A study on heating of residential buildings in the Yangtze River Valley of China

Xujuan Dong¹, Zengfeng Yan², Xiaofeng Shi¹

¹ College of Architecture, Taiyuan University of Technology, Taiyuan, Shanxi, 030024, China
² College of Architecture, Xi’an University of Architecture and Technology, Xi’an, Shaanxi, 710055, China
*Corresponding author’s e-mail: dongxujuan@tyut.edu.cn

Abstract. Yangtze River is China’s densely populated and the most economically prosperous region. It’s hot and humid in summer and cold in winter in this region. This area is considered as a non-heating region in winter. The residential building design usually does not consider the building heating requirements. The building envelope thermal performance is poor, and the indoor thermal environment quality is worse in the residential building in this region. In recent years, local experts and residents in the area have expressed strong willingness to building heating in winter. Consequently, on the basis of field investigation and field test, this paper has analyzed the choice of building heating mode from the aspects of local meteorological conditions, indoor environment status, local residents’ living habits and residents' heating demand. Based on the results of the technological economic comparison of preliminary studies, suggestions on the suitable building heating mode were given in the Yangtze River Valley of China.

1. Introduction

In China, energy and environment problem has become urgent issue in the development process. Chinese building energy consumption makes up to nearly 25 percent of total national energy consumption [1, 2]. It includes building heating, air conditioning, water supply, cooking, lighting and electrical building energy consumption. Chinese government has adopted a series of means for energy saving and a number of standards for building energy efficiency has been issued since 1980s, which contributed a lot to improve the energy saving level for existed buildings and new constructions [3~6].

Code for thermal design of civil building（GB 50176-2016） of China [3] divides the whole country into five thermal design zones, i.e. severe cold zone, cold zone, hot in summer and cold in winter zone and temperate zone. According to this code, cities, in which the climate as follows, belong to the hot in summer and cold in winter zone of China, and also called the region of transition, 0-90 days of the coldest month average temperature (0~10℃) and day average temperature which is not higher than 5℃, and 40-110 days of the hottest month average temperature (25~30℃) whose average day temperature is not lower than 25℃. Geographically, it is in the Yangtze River Valley of China.

The hot summer and cold winter zone of China covers two municipalities (Shanghai city and Chongqing city) and fourteen Provinces (all of the Hubei Province, Hunan Province, Zhejiang Province, Anhui Province, Jiangxi Province; and part of the Fujian Province, Jiangsu Province, Sichuan Province, Guizhou Province, Henan Province, Shaanxi Province, Gansu Province, Guangdong Province and...
Guangxi Province). The city population of this region is about 600 thousands and the city house area is about 6 billion square meters.

This area is considered as a non-heating region in winter during the last fifty years. The residential building design usually does not consider the building heating requirements, and the building envelope thermal performance is also poor, and the indoor thermal environment quality is worse in the residential building in this region. It illustrated that the heating energy consumption in hot in summer and cold in winter zone is 1,240 TEC, which is 1.5% of the building total energy consumption and which is 2.4kgce per square meter [7, 8]. The total energy consumption and energy consumption per unit area increased year by year in hot in summer and cold in winter zone of China.

In recent years, local experts and residents in the area have expressed strong willingness to building heating in winter, even the Chinese National People's Congress debated a motion on residential buildings heating in winter in the Yangtze River Valley.

Based on the results of preliminary studies, the suitable building heating mode in the Yangtze River Valley of China were proposed.

2. Climate characteristics in hot summer and cold winter zone of china

The climate characteristic in hot in summer and cold in winter zone of China is that it is hot and humid in summer and cold and humid in winter, the temperature difference is small in the day, annual precipitation is big and sunshine is less.

The summer’s characteristic in this region is: the hottest month average temperature is 25~30℃, average relative humidity is 80%. The winter’s characteristic in this region is: the coldest month average temperature is 0~10℃, average relative humidity is 80% and the performance is cold and damp. Although the temperature in winter is higher than north region, sunshine rate is lower than that in the north region of China. Along the middle and lower reaches of the Yangtze River and its north, the days when the daily minimum temperature is lower than 5℃ are as long as 2~2.5 months. So, these regions need house space heating.

3. Survey of way of space heating in hot summer and cold winter zone of china

Table 1. Results of the way of the house space heating in winter

|                          | Chengdu | Wuhan | Nanchang | Hefei | Ave.  |
|--------------------------|---------|-------|----------|-------|-------|
| Split Air-conditioner    | 81.02%  | 70.0% | 73.04%   | 68.22%| 73.07%|
| Natural gas boiler       | 0.87%   | 2.28% | 0.94%    | 6.56% | 2.66% |
| Central Air-conditioner  | 0.23%   | 0     | 0.75%    | 0.52% | 0.38% |
| Thermal power plant waste heat | 0     | 7.86% | 0.75%    | 14.20%| 5.70% |
| Water Source Heat Pump   | 5.86%   | 2.83% | 7.62%    | 0     | 4.07% |
| Soil Heat Pump           | 0.46%   | 0.17% | 0        | 0     | 0.16% |
| Other heating            | 0.56%   | 7.10% | 0        | 0     | 1.92% |
| Non heating              | 11.00%  | 9.76% | 16.9%    | 10.5% | 12.04%|

In winter of 2014, we have conducted the field survey and on-site measurements of house space heating in Chengdu city (capital of Sichuan province), Wuhan city (capital of Hubei province), Nanchang city (capital of Jiangxi province) and Hefei city (capital of Anhui province). The table 1 gives the results of the way of the residential buildings space heating in winter in these cities. Many other research groups have conducted the field survey and on-site measurements of house space heating in the Yangtze River Valley. Similar results have been reported on this issue. The following table 2 gives the results of the way of the residential buildings space heating in winter in other cities reported by Tsinghua research group in 2009 [5].
The results showed clearly that the current way of the house space heating in winter in the Yangtze River Valley cities is diversity, the central heating is much less. The split Air-conditioner has been widely used for heating and cooling in this region. It is used in the 73 percentage of the surveyed houses. In the 90 percentage of the surveyed houses, it is used less than 8 hours as shown in Figure 1.

