The impact of rural house’s orientation on heating energy consumption in severe cold regions of China

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Abstract. The severe cold regions of China with characteristics of winter long, cold and snowy, summer short-lived, the heating period lasts for half a year. The heating energy consumption accounts for more than eighty percent of total energy consumption of rural residence. Because the rural houses are single-storey detached house, the heat of solar radiation has greater impact on energy consumption than urban buildings. Firstly, the temperature sensors were used to test the indoor thermal environment of different orientation rooms to clarify the effect of building orientation. Secondly, taking building orientation as main variable (set up twenty-four values, every 15°), building envelope’s thermal performance as auxiliary variables (set four groups), the simulation software DesignBuilder was adopted to analyse the influence rule of building orientation on heating energy consumption under different conditions. It concluded that with the enhance of building envelope’s thermal performance, the impact of building orientation on heating energy consumption and indoor temperature gradually increase, thus focus on the building orientation become more meaningful.

1. Introduction

Solar energy is one of the important renewable energy sources. The influence of orientation on building energy consumption mainly relies on the different utilization degree of solar radiant heat. Due to the uneven solar radiation of each orientation, the heat gain of rural house with different orientation will surely be different, so that the heating energy consumption required maintaining indoor comfortable temperature in winter is also different. Several studies have been carried out to show the correlation between orientation and energy consumption. Hussain et al (2011) [1] taking educational building for example, applied DEROB-LTH software to analyse the energy consumption and PMV values of rooms with different orientations. Abanda et al (2016) [2] used BIM technology to analyse the effect of building orientation on heating energy consumption and indoor temperature gradually increase, thus focus on the building orientation become more meaningful.
rural houses, appeared regional characteristics, as well as usually aims at single condition. If the design criteria for other factors are changed, the impact of orientation on building energy consumption how to change is worthy of further study.

This paper, taking rural houses of severe cold regions as research object, sets building orientation as main variable, building envelope’s thermal performance as auxiliary variables, and adopts DesignBuilder software to analyse the influence rule of building orientation on energy consumption and indoor temperature under different conditions.

2. Methods

2.1. Field testing
A two-story detached rural house which is uninhabited and unheated was selected to carry out field test between February 25 and 27, 2015. Solar radiation is the main factor affecting indoor thermal environment, avoiding other factors interfere. The building appearance and layout of testing points are as shown in Fig.1 and Fig.2. BES-02 temperature sensors (temperature precision: ≤0.5℃) are applied to continuous monitoring indoor thermal environment. The indoor testing points are arranged in the plane geometry centre of each room, with 1.6m height, and the data is automatically recorded every 5min. The instruments are wrapped in aluminium foil to prevent the effects of solar radiation.

![Figure 1. The appearance of testing house](image)

![Figure 2. The layout of testing points](image)

2.2. Numerical simulation
DesignBuilder software is used to simulate the heating energy consumption of rural houses in severe cold regions. The software taking EnergyPlus as energy consumption simulation engine has passed the building envelope thermal performance and energy consumption of ASHRAE Standard (ASHRAE, 2006 [8]). According to the survey results of rural houses in severe cold regions (Teng Shao et al, 2017 [9]), the form and envelop structure of benchmark building are as shown in Fig.3 and Table 1.
Figure 3. The plane and appearance of benchmark building

Table 1. The building envelope parameters of benchmark building

| Building envelope | Construction                                                                 | U-value (W/m²·K) |
|-------------------|-------------------------------------------------------------------------------|------------------|
| Exterior wall     | 20mm cement mortar + 370 mm brick + 20mm composite mortar                     | 1.58             |
| Roof              | suspended ceiling + wood joist + 100mm plant ash + wood roof truss + plank + waterproof layer + tiled roof | 0.93             |
| Exterior window   | single wooded window                                                         | 4.70             |
| Exterior door     | single wood door                                                             | 3.50             |
| Ground            | 20mm cement mortar + concrete cushion + rammed earth                          | 3.00             |

It takes building orientation as main variable, building envelope’s thermal performance and south window-wall area ratio as auxiliary variables, and explores the influence of building orientation on heating energy consumption under multifactorial interaction. Setting 0° as the south orientation, every 15° set a model, a total of twenty-four cases. The performance parameters of building envelope are selected according to the survey data and relevant energy saving design standards, including four groups parameter. The values of variables are as show in Table 2.

