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Abstract

Considering "resource-saving and environment-friendly" small town demonstration project as an example of residential energy conservation, through design and selection of the materials to main parts such as exterior wall, roof, ground, external door, window and thermal bridge, studying on the basic methods of energy-saving design and analyzing the energy-saving effect of the housing, and empirical studying the rationality of the thermal-insulating and energy-saving design.

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Introduction

The small-towns’ residences which distribution is high density in large area have the disadvantages of high energy consumption and low environmental comfort which would restricted the construction of "the resource-saving and environment-friendly" (hereinafter referred to as “Two-Types”) town. This paper will study the design method and energy-saving effect of the construction in the “Two-Types” town.

Project Overview

This project is the demonstration promotion project of energy-saving residence in local “Two-Types” town which located in Zhuhu farm where is the “Two-Types” society construction test area of Wuhan city circle.

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Energy-saving Design

The exterior walls. The main materials of the exterior walls is the 200mm-thick foamed concrete block which has a good characteristic of thermal-insulating, and the dry density of which is 500kg/m$^3$, and the thermal conductivity is 0.19w/m·k that is smaller than 1/4 of the clay brick blocks$^3$. Besides, a 20mm thick thermal insulation mortar and cement mortar is renovated in both of the internal and external surfaces.

The heat transfer coefficient of the exterior envelope can be calculated as Eq.1:

$$K_1 = \frac{1}{R_n} = \frac{1}{R_i + R_1 + R_2 + R_3 + R_e}$$

$$= \frac{1}{0.11 + 0.02 + \frac{0.2}{0.29} + \frac{0.02}{0.19} + 0.02 + 0.04} = 0.77(W/m^2.K)$$

And the thermal inertia index of the exterior envelope can be calculated as Eq.2:

$$D_1 = S_1R_1 + S_2R_2 + S_3R_3 = 0.069\times4.44 + 1.053\times2.76 + 0.022\times1126 = 3.48$$

The roofs. The roofs are composition of a 20mm thick roll-up asphalt felt used as waterproofing layer, a 20mm thick thermal insulation mortar, a 70mm thick polystyrene board, a 120mm thick cast-in-place reinforced concrete floor, a 20mm thick plaster layer of thermal insulation mortar.

The heat transfer coefficient of the roofs can be calculated as Eq.3:

$$K_2 = \frac{1}{R_n} = \frac{1}{R_i + R_1 + R_2 + R_3 + R_4 + R_e}$$

$$= \frac{1}{0.11 + 0.02 + \frac{0.07 + 0.12 + 0.02}{0.29 + 0.047 + 1.74 + 0.29} + 0.04} = 0.5(W/m^2.K)$$

And the thermal inertia index of the roofs can be calculated as Eq.2:

$$D_2 = S_1R_1 + S_2R_2 + S_3R_3 + S_4R_4 + S_eR_e = 0.118\times3.33 + 0.069\times4.44 + 1.489\times0.69 + 0.069\times17.2 + 0.069\times4.44$$

$$= 3.219$$

The Ground. The design of underlying ground structure is shown as following: A 15mm thick composite floor, a 20 mm thick thermal insulation mortar, a 120mm thick cast-in-place reinforced concrete plates which can ventilate by natural if installed as overhead, a 20 mm thick polystyrene board and a 20 mm thick thermal insulation mortar.

The heat transfer coefficient of the underlying ground can be calculated as Eq.5:

$$K_3 = \frac{1}{R_n} = \frac{1}{R_i + R_1 + R_2 + R_3 + R_4 + R_5 + R_e}$$

$$= \frac{1}{0.11 + 0.017 + \frac{0.10 + 0.12 + 0.02}{0.29 + 1.74 + 0.047 + 0.29} + 0.04} = 1.15(W/m^2.K)$$

And the thermal comfort degree of the underlying ground surface calculated as Eq.6:

$$B = \frac{b_1}{A_{c_1}^\gamma} = \sqrt{0.17\times2.51\times600} = 16.0\left(\frac{W}{m^2 h^{\frac{1}{2}}.K}\right)$$
It can take the value approximately as 16.0, which is smaller than 17 and meet the ‘Ⅰ’ level’ residential building ground hot work performance, and have a high ground thermal comfortable degree as well.