Table 2. Results of the way of the house space heating in other three cities

|                      | Shanghai | Wuhan | Suzhou |
|----------------------|----------|-------|--------|
| Spilt Air-conditioner| 30%      | 6%    | 32%    |
| Electric heating     | 7%       | 6%    | 28%    |
| Air-conditioner and electric heating | 19 | 30% | 31% |
| Central heating      | 2%       | 3%    | 0      |
| Other heating        | 41%      | 45%   | 9%     |

Figure 1. Duration of application of the Air-conditioner

4. Indoor temperature in hot summer and cold winter zone of china

Based on the on-site measurements of house in the four cities above, the indoor temperature is between the 12~18 degree ℃ as shown in Figure 2. The following figure 3 gives the results of indoor thermal environment test in detail of the residential buildings in winter in other cities.

Test results show that: the indoor average temperature in the non-heated houses in 7~15 ℃, Different heating modes of heating residential indoor average temperature in the range of 11~25 ℃, mainly concentrated in 11~16 ℃. Under no heating condition, the indoor thermal environment in the area is poor. Therefore, it is necessary to heating in winter in residential of hot summer and cold winter zone. And the heated houses have a big gap between the average temperature, mainly due to the residential in the area usually have the intermittent space heating.
The result reported by Tsinghua research group in 2012 in Shanghai city gives the range of the 15~18 degree ℃ in the heated houses and the 8~16 degree ℃ in the non-heated houses [4,5].

5. Heating behaviour in hot summer and cold winter zone of china

Survey shows that most houses in the Yangtze River Valley of China usually have the intermittent space heating. That means that people usually close the heating equipment when there is no person at home, and they turn on the space heating equipment when there is anyone in the room (as shown in Table 3). The electric heating equipment and other non-central heating equipment can easily be turn on and off. The outdoor temperature is not so much lower. The way of intermittent and partial space heating can maintain the house temperature between the 12~18 degree ℃.
Table 3. Results of the living habits of the residents in winter

| Period of time | 6:30~7:30 | 7:30~12:30 | 12:30~13:30 | 13:30~18:30 | 18:30~22:30 | 22:30~6:30 |
|---------------|-----------|------------|-------------|-------------|-------------|------------|
| The average outdoor temperature | 4.97 | 7.24 | 10.36 | 9.9 | 7.47 | 6.22 |
| People in the room | The whole family | The elderly and children | Part of the people | A few people | The whole family | The whole family |
| Activity | Much less | Less | Much more | Much more | More | Tiny |
| Clothes | Less | More | Much more | Much more | Much less | Tiny |

Survey shows that people in the Yangtze River Valley of China usually wear thick clothes, such as cottons and sweater at home [7,8]. Also, people tend to open the door and window even in winter in the Yangtze River Valley of China. Less 7 percentage of the surveyed house usually close the window in winter as shown in Figure 4.

Figure 4. Window status in winter

6. Why not suitable the central heating in hot summer and cold winter zone of china

In 2012, severe cold has spoiled the south of China. Local experts and residents in the hot summer and cold winter zone of China have expressed strong willingness to building heating in winter, even the Chinese National People's Congress debated a motion on residential buildings heating in winter in the Yangtze River Valley. Debates on the heating and central heating have spread in this region. However, the central heating system is not the suitable heating choice compared to the space heating way of the north part of China.

First, the house heating period is short, heating load is less and it varies largely in the hot-summer-and-cold-winter zone in China.

Secondly, the energy resources supply structure is special in this area. The gas and power are basic energy supplies.

Thirdly, people living in this area tend to open the door and window more often.

Consequently, the central space heating is not suitable in the hot-summer-and-cold-winter zone in China, based on the above analysis from the climate characteristic, energy resources supply structure and habitats behaviors.
On the other hand, the distributed space heating way is much more suitable, compared to the central space heating system. And the distributed system is less initial cost and can meet the different space heating needs.

To improve the building thermal performance, such as walls, roofs and windows, to use the distributed and partial space heating way, such as split air conditioner, gas boiler, partial space radiant electric heating, can create a better indoor thermal environment in winter in the Yangtze River Valley of China. In addition, the field investigation found that the region from north to south heating needs are quite different and district heating can be considered.

7. Conclusions
Yangtze River is China's densely populated and the most economically prosperous region. It’s hot and humid in summer and cold in winter in this region. The local people have experienced the humid cold winter. Through on-the-spot investigation and field measurement, this paper has analyzed the selection of building heating mode from the aspects of local meteorological conditions, indoor environment status, local residents' living habits and residents' heating demand. Based on analysis, this paper suggests the way of the distributed space heating is most suitable building heating mode in this region. In addition, according to the results of field investigation, it is suggested to consider district differential heating in view of the large difference in heating demand from north to south in this area.

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