APPLICATION OF ENERGY-SAVING STRUCTURAL DESIGN UNDER NUMERICAL SIMULATION IN SOLAR HEATING BUILDINGS

by

Yang LI *

Xuancheng Vocational and Technical College, Xuan Cheng, China

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The research is to explore the changes in solar heating buildings under energy-saving structural design. This paper analyzes the changes in solar heating buildings under energy-saving structural design by constructing a numerical simulation method. It mainly studies the effects of the space temperature of the house, different thermal insulation methods, and wall thermal resistance on solar heating buildings. The energy-saving structural design mainly includes expanding the area of exterior windows, increasing heat retainers, adopting energy-saving walls, and improving the building envelope. The results show that after the energy-saving structural design, the indoor temperature of the solar heating building after the renovation has been greatly increased, with an average increase of about 6 °C. Compared with the external insulation and internal insulation modes, the solar heating building under the sandwich insulation mode has the best effect, and the room temperature increases the most. Also, it shows that the east wall, west wall, and north wall of the building are increasing the energy saving per unit area of the wall as the wall thermal resistance increases. The difference is that the increasing range of the north wall has significant advantages over the east wall and the west wall. The energy-saving structural design for solar heating buildings under the numerical simulation method has significantly improved the utilization efficiency of solar energy. It reduces the consumption of traditional fossil resources and improves the quality of the environment. This paper's research has a positive effect on subsequent research.

Key words: *solar energy, building, temperature, heating, insulation*

Introduction

Solar energy, as a currently known clean energy with huge storage capacity and the least pollution, has received great attention and utilization [1]. Human has known and used solar energy for quite some time. As time progresses to the current era, the role of solar energy has penetrated daily lives [2]. Compared with ordinary fossil energy, there are three main advantages of solar energy. First, solar energy storage is very huge, exceeding the human imagination. In the past billions of years, the sun has consumed only 1% of its energy. Therefore, solar energy storage can be said to be inexhaustible [3, 4]. Second, the use of solar energy is very convenient. Solar radiation is present in almost all regions of the earth every day. Especially for some remote areas, the use of solar energy will be particularly important [5]. Third, solar energy is clean energy. During the process of processing and utilization, it will not produce

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* Author's e-mail: liyang518518518@126.com

substances that pollute the environment, affect the environment, and cause ecological changes [6]. China has a vast area and most regions of the country can receive abundant solar radiation. Therefore, China has the prerequisites for using solar energy resources [7]. The current residential heating mainly uses traditional municipal heating, which consumes a lot of resources and brings very large air pollution [8]. This paper mainly realizes the efficient use of solar heating by performing the energy-saving structural design for solar heating buildings [9]. At present, the solar radiation utilization efficiency of solar heating buildings in China is relatively low. The main problems include relatively low room temperature, unstable temperature, and large heat loss. Especially China has a large population, and the utilization rate of solar heating buildings is relatively poor, causing huge waste [10]. Solar energy has a wide range of functions in daily life. Whether in the military, aerospace, industry, or daily life, solar energy can become a driving force for making many things after being converted and processed [11]. In this paper, the energy-saving reconstruction is performed in the solar heating buildings. Then, the qualitative and quantitative analysis for the structural design of buildings is made to improve and innovate the role of solar energy in resources and the environment [12].

In this paper, a numerical simulation method is used to study the effects of solar heating buildings from several aspects under the energy-saving structural design. These aspects include the space temperature of the house, different thermal insulation methods, and wall thermal resistance. The results show that the energy-saving structural design for solar heating buildings increases the utilization efficiency of solar energy. Also, it reduces the consumption of traditional fossil resources and improves the quality of the environment. The innovation of this paper lies in the design and analysis of energy-saving structures for solar heating buildings. This paper has a very important value for the research on the energy-saving structural design of solar heating buildings.

