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Research on Energy Consumption of Building Layout and Envelope for Rural Housing in the Cold Region of China

Research on Energy Consumption of Building Layout and Envelope for Rural Housing in the Cold Region of China

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Abstract. Rural housing is an important part of residential buildings in China, which has large construction amount, high energy consumption and large potential for energy saving. Unreasonable building layout and poor thermal performance of building envelope are the main reasons for high energy consumption through field survey of rural housing in cold region. Based on computer-aided simulation, this study uses DesignBuilder to simulate the energy consumption of typical rural housing, and compares it with other energy consumption under different strategies of building layout and envelope. Energy-saving strategies of building layout and envelope suited for rural housing are obtained. The research has significant reference value to the energy-saving design of rural housing.
Keywords. Rural housing, Building layout, Building envelope, Energy consumption

1. Introduction

Rural housing is an important part of China's residential buildings, which is self-established by residents. In 2016, rural housings account for 45% of the total area in residential building, consuming about 25% of the total building energy consumption [1]. The per capita energy intensity was 1454kgce/h, which was twice that of urban housing [2]. China'13th plan Five-Year Plan of national development will vigorously promote energy efficiency of the rural housing. The construction of rural housing still remains the traditional building layout and techniques, lacking guidance and constraints. Therefore, rural housing has great potential for energy saving. Moreover, as a computer-aided tool, DesignBuilder could simulate energy consumption under different strategies, and assist residents to select better measures to improve building performance, which’s more consistent with spontaneous construction.

This paper aims to study the energy consumption performance under different building layouts and envelope through simulation of rural housing in the cold region based on field research, and provides suggestions to reduce operating energy consumption for residents during the construction process.

2. Methods

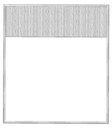
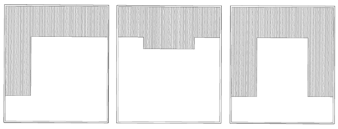
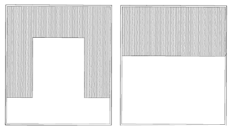
This section is divided into four parts. Section 2.1 describes the current status of rural housing in the survey area. Section 2.2 analyses energy-saving potential based on the status. Section 2.3 shows typical model details of building layout and envelope. The energy consumption of different strategies are simulated and discussed in Section 2.4.

2.1. Field research

This study selected the central of Shandong, a typical area in the cold region of China, to investigate through measurement, image recording and interview. The rural housing under different time to build have continuity and similarity characteristics due to the spontaneous construction on the homestead, which's a combination of building and courtyard. The investigation is as follows:

In terms of building layout, Table 1 shows the building layout types based on the survey results. The trend is that the building area and depth of the building are increasing.

Table 1. Type of building layout for rural housing.

Time to build	Before 1980	1980-2000	After 2000
Type	Strip-shaped	L-shaped, convex/ concave shape	Concave/rectangular shape
Sketch			
Orientation	North-south	North-south	North-south
Storey	1	1	1-1.5
Height	h≤3m	3m<h<3.6m	h≥3.6m

The building envelope, including external wall, roof and external window, are shown in Table 2. The building envelope before 1980 used traditional materials such as soil, wood and straw. After 2000, industrial materials such as concrete, brick and aluminum alloys were used. The rural housing from 1980 to 2000 were in a transitional stage.

Table 2. Information on building envelope of rural housing.

Building envelope	Layers	Ratio(Before 1980/ 1980-2000/After 2000)
External wall	10mm lime + 40mm wheat straw mud + 400mm mud brick + 40mm wheat straw mud	100%/ 10.7%/ 0%
	20mm cement mortar + 240mm brick + 20mm cement mortar	0%/ 89.3%/ 100%
Roof	20mm wheat straw mud + 20mm sorghum foil	100%/ 87.2%/ 11.1%
	20mm cement mortar+80mm reed board	0%/ 12.8%/ 89.9%
External window	Single glazing (6mm)	100%/ 89.3%/ 66.7%
	Double glazing (6mm+12Air+6mm)	0%/ 10.7%/ 33.3%

As for energy and equipment, energy is used primarily for heating, cooling, lighting and cooking. Coal heating is the most used in rural housing, accounting for 80% of total energy consumption [3]. In the survey area, small coal-fired furnace is the equipment used by most residents for heating. The heating period is from November 15 to March 15, and the average annual coal consumption is 1.5-2 tons per household.

