Research on Energy-Saving Design of Thermal Insulation Structure of Residential Buildings in Severe Cold Areas

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Abstract. With the general improvement of people's living standard, residents in severe cold areas have further increased their requirements for residential insulation, which provides new issues for the energy-saving design of thermal insulation of their residential buildings. This paper mainly introduces the energy-saving design of the thermal insulation structure of residential buildings in severe cold areas such as exterior walls and roofs, including the selection of their specific materials. It is hoped that the insulation performance can be higher and the energy-saving effect can be better.

1. Introduction
In recent years, China's construction industry has been gradually developing towards an intensive mode, and the design of buildings will consider whether their energy-saving effects meet the needs of sustainable development of society. Among them, the energy-saving design of thermal insulation structure has obvious effect of energy-saving and emission reduction, especially in severe cold areas. Therefore, relevant designers make full use of the energy-saving design of thermal insulation structure to promote its energy-saving effect when designing residential buildings in harsh cold regions.

This paper mainly focuses on the energy-saving design of three kinds of thermal insulation structures of residential buildings: exterior walls, roofs and windows.

2. Energy-saving design of external wall insulation structure
China’s severe cold areas have long winters and large temperature differences between day and night. Residents’ demand for thermal energy is generally uneven throughout the day. With the improvement of people's living standards, their energy consumption is also increasing, involving all aspects of daily life of residents in severe cold areas, as show in table 1. We need the construction industry to pay attention to the energy-saving design of the thermal insulation structure of its residential buildings, and use energy-saving thermal insulation structures to ensure that the temperature of residential buildings will not lose too quickly, so that residents can reduce related energy consumption and promote the sustainable development of our society.
Table 1. Types and methods of main energy consumption of residents in severe cold areas in my country

| Energy consumption type          | Energy consumption method                                      |
|---------------------------------|----------------------------------------------------------------|
| Building heating energy         | Heat dissipation and heat absorption of building walls, etc.   |
| consumption                     | Living catering, hot water, etc.                              |
|                                 | Ventilation energy consumption                                 |
| Energy consumption              | Air conditioning and heating                                   |
|                                 | Radiator heating                                               |
|                                 | Floor heating                                                  |
|                                 | Lighting energy consumption                                    |

2.1. Ways of external wall insulation

The external wall insulation methods in severe cold areas are divided into two modes: internal insulation and external insulation.

2.1.1. Internal insulation.

Internal insulation means that the insulation material is set on the inner side of the wall. This method does not require high quality of the insulation material, does not require good waterproofness, and will not affect the exterior decoration of the wall.

2.1.2. External insulation.

The corresponding External insulation means that the thermal insulation material is set on the periphery of the wall, which can effectively reduce the appearance rate of cold bridges and facilitate interior decoration. According to relevant investigations, it is shown that autoclaved aerated concrete blocks and rigid foam polyurethane boards are the best choice for exterior wall insulation materials. When designing, the designer should make scientific design based on its thermal insulation and energy-saving and pay attention to maintaining communication with the construction staff to formulate the construction technology that needs to be used in the construction process\(^{(1)}\), as show in figure 1.

![Schematic diagram of the external wall insulation system](image)
2.2. Selection of exterior wall materials

In the selection of materials for the external walls of the main building, the economic level of the residents should be taken into consideration, and the design should be selected and designed in accordance with the principles of economy and universality. At present, the more common base materials for residential buildings include sintered fly ash bricks, autoclaved aerated concrete blocks, sintered coal gangue porous bricks, and ordinary concrete small hollow blocks. Rock wool board, polystyrene foam board, rigid film polyurethane board, etc. are usually used in the design of insulation materials [2], as shown in table 2.

| Serial number | Base material                  | Insulation Materials       | Insulation method |
|---------------|--------------------------------|----------------------------|-------------------|
| 1             | Sintered fly ash brick         | Hard film polyurethane board | External insulation |
|               |                                | Styrofoam board            | Internal insulation |
| 2             | Autoclaved aerated concrete block | Hard film polyurethane board | External insulation |
|               |                                | Styrofoam board            | Internal insulation |
| 3             | Sintered coal gangue porous brick | Styrofoam board            | External insulation |
|               |                                | Hard film polyurethane board | Internal insulation |
| 4             | Ordinary concrete small hollow block | Rock wool board          | External insulation |
|               |                                | Styrofoam board            | Internal insulation |

We have obtained the energy-saving rate data of different base materials through many experiments. From figure 2, it can be seen that designers need to combine the actual situation of residential buildings to get the following conclusions. When the autoclaved aerated concrete block + rigid film polyurethane board is adopted, and the external insulation is adopted, the energy-saving rate is 46.2%, and the energy-saving effect is the most obvious [3].

![Figure 2. Comparison of energy-saving rate under different materials](image)

3. Roof insulation and energy-saving design

The roof is an important part of the envelope structure of residential buildings in severe cold areas, and the contact area with the external environment is second only to the external walls. Compared with other structures, the heat consumption is a relatively large, so relevant designer need to pay attention to optimizing the roof of related residential buildings during the design to promote the improvement of indoor temperature stability.

