Research on envelope design of ultra low energy consumption passive building in severe cold area

Ruiheng Sun1,a
1School of architecture and design, Changchun Institute of Technology, Chang Chun, JiLin, China
aemail: sunruiheng@ccit.edu.cn

Abstract. At present, the common solid clay brick structure is widely used in residential building walls, which leads to higher indoor humidity, serious energy loss, waste of economy, environmental pollution and lower people's comfort. The passive technology of ultra-low energy consumption can improve the insulation performance of the enclosure, reduce the energy consumption of heating and improve the comfort of the owner, and finally achieve the goal of energy saving of low energy consumption buildings in the cold area.

1. Introduction
With the rapid development of economy and urbanization in China, the total energy consumption is increasing year by year and the resources are short. Therefore, reducing the total energy consumption of buildings and developing low-energy buildings is the inevitable trend of social development. Passive design is a fundamental technology in the realization of low energy consumption building technology elements. In the heat loss of the whole building, the heat loss of the enclosure is 70% - 80%[1]. Most of the building envelope is still made of ordinary solid clay brick with 100 mm thick EPS insulation board. The traditional aluminum alloy or plastic steel doors and windows make the heat transfer coefficient far exceed the national standard, resulting in poor sealing and more thermal bridges, resulting in a lot of energy loss, increasing the cost and reducing the comfort. According to the current situation of building envelope in severe cold area, this paper analyzes and studies the material of envelope, the method of thermal insulation layer, the shape coefficient, and the air tight thermal insulation technology. According to the standard requirements of passive room, combined with the climate characteristics of severe cold area in China, the thermal insulation measures are taken to improve the thermal performance of envelope, minimize the use of disposable energy and reduce the heat bridge, improve the comfort of owners, and strive to achieve the goal of energy saving of low energy consumption buildings in severe cold areas.

2. Current situation of residential building environment in severe cold area

2.1. Climatic characteristics of severe cold area
The objects of this survey are some residential buildings in the suburbs of Changchun City. Because the climate in Changchun has the typical climate characteristics of (b) zone of severe cold climate, the winter is colder than that in the same latitude area, the annual and daily temperature ranges are relatively large, the rainfall is scarce, the climate is dry, the wind and sand are large, the average temperature in the coldest month is lower than - 10 °C, and the period of heating needs to occupy most of the year, from the end of October to march of the year.
2.2. Current situation of architecture in severe cold area
The envelope structure of residential buildings is simple in form, large in heat transfer coefficient, poor in thermal insulation effect, high in building energy consumption and low in indoor comfort index. The traditional heating method in winter leads to the increase of building loss. In recent years, some owners spontaneously take measures to improve the thermal insulation performance of building envelope. However, due to their lack of energy-saving awareness and technical guidance, their thermal insulation practices have achieved little effect, far from meeting the construction requirements of low-energy buildings. Through investigation, the main problems of residential building envelope are as follows:

2.2.1. The thermal insulation effect of exterior wall is poor. The external wall is basically made of ordinary clay brick wall with EPS external insulation. The clay brick has large heat transfer coefficient and poor thermal insulation effect, which leads to the increase of building energy consumption; At the same time, there are many types of heat bridges in the weak links of insulation such as ring beam, doors and windows, balcony, etc; The interior wall is mainly made of cement mortar or mixed mortar, covered with paper reinforced mortar, and painted with large white mortar. The indoor humidity is relatively high. In addition to the heat bridge, the interior wall of the exterior wall is prone to condensation, mildew and falling off.

2.2.2. Unreasonable window to wall ratio. The ratio of windows to walls in the south-north direction is quite different. The ratio of windows to walls in the south direction is larger than 0.5, while the ratio of windows to walls in the north direction is smaller, some even less than 0.25. In winter, the window to wall ratio is too large to increase heating energy consumption, and in summer, it increases refrigeration energy consumption.

2.2.3. The shape coefficient is large. The shape coefficient of a building is the ratio of the outer surface area of the building in contact with the outdoor atmosphere to its surrounding volume. It is stipulated in the standard for energy efficiency design of public buildings (GB 50189-2005): The shape coefficient of buildings in severe cold area and cold area should be less than or equal to 0.40. Due to the pursuit of shape change of existing residential buildings, the shape coefficient increases, which increases the building heating energy consumption.

2.2.4. Poor air tightness of windows. Most of the windows are traditional aluminum alloy or plastic steel doors and windows. There are different degrees of energy penetration between the window frame and glass, between the window frame and the wall. The temperature difference between indoor and outdoor is large, which reduces the indoor comfort and increases the energy consumption.

