Thermal environment analysis and energy conservation research of rural residence in cold regions of China based on BIM platform

J Y Dong¹,²*, W Cheng¹, C P Ma², L S Xin² and Y T Tan²

¹School of Architecture, Harbin Institute of Technology, Harbin 150000, China.
²School of Architecture and Design, Changchun Institute of Technology, Changchun 130000, China.

Corresponding author: djyrob@gmail.com

Abstract. In order to study the issue of rural residential energy consumption in cold regions of China, modeled an architecture prototype based on BIM platform according to the affecting factors of rural residential thermal environment, and imported the virtual model which contains building information into energy analysis tools and chose the appropriate building orientation. By analyzing the energy consumption of the residential buildings with different enclosure structure forms, we designed the optimal energy-saving residence form. There is a certain application value of this method for researching the energy consumption and energy-saving design for the rural residence in cold regions of China.

1 Introduction
Most of the northern part in China is in the cold or severe cold area. However, with the increase of the population, traditional residential buildings cannot satisfy the modern living environment in terms of winter heating, especially winter thermal environment. Meanwhile, from the perspective of building energy saving and environmental protection, due to the increase in the building area and residents’ demands for the improvement of indoor thermal environment, the proportion of the rural building energy consumption in the total energy consumption has been increasingly high. Energy saving of rural buildings has aroused more and more attention. With the deepening of projects on building energy saving in China, the issue of building energy saving in rural areas has been gradually put on agenda. Rural residential heat-supply energy consumption in the cold area accounts for a large proportion of the total building energy consumption, so lowering rural residential energy consumption in the cold area is quite essential for building energy saving in China. Therefore, in the early days of constructing rural buildings, it is of great significance to make rational planning to explore and design energy-saving buildings that meet the local climatic and geographic conditions, match the local traditional residential characteristics, and have significant improvement in the indoor thermal environment.

2 Indoor thermal environment-related problems of rural buildings in the cold area of China
2.1 Building Form and Indoor Thermal Environment
The self-built single-storey or tile-roofed residence is the main type of rural buildings in the northern cold area of China. Due to the lack of unified planning and design for rural buildings, most buildings are constructed randomly, which affects, adversely, heating in the winter.

In the selection of the building envelope structure, the wall of rural residence is mainly divided into 3 types: the brick wall, cob wall and stone wall. The cob wall and stone wall were mainly used in old buildings, while the clay brick wall is the most basic form of the envelope structure for existing buildings and newly-built residential buildings. The brick wall thickness ranges from 240mm to 370 mm. To protect against cold, the northern wall thickness of some buildings increases to 370 mm, while the wall thickness of other sides is 240mm. The vast majority of walls do not have an insulation layer, so the wall insulation is poor and heat loss in winter is quite large.

In the selection of doors and windows, the single-glazing window is commonly used in rural buildings, while the double-glazing window or the hollow-glass window is rarely used. The old wooden single-glazing window has the problem of aging and deformation. Some new buildings choose aluminum alloy windows. However, because the installation of aluminum alloy windows is not professional enough, the gap between the window and wall is usually large, thus affecting the overall air tightness. Moreover, in order to improve indoor lighting and make full use of sunlight, the window-wall ratio of southern walls of some buildings is quite large, which results a lot of heat loss. In terms of the anteport material, the single-layer wooden door is usually used. However, some new buildings choose steel doors or metal insulation doors. In the winter, although the cotton door curtain is set inside the door, or the simple foyer is added outside the door, to reduce the heat loss caused by cold air infiltration, it is still difficult to ensure a comfortable indoor temperature.

In the selection of the roof shape and materials, the wood-trussed slope roof is usually selected. The newly-built flat roof mainly uses the cast-in-place concrete structure. Reed, straw, clay and other insulation materials are usually added to the slope roof. However, to save money, many buildings do not have ceiling, or do not add an insulation layer for the ceiling, so the insulation effect is not good. Winter of the cold area in China lasts for a long time, and the temperature is quite low. In order to maintain a relatively comfortable indoor temperature, greater heat supply is needed, so the proportion of heating energy consumption in the overall building energy consumption is greater. At present, the heated brick bed and the bag wall are mainly based to supply heat for rural buildings in the cold area of China. Old-fashioned heating installation is used as supplement. In old-fashioned heating installation, coal and straw are used as fuel, which can not only provide heating, but also satisfy cooking demands. Due to the low temperature outside the door, human activities in the cold area are limited inside the door, especially the heated brick bed. An actual test was made of the rural indoor temperature in the cold area. Test results show that the average indoor temperature in rural areas is just 5.6 ℃, so the indoor thermal environment in rural areas in relatively poor in the cold area.