3.1. Selection of insulation materials

In the choice of roof thermal insulation materials, priority is given to selecting lightweight porous thermal insulation materials with low thermal conductivity and low hygroscopicity water-repellent...
materials, and specific designs are carried out according to the types of houses actually required by residents. For example, if the type of residential building is a bungalow or a low-rise building, block-like materials such as foam glass panels, steam concrete, extruded polystyrene panels, and modified expanded perlite panels can be used. They have small thermal conductivity, large thermal resistance, good thermal insulation performance, and also have the advantages of fast construction and good thermal insulation effect, and can be widely used in severe cold areas [4], as shown in table 3.

Table 3. Properties of commonly used residential roofing insulation materials

| Material name                  | Thermal conductivity W/(m·K) | Burning class         | Thermal resistance (m²·K/W) |
|-------------------------------|-----------------------------|-----------------------|-----------------------------|
| Foam glass panel              | 0.066                       | Non-combustible A     | 0.38                        |
| Steam concrete                | 0.098-0.12                  | Non-combustible A     | 0.21-0.26                   |
| Extruded polystyrene board   | 0.030                       | Flame retardant B2    | 0.83                        |
| Modified expanded perlite board | 0.52                      | Non-combustible A     | 0.048                       |

3.2. The form of the insulated roof
At present, the common thermal insulation roofs mainly include upright thermal insulation roofs and inverted thermal insulation roofs.

3.2.1. Upright insulation roof.
Upright insulation roof is a more traditional insulation design method. According to the structural level of the roof itself, the insulation layer is added, which can effectively prevent the reinforced concrete structure in the residential building from being affected by excessive temperature stress and ensure the durability and stability of the roof [5].

3.2.2. Inverted thermal insulation roof.
The inverted thermal insulation roof is adjusted in the arrangement of the thermal insulation layer structure and placed it on top of the waterproof layer. This method can guarantee or even extend the life of the waterproof layer to a certain extent, reduce the influence of the atmosphere and solar radiation on it and this structure can eliminate the exhaust layer, reduce the amount of construction, and improve the efficiency of construction. However, compared with the front-mounted thermal insulation roof, the cost will be larger. The designer should comprehensively select factors such as geographical environment and residents' income when designing, so that the roof structure can exert the best thermal insulation effect under effective conditions. This can promote the energy-saving development of residential buildings [6].

3.3. Other solutions
There are many alternatives for roof insulation design. Designers need to make selections based on the characteristics of regional precipitation, make appropriate adjustments and innovations on the basis of the original roof design, and provide design support for their insulation and energy-saving effects [7].

4. Energy-saving design of window insulation structure
Windows have the functions of ventilation, lighting, and beautification of buildings, and are the structure that every residential building will design. The windows of residential buildings in severe cold areas are structures that consume a lot of heat and have high heat dissipation. According to research statistics, it is found that the total heat consumption of windows accounts for about 50% of the overall heat consumption of residential buildings, which is a part that requires special attention in the energy-saving design process.
4.1. Window orientation

- Designers should pay attention to the orientation of the windows when designing. The easiest way is to observe the sunlight and choose the direction that has the longest average exposure time.
- Considering the actual geographic location of most severe cold areas in my country, the orientation of most windows should be south so as to have more sunlight in winter.
- In addition, the choice of direction should also be combined with the specific wind direction to avoid the windows facing the dominant wind direction in winter.

4.2. The shape and size of the window
In the design of window shape and size, daylighting requirements must also be fully considered. In the design of energy-saving residential buildings, the thermal performance should be fully analyzed, and the size and shape should be reasonably designed. In the specific selection of windows, multi-layer glazing can be selected to enhance its thermal insulation performance. Multi-layer glazing usually forms an air gap between the glasses to prevent indoor heat dissipation.

4.3. Selection of energy-saving and heat-insulating materials in window frames
The window frame is the frame of the window and an important part of it. It also has a great influence on the indoor thermal insulation effect. At this stage, the choice of window frame materials in severe cold areas in my country is generally plastic steel materials that have been mature after years of development, which can save energy. The lower the heat transfer coefficient of the window frame, the better the thermal insulation performance of the window frame. It can be seen from table 4 that the heat transfer coefficient of PVC plastic steel is the lowest. Therefore, designers can add plastic steel window frames to the design of residential buildings in severe cold areas [8].

| Window frame material | Aluminum alloy | Bridge aluminum | PVC plastic steel | Wood |
|-----------------------|----------------|-----------------|-------------------|------|
| Heat transfer coefficient | 4.2-6.2         | 2.4-3.8         | 1.8-2.2           | 1.5-2.4 |

4.4. Deal with the tightness of the window structure

4.4.1. Treatment of gaps.
During the construction and installation of windows, there will often be a certain gap between them and the wall, which will cause the loss of indoor temperature. Designers can choose new airtight steel windows to improve energy-saving.

4.4.2. Add thermal insulation window.
Finally, some thermal insulation window panels can be added to the windows to provide auxiliary effects for their thermal insulation effect. Generally, thermal insulation window panels filled with foamed perlite as the main material are selected, which can further improve the thermal insulation performance of the window while also enhancing the energy-saving effect [9].

5. Conclusions
In summary, the energy-saving design of the thermal insulation structure of residential buildings in severe cold areas can effectively ensure that the indoor temperature will not lose quickly in cold weather, thereby reducing its use of related energy. This can promote the development of energy conservation and emission reduction, so that resources can be more fully utilized, and promote the sustainable development of our society as a whole.
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