3. Overview of passivhaus

3.1. The concept of passivhaus
The concept of Passivhaus was proposed by German physicist Dr. Wolfgang Feist. It means that do not use building equipment systems such as heating and cooling. Only through the effective use of the energy of the sun and the surrounding natural environment, to achieve a comfortable winter and summer indoor environment of the building. In 1996, phi (passive house Institute) was established in damstad, Germany. Then, the first certification and evaluation standard for passive houses was also produced in Germany[2].

3.2. Key technical indicators of passivhaus
The core technologies of passivhaus are as follows:

3.2.1. Adiabatic performance. The building envelope must be well insulated, even in the coldest climate, the envelope heat transfer coefficient U value is 0.15w / (M² · K).
3.2.2. Windows of passivhaus. The window frame is well insulated and equipped with LOW-E glass filled with argon or krypton to prevent heat transfer. In the coldest climate, the U value of the window frame is 0.80w / (M² · K) or less, and the solar absorption coefficient maintains about 50%.

3.2.3. Ventilation heat recovery. Efficient heat recovery ventilation is the key to allow good indoor air quality and energy saving. In passivhaus, at least 75% of the heat is transferred from the exhaust air to the fresh air again through the heat exchanger.

3.2.4. Air tightness of buildings. By controlling the leakage gap, it must be less than 0.6 total room volume per hour (pressurization and decompression) during the pressure test of 50 PA.

3.2.5. No thermal bridge design. All edges, corners, connections and penetrations of the enclosure structure shall not have acute angles, and obtuse angle measures shall be taken, which must be strictly designed and implemented. In this way, thermal bridges can be avoided, and the unavoidable hot bridges must be minimized, passivhaus should meet several basic conditions: The energy consumption of building heating shall not exceed 15kwh / (M² · a), and the total energy consumption of building each year (heating, air conditioning, domestic water, lighting, household appliances, etc.) shall not exceed 120kwh / (M² · a). As shown in Table 1.

Table 1. Design and construction standard of passivhaus in Germany

| index | Standard value |
|-------|----------------|
| The maximum annual heating demand is less than or equal to | 15kWh/ (m²·a) |
| Heat load less than | 10kWh/ (m²·a) |
| Air tightness less than or equal to | 0.6/h |
| Equivalent disposable energy demand less than or equal to | 120 kWh/ (m²·a) |

Comfort index of passivhaus: The indoor temperature is 20 -25 ℃; The indoor surface temperature of the enclosed room shall not be lower than 3 ℃ of the indoor temperature; Air relative humidity: 40%- 60%; The indoor air velocity is less than 0.2m/s; Good heat recovery rate of fresh air system reaches 75%; No condensation and mildew on the interior surface[3].

4. Structural design of passive low energy consumption building envelope in severe cold area

4.1. Types and materials of external wall thermal insulation

According to the relationship between wall and insulation layer, external wall insulation includes external wall insulation, internal wall insulation and sandwich insulation.

4.1.1. External wall internal insulation. External wall internal insulation is to set insulation layer inside the building external wall. Polystyrene board polymer, rigid polyurethane foam, rock wool board and other insulation materials can be selected as insulation materials. The disadvantage is that in the ring beam, floor, structural column and other places, it is easy to produce thermal bridge and condensation phenomenon, which is more destructive to the external wall safety and insulation board, and it will also occupy the effective use area of the building, affect the house decoration and extend the construction period, so it should be carefully considered in practical application. The specific methods are as follows: Base wall+ Bonded gypsum layer+ 150 mm polystyrene board+ There are two layers of plastering gypsum composite medium alkali glass fiber mesh cloth. One layer of mesh cloth is pasted with adhesive after the plastering gypsum layer is dried+ Flexible waterproof putty+ Interior finish.

4.1.2. External thermal insulation of exterior wall. External thermal insulation of exterior wall is mainly through setting thermal insulation layer on the surface of exterior wall. External thermal insulation of external wall can protect the main structure, reduce the erosion of external climate environment on the main structure, and extend the service life of buildings. It can increase the use area, people's indoor
activity space is relatively free, the integrity of the indoor space is intact, especially suitable for the transformation of old buildings, does not affect people's daily life. The thermal insulation effect is obvious, basically eliminating the thermal bridge effect, the inner side of the outer wall will not produce condensation. Improve the durability of building load bearing performance and thermal insulation performance. Common insulation materials are molded polystyrene board (EPS board), extruded polystyrene board (XPS board), graphite polystyrene board, etc. According to the technical index requirements of passive building and economic considerations, the graphite polystyrene board with high cost performance is selected after comparison. The specific methods of passive building external wall external insulation are as follows: Facing layer+ Plastering mortar+ One layer of alkali resistant glass fiber mesh cloth+ Bonding mortar + 50mm EPS insulation board+ Bonding mortar+ 150mm EPS insulation board+ Bonding mortar+ Concrete wall.

