The research on the influence of building air tightness to energy consumption of residential building in a hot summer and cold winter zone in China

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Abstract. The hot summer and cold winter zone in China belong to the non-central heating area. In recent years, with the improvement of people's living standards, more and more residential building have begun to adopt various heating methods. However, many existing buildings have poor air tightness level, and the indoor thermal environment is in a bad condition, which also causes a great waste of energy. Based on the actual measurement of the airtightness of a demonstration building, this paper studies the effects of residential airtightness on heating and air conditioning energy consumption and indoor thermal environment in winter. The simulation results show that in the hot summer and cold winter zone, the level of air tightness also influence the heating and air conditioning energy consumption, but the impact on heating energy consumption is more obvious. In addition, when selecting energy-saving measures, the relationship between the level of air tightness and the level of insulation should be weighed. We should not reduce energy consumption only by improving the airtightness level. Otherwise, the investment is large and the energy saving effect is very poor.

1. Introduction
The hot summer and cold winter zone (HSCW) account for about a quarter of China's area, and the population accounts for about half. The HSCW zone’s climate is hot in summer, cold in winter, high in humidity throughout the year[1]. Many existing buildings with poor air tightness, which result in poor indoor thermal environment. The problem of air tightness in HSCW zone is not outstanding because of rarely adopt heating in winter. However, with the improvement of people's living standards and the people's yearn for a better life, more and more residential buildings in HSCW zone have begun to adopt different forms of heating. Therefore, the indoor and outdoor temperature differences become larger under heating condition, the problems caused by the airtightness of the buildings are more and more serious worth attention.

According to the literature[2,3,4], the research on the airtightness of buildings in developed countries started earlier, the relevant building codes are more perfect than Chinese, and the requirements for building airtightness are relatively high. Besides, the total number of literature researches on building airtightness in China is relatively small and mostly concentrated in the past ten years[5,6]. Most of the research objects are residential buildings in the cold regions of the north. Domestic research on building airtightness is still in initial stage. Compared with foreign countries, there are only a small amount of building airtight tested data available for reference in China[7,8]. Therefore, it is very necessary to study the airtightness of residential buildings in China's HSCW zone by filed testing. In this paper, the airtightness of the affordable housing of Baoyin County Xinyi Homestead in Yangzhou City, Jiangsu Province (HSCW zone) was filed tested by blow door method on October 21, 2018. Based on the test data, Simulation analysis was performed on energy consumption.
2. Test Method

2.1 Building information
The building is located in Yangzhou City, Jiangsu Province. This demonstration project belongs to the China National key R&D programme ‘Solutions to Heating and Cooling of Buildings in the Yangtze River Region’. The project’s completion time is September 2018. The building faces south and has 6 floors, one of which is the basement. There are 5 units in each floor, two families share one floor, and a total of 50 households. The floor area of each household is 40.88m\(^2\), the building area is 3689.33m\(^2\), and shape coefficient is 0.36. Figure 1 shows the exterior of the building, and Figure 2 shows the floor plan of the building.

![Figure 1. Exterior of the residential building](image1)

![Figure 2. Floor plan of the building](image2)

Figure 1. Exterior of the residential building  
Figure 2. Floor plan of the building

The building thermal parameters studied in this paper are set according to the requirements of ‘Design standard for energy efficiency of residential buildings in hot summer and cold winter zone’ (JGJ134-2010) and ‘Design standard of thermo-environment & energy conservation for residential buildings in Jiangsu province’ (DGJ32/J 71-2014). The designed building energy efficiency is 65%. The U-value of external wall and external window is 0.8W/㎡K and 2.6 W/㎡K. The airtightness level of buildings is V\(I\), which is depend on the requirements of ‘Graduations and test methods of air permeability, water tightness, wind load resistance performance for building external windows and doors’ (GB/T 7106-2008).

2.2 Test procedure and results
The blower door tests were performed in accordance with ASTM[9] Standards E779-11[10]. In addition, the fan pressurization approach described by Canadian general Standards Board(CGSB) Standard 149.10 [11] and ISO Standard 9972 [12] were applied. The airflow data are generally fit to a curve using the power law equation. The main components and connections of the system are shown in Figure 3, and the details of the experimental shown in Figure 4.

