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Design of Passive Solar Houses for Toilets in Rural Areas of Tibet

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Abstract: Passive solar houses are one of the main forms of solar heating. In order to fully utilize solar energy to solve the winter heating problem of toilet buildings, this article will compare and analyze different passive solar houses from three aspects: thermal characteristics, thermal comfort, and energy efficiency, select the most suitable technology, and further optimize and analyze the parameters, providing a basis for the subsequent use of active passive combined solar heating technology to improve the indoor thermal environment of toilets.

Keywords: Tibet region, Township toilets, Passive utilization, Sun House Design.

1. Technical Type Analysis

1.1. Direct benefit formula

Direct benefit passive solar heating technology is a form of heating that allows sunlight to directly provide indoor heating through direct benefit windows. The sunlight directly benefits the interior walls and ground by absorbing its heat through the window, thereby increasing the temperature. A portion of the heat absorbed indoors accumulates inside the walls and gradually releases heat outward. The other part is transmitted indoors through convection, radiation, and other means.

Its characteristic is that the structure is relatively simple, and construction, management and maintenance are more convenient; When the sunlight conditions are good during the day, the indoor temperature is higher and the temperature rise is faster; However, due to the low outdoor temperature at night and rapid heat dissipation, the indoor temperature fluctuates greatly day and night, making it more suitable for rural toilets that are mainly used during the day[1]. The direct benefit technology is shown in Figure 1.

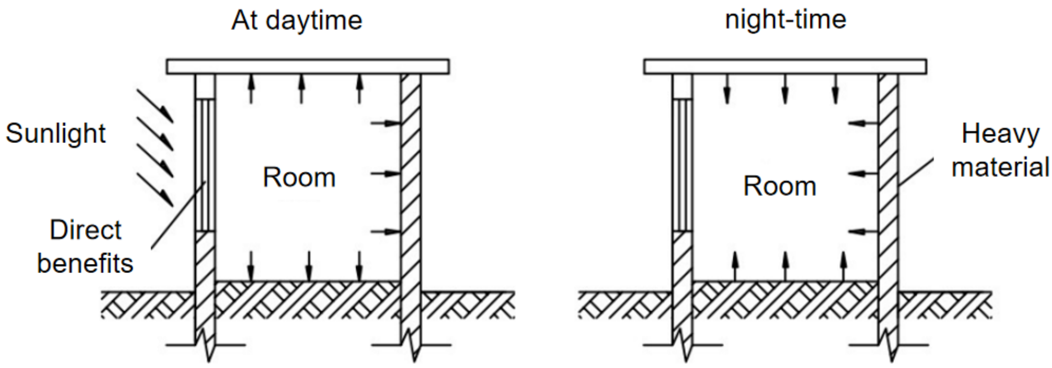

Figure 1. Direct Benefit Technology

1.2. Additional Sunlight Room Type

A form of heating that utilizes the glass room on the south side of a building for heating, using passive solar heating technology with additional sunlight. The basic structure of the sunlight room is a greenhouse surrounded by glass and building walls; The solar radiation directly passes through the glass enclosure structure to heat the internal air, and exchanges heat with the interior through holes such as public walls and doors and windows. The remaining heat is stored on the ground and public walls in the sunlight room, used to regulate the day and night room temperature.

Its characteristic is that the heat collection effect is better than the direct benefit window, with a certain temperature buffering effect, and there are certain requirements for depth based on whether there is storage use. So an additional sunlight room is more suitable for rural toilets that are mainly used during the day, but also have a balance at night[2]. The additional sunlight room technology is shown in Figure 2.

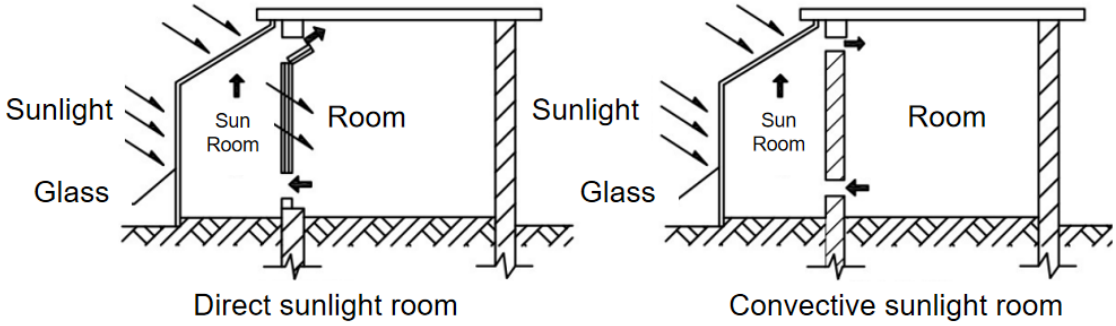

Figure 2. Additional Sunlight Room Technology

1.3. Heat collection and storage wall type

The passive solar heating technology with a heat storage wall is a heating form that absorbs and stores solar radiation through the heat storage wall on the south side of the exterior wall, thereby providing indoor heating. The structure of the heat storage wall type is relatively complex, generally composed of glass covers, air layers, and walls; The heat absorbing layer of the wall absorbs solar radiation through the glass cover plate, causing the middle air interlayer to receive heat and heat up. The ventilation holes between the wall and the indoor area transfer heat to the indoor area through flow, heat transfer, radiation, and other means.