![Diagram](image)

**Figure 1.** External thermal insulation of passivhaus exterior wall

4.1.3. *Intermediate insulation.* The middle insulation is mainly placed in the middle of the structure layer. The two sides of the insulation layer are walls with high density. The indoor heat enters into the insulation layer through the inner side of the wall and is difficult to be emitted. It stays in the insulation material for a long time, causing the insulation material moldy and seriously affecting the insulation effect of the wall.

4.1.4. *Thermal insulation of passivhaus.* There are many ways of external thermal insulation for passivhaus.

4.2. *Energy saving measures for windows*

Window is an important part of building envelope, and it is the most active and sensitive part of building heat exchange. Its heat loss is 5-6 times of wall. The energy saving of windows is mainly carried out from three aspects: controlling the ratio of window to wall, selecting the appropriate window structure and opening mode, and selecting the energy-saving glass[4].

4.2.1. *Choose the right window to wall ratio.* According to the design standard for energy efficiency of civil buildings, the area ratio of North, east-west and south windows to walls should not exceed 25%,
30% and 35% respectively. Generally, the area ratio of window to wall should be controlled at about 30%. Therefore, while meeting the requirements of sunshine, daylighting, ventilation and landscape, windows should be avoided as far as possible on the East-West exterior wall, and the building thermal insulation and heat insulation should be fully considered in the south, so as to control the window wall ratio.

4.2.2. Choose suitable window structure and opening mode.

Table 2. Energy saving situation of various types of windows

| Window form | Energy saving rate% |
|-------------|---------------------|
| Single frame single layer FRP window | 0 |
| Single frame double layer FRP window (20 mm air interlayer) | 7.55 |
| Double window | 13.86 |
| Single frame single layer glass plastic window | 19.84 |
| Single frame double glass plastic window (20 mm air interlayer) | 25.03 |
| Double window | 37.68 |

According to the experience of window opening mode in developed countries, it is known that the sealing effect of casement window and fixed window is good, and the energy saving is good. At present, the most commonly used windows in Germany are the lower hung windows, which are air tight, watertight, sound proof and clean after being closed. The United States mainly uses up and down pull-up windows and casement windows outside the United Kingdom, while China currently uses more push-pull windows.

In addition, there are a large number of thermal bridges between the window frame and the glass, and between the window frame and the wall, which are also the weak link of the whole air tight layer. Large area window frame will increase the heat loss in winter, so it is necessary to control too many window frames to divide the window and do a good job in the air tight treatment of the window.

4.2.3. Energy saving glass and its classification. The thermal performance of glass is mainly determined by the transmission performance of solar radiation (heat transfer performance) and thermal insulation performance, that is, G and K parameters. $G = \%$ (solar energy passing coefficient); $K = w / (M2 \cdot K)$ (heat transfer coefficient)[5].
According to the brief comparison of building energy-saving glass in production, energy saving, economy and application, energy-saving glass can be divided into the following four types:

1. **Hollow or vacuum glass**
   - Insulating glass is evenly separated by at least two or more layers of glass, and the middle cavity is filled with dry air or inert gas. Depending on the filled gas layer to reduce the heat transfer coefficient, the effect of heat preservation and energy saving is better. However, the shielding coefficient of common insulating glass is high, and the effect of heat insulation is not very prominent. It is mainly used for winter insulation in cold areas and hot summer and cold winter areas. The vacuum layer is formed by drawing the gap between two flat glass layers to become vacuum glass. It has a very good effect on heat conduction and convection. Therefore, the heat transfer coefficient is lower than that of hollow glass, and the heat insulation and insulation performance is better. However, the price is 5-7 times of that of hollow glass, so it is not easy to produce large area vacuum glass.

2. **Heat reflecting glass**
   - Heat reflective glass is coated with one or more layers of metal or metal oxide film on the surface of glass, which makes it have high reflectivity and keep a certain degree of light transmittance. The shading coefficient is small, but at the same time, the visible light transmittance is low, which will affect the indoor lighting coefficient after use. In addition, the heat transfer coefficient of the glass is not different from that of ordinary white glass, so the heat preservation effect is not very good.