2.2 Factors Affecting Rural Residential Thermal Environment
Most of the rural buildings in northern China are designed and built by farmers, and the buildings lack unified planning and have great randomness. Worse still, rural buildings are built based on poor construction technology and previous construction experience. In the selection of the rural residential location and orientation, most rural residences face south. This helps to accept sunlight, fully use solar energy and improve indoor lighting, but no consideration is given to avoid the winter monsoon in a reasonable way, and reduce heat loss. Meanwhile, some research shows that the heat transfer and cold air infiltration of the residential building envelope structure in the cold area are the main factors affecting the energy consumption of buildings. The heat dissipation of the building envelope can reach 1/3 of heating energy consumption. The air tightness of residential buildings causes serious cold air infiltration, which further exacerbated the heat loss.

According to an analysis of the influence of the roof, window, sunshade and external wall envelope structure on the energy consumption of buildings, it can be seen that during the winter heating, the influence on thermal properties of the exterior wall is the most significant. At present, the pure 240mm or 370mm-thick brick wall is commonly used for the rural residential envelope structure. Such bricks
have a large heat transfer coefficient. However, no appropriate insulation is set, so the thermal insulation effect is poor, and the heat loss is serious. Therefore, it is difficult to meet the indoor insulation demand.

Under winter heating conditions, the door and window are the most vulnerable part of the heat loss. The low thermal conductivity and high air tightness of the door and window and a reasonable window-to-wall ratio have great significance for improving the energy efficiency of residential buildings. However, the single-glazing window and wooden door are mainly used for rural buildings. The heat transfer coefficient often fails to meet thermal requirements. Worse still, windows and doors of many rural buildings fall into disrepair and deformation, so the air tightness of the windows and doors are poor. Hot and cold air exchanges frequently, and cold air infiltration is further exacerbated. As a result, energy is greatly wasted.

The roof is the most powerful building component which can withstand climatic elements, playing a greater role in the insulation of buildings. The traditional slope roof approach, to a certain extent, improves the indoor thermal environment, but still has room for improvement. It is necessary to properly increase the thickness of the insulation layer, set ceiling, add a vapor-proofing layer, and form air compartment, to make winter fairly mild and summer cold, thus effectively improving the indoor thermal environment.

3 Analysis of rural residential energy consumption based on the BIM platform

BIM has been widely applied and affirmed in the green building. In the energy-saving design of buildings, visualization can be implemented to directly get results of the building energy consumption analysis. Compared to the traditional 2D design, visualization has obvious advantages in the collaborative design, efficiency, visibility and economical efficiency. However, the analysis of energy consumption of rural residential buildings is small in number. In this paper, a rural residential building in a cold area was selected for design, analysis and research. Revit was adopted to build the 3D model, and the model with attribute information was introduced to Ecotect energy analysis software, in order to quickly and conveniently get energy consumption analytical results of the whole building.

3.1 Selection of the Best Building Orientation

In the site selection for rural residential buildings in the cold area, sunlight, lighting and ventilation demand should be satisfied, so that the buildings can have function of heat preservation in the winter and ventilation function in the summer. In terms of the orientation, the buildings should face south or approximately face south. Houses should avoid the dominant wind direction in the winter, and the window-wall ratio should be controlled within the specified range. First of all, the WEA file of the corresponding area is imported into the Weather tool software, and time is set according to specific demands. Climatic conditions on the day with the lowest average temperature in this area are analyzed. According to the day-by-day temperature variation range through the year, it can be seen that the average temperature of this area in January, February and December is around -10 ℃. Moreover, in the selection of the building orientation, the dominant wind direction of the winter should be avoided to prevent rapid heat loss, because it goes against heat preservation in the winter. As can be seen from the winter wind rose diagram of this area, the dominant direction of the winter monsoon is the southwest. Therefore, the southwest orientation should be avoided in the selection of building orientation. According to the orientation analysis, the best orientation of the building can be identified. Moreover, solar radiation of each orientation in this area in the hottest month and coldest month and the average solar radiation through the year is analyzed, to determine that the best orientation of the building is 10 ° south by the east. This meets the norm that rural buildings should face south as much as possible and avoid the dominant wind direction in winter. Therefore, this orientation is selected as the best orientation for the building model.

