The Effect of Energy Saving and Emission Reduction of Semi-External Window Installation

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Abstract. As an important part of passive ultra-low energy building envelope structure, exterior windows play a very important role in lighting, heat gain, and thermal insulation. Passive doors and windows are currently mostly installed externally, and high installation costs, material costs, and safety have become obstacles in the promotion of energy-saving policies. We calculated and simulated the linear heat transfer coefficient of the window opening based on the software flixopro8, and obtained the window installation position with the smallest linear heat transfer coefficient between the door and window and different wall structures and the decisive factors affecting the linear heat transfer coefficient of the door and window opening.

Keywords: Semi-exterior external windows, door and window installation, building energy saving, heat conduction effect, heat transfer coefficient.

1. Introduction

From February 2014 to January 2016, more than 20 provincial and municipal policies have been issued and implemented to encourage the development of passive ultra-low energy green buildings (hereinafter referred to as ultra-low energy buildings). In February 2016, the "Several Opinions of the Central Committee of the Communist Party of China and the State Council on Further Strengthening the Management of Urban Planning and Construction" issued by the Central Committee of the Communist Party of China and the State Council clearly stated that "the development of passive housing construction and green energy-saving buildings." issued by the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development "City Adaptation to Climate Change Action Plan" proposes "actively develop ultra-low energy consumption buildings." It can be seen that improving the quality of buildings and developing ultra-low energy buildings has become the focus of Chinese policy leadership. At the same time, it is reflected from the side that ultra-low energy buildings have become Chinese buildings. An important direction of energy-saving technology [1]. The transparent part of the envelope structure is one of the most important components in the passive ultra-low energy building. Its area accounts for 12% of the maintenance structure area in the entire building. However, in the heat loss of the building envelope structure, the heat loss of doors and windows is It accounts for 50% of the overall heat loss and is called the "black hole of building energy loss" by the industry. If the passive ultra-low energy building doors and windows are installed in an improper location, it will completely offset the designer's research and design to improve the insulation performance of the doors and windows themselves. Based on the above situation, this paper
analyses and researches the thermal bridge of the door and window installation position, and strives to minimize the heat loss in the location of the door and window installation on different wall structures.

2. Energy-saving development of doors and windows and the current situation of passive window installation

Passive ultra-low energy consumption buildings have been developed for nearly 30 years, and related technologies have matured. In recent years, the number of new buildings and existing building renovations built in accordance with passive ultra-low energy consumption standards has increased in China, but the proportion of volume is still small. According to incomplete statistics, there are 160 completed projects and projects under construction, accounting for less than 0.1% of the total domestic construction projects. The relevant standards are not perfect. The number of passive residential projects that have been occupied is even rarer. China is still in its infancy and has a long way to go. In Chinese buildings, the volume of one-step energy-saving to four-step energy-saving buildings are huge, including rural self-built houses, old project renovation, and window installation positions. There are basically no uniform requirements [2]. Most of them are based on the structure or the size of the indoor window sill. The position of installing doors and windows does not fully consider the influence of the position of installing doors and windows on the overall performance of doors and windows. Because doors and windows as a transparent outer protective structure not only play the role of heat preservation, but also ensure the basic use requirements such as lighting and sound insulation.

Figure 1 shows a schematic diagram of passive window installation. The current passive window installation still has the following major problems:

2.1. Security hazards

First of all, the external installation safety problems of passive windows are mainly caused by the service life of the window frame support brackets and the firmness of the corner pieces, as well as the problems caused by the structure of the window installed outside the opening. The first is that there is a risk of cracking in the wooden piers of the load-bearing brackets. In order to save material costs, the corner pieces used to fix the passive windows are less than 2mm thick; the second is the tension bolts for fixing the corner pieces and the bottom wooden piers and the wood for fixing the window frame. During the on-site construction process, the screws were directly smashed in, and they were not fixed according to the process requirements; the third is that the passive window is completely installed outside the opening [3]. If the bottom bracket cracks or falls off, the passive window will fall at any time and hurt people. Hidden dangers.

The second is that most of the installation and construction of passive windows require workers to work outdoors, which greatly increases the potential safety hazards of workers falling from heights. The passive window adopts the configuration of 5mm thick three-layer glass and is installed with glass. The weight of a single frame is generally ≥100kg. It also puts forward higher requirements for the service life and durability of installation aids, baskets and scaffolding.