2.2. Analysis of energy-saving potential

It could be found that the building layout of rural housing has become more complicated, and building area has increased. These lead to growth in the external surface area and a decrease in space utilization, which in turn causes energy consumption raised. The building envelope lacking of insulation measures, inefficient heating equipment exacerbate energy consumption, which makes the indoor environment susceptible to external influences. Therefore, rural housing should adopt passive energy-saving strategies. It could radically reduce energy demand and save operation consumption.

2.3. Typical model details

This paper selects the rural housing after 2000 as the research object, which's the closest to the present time. Figure 1 shows the building layout of the typical model for calculation, which has a building area of 112.5m^2, a floor height of 3.9m and a roof slope of 30°. Table 3 lists the layers and thermal performance of the building envelope.

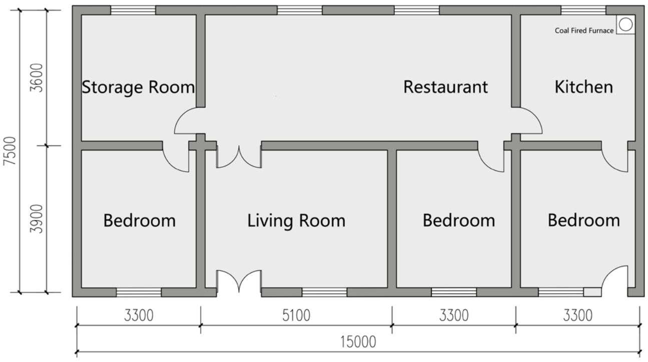


Figure 1. The layout of the typical model (mm).

Table 3. Layers and the thermal performance of the building envelope.

Building envelope	External wall	Roof	External window
Layers	20mm Cement mortar+240mm brick+20mm cement mortar	20mm Cement mortar+80mm reed board	6mm Single glazing
U-value	2.02 W/m^2·K	1.13 W/ m^2·K	5.78 W/ m^2·K

2.4. Energy simulation

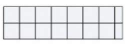
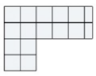
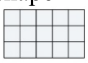
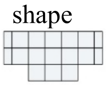
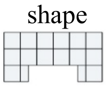
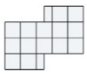
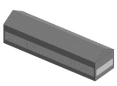
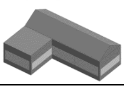
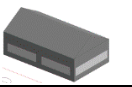
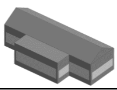
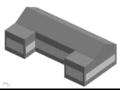
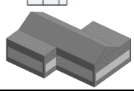
Once the building model is determined, the next step is to simulate the energy consumption of different building layout and envelope. DesignBuilder is chosen for specialist energy simulation. Firstly, the model is built according to the information of Figure 1, and parameters are input secondly. The parameters such as activity, lighting power, HVAC system are input on the basis of research results, which are listed in the Table 4. Information about building envelope is from the Table 3.

Table 4. Main design parameters of rural housing in DesignBuilder.

Parameters		Value
Activity	Density (people/m^2)	0.05
	Interior environment (◦C)	16/26 (winter/summer)
Lighting	Lighting power density (W/m^2)	7
HVAC	Heating/Cooling schedule	11.15-3.15/06.15-08.15
	Heating/Cooling system seasonal COP	0.64(Coal)/3.2(Electricity)
	Daily hot water COP	0.85

In the study of the impact of building layout on energy consumption, this paper selects six layouts based on the research data (Table 5). Those models under six layouts ensure that the area, height, slope and envelope of building are consistent with typical model.