3. **Low-E glass**
   - Low-E glass, also known as low radiation glass, is coated with one or more layers of metal or semiconductor film on the surface of the glass. It has low reflectance for near-infrared radiation and high reflectance for far-infrared radiation. It not only has good heat preservation and energy saving effect, but also has good light transmission performance. Low-E glass is generally used to make
composite insulating glass, and three-layer insulating Low-E glass has good effect in passive house design, but the price is higher.

(4) Coated glass
Glass film is a kind of multi-layer polyester film, which can improve the performance and strength of glass by sticking it on the surface of flat glass. Among them, the thermal reflective film has smaller shielding coefficient and cheaper price, but lower visible light transmittance. Low radiation film has the advantages of low shielding coefficient and high visible light transmittance, but the price is high.

The passivhaus adopts aluminum clad wood profiles, the glass adopts three-layer hollow Low-E glass, and the special expansion water sealing belt is used between the window frame and the base wall, which effectively ensures the sealing effect and prevents air and rain infiltration; Waterproof and breathable tape is used between the outside of the window and the wall to achieve water tightness; Waterproof and air tight tape is used inside the window frame and the wall, and the tape wraps the positioning position of the whole frame to achieve air tight effect.

4.3. Control of building shape coefficient
Under the condition of the same temperature difference standard, the total heat transfer is directly proportional to the surface area of building envelope. Reducing the exterior envelope surface area can not only reduce energy consumption, but also save construction costs. Shape coefficient is one of the commonly used shape control indexes, which is expressed by the ratio of building surface area to volume. It is an important index of heat gain and heat dissipation. Under the same volume, the smaller the shape coefficient is, the smaller the external wall area is, the smaller the radiation heat gain in summer and the heat loss in winter are, the more energy-saving significance is.

According to the path of temperature heat conduction, it first passes through the outer enclosure, penetrates from the outer enclosure to the inner side of the enclosure, and then penetrates into the room. The calculation of heat transfer through the enclosure is as follows:

\[ Q = K \cdot A \cdot (T_a - T_i) \]  \hspace{1cm} (1)

Q: quantity of heat
K: Heat transfer coefficient of building envelope
A: Shape coefficient of building
T_a – T_i: Temperature difference between inside and outside of building envelope

4.4. Air tightness
Building air tightness refers to the ability of the building to prevent the invasion of outdoor air when the doors and windows are closed, and its measurement index is the amount of outdoor air penetration. Air tightness is closely related to building heating energy consumption. In winter heating period, poor air tightness will cause a large number of outdoor cold air to enter the room through the cracks of windows and exterior walls.

The cold air entering the room can bring both positive and negative effects: Indoor cold air is fresh air, which can improve indoor air quality; At the same time, due to the large temperature difference between indoor and outdoor in winter, entering the indoor cold air will increase the indoor heating energy consumption. Therefore, reasonable control of building air tightness is very important for heating in winter and cooling in summer.

5. Conclusions
At present, China's urbanization is developing rapidly, but resources are scarce, energy is wasted, and the environment is polluted. Therefore, how to improve the building thermal insulation performance, improve the comfort of building use, especially in cold areas, advocate passive low-energy envelope construction technology is an important means to reduce building energy consumption. At the same time,
it is also the inevitable development trend of energy-saving building, green building, ecological building and low-carbon building in the future.

Based on the investigation and research of some buildings in Changchun area, according to the requirements of passive standard, combined with the special climate conditions in severe cold area, this paper mainly expounds the methods of heat preservation and heat insulation of enclosure structure. This paper introduces the thermal insulation classification, advantages and disadvantages, window structure, shape coefficient, air tightness and other aspects of envelope structure, so as to achieve the goal of low energy consumption building and provide high quality and low energy consumption living environment for owners.

Acknowledgments
This work was supported by Science and Technology Projects of the Education Department of Jilin Province (120210012).

References
[1] Wang, L.Y. (2010) Research on Key Technologies of energy saving of rural residential buildings in severe cold area. Journal of Changchun Institute of Technology: Natural Science Edition, 11: 2-4.
[2] Lu, Q. (2015) German passive house ultra low energy consumption building technology system. Dynamic (eco city and green building), 01: 2-3.
[3] Liu, J.P. (2012) Introduction to green building. China Construction Industry Press, Beijing.
[4] Zhang, H.P. (2006) Building energy saving and building energy saving measures. Building Science Research of Sichuan, 08: 2-3.
[5] Wang, L.H. (2014) Interpretation of passive architecture and its development in China. Dynamic (eco city and green building), 03: 1-3.