The third is that with the development of building energy efficiency and the implementation of standards, the passive window market will become a low-threshold market. Large manufacturers will
gradually have their own mature technology and auxiliary materials through strict testing, testing and project demonstration, but at the same time, some unscrupulous small factories will be able to "imitate" high-quality products without research and material demonstration. Copy the installation and construction methods of other products, leaving potential risks.

2.2. Construction problems of plug-in installation

The external installation of passive windows is divided into 11 steps, of which 3 steps can be completed indoors, and 8 steps need to be performed outdoors refer to Figure 2. The construction steps are many and cumbersome, and there will be process conflicts with the insulation construction during the construction process. The insulation needs to wait for the door and window construction to be completed, and the last process of installing the window sill needs to wait for the insulation construction to be completed, which is very big to a certain extent, the use time of scaffolding and hanging basket is extended, and the construction period of the entire project is also lengthened due to process conflicts.

![Figure 2. Process flow of passive installation outside the window](image)

2.3. The cost of plug-in installation

As shown in Table 1, the cost of plug-in installation is mainly composed of labour costs, installation materials and measures. The current market plug-in installation cost is about 595 yuan/m², which is 3 to 4 times that of ordinary in-mouth installation, resulting in passive the installation method of hanging outside the window has become a larger part of the incremental cost increase of "passive windows". In addition, the external construction work needs to be carried out outdoors, which greatly increases the use time and construction period of auxiliary equipment such as hanging baskets. The later replacement of doors and windows still needs to be done outdoors, and at the same time, the insulation and shading around the outdoor opening must be removed [4]. The replacement and maintenance cost of passive windows in the later period is much greater than the installation cost of passive windows. The cost will be 2 to 3 times the initial installation cost.
Table 1. Cost composition of passive window external installation and internal installation

| Project                  | External installation (yuan/m²) | Ordinary installation in the mouth (yuan/m²) | Remarks                                           |
|--------------------------|---------------------------------|---------------------------------------------|--------------------------------------------------|
| Labour cost              | 190                             | 80                                          | -                                                |
| Installation material fee| 100                             | 25                                          | Contains only fixing materials                    |
| Sealing material         | 280                             | 40                                          | Self-adhesive internal and external waterproof membrane/foaming agent, sealant |
| Measure’s fee            | 25                              | 5                                           | Safety and construction auxiliary measures        |
| total                    | 595                             | 150                                         | -                                                |

3. Thermal coefficient index and related standard definition

3.1. Index design of heat transfer coefficient of external window

According to the “thermal comfort criterion” and the principle of heat transfer for passive ultra-low energy building exterior windows, the calculation formula for the heat transfer coefficient of exterior windows can be derived as follows: Consider the exterior windows as a whole, and the typical heat transfer process is shown in Figure 3. The indoor air temperature $t_1$ is 20°C, the inner surface temperature $θ_1$ of the outer window is 17°C, the heat transfer coefficient of the inner surface of the outer window is $8W/(m^2·K)$, and the outdoor air temperature is $t_2$.

![Figure 3. The overall heat transfer process of the outer window](image)

According to the basic principles of heat transfer, heat is transferred from the indoor air to the left wall through surface heat transfer, and its heat flux density is:

$$q = h_1(t_1 - θ_1) = 8 \times (20 - 17) = 24W/(m^2K)$$  \hspace{1cm} (1)

Defined by the heat transfer coefficient $K$ value, it can be seen that the heat transfer coefficient of the outer window should be:
In the same way, knowing the heat transfer coefficient \( k \) value of the outer window, the applicable outdoor air temperature \( t_2 \) can also be obtained:

\[
t_2 = 20 - \frac{24}{k}
\]  

(3)

