Research on Energy Saving Design of Steel Structure Residence in Severe Cold Area

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Abstract. China has begun to advocate energy saving for the whole people, "Green buildings" have received social attention in large and medium cities. At present, China's urban central heating is basically at a high energy consumption, high pollution, low efficiency, and extensive level. Most Chinese buildings are non-energy-saving buildings, and the thermal insulation performance of the envelope structure is poor. Over the years, China’s steel production has been ranked first in the world. The light steel structure housing system is currently a relatively environmentally friendly and reliable building system in the world. It has been widely promoted in Europe, America, Japan and other countries, especially in the cold regions of Northern Europe. Extensive use. Therefore, it is imperative to promote the upgrading of the construction industry structure and to use steel as the construction material for light steel fabricated buildings. In this paper, through field investigation and measurement research on prefabricated steel structure residences in severe cold areas, this paper explores an energy-saving optimization system suitable for prefabricated steel structure residences in severe cold areas of Xinjiang, and provides a reference for the design and construction of the energy-saving optimization system for key nodes of this type of residence.

1. Introduction
In 2019, China's steel production accounted for 49% of the world's steel production. After decades of experience, China's steel has made great achievements in terms of quality and quantity. The types of steel can meet various needs. The steel structure has good machinability, easy assembly, light weight, high strength, and is most suitable for the industrialization and assembly of buildings. In the current situation of severely excessive crude steel production in China, the promotion of steel structure housing is indispensable, which can not only develop green buildings, but also consume steel. Now China's steel production can be used in the construction industry. The construction process of the fabricated steel structure is simple, and it is superior to the existing brick-concrete structure in terms of function and comfort. At present, relying on the development of prefabricated houses, in the context of energy saving and emission reduction, the combination of prefabricated houses and steel structures should be vigorously promoted in the cold and severe cold regions of the north. This can reduce the energy consumption of Chinese buildings, and consume China's massive production of steel Products, and actively promote the development and application of prefabricated steel structure houses in northern China.
2. Architectural energy-saving design and steel structure housing reform energy-saving technology analysis

2.1 Building energy efficiency design
Building energy-saving design mainly relies on building materials and building methods to reduce energy consumption; energy-saving building design is to reduce energy consumption through planning and design methods, according to differences in climate and region. There are two types of building energy efficiency indicators: one is the sub-index control method, and the other is the comprehensive control method.

![Classification diagram of building energy efficiency design](image)

2.2. Energy-saving technology analysis of steel structure residential

2.2.1. External wall insulation technology.
At present, there are two types of thermal insulation in the external wall thermal insulation technology, one is thermal insulation through composite thermal insulation boards, and the other is thermal insulation through structural measures. The composite insulation board has the advantages of quick installation, integrated structural insulation, beautiful appearance, and long-term use in cities. Thermal insulation through structural measures also has a good thermal insulation effect, and thermal insulation layers are arranged on both sides or in the middle of the wall to form an integrated thermal insulation with the wall. Structural insulation is more common in residential buildings.

At present, due to the rapid assembly characteristics of the composite thermal insulation external wall, it is applied in the construction of many houses. Adding an insulation layer to the external wall through structural measures can effectively achieve the purpose of building thermal insulation. Since internal thermal insulation occupies effective indoor space, it is not often used in residential thermal insulation structures, and in steel-structured houses, internal thermal insulation has less effect on reducing the thermal bridge of steel structure than external thermal insulation.

The materials used in steel structure housing in China have poor weather resistance to a large extent and do not meet the requirements of steel structure housing assembly, such as aerated concrete block, steam pressurized concrete block, sand aerated concrete block or aerated. For concrete slabs, the complicated construction process, high cost and long construction period make the advantages of steel structure residential buildings insufficient.

2.2.2. Energy-saving technology for doors and windows.
According to the wall heat loss composition table, it can be reflected in the building envelope. Among the main components of the roof, ground, walls, doors and windows, the largest heat loss is the doors and windows. Therefore, doors and windows are the most influential part of the indoor thermal
environment quality and the energy saving of the entire building. It is more than 20 times the energy consumption on the ground, about 5 times that of the roof, and 4 times that of the wall.

2.2.3. Detailed energy-saving technology.
In steel-structured houses, certain energy-saving technologies are required for the steel frame and exterior windows. Compared with the energy-saving of the entire building envelope, this part is a detailed energy-saving in steel-structured houses. According to statistics, the heat dissipated by the building envelope accounts for 70% of the total heat loss, of which the cold and thermal bridge losses account for more than 20%. The high heat transfer coefficient of steel makes the steel structure house due to the energy generated by the cold and thermal bridges. Energy consumption cannot be ignored. To study the energy-saving problems of steel structure houses, energy-saving optimization of cold and hot bridges is essential.