Table 5. Building layout types of rural housing.

Type	Strip shape	L-shaped	rectangular shape	convex shape	concave shape	double-rectangular shape
Diagram						
DB model						

The heat transfer coefficient (U-value) is employed as an index to measure the performance of building envelope. So, this paper chooses it as the variable to explore energy consumption. Table 6 lists the layers and corresponding U-value of the building envelope for simulation, which contains the interval of variable.

Table 6. Layers and U-value range of the building envelope.

Building envelope	Layers	U-value (W/m^2·K)
External walls	20mm Cement mortar+0/10/15/20/25/30/35/40 /45mm EPS+240mm brick+20mm cement mortar	2.02/1.36/1.17/1.03/0.92/ 0.83/0.75/0.69/0.65
Roof	20mm Cement mortar+0/10/15/20/25/30/35/40 /45/50mm EPS +20mm cement mortar+80mm reed board	1.13/0.97/0.87/0.79/0.72/ 0.66/0.61/0.57/0.54/0.5
External window	Single glazing 6mm/single reflection glazing 6mm/ single Low-E glazing 6mm/double glazing 6+6mm Air+6/ double glazing 6+12mm Air+6	5.78/4.6/3.8/3.0/2.8
"_" refers to typical model values; "_" refers to the value specified in the rural housing standard [4].		

3. Results and discussions

3.1. Energy consumption of different spatial layouts

Figure 2 displays the simulation results under six building layouts. Energy use intensity is the indicator of energy consumption. This result proves that the building layout has the greatest impact on heating, and has less impact on cooling and lighting. Among them, the lowest energy consumption layout is rectangular shape, which is 53.81kWh/m^2•a, followed by the strip shape with an energy consumption of 56.9 kWh/m^2•a. The convex shape layout has the largest energy consumption of 61.12 kWh/m^2•a, which is 14% more than rectangular shape layout.

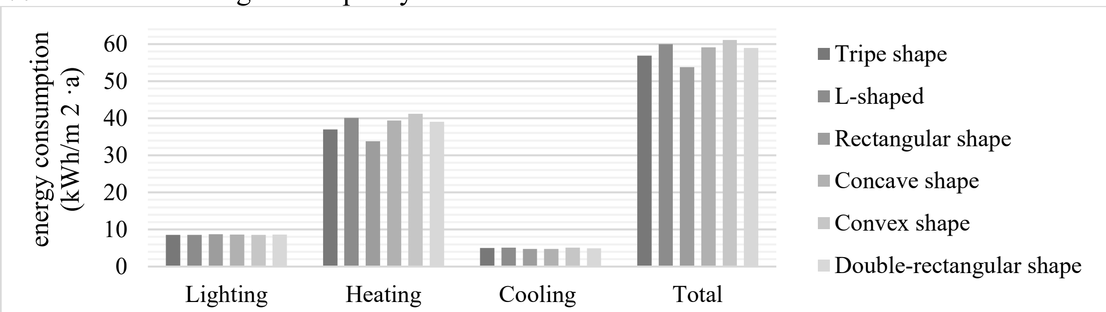


Figure 2. Comparison of energy use intensity under different building layouts.

This section also simulates indoor sensible temperature fluctuations. The result shows that the sensible temperature in different layouts is similar in summer, and different obviously in winter. The sensible temperature of the building layout in strip shape is the most comfortable than others (Figure 3).