For the stratified floors, the upper surface of which is laying a 15mm thick composite floor, 30 mm thick thermal insulation mortar and a 120mm thick cast-in-place reinforced concrete plates while the lower surface is laying a 30mm thick thermal insulation mortar only.

The heat transfer coefficient of the stratified floors can be calculated as Eq.7:

\[
K_s = \frac{1}{R_0} = \frac{1}{R_1 + R_2 + R_3 + R_4 + R_e} = \frac{1}{0.11 + 0.015 + 0.03 + 0.17 + 0.03 + 0.29 + 0.03 + 0.04} = 2.0 (W/m^2.K)
\]

And the endothermic index and the thermal comfort degree of surfaces of the stratified floors are the same as the underlying grounds’.

**The staircase wall and the door.** The thermal resistance of the staircase wall \( R_0 \) must be satisfied by \( R_0 \geq 0.37 m^2.K/W \) according to the specification and the main body structure of the wall plastering 20mm thick thermal insulation mortar in both surfaces is composed of 240mm thick KPI porous hollow blocks.

The thermal resistance of the staircase wall can be calculated as Eq.8:

\[
R_0 = R_1 + R_2 + R_3 + R_4 + R_e = 0.11 + \frac{0.02}{0.29} + \frac{0.24}{0.58} + \frac{0.02}{0.29} + 0.04 = 0.7 (m^2.K/W)
\]

And the heat transfer coefficient of the staircase partition can be calculated as Eq.9:

\[
K_s = \frac{1}{R_0} = \frac{1}{0.7} = 1.43 (W/m^2.K)
\]

The main door of which thermal resistance must be satisfied by \( R_0 \geq 0.37 m^2.K/W \) according to the specification is designed as combination of the double wood plane and the air space and the lining steel plates.

The thermal resistance of the vice door can be calculated as Eq.10:

\[
R_0 = R_1 + R_2 + R_3 + R_4 + R_e = 0.11 + \frac{0.035}{0.14} + \frac{0.008}{58.2} + \frac{0.035}{0.18} + \frac{0.04}{0.14} = 0.58 (m^2.K/W)
\]

And the heat transfer coefficient of the vice door can be calculated as Eq.11:

\[
K_s = \frac{1}{R_0} = \frac{1}{0.58} = 1.72 (W/m^2.K)
\]

**The external doors and windows.** (1)The external doors design .The external door is the market supply insulating door within which is the 30mm thick lightweight heat preservation material sandwich, and the
thermal resistance and the heat transfer coefficient of which be respected by
\[ R_0 = 0.59 \left( \text{m}^2 \cdot \text{k} / \text{W} \right) \quad \text{and} \quad K_i = \frac{1}{0.59} = 1.7 \left( \text{W} / \text{m}^2 \cdot \text{K} \right) \]

(2) The external windows. It must control the area ratio of window to wall in the premise of ensuring the natural lighting circumstance from the view of building insulation. The ratio should meet the following requirement according to the specification:

The North: \( \leq 20\% \) (Suitable for both of single and double layer window);

The East and the West: \( \leq 25\% \) (Suitable for both of single layer window); \( \leq 30\% \) (Suitable for both of double layer window);

The South: \( \leq 35\% \) (Suitable for both of single and double layer window).

The model selection: The model of the external windows in this project is the double layer with plastic steel frame and the thermal resistance and the heat transfer coefficient of which respectively is 0.38m\(^2\cdot\text{K}/\text{W}\) and 2.6W/m\(^2\cdot\text{K}\) when the area ratio of window to wall of the window is 30%—40%.

According to “Graded insulation performance of windows and monitoring methods”(GB8484), the level of the windows in all directions in the cold regions should not smaller than V-level that the heat transfer coefficient should be no smaller than 3.5 and smaller than 4.0; while for the North facing one should be IV-level and the heat transfer coefficient should be no smaller than 3.0 and smaller than 3.5.

**Thermal bridge treatment**

The thermal bridge sites of the building envelope such as reinforced concrete beam, plate, column and pile foundation etc. should be treated singly. We add a 30mm thick polystyrene board to the thermal bridge sites and increase a 20mm thick insulation mortar in both internal and external surface in this project.