Its characteristic is that when the sunlight is good, the indoor temperature fluctuation is smaller and the indoor temperature is more uniform, but the rate of indoor temperature rise is slower than other methods; Has good heat storage capacity and can provide indoor heating at night; Suitable for rural toilets used all day or mainly at night[3]. The heat storage wall technology is shown in Figure 3.

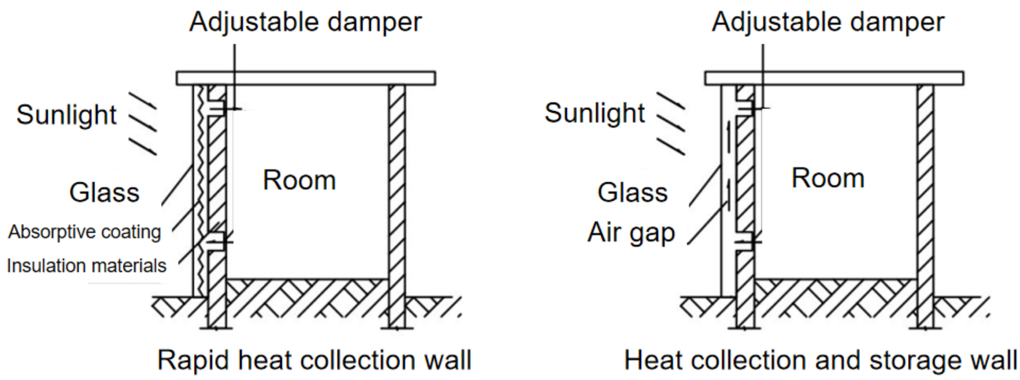

Figure 3. Heat Storage Wall Technology

2. Design Parameters of Passive Solar Houses

To explore a passive solar heating technology suitable for rural toilets in the Nagqu region of Tibet, and select the most suitable heating scheme. Several passive heating technologies are direct benefit type, heat storage wall type, and additional sunlight room type. The optimal design parameters of these technologies are summarized as follows based on literature:

(a) The direct benefit solar heating technology mainly relies on the direct benefit window to obtain heat, and the direct benefit is mainly affected by the window material and window size. From literature[4], it can be concluded that the types of glass directly benefiting from the window have different degrees of sunlight transmission, which affect the indoor heat gain. Regardless of the intensity of solar radiation in the region, the use of ordinary double-layer insulating glass is the best overall effect. The size of the window to wall ratio also affects the degree of heat loss directly benefiting both the window and the indoor environment; If the window to wall ratio is too large, it will cause a greater variation in the temperature difference inside the solar room, while if the window to wall ratio is too small, it will lead to insufficient indoor lighting. According to the Technical Specification for Passive Solar Energy Buildings (JGJ/T 267-2012), in order to meet indoor lighting requirements, the area of southbound direct beneficiary windows should account for about 30% to 50%. In reference[5], it is pointed out that under the same heating duration guarantee rate, the direct benefit window has the highest allocation cost, so excessive window costs can affect the overall economy of the room. Therefore, this article selects ordinary double-layer insulating glass (5+16+5) with a window to wall ratio of 0.5 as the thermal simulation parameters for direct benefit solar houses.

(b) The heating effect of the additional solar energy heating technology is mainly related to the orientation of the building, the depth of the sunlight room, and the material of the enclosure structure. In reference[6], it is pointed out that after considering the building function and thermal performance comprehensively, the optimal depth of sunlight is 0.9m~1.5m. Studies in references[7] and[8] indicate that the depth of additional sunlight that is only used as a heating measure should not exceed 0.6m. The material of windows in the sunlight can affect the heat gain from the sun, so like the direct benefit windows mentioned earlier, double or single-layer glass windows have better heat gain effects. For toilet buildings, the additional sunlight room is only used as a heat collection component and has no other functions. Therefore, this article selects a southbound depth of 0.6m, a shared wall to window ratio of 0.3, a glass type of ordinary double-layer hollow glass (5+16+5), and the surrounding enclosure structure is the same as the basic building.

(c) The heat collection performance of a heat storage wall is influenced by factors such as the thickness of the air interlayer, the area of the ventilation hole, and the wall material. References[9] and[10] point out that an excessively thick air layer can lead to turbulent convection and increase heat transfer losses. If it is too thin, the thermal efficiency will decrease. Moreover, the more layers of glass, the more it reflects sunlight, so single or double layer glass is more suitable. Reference[11] points out that single-layer glass with a large shading coefficient should be used. The air interlayer is generally recommended to be 5-8cm. The area of the ventilation hole should be 3%~5% of the wall area. Therefore, this article selects the south facing wall as the heat storage wall, with a glass cover plate made of 3mm single-layer glass and an air interlayer of 5cm. The absorption coefficient of the heat absorption part is 0.9, the emissivity is 0.95, and the ventilation hole is the heat collection wall of 3% of the wall area.