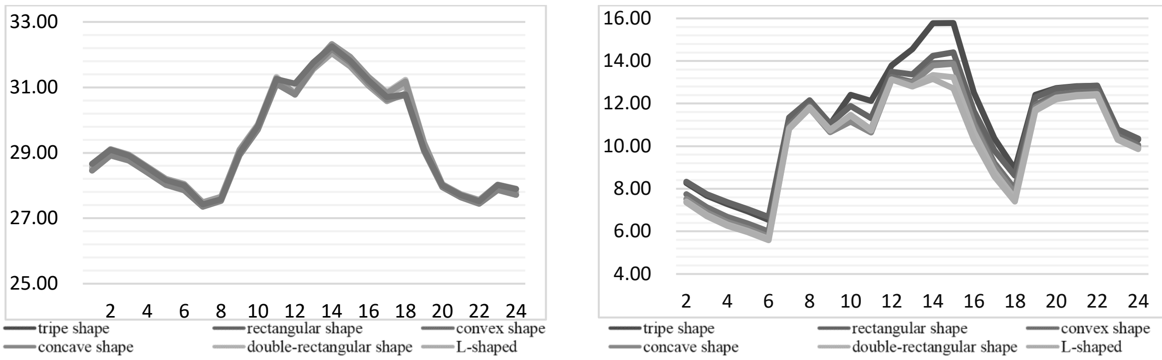
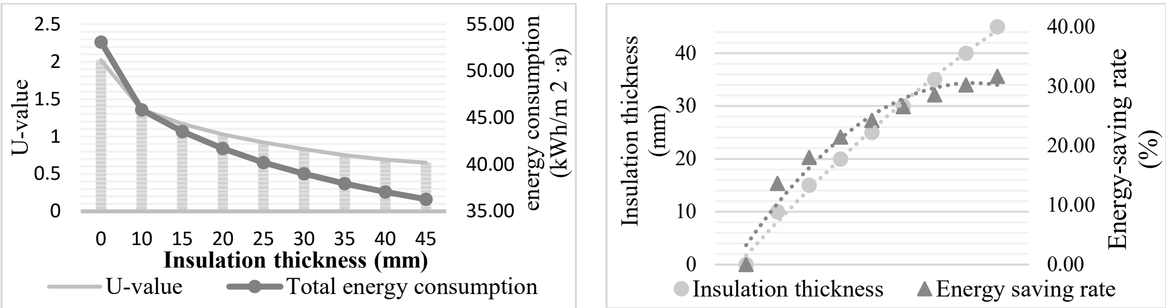


Figure 3. Sensible temperature fluctuations under different building layouts in summer and winter. (Intermittent heating in winter, running time is 6:00-8:00, 12:00, 18:00-22:00)

3.2. Energy consumption of building envelope

In this section, energy consumption under different thermal performance of the building envelope is simulated. It includes external wall, roof and external window. The energy consumption of the typical model is 53.11kWh/m^2•a.

Figure 4 shows the variation of U-value and energy consumption in the external wall with different thickness insulation. Energy consumption has dropped significantly after the insulation layer is added. When U-value reaches the standard limit, total energy consumption is 36.30kWh/m^2•a, which saves 31.65% of energy. In Figure 4 (b), it's noted that the growth rate of the energy-saving rate slows down as the enhancement of insulation thickness. The growth rate tends to be horizontal at the thickness of 35mm. Meanwhile, the sensible temperature increases by nearly 2°C in winter (Figure 5).



(a) Trend of U-value and energy consumption under different insulation thicknesses

(b) Relationship between insulation thickness and energy-saving rate

Figure 4. Relationship between thermal performance and energy consumption of external wall.