Table 2. The values of variables

| Building orientation | Wall | Roof | Window | Ground | Door | Reference standard |
|----------------------|------|------|--------|--------|------|--------------------|
| 0° (south)           | 1.58 | 0.93 | 4.70   | 3.00   | 3.50 | A. Traditional rural houses ( uninsulated measures) |
| 15°                  | 0.50 | 0.45 | 2.00   | 0.30   | 2.00 | B. <Design standard for energy efficiency of rural residential buildings (GB/T50824-2013)> |
| 30°                  | 0.30 | 0.25 | 1.80   | 0.14   | 1.50 | C. <Design standard for energy efficiency of residential buildings in severe cold and cold zones (JGJ26-2010)> |
| 45°-345°             | 0.10 | 0.10 | 0.80   | 0.10   | 1.00 | D. <Criteria for the Passive House, German> |

The rural house is considered as a single zone in the simulations carried out by the DesignBuilder program for the calculation of heating energy consumption during winter heating season (October 20
to the next year April 27, a total of 175 days). This reduces the required simulation time with negligible effect on the accuracy of the results. According to the Design standard for energy efficiency of rural residential buildings (GB/T50824-2013), the indoor calculation temperature is set to 14 °C, and the ventilation rate is 0.5h⁻¹. Using the radiator and heated kang as internal heat sources. The heat dissipation of equipment, human clothing and metabolism, illumination and so on are set according to the actual situation of rural houses.

3. Results and discussions

3.1. Field testing result

Taking air temperature as the evaluation index of indoor thermal environment, the test data of February 26 are selected to compare and analyse. To compare the indoor temperature of different orientation rooms, two groups are selected for comparative analysis. Group1: bedroom and kitchen of first floor, the bedroom on the south side and the kitchen on the north side. Group2: secondary bedroom and study of second floor, the secondary bedroom with south window and the study with north window. The temperature changing curves of the two groups are shown in Fig. 4. The average temperature of bedroom (south room) is -1.07 °C, and the maximum and minimum temperature respectively are 0.4 °C and -1.7 °C. The average temperature of kitchen (north room) is -1.82 °C, and the maximum and minimum temperature respectively are -0.88 °C and -2.32 °C. The results show that the average, maximum and minimum temperature of south room are respectively higher 0.75 °C, 1.28 °C and 0.62 °C than north room.

![Figure 4. The changing curve of indoor temperature. a) Group 1, b) Group 2.](image)

As shown in Fig.4 b), the average temperature of secondary bedroom (with south window) is -1.31 °C, and the maximum and minimum temperature respectively are 0.6 °C and -2.01 °C. The average
temperature of study (with north window) is -1.74°C, and the maximum and minimum temperature respectively are -0.40°C and -2.40°C. The results show that the average, maximum and minimum temperature of south room are respectively higher 0.43°C, 1.0°C and 0.39°C than north room. Among the time 12:00 to 14:00, the sunshine directly on the south room, thus the temperature difference of two groups reached the maximum, other times the temperature difference remaining stable. To sum up, the solar radiation has a certain heating effect on the interior. The temperature of south room is higher than the north room. Building orientation has effect on the indoor thermal environment, also play a role in reducing heating energy consumption in winter.

3.2. Simulation result

The changing curve of energy consumption absolute value with building orientation under four different type envelopes are as shown in Fig.5.