The difference between steel structure house and other traditional brick-concrete structure and reinforced concrete structure house is mainly reflected in the structural beams and columns composed of load-bearing steel components. The heat transfer coefficient of steel is more than 50 times that of ordinary materials. It can quickly transfer heat when it is cold or heated, and it acts as a bridge in heat transfer, forming a series of thermal bridges. Insulation is unfavorable, especially for severe cold and cold areas, the problem of hot and cold bridges brings more heat loss. The building has a large temperature difference between the inner and outer surfaces of the wall formed by the cold and hot bridges, which is prone to indoor condensation, which affects the use and durability of the building. Therefore, the impact of cold and hot bridges on the energy consumption of steel-structured houses is inevitable, and effective bridge breaking measures should be taken in specific construction to reduce its impact on building energy consumption.

3. Energy consumption analysis of residential buildings

3.1. Heat transfer process analysis
When the building is exposed to indoor and outdoor heat, the heat is exchanged between indoor and outdoor through the enclosure structure. For the envelope structure, the heat transfer mainly has the following three processes: surface heat absorption-the inner surface absorbs heat from the interior (in winter), or the outer surface absorbs heat from the outdoor space (in summer); The structure itself transfers heat-heat is transferred from the high temperature surface to the low temperature surface; Surface heat release-the outer surface radiates heat to the outdoor space (in winter), or the inner surface radiates heat to the room (in summer).

On the one hand, the interior of the building is constantly exchanging heat with the outside world through the outer envelope (outer walls, doors and windows); on the other hand, the temperature distribution in the building room is also uneven, and there is still continuous heat in the inner enclosure. Between protective structures (inner walls). Through the heat storage and heat release of the inner wall itself, heat exchange with the surrounding air is also continuously carried out. Therefore, in the study of room thermal stability, the thermal inertia index of internal walls is also an aspect that needs to be considered.

3.2. Cause analysis of energy consumption in residential buildings
It is understood that the heat loss of buildings is mainly composed of heat loss generated by the heat transfer process of the envelope structure, accounting for about 73%-77%. Including external walls, accounting for 23%-34%; external windows, accounting for 23%-25%; partition walls, accounting for 6%-11%; roofs, accounting for 7%-8%; balcony doors, accounting for 2%-3%; household doors, accounting for 2%-3%; The ground accounts for about 2%. The second is the heat loss caused by the air passing through the gap between doors and windows, accounting for about 23%-27%. If the airtightness of the doors and windows is not good, a large part of the heat will be lost through the gaps between the doors and windows, resulting in thermal bridges, causing condensation on the inner surface of the walls.
of the thermal bridge nodes. Corrosion of building materials will also affect people's lives. Doors and windows are the nodes that are most prone to thermal bridges and are also the key part of energy saving; at the same time, the thermal insulation performance of doors and windows is closely related to the air tightness of doors and windows. However, while improving the air-tightness of doors and windows, it is necessary to ensure that the air exchange frequency of the room is not too low. Too low air exchange frequency will result in poor indoor air quality and fail to meet the basic hygiene requirements. Without good ventilation, indoor air If the humidity remains high, the steam will easily condense on the temperature difference between indoor and outdoor, and condensation will also form. This will have many adverse effects on people's lives and the quality of the indoor environment. Over time, indoor walls will gradually become moldy and will also affect the service life of the building. Therefore, the air tightness of windows and doors only needs to meet the air tightness performance and efficiency standards of windows and doors.

4. Energy consumption analysis and optimization design of steel structure residence

Due to space limitations, this article mainly studies the energy consumption and optimization of external walls.

4.1. Survey of actual project

The measured object on site is Building No. 1 of a community in Yili City, Xinjiang. It belongs to the severely cold climate zone C. It is cold in winter and dry and hot in summer. The temperature difference between day and night is large. It is dry and rainless throughout the year. The average outdoor temperature in winter is around -17℃. The building is a prefabricated steel structure residence, built in 2013, the basement is the basement, and the six floors above the ground are residences. The exterior wall uses sandwich insulation panels and external polystyrene insulation panels. From the outside to the inside, there are ET boards, C-shaped steel components fixed and assembled DK boards, and indoor gypsum boards. Among them, the ET board is an integrated external wall insulation board developed by a local building material company in Yili City, and is an integrated external wall insulation board made of EPS board and calcium silicate board; DK board is a composite sandwich insulation wall board independently developed by a local building material company in Yili City. The wallboard is mainly made of low-alkalinity cement, fly ash steel slag, etc., using 75 mm thick polystyrene board sandwich insulation, reinforced with steel mesh or glass fiber mesh on both sides. The board thickness is 120mm, so the exterior wall board is referred to as DK-120 composite board.