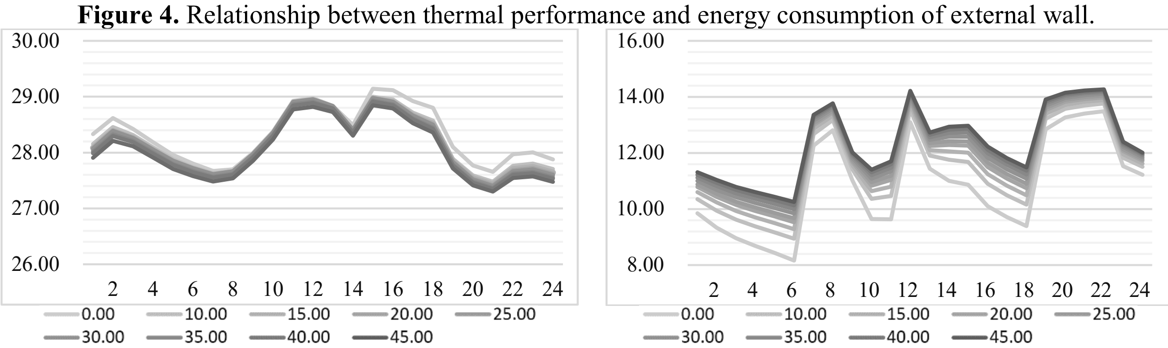
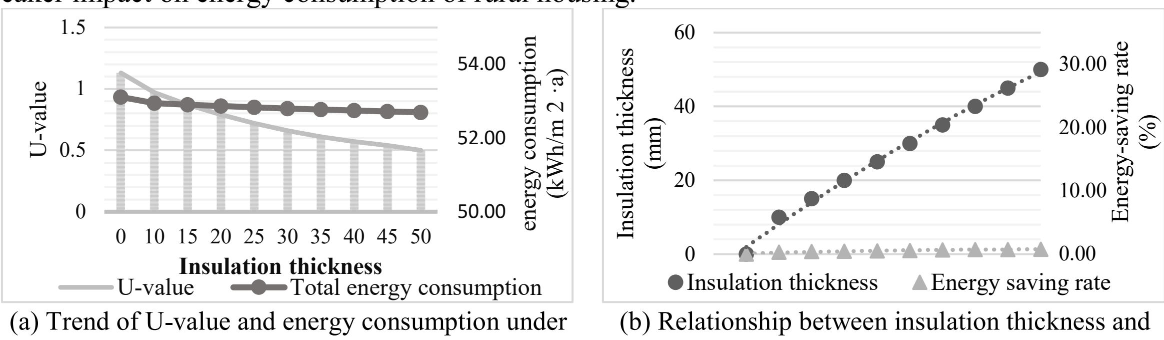


Figure 5. Relationship between thermal performance and sensible temperature fluctuations of external wall in summer and winter.

Total energy consumption changes a little as the raise of the roof insulation thickness. When U-value reaches the standard limit, energy consumption is 52.70kWh/m^2•a, which only saves 0.78% of energy. The horizontal growth curve of energy-saving rate in Figure 6 (b) and the similarity of sensible temperature in the Figure 7 further indicate that the improvement of roof thermal performance has a weaker impact on energy consumption of rural housing.



(a) Trend of U-value and energy consumption under different insulation thicknesses

(b) Relationship between insulation thickness and energy-saving rate

Figure 6. Relationship between thermal performance and energy consumption of roof.

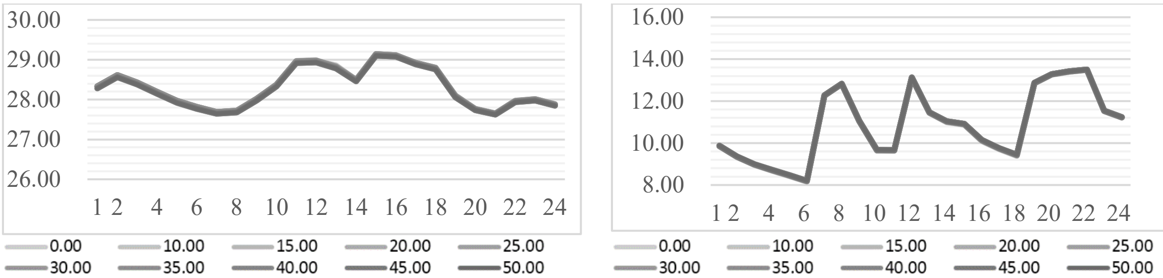
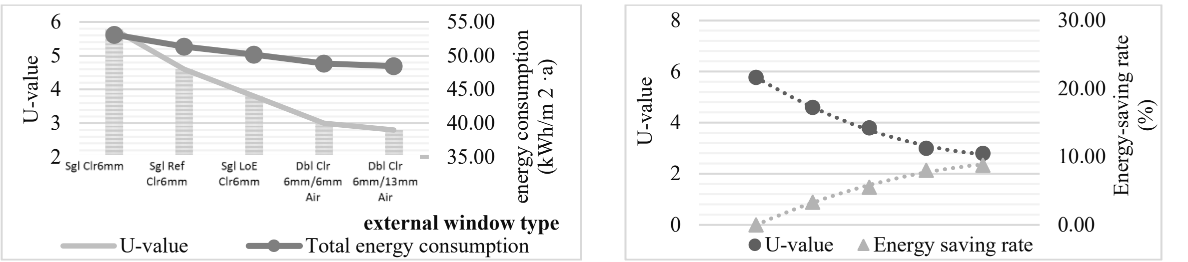