![Figure 3. Connection of main devices](image3)

![Figure 4. Details of the experimental](image4)

Figure 3. Connection of main devices  
Figure 4. Details of the experimental
In order for the equalization of air pressures in the apartment unit, a blower door was installed in the entrance door while all the interior doors were opened. The fan induced pressure differences in a range of approximately 10–60 Pa. All data were collected by a data logger. For the wind direction and speed, the wind data at 10m height from the ground. Before the air leakage measurement, all parts were sealed with plastic films and duct tapes in the unit. For the window, a plastic film was also used to cover the inside window and pasted on the frames by duct tapes. Part of the test data and results are shown in Figure 5 and Figure 6.

**Figure 5.** The result of test

**Figure 6.** The output of test

Figure 5 is a pressure-flow curve for positive pressure and negative pressure, which is obtained by software indexation. Through the test data, the correlation coefficients of the curves under negative pressure and positive pressure are 0.999 and 0.92742, so the theoretical test data is accurate. The test results showed that the number of air changes tested by the pressurization method was 5.19 h\(^{-1}\), and the number of air changes measured by the depressurization method was 1.58 h\(^{-1}\), and the average value was 3.88 h\(^{-1}\). The air change rates tested by the blow door method is under the pressure of 50 Pa. If further simulation analysis is required, it is necessary to convert the ACH\(_{50}\) to the air change rates under normal pressure. ‘Code for acceptance of energy efficient building construction’ (DB11/T55) shows the relationship between ACH\(_{50}\) and ACH.

\[
ACH = \frac{ACH_{50}}{n} \quad (1)
\]

Where \(n\) is the conversion factor, which is related to the meteorological parameters of each place. According to the actual engineering experience, China's specifications are taken 17 as conversion factor. Therefore, after conversion, the number of air changes under normal pressure is 0.2 h\(^{-1}\). At present, the number of air exchanges in cold zone given by China's standards is 0.5 h\(^{-1}\), and that in HSCW zone is 1 h\(^{-1}\). It can be seen that the air tightness of the demonstration project is ideal, but it should be noted that the reason why such a high airtightness level can be achieved is that the building meets the evaluation criteria of the demonstration project and is strictly carried out during the construction process. The airtightness was treated, and the air leakage site was further blocked to achieve a pressure difference of 50 Pa during the test. But many existing residential buildings are hard to reach this level. Therefore, to study the energy consumption changes under different airtightness levels of the building, the number of air changes is changed on the basis of 0.2 h\(^{-1}\) in the energy consumption simulation section below.

### 3. Influence of building air tightness on energy consumption

#### 3.1 Model establishment and parameter setting
Based on the test data, this paper studies the impact of different air tightness on building energy consumption through EnergyPlus. The author uses SketchUp to build the model, as shown in Figure 7.

Figure 7. Testing building model

The airtightness of buildings mainly depends on the sealing conditions of the external doors and windows, but there are many factors affecting the overall air tightness of the building, which cannot be determined one by one. Therefore, from the perspective of theoretical analysis, this paper studies the effect of external window air tightness on the building's heating and cooling energy consumption, ignoring the influence of other factors.

3.2 Results and discussion

In order to study the change of air-conditioning energy consumption of the building with air tightness, the number of air changes was gradually reduced from 1 h\(^{-1}\) to 0.2 h\(^{-1}\) in EnergyPlus. The simulation results are shown in Fig. 8.

Figure 8 Annual cooling and heating energy consumption under different levels of airtightness

It can be seen from Fig. 8 that with the increase of the airtightness level, the annual heating energy consumption per unit area of the building is gradually reduced from 38.97 kWh/m\(^2\) to 19.88 kWh/m\(^2\), and the reduction degree is about 49%. The decline is obvious, which shows that the airtightness has a significant impact on the energy consumption of heating and air conditioning. At the same time, it can be seen that when the airtightness level is increased, although the energy consumption of heating and air conditioning is reduced, the degree of reduction in heating energy consumption is different from that of air conditioning. The energy consumption of air conditioning is 19.62 kWh/m\(^2\). It has been reduced to 18.40 kWh/m\(^2\), which is 6.22% lower. The heating energy consumption has gradually decreased from 19.35 kWh/m\(^2\) to 1.48 kWh/m\(^2\), which is reduced by 92.35%, indicating that the heating energy consumption is reduced more significantly.