3.2. Thermal bridge

3.2.1. Definition of thermal bridge. In the thermal calculation of the building envelope, since the temperature potential in the thickness direction is much greater than the height and width directions, the heat transfer through the envelope structure is often calculated as one-dimensional heat transfer. But it is inevitable that some nodes have two-dimensional and three-dimensional heat transfer, forming thermal bridges. The thermal bridge is defined as the part where the intensity of heat flow in the envelope structure increases significantly. The definition of building thermal bridge in European standard ENISO10211-1 is as follows: building envelope thermal bridge is caused by the penetration of materials with different thermal conductivity or changes in the thickness of the structure or the difference between the inner and outer areas (such as the joints of walls, ceilings and floors). Thermal bridges can be divided into line thermal bridges and point thermal bridges [5]. Line thermal bridges are thermal bridges with the same cross section along one direction, and point thermal bridges are local thermal bridges that can be expressed by a point thermal bridge coefficient. Thermal bridges have two effects on buildings. One is to increase the energy consumption of the building. The existence of thermal bridges increases the average heat transfer coefficient of the unit wall, which leads to an increase in heat flow and energy consumption. The second is that the temperature of the inner surface of the thermal bridge in winter is lower than that of the main section. Poor handling may cause condensation or even mildew on the inside of the wall, which affects indoor sanitation.

3.2.2. Line thermal bridge coefficient. The thermal bridge itself can be regarded as two-dimensional or even three-dimensional heat transfer, and the calculation of the heat transfer of the envelope structure is usually based on one-dimensional heat transfer. Therefore, the thermal bridge coefficient is used to measure the ratio of two-dimensional and three-dimensional heat transfer parts to one-dimensional heat transfer. The extra heat transfer after calculation is the additional heat transfer. Most of the thermal bridges in the building are linear thermal bridges, as are the upper and lower openings and side openings of the windows. The line thermal bridge coefficient is calculated as follows:

\[
\Psi = L_{2D} - \Sigma \frac{N_i}{U_j} l_j
\]  

(4)

In the formula: \( \Psi \) is the linear thermal bridge coefficient, also known as the linear heat transfer coefficient, w/m•K. \( L_{2D} \) is the linear coupling coefficient, calculated by the two-dimensional heat transfer of the thermal bridge, w/(cm•K). \( U_j \) is the heat transfer coefficient of the one-dimensional heat transfer part \( j \), w/ m²•K. \( l_j \) is the length of the one-dimensional heat transfer part \( j \), m; the thermal coupling coefficient \( L_{2D} \) is calculated by the following formula:

\[
\Phi = L_{2D} (t_{in} - t_e)
\]  

(5)
Where: $\Phi$ is the heat flow per unit thermal bridge length, the total heat flow in the two-dimensional numerical simulation, w/m; $t_{int} - t_e$ is the temperature difference between indoor and outdoor, K.

3.3. Reference standards

3.3.1. German standards. The formula is derived based on the calculation method of the heat transfer coefficient of the outer window, and according to Professor Feist’s "German Passive House Design and Construction Guide" pointed out that the heat transfer coefficient of the entire window is less than 0.85W/(m²·K):

$$t_2 = 20 - \frac{24}{k} = 20 - \frac{24}{0.85} = -8.2^\circ C$$

(6)

Since the heat transfer coefficients of the internal and external surfaces used in the calculation refer to relevant domestic standards and are different from the German standards, the applicable climatic conditions will be different from the actual outdoor air temperature of the German "passive house", but the difference is not significant. In other words, in China, the heat transfer coefficient of the whole window is less than 0.85W/(m²·K), which is only suitable for areas where the outdoor air temperature is higher than -8.2°C.

3.3.2. Chinese standards. The heat transfer coefficient indexes of exterior windows in different climatic regions in China should be determined according to the outdoor calculated temperature in winter. For the outdoor calculated temperature in winter, please refer to "Appendix 3 Outdoor Calculation" of GB50176-93 "Code for Thermal Design of Civil Buildings" Type IV data in "Parameters" is determined [6]. The heat transfer coefficient index of the outer window is determined according to the calculation of this paper. Table 2 shows the limits of outdoor calculated temperature and heat transfer coefficient of exterior windows in typical cities in different climate regions.

| Climatic region                  | Typical city | Outdoor calculated temperature in winter/°C | Limit of heat transfer coefficient of outer window/[W/(m²·K)] |
|----------------------------------|-------------|---------------------------------------------|---------------------------------------------------------------|
| Severe cold area                 | Harbin      | -33                                         | $\leq 0.45$                                                   |
| Cold area                        | Beijing     | -16                                         | $\leq 0.67$                                                   |
| Hot summer and cold winter area  | Shanghai    | -7                                          | $\leq 0.89$                                                   |
| Hot summer and warm winter area  | Guangzhou   | 3                                           | $\leq 1.41$                                                   |
| Temperate area                   | Kunming     | 9                                           | $\leq 2.18$                                                   |