As shown in Fig.5, when the building orientation is 0° (south), the energy consumption reaches to the minimum value, with the orientation rotating from 0° to 360°, the energy consumption presenting the changing rule “low-high-low-high-low”. As shown in Fig.6, when the building orientation is 90° and 270° (west and east), the energy consumption is higher because of the less gain of solar radiation heat. It's important to note that the benchmark building with window-wall ratio of frontage is 0.4 and of rear face is 0.3, when the building orientation is 180°, that is the frontage faces north and the rear face towards south, a certain amount of solar radiation heat also can be obtained, but the window-wall ratio less than frontage, the heat gain of solar radiation less than the condition of 0° orientation. Thus, the energy consumption is in the middle level, not reach to the minimum value.
In general, the changing rule of energy consumption with building orientation under four types building envelope is consistent. However, with the change of building envelope’s thermal performance, the change rate of every orientation’s energy consumption is different. Using relative value to show the change of every orientation’s energy consumption, the energy consumption value of south is set as one and other orientations’ energy consumption are expressed by relative value. As shown in Fig.7, with the enhance of building envelope’s thermal performance, the difference of relative value gradually increases, indicating that the change of building orientation has more effect. For example, when the A type building envelope is adopted, the relative value of north’s energy consumption is 1.02, while applying the D type building envelope, this vale increases to 1.20. Therefore, when the building envelope’s thermal performance is improved, the rural houses’ orientation should be as south as possible, the energy saving effect is more significant, thus focusing on the building orientation become more meaningful.
The indoor temperature changing rule with building orientation is shown in Fig.8. With the improvement of building envelope’s thermal performance, the air temperature gradually increases, but the fluctuation rules are different. For example, when the D type building envelope is adopted, the air temperature is highest, but the temperature of different orientations has obvious difference, the standard deviation of temperature data is 0.36. The building orientation has a significant effect on indoor temperature. While applying the A type building envelope, the air temperature is lowest, but the temperature of different orientations is basically the same, the standard deviation of temperature data is only 0.009, indicating that the building orientation has a minimal effect on indoor temperature. It also proves that the higher thermal performance the building envelope, the more attention should be paid.

4. Conclusions
Through the field testing and numerical simulation, it can be concluded that building orientation has an impact on energy consumption and indoor thermal environment in winter, while the design criteria for other factors are changed such as building envelope’s thermal performance, the effect extent of building orientation on energy consumption is also changing. According to the testing results, the solar radiation has a certain heating effect on the interior, and the temperature of south room is higher than the north room. On the basis of simulation results, the changing rule of energy consumption with building orientation under four types building envelop is consistent, but with the improvement of building envelope’s thermal performance, the change rate of every orientation’s energy consumption and the indoor temperature fluctuation increase, that is the building orientation has greater impact on heating energy consumption and indoor temperature. It's more meaningful to focus on the building orientation.

5. References
[1] Hussain H. Alzoubi and Amal T. Malkawi. 2011. Investigating the Effect of Building Orientation on Thermal Comfort and Energy consumption in Educational Buildings. *Global Conference on Renewable energy and Energy Efficiency for Desert Regions*, 1-10
[2] Abanda F H and Byers L. 2016. An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modeling). *Energy*, 97, 517-527
[3] Tokbolat S, Tokpatayeva R et al. 2013. The Effects of Orientation on Energy Consumption in Buildings in Kazakhstan. *Journal of Solar Energy Engineering*, 135(4), 1-8.
[4] Dong Tan, Li Nianping et al. 2011. The influence and analysis of residential building orientation on energy consumption in Changsha. *Proceedings of the conference on building environment and equipment technology*, 403-405
[5] Yu Wei. 2011. The low Energy-Consumption Strategy for Improving Indoor Thermal Environment Quality in Residential Building. *Ph.D. Thesis*, Chongqing University.
[6] Morrissey J, Moore T et al. 2011. Affordable passive solar design in a temperate climate: An experiment in residential building orientation. *Renewable Energy*, 36(2), 568-577.
[7] Florides G A, Tassou S A et al. 2002. Measures used to lower building energy consumption and their cost effectiveness. *Applied Energy*, 73(3), 299-328.
[8] ASHRAE. 2006. ANSI/ASHRAE Standard 140-2004, Building Thermal Envelope and Fabric Load Tests-DesignBuilder Version 1.2.0. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc
[9] Teng Shao, Hong Jin et al. 2017. Current Situation and Improving Strategies for Northeast China’s Rural Housings. *Open House International*, 42(4): 70-77.

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