4.2. Comparison of total external wall load

First of all, starting from the structural form of the wall, three types of external wall construction are set up, namely wall self-insulation, external insulation and internal insulation. It is difficult to meet building energy-saving standards through the insulation effect of the wall material itself. Therefore, this paper conducts wall insulation by setting up an insulation layer to study the impact of three external wall construction forms on building energy consumption.

Figure 2. Comparison of the cumulative load of the whole year under different structural forms of the envelope structure
It can be seen from Figure 2 that compared with the self-insulating external wall, when 60mm thick EPS polystyrene board is used as the thermal insulation material, the annual cumulative heat load of the external thermal insulation structure is reduced by 39.55%. The load was reduced by 22.19%, and the annual cumulative total load was reduced by 35.93%; the annual cumulative thermal load of the external wall of the internal insulation structure was reduced by 39.68%, the annual cumulative cooling load was reduced by 15.08%, and the annual cumulative total load was reduced by 36.97%. When the thermal insulation material is replaced with 60mm rock (mineral) wool board, compared with the self-insulating exterior wall, the annual cumulative heat load is reduced by 37.56%, the annual cumulative cooling load is reduced by 21.56%, and the annual cumulative total load is reduced 34.8%; the annual cumulative heat load of the external wall of the internal thermal insulation structure decreased by 37.69%, the annual cumulative cooling load decreased by 14.92%, and the annual cumulative total load decreased by 33.77%.

It can be seen that the use of certain thermal insulation measures for external walls has a greater impact on the reduction of building energy consumption throughout the year, while the difference in building energy consumption between external thermal insulation measures and internal thermal insulation measures is very small. The structural measures of thermal insulation can effectively reduce the cooling and heating load, and can also effectively reduce the impact of the cooling and heating bridge problem on the energy consumption of the building. In the subsequent research, the structural measures of the external wall insulation are used for research.

The material of the insulation layer is too thin, which has little impact on the energy consumption of the building, and does not have the effect of energy saving. The material of the insulation layer is too thick, which increases the construction cost and causes waste at the same time. Therefore, it is particularly important to determine the appropriate thickness of the insulation material in the external wall. The following structural forms of external wall insulation use EPS board and rock (mineral) wool board as insulation materials for research, and the thickness of EPS board is increased by 10mm each time, increasing from 30mm to 160mm, and its cumulative heat load and cold load throughout the year. The relationship with the thickness of the insulation layer is shown in Figures 3 to 4 below.

![Figure 3. The relationship between the heating and cooling load of the EPS board and the thickness of the insulation layer](image1)

![Figure 4. Insulation material: relationship between rock (mineral) wool board heating and cooling load and insulation layer thickness](image2)
4.3. Energy-saving optimization plan

The thermal bridge on the outer wall of the steel structure residence has not been treated, and the steel beam is exposed in the outer wall and needs to be treated. In order to reduce the impact of cold and hot bridges on building energy consumption, external wall thermal insulation can be adopted to install thermal insulation layer outside the original clay brick wall. On the one hand, the performance of the wall’s thermal insulation and heat insulation is optimized, on the other hand, Reduce the impact of thermal bridges on building energy consumption. The specific optimization plan is shown in Figure 5.

![Figure 5. Comparison of exterior wall optimization scheme and original scheme](image)

5. Conclusion

From the discussion in this article, we can see that the steel structure house is constructed by combining on-site assembly technology and steel structure. Therefore, in steel-structured houses, it is relatively easy to produce gaps between components and other factors that lead to problems such as thermal bridges and poor air tightness. Using De ST-h software to simulate and calculate: When the external wall is insulated, the EPS board is 130mm, and the rock (mineral) wool board is 150mm. For the energy-saving scheme of steel-structured houses in cold areas, considering economic factors, the outer wall preferentially adopts the structural form of external insulation, and 130mm thick EPS board is selected. This scheme can meet the requirements of normative energy saving and is economically suitable for the construction of residential buildings.

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