At present, China has not issued design standards for the performance of passive ultra-low energy building exterior windows in different climate regions. The development of such standards is of great significance for the promotion of passive ultra-low energy buildings in different climate regions in China. Take Hebei Province as an example. The province belongs to a cold region in China and has a vast area. The calculated outdoor temperature in typical cities in winter ranges from -13 to -25°C. The corresponding heat transfer coefficient of the outer window that meets the thermal comfort criterion should be Located between 0.53~0.73W/(m²·K). Therefore, the method proposed in this paper has important reference value for China to formulate the heat transfer coefficient index of passive ultra-low energy building exterior windows in different climate regions.
4. Passive ultra-low energy building exterior window technology

4.1. Energy-saving profile technology
The profile is an important part of the exterior window for energy saving and anti-condensation. In the German passive ultra-low energy building standards and related standards in China, the heat transfer coefficient of the profile is required to be ≤0.8 W/(m²·K). At present, China's main energy-saving profile products include multi-cavity PVC profiles, aluminum-clad wood profiles, etc. Among them, PVC profiles are more cost-effective. At present, some domestic profile companies have developed high-performance PVC passive windows (that is, windows for passive ultra-low energy buildings).

4.2. Energy-saving glass technology
To meet the requirement of heat transfer coefficient K≤1.0 W/(m²·K) of external windows, energy-saving glass with high thermal insulation, such as three-layer Low-E glass filled with inert gas, vacuum glass, etc. must be used. It is worth noting that in order to reduce the heat transfer coefficient of the entire window, glass with too low heat transfer coefficient should not be used to avoid condensation caused by excessive temperature difference between the inside and outside of the glass [7]. In order to reduce the heat loss at the joint between the insulating glass and the profile, and reduce the possibility of condensation at the edge of the glass, a warm-edge spacer with good durability should be used.

4.3. Sealing technology
Under the condition that the pressure difference between indoor and outdoor is 50 Pa, the number of air changes per hour should not exceed 0.6 times. This requires very high airtightness of the external window. The outer window should be made of elastic and durable sealing materials, such as foamed composite rubber strips, etc.; at the same time, the joints between the outer window and the wall should be sealed, and the gap between the outer window and the opening should be self-adhesive pre-compressed Self-expanding sealing tape, or use a waterproof membrane sealing system at the junction of the window frame and the external wall to improve the sealing performance of the joint.

4.4. Shading technology
Passive energy-saving exterior windows should be made of glass products with good shading performance, and products such as roller blind exterior shade, louver exterior shade and hollow built-in louver shade glass can be used.

4.5. Installation technology
The installation of passive windows includes the following steps: Install special fixing parts for fixing windows at designated positions on the four sides of the window opening. The fixing parts are fixed to the outer wall with tensile stainless steel expansion screws, the outer window is connected with stainless steel self-tapping screws, and the inner edge of the window frame is pasted. Put on the expansion sealing strip, stick the anti-crack sealing tape on the inner and outer corners of the window frame and the wall, and then inlay the insulation board.

5. Calculation of heat loss of door and window opening and simulation of installation position change

5.1. Heat loss calculation
In this paper, flixo pro8 thermal analysis software (hereinafter referred to as "analysis software") is used for thermal simulation (see Figure 4), and the finite element method is used for thermal analysis. Parameter editing is carried out in accordance with "Civil Thermal Building Design Code" GB50176-2016, EN ISO 10077-2, EN ISO 10211-1 and other standards. According to the wall structure and
passive 130 C determined in Table 3 and Table 4, the heat loss of the opening was simulated and calculated and the calculation results were generated.

Table 3. Wall structure

| No insulation          | With heat preservation (K≤0.15W/(m²·K))                           |
|------------------------|------------------------------------------------------------------|
| Brick structure 370mm  | 200mmSEPS attached to brick structure                             |
| Concrete structure (200mm) | 210mmSEPS externally attached to the concrete structure          |
| Wooden structure (200mm) | Wooden structure filled with 250 rock wool                      |

Table 4. Installation location

| No insulation | Has insulation | |
|---------------|----------------|
| Indoor side   | Indoor side    | |
| Centered      | Centered       | |
| Outdoor side  | Outdoor side   | |
| Plug-in       | Externally hung and insulated to cover the window frame         |