According to the climate data (degrees of day, relative humidity, solar radiation, etc.) in the HSCW zone, Xiongjie [13] divides the HSCW zone into seven sub-zones by cluster analysis. They are: A1: the highest demand for cooling and the highest the demand for heating; A2: the highest demand for cooling and the second highest for heating; A3: the highest demand for cooling and the lower demand for heating; B1: higher demand for cooling, the highest the demand for heating; B2: the cooling demand is the second highest, the heating demand is the second highest; C1: the cooling demand is the lowest, the highest the demand for heating; C2: the cooling demand is the lowest, and the heating demand is the second highest. Therefore, this paper selects Wuhan, Changsha, Chongqing,
Xinyang, Yichang, Hanzhong and Chengdu as the typical cities of the sub-zones for the research objects. Compare with the Yangzhou city.

![Energy consumption of heating and cooling in typical cities](image)

**Figure 9.** Energy consumption of heating and cooling in typical cities in the Yangtze river basin under different air changes

It can be seen from Figure 9 that the energy-saving effect of improving the airtightness of the building is directly related to the climatic conditions of the sub-zone where the building is located. Although all the eight cities belong to the HSCW zone, there are still some differences in the microclimate of each city. Therefore, the same building with the same airtightness level has different heating and air conditioning energy consumption in different cities. When air changes rate of building is 1 h⁻¹ the energy consumption of heating and air conditioning in each city is basically arranged in the order of A1 to C2, the largest is Wuhan, and the smallest is Chengdu. The relative humidity in Wuhan is very high in summer, the average relative humidity of the hottest month can reach 90%, and the annual solar radiation intensity is high, which result in the cooling consumption is the highest. The annual solar radiation intensity in Chengdu is low. The average outdoor temperature in winter is above 0 °C, and the average wind speed is low. Therefore, both heating and cooling energy consumption are maintained at a low level. When the rate of air changes was reduced to 0.6 h⁻¹, the heating and cooling energy consumption of each typical city significantly reduced. The largest change city is Xinyang, the energy saving rate is 33.54%, followed by Hanzhong that the energy saving rate was 25.72%. The city with the lowest rate of change is Yichang, which is 4.61%. Basically, the greater the indoor and outdoor temperature difference in winter, the more obvious the energy-saving effect of improving air tightness. When the number of air changes is reduced to 0.2 h⁻¹, the largest energy consumption of heating and cooling is still Wuhan, the energy consumption from 39kWh/m² at 1 h⁻¹ to 32.5kWh/m² at 0.2 h⁻¹, the decline is not large, because The energy consumption of heating is originally small in winter. The reduction of the rate of air change can only slightly reduce the heating energy consumption of this part. However, the city with the lowest energy consumption of heating and cooling has changed from Chengdu to Hanzhong, the reason is that the latitude of Hanzhong is higher than that of Chengdu, the average outdoor temperature in winter is -5 °C, and the solar radiation intensity is lower than that of Chengdu, so the energy saving achieved by improving airtightness is achieved. So, the effect is more obvious than Chengdu. In summary, the method of reducing the energy consumption by improving the level of air tightness is more effective in cities with large indoor and outdoor temperature differences in winter. When formulating air-tightness regulations for cities in HSCW zone, it is not possible to simply set uniform standards, and local climate conditions should be fully considered.

4. Conclusions
The test method used in this paper is the ‘Blower Door Method’, which is widely used in the field of building airtightness testing in developed countries. However, during actual test, the pressure inside and outside the room affected by wind pressure and hot pressing. It is subject to change at any time, and it does not reach the 50Pa required by the bower door method. Therefore, how to reasonably and
objectively convert the test results under 50 Pa into atmospheric pressure has not been a simple and effective method. The domestic standard mentions that the rate of air changes tested at 50 Pa is divided by the empirical coefficient n to convert, but the value 17 taken by n is the empirical value obtained during the lots of projects, and the source of the conversion factor is not specifically analyzed. Further research about n value is needed for HSCW zone.

The air tightness level has little effect on the cooling energy consumption of typical cities in the HSCW zone, and has a great impact on the heating energy consumption. Therefore, it is necessary to adjust the relevant standards for the airtightness in the HSCW zone according to the climate of the sub-zones. For cities with high latitude and large temperature difference between indoor and outdoor in winter, such as Hanzhong and Xinyang, it is necessary to raise the standard of air tightness. For cities with lower solar radiation intensity, lower winter heat pressure and wind pressure, such as Chengdu, the airtightness level do not need to be set too high.

Acknowledgement
The authors would like to thank the support from National Key R&D Programme ‘Solutions to Heating and Cooling of Building in the Yangtze River Region’ (Grant No:2016YFC0700301)

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