3. Impact on Heating Capacity

3.1. Impact of Air Interlayer Thickness

The thickness of the air interlayer in the heat storage wall directly affects the flow state of internal air, thereby affecting the efficiency of indoor heat exchange. If the air interlayer is too thick, internal air can easily form convection and cause heat transfer loss on the glass cover plate; If the air interlayer is too thin, the air flow rate is insufficient; This leads to an increase in surface temperature and temperature difference of the heat storage wall, which in turn causes heat to dissipate from the glass cover plate to the outside. Therefore, designing a reasonable thickness of the air interlayer is crucial for the heating capacity of the heat storage wall. This article simulates and calculates the thickness of the air interlayer in steps of 2cm from 2cm to 20cm, and obtains the heat supply under different air layer thicknesses. The results are shown in Figure 4.

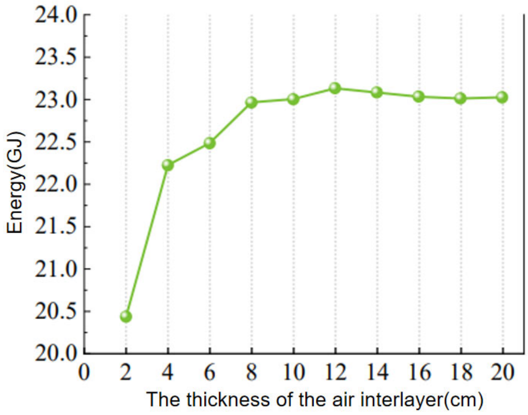

Figure 4. Heating Capacity of a Heat Storage Wall with Different Air Interlayer thicknesses

From Figure 4, it can be seen that the heating capacity of the thermal storage wall increases first and then decreases with the increase of the thickness of the air interlayer, reaching its maximum at 12cm. Subsequently, the heating capacity gradually decreases with the increase of thickness; It can be seen that the thickness of the heat storage wall is not necessarily the better. An excessively thick air layer will affect the flow of air, thereby affecting its heating capacity; From the simulation results, it can be seen that the optimal design value of the thermal storage wall in Qinghai region is between 10cm to 14cm, so the thickness of the air interlayer selected in this article is 12cm.

3.2. Impact of ventilation hole area size

The size of the ventilation hole area of the heat storage wall affects the air flow rate, which in turn affects the heat exchange rate with the indoor environment; The smaller the area of the ventilation hole, the smaller the flow rate, resulting in a decrease in convective heat transfer and an increase in outward heat loss; Therefore, an appropriate ventilation port area is crucial for improving the heat gain of the heat storage wall. This article simulates and calculates the proportion of the ventilation hole area of the heat storage wall to the wall from 1% to 10% in steps of 1%, and obtains the heat supply under different ventilation hole areas. The results are shown in Figure 5.

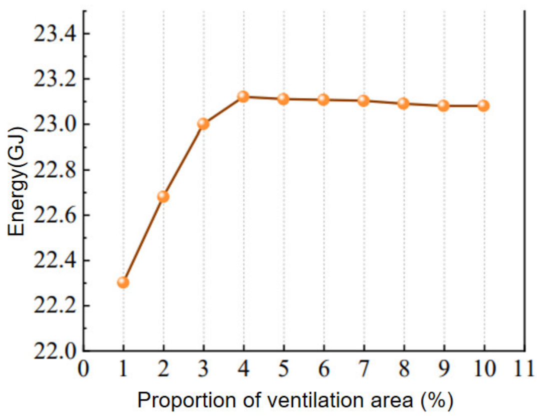

Figure 5. Heating Capacity of Heat Storage Wall under Different Ventilation Port Areas

From Figure 5, it can be seen that the heat collection capacity of the heat storage wall increases first and then stabilizes with the increase of the ventilation hole area; When the area of the ventilation hole accounts for more than 4% of the wall area, the heat supply of the heat storage wall does not change significantly. This is because the larger the area of the ventilation hole, the faster the air flow rate, and the stronger the heat exchange rate between the wall and the indoor environment. Therefore, the optimal ventilation hole area should be around 4% of the wall area.

4. Conclusion

In order to better adapt to the climate conditions in this region, this article further optimizes the structural parameters of the thermal storage wall for rural toilets based on the selection of passive solar heating technology, including the thickness of the air interlayer and the size of the ventilation hole area. Conclusion: (a) If the thickness of the air interlayer is too large or too small, it will affect the heat supply, and the most suitable thickness of the air interlayer is 10cm~14cm. (b) The optimal ventilation port area should be around 4% of the wall area.

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