Table 5. The heat transfer coefficient of the opening line of the passive window installed in different positions of the different walls

|                | Brick structure | Concrete structure | Wood structure |
|----------------|-----------------|-------------------|---------------|
| No insulation  | Indoor side     | 0.198             | 0.12          | 0.031         |
|                | Centered        | 0.126             | 0.139         | 0.018         |
|                | Outdoor side    | 0.21              | 0.176         | 0.027         |
| With heat preservation K ≤ 0.15w/(m²·K) | Indoor side | 0.644             | 0.722         | 0.055         |
|                | Centered        | 0.426             | 0.549         | 0.043         |
|                | Outdoor side    | 0.173             | 0.284         | 0.053         |
|                | Plug-in         | 0.016             | 0.017         |               |
|                | Externally hung and insulated to cover the window frame        | 0.015           | 0.016         |
Figure 5. The change of the heat transfer coefficient of the opening line of the window installation position of the non-insulation wall structure

As shown in Figure 5, when the brick structure wall (hereinafter referred to as "brick wall") is not pasted for heat preservation outdoors, the heat transfer coefficient of the central installation hole of the door and window is the lowest, which is 0.126w/(m·k); close to the room the heat transfer coefficient of the outer installation hole line is the highest, which is 0.21w/(m·k). In the case of concrete structure walls (hereinafter referred to as "concrete walls") without insulation, the minimum heat transfer coefficient of the doors and windows near the indoor side installation opening is 0.12w/(m·k), and the maximum heat transmission coefficient of the outdoor installation opening is 0.176. When installing windows on the concrete wall, it can be seen from Figure 6 that when the installation position moves from indoor to outdoor, the heat transfer coefficient of the opening line will gradually increase, and the heat loss will also be greater. When the concrete wall is not insulated, the windows should be installed as close as possible to the indoor side.

Figure 6. The broken line graph of the heat transfer coefficient changes of the opening line of the window installation position change of the insulated wall structure

6. Semi-external installation economy and cost analysis

The cost of semi-external installation of passive windows is lower, mainly because the construction period is short, and the reduction of procedures has greatly reduced the installation labour cost. After removing the waterproof vapor barrier and waterproof breathable membrane, the installation method of the external straddle installation is basically the same as the construction process of the internal installation [8]. There is no need to install steel parts and brackets on the outside of the opening in advance. The indoor installation part can also reduce scaffolding, hanging baskets, and cranes. The use of other equipment. The reduction of installation materials further reduces installation costs. The semi-external installation saves about 200 yuan per square meter compared with the external installation.
(Table 6). The reduction in incremental cost is conducive to the promotion and application of passive windows and even ultra-low energy buildings.

**Table 6.** Cost comparison between externally-mounted passive window installation and external-span installation

| Installation cost (yuan/ m²) | Remarks                                                                 |
|------------------------------|--------------------------------------------------------------------------|
| Labour cost                  |                                                                          |
| Plug-in                      | 190                                                                      |
| Semi-external save costs     | 130                                                                      |
|                               | 60                                                                       |
| Installation material fee    |                                                                          |
| 100                          | 50                                                                       |
| 50                           |                                                                          |
| Contains only fixing parts,  |                                                                          |
| does not contain water and  |                                                                          |
| vapor barrier water vapor    |                                                                          |
| permeable membrane           |                                                                          |
| Sealing material fee         |                                                                          |
| 280                          | 200                                                                      |
| 80                           |                                                                          |
| Self-adhesive inner and outer |                                                                          |
| waterproof membrane / different dosages |                                                              |
| Measure’s fee                |                                                                          |
| 25                           | 15                                                                       |
| 10                           |                                                                          |
| Safety and construction     |                                                                          |
| auxiliary measures          |                                                                          |
| total                        | 595                                                                      |
| 395                          | 200                                                                      |
| -                            |                                                                          |

7. Conclusions
Building energy consumption is divided into two major energy consumptions, namely construction energy consumption and operating energy consumption. While pursuing rigorous calculation results to reduce operating energy consumption or related technical standards, the construction energy consumption of buildings cannot be ignored. The installation method of passive ultra-low energy building doors and windows semi-exterior, in terms of safety, reducing energy consumption, reducing incremental costs, and sustainable development, it has obvious advantages compared with the currently adopted external installation, and it is suitable for the localization of China's national conditions solution.

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