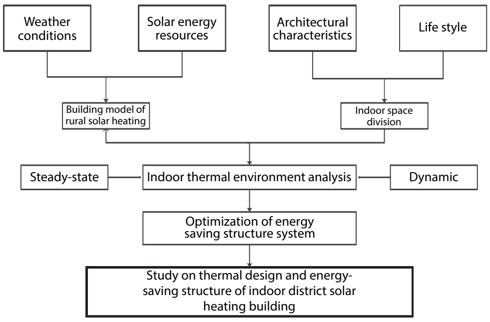

Figure 1. The technical route of energy-saving structural design

Methodology

Solar heating building

At present, solar heating buildings are divided into two categories based on the criteria of whether external energy assistance is required [13]. The first is the active solar heating building, which uses solar energy to replace other traditional temperature-regulating equipment. It uses other devices to collect solar energy and uses solar energy to transfer energy to the temperature-regulating equipment to promote the machine's work [14]. The second is the passive solar heating building, which needs no assistance from external energy. It relies on the special structure of the building itself, building materials, heat storage modes, and building envelope to achieve heating control of the building under natural conditions. Then, the problem of winter heating is solved [15]. The technical route of energy-saving structural design is shown in fig. 1.

Establishment of the numerical simulation model

The core link of numerical simulation is to establish a physical model. The degree of fit between the physical model and the real state has a great influence on the final results of the numerical simulation [16]. The critical step in numerical simulation is to divide the mesh, especially for some difficult processes. If there is a problem with the quality and rationality of the mesh generation, the reliability and accuracy of the numerical simulation results will have a very large deviation [17]. According to the mode of mesh generation, the mesh can be divided into the mixed mesh, unstructured mesh, and structured mesh. Structured mesh means that the neighboring nodes are clearly connected and arranged in order. It has some advantages such as a short time for mesh generation, the better quality of the mesh, and the great convergence of data [18]. Unstructured mesh means that the unclear connection and disorderly arrangement of the neighboring nodes. It takes a long time to generate the mesh. The quality of the mesh and the data convergence are relatively poor. Also, there is no regularity. The hybrid mesh is a hybrid structure of the aforementioned two meshes and has a better effect [19]. The installation diagram of the collector is shown in fig. 2.

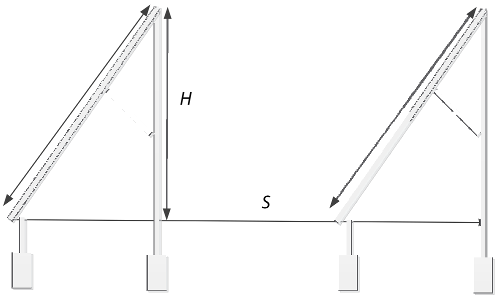

Figure 2. The installation diagram of the collector

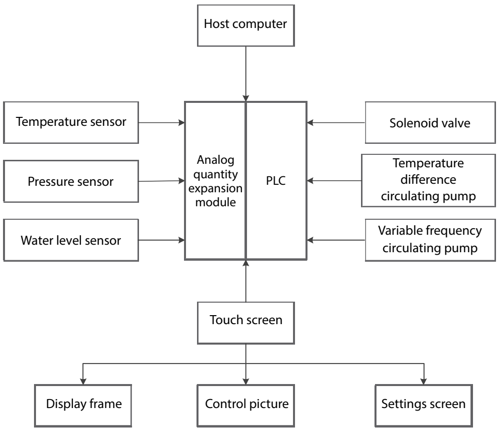

Figure 3. Hardware principle of solar heating control system

Mesh independence means that after the number of mesh units reaches a certain level, the numerical change will not affect the results of numerical simulation [20]. If the change can also affect the results of the numerical simulation, it shows that the current number of mesh units is not enough, and the number of meshes needs to continue to increase. The mesh-independent experimental process is to divide the current model into models with different densities and perform the numerical simulation on each model to obtain the results [21]. Then, a number of key parameters are selected for horizontal comparison research until the numerical changes of mesh units will not affect the results of numerical simulation. At this time, the accuracy of the numerical simulation results reaches the design requirements [22]. The hardware principle of the solar heating control system is shown in fig. 3.

Improvement measures of energy-saving structure

Lhasa and Zhongwei cities are rich in solar energy. At present, the indoor temperature of the building is relatively low and the temperature fluctuation is large. It is difficult to meet the requirement of indoor thermal comfort. Therefore, according to the actual conditions of the local solar energy resources, improvement measures for heat collection, heat storage, and thermal insulation are proposed.

