PCM (Phase Change Materials) could be applied to passive solar houses, combined with ventilation cooling storage in summer night and heating storage in winter [13]. In addition, it could strengthen the natural ventilation with TBW (Trombe wall) in the residential building to improve heating effect in winter [14][15][16].

5. Conclusion

The urban climate characteristics and residents living habits directly impact the residential building energy consumption in hot summer and cold winter zone in China. Passive design technology provides better autonomy and flexibility for residential building energy saving, such as natural ventilation, lighting, heat insulation and so on. Appropriate passive technology should have good balance, coordination and unity, to meet the thermal comfort and energy efficiency as the goal, fully combined with systemic quantitative control of regional climate characteristics. Combining Weather Tool data analysis, this paper discussed the passive technology applicability of residential building in different cities in hot summer and cold winter zone in China, and passive energy saving design ideas and methods were provided.

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