The thermal resistance of the thermal bridge before treated can be calculated as Eq.12:

\[
R_0 = R_1 + R_2 + R_3 + R_4 + R_5 = 0.11 + \frac{0.02}{0.93} + \frac{0.24}{1.74} + \frac{0.02}{0.93} + 0.04
\]

\[= 0.332 \left( \text{m}^2 \cdot \text{K} / \text{W} \right) \]

\[K_i = \frac{1}{R_0} = \frac{1}{0.332} = 3.0 \left( \text{W} / \text{m}^2 \cdot \text{K} \right) \]  (12)

The thermal resistance of the thermal bridge had been treated can be calculated as Eq.13:

\[
R_0 = R_1 + R_2 + R_3 + R_4 + R_5 = 0.11 + \frac{0.02}{0.29} + \frac{0.03}{0.047} + \frac{0.24}{1.74} + \frac{0.02}{0.29} + 0.04
\]

\[= 1.06 \left( \text{m}^2 \cdot \text{k} / \text{W} \right) \]

\[K_i = \frac{1}{R_0} = \frac{1}{1.06} = 0.94 \left( \text{W} / \text{m}^2 \cdot \text{K} \right) \]  (13)

It can be seen that the thermal resistance of the thermal bridge has increased as
\[ \Delta R = 1.06 - 0.332 = 0.728 \left( \text{m}^2 \cdot \text{k} / \text{W} \right) \] after treatment and the increasing rate of the thermal resistance is
\[ \frac{0.728}{1.06} = 68.7\% \] , which could consider that the ability of insulation and energy saving have improved as 68.7% in the place of thermal bridge.

Meanwhile, the treated thermal resistance that is 1.06 that greater than 0.52 also satisfy with the relevant standards on the heat transfer resistance regulation of bridge site.

**Conclusions**
The comparative analysis of the effect of the energy-saving design and the national standard that “Design standard for energy-efficiency of residential buildings in hot summer and cold winter zone” shown as table1.

<table>
<thead>
<tr>
<th>Parts</th>
<th>heat transfer coefficient $K_i$ (W/m².k) / thermal inertia index $D$</th>
<th>National standard (JGJ134-2001) $K_i$ (W/m².k)</th>
<th>K-value is below the standard/ D-value is greater than standard</th>
<th>Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>The roof</td>
<td>0.51/3.48</td>
<td>$\leq 1.0/\geq 2.5$</td>
<td></td>
<td>4.0.8</td>
</tr>
<tr>
<td>The exterior wall</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East-West</td>
<td>0.77/3.219</td>
<td>$\leq 1.5/\geq 2.5$</td>
<td></td>
<td>4.0.8</td>
</tr>
<tr>
<td>South</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The external window</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>2.6</td>
<td></td>
<td>$\leq 20%$</td>
<td>4.7 $\leq 30%$</td>
</tr>
<tr>
<td>East-West</td>
<td></td>
<td></td>
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<tr>
<td>South</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>The external door</td>
<td>1.7</td>
<td></td>
<td>$\leq 3.0$</td>
<td>4.0.8</td>
</tr>
<tr>
<td>the stratified floors</td>
<td>2.0</td>
<td></td>
<td>$\leq 2.0$</td>
<td>Table</td>
</tr>
<tr>
<td>The underlying ground</td>
<td>1.15</td>
<td></td>
<td>$\leq 1.5$</td>
<td>4.0.8</td>
</tr>
<tr>
<td>The staircase wall and the door</td>
<td>1.43</td>
<td></td>
<td>$\leq 2.0$</td>
<td>4.0.8</td>
</tr>
<tr>
<td>The thermal bridge</td>
<td>0.94</td>
<td>$\leq 1.5$ (The exterior wall standard)</td>
<td></td>
<td>4.0.8</td>
</tr>
</tbody>
</table>

Relative to the “Design standard for energy-efficiency of residential buildings in hot summer and cold winter zone” (JGJ134-2001), we know that six of the eight energy-saving projects whose K-value are below standard and another two are equal, and the D-value of the exterior walls and roofs are far greater than the standard’s value, which prove that the energy saving design for promotion demonstrative project is reasonable and achieve desired objectives.

References