3.2 The Initial Planning of the Building

To meet the needs for modern rural residence and improve the comfort of the residential building and demand for the residential area, this building has 2 floors and a total construction area of 411.19 m²
(excluding sunspace area of 19.94 m²). The Weather tool software is used to determine the best orientation of the building. To facilitate a comparative analysis of energy consumption, this paper provides 3 design schemes for the building: the building design according to the traditional method, the building design with insulation measures on the envelope structure, and the building design with insulation measures on the envelope structure and sunspace. In the 3 design schemes, the building type is the same, but building envelope materials are different. To reduce the cost, the wood-trussed slope roof is selected for this building. The interior layout of the residential building is shown in Figure 1. The wall-to-wall ratio and other parameters of the buildings meet relevant standards and match local characteristics and living requirements.

According to relevant norms for the main functions of bedrooms in the rural residential buildings in the cold area, indoor thermal environment parameters of the building in winter are calculated according to the “Rural residential building energy efficiency design standards” (GB/T 50824-2013). The indoor bedroom temperature takes the value of 14 ℃, while the ventilation rate is 0.5 h⁻¹ h. Considering rural living habits in the cold area, the building just takes appropriate heating measures, but has no air conditioning and refrigeration measure. The energy consumption of the whole building is calculated and compared. A comparison is made between the energy consumption of the simulated traditional building and the modern building with insulation within a year (Figure 2). According to the comparison results, energy consumption occurs mainly in the winter. The total annual energy consumption of the traditional building is 89656 kW • h, while the corresponding figure of the building with insulation is 42431 kW • h. If the building is designed with insulation and sunspace, the total annual energy consumption of the building is 36898 kW • h. The annual energy consumption per square meter of the traditional building, the building with insulation and the building with insulation and sunspace is 218 kW • h / m², 103.2 kW • h / m² and 89.7 kW • h / m², respectively. After insulation measures are taken on the envelope structure, the building energy consumption is reduced significantly. The total energy consumption decreases by 52.6%. The energy consumption could be further reduced if sunspace is added to the building. If insulation and sunspace are designed for the building, the total energy consumption can decrease by 58.8%. Thus it can be seen that the envelope structure type has a significant impact on the building energy consumption.
A horizontal comparison is made of the annual energy consumption of the bedroom on the first floor of the simulated traditional building, the modern building with insulation and the modern building with insulation and sunspace room. The annual energy consumption of the bedroom in the simulated traditional building, the modern building with insulation and the modern building with insulation and sunspace room is 4577.1 kw·h, 2156.5 kw·h and 1578.1kw·h. Compared with the traditional building, the modern building with insulation and the modern building with insulation and sunspace room have a 52.9% and 63.4% cut in energy consumption.

4 Conclusions
In this paper, the BIM platform was based to build models for rural residential buildings. Through the selection of the best orientation for the residential building and simulation of the energy consumption for 3 building types with different envelope structures, the quantitative impact of the envelope structure, material and sunspace on the building energy consumption. In the simulation of energy consumption calculations, a visualized data model was presented to provide data support for the scheme decision making. Analog simulation can be used as a reference for preliminary planning and design, thus greatly improving the work efficiency. Meanwhile, the model was introduced to effectively connect software, lower the error rate, and ensure the accuracy of the model.

Results of this research show that in the design of rural residential buildings, creating a virtual model that contains all building information, accurately calculating energy consumption and designing the best energy-saving and heat-preserving residential building based on energy consumption results have great practical significance for alleviating energy issues and popularizing green buildings in China.

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