Figure 7. Relationship between thermal performance and sensible temperature fluctuations of roof in summer and winter.

Moreover, the energy consumption results of external window under different U-value of are shown in the Figure 8 (a). Total energy consumption is decreased when thermal performance is improved. When U-value reaches the standard limit, total energy consumption is 48.46kWh/m^2•a, which decreases 8.76% of energy. Through the relationship between U-value and energy-saving rate of external window in Figure 8 (b), the growth rate of energy-saving rate remains stable. The sensible temperature in winter is correspondingly increased by 0.5°C (Figure 9).



(a) Relationship between external window type and energy consumption

(b) Relationship between external window type and energy-saving rate

Figure 8. Relationship between thermal performance and energy consumption of external window.

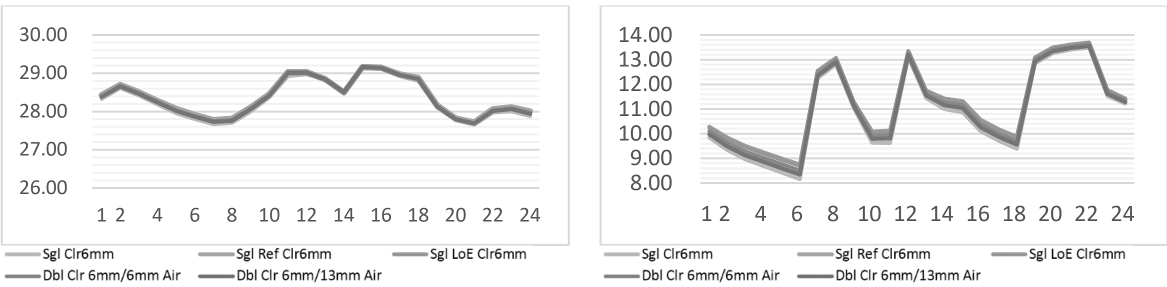


Figure 9. Relationship between external window type and sensible temperature fluctuations in summer and winter.

4. Conclusion and implications

The focus of the present study is energy consumption performance under building layout and envelope of rural housing in cold region, which may show distinct when compared to other climate zones or building type. This paper summarizes that rural housing has a large energy-saving potential through investigation. Therefore, energy-saving research is carried out in terms of building layout and envelope. The following conclusions can be drawn:

- The rectangular or strip building layout should be chosen when rural housing is built, avoiding convex shape or L-shaped. As the compact building layout could reduce heat loss by reducing the external surface area of the building.

- Considering energy saving and comfort, the building layout with rectangular shape is the most energy saving, and residents feel comfort living in the rural housing with stripe shape.
- According to the energy-saving rate of building envelope, the priority of insulation measures selected is external wall, external window, and roof. Among them, insulation measures of roof can be neglected for its little effect.
- There is no clear correlation between thermal performance enhancement of the building envelope and energy consumption reduction. Hence, the strategy that matches the economic situation can be selected during construction according to the energy-saving rate.

Based on the present research, it’s beneficial to residents to choose appropriate building layout and envelope according to specific need. It has guiding significance for energy-saving construction of rural housing. In addition, energy-saving targets in rural areas can be achieved as early as possible by providing reference for other areas in cold region.

5. References

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