Expansion of the area of the south-facing outer window

The south-facing outer window is the main way to obtain solar energy for a direct gain solar house. Its impact on the indoor thermal environment is very significant. When the window-to-wall ratio is too large, it will cause excessive heat loss and temperature fluctuations through the window in winter. It will also cause excessive indoor temperature in summer. When the window-to-wall ratio is too small, the solar energy utilization rate of the house will be lower. The south window-to-wall ratio of the building tested this time is about 0.3, which is lower than the recommended value of 0.5147 in the *Technical code for passive solar buildings*. Therefore, to solve the problem of indoor temperature deviation, the window area in the south direction should be increased on the premise of meeting the indoor thermal environment requirements and natural lighting.

Adding heat retainers

The indoor heat retainer can effectively adjust the day and night temperature difference of indoor air. It plays an important role in improving the thermal performance of passive solar buildings and improving the thermal comfort of rooms. To avoid frequent entry and exit, residents usually place water storage containers indoors. At the same time, the specific heat capacity of water is large, which is a good heat storage material. Therefore, it is recommended that transparent glass water tanks are used as water storage containers in rural areas. Then, these are placed in an area where the Sun can directly shine so that the water tanks can be used as heat retainers indoor. The position change of the internal heat retainer is shown in fig. 4. The heat retainer arranged indoor has the function of flooding and releasing heat. It can play a role of peak cutting and valley filling for the fluctuation of indoor temperature, and smooth the excessive fluctuation of indoor temperature.

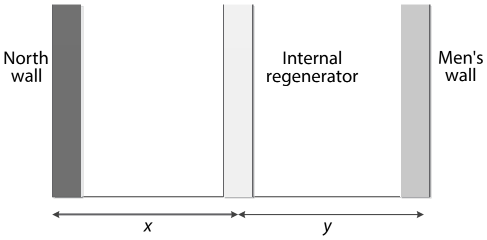

Figure 4. Position change diagram of the internal heat retainer

Use of energy-saving wall

The insulation treatment of the wall can effectively reduce the wall heat loss and play a very important role in improving the indoor thermal environment. Therefore, it is recommended to perform external insulation treatment on the external wall of the local building. If possible, the single-layer outer window can be replaced with a double-layer or triple-layer window. Double-layer insulation curtains or insulation boards are set inside the direct gain room. These are closed at night and opened during the day. This can improve the night-time heat insulation ability of windows and effectively reduce the heat loss through the glass at night, thereby significantly improving the indoor temperature.

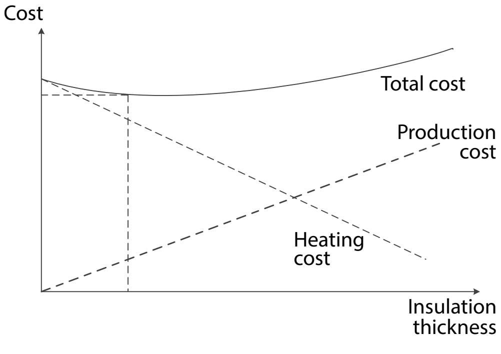

Figure 5. The total heating cost per unit area during the life cycle of the insulation layer

Renovation of the building envelope

The heat transfer coefficient of the building envelope of the heating building is large. The airtightness of the house is poor. The cold wind penetration is serious. These increase the heat load on end heating buildings. Therefore, all buildings should be insulated on the outside wall and on the roof. Different reconstruction schemes are adopted for different doors and windows to improve the insulation performance and tightness of the building and reduce the cold air penetration of the house. The total heating cost per unit area during the life cycle of the insulation layer is shown in fig. 5. There are many research materials for this project.

Heat transfer of solar heating building

The indoor heat gain during the heating period is composed of solar radiant heat, indoor waste heat and auxiliary heat consumption obtained by heat collection components. The heat loss is the sum of the heat transfer loss of the building envelope and the heat consumption of air penetration. The heat gain and loss balance:

$$Q_s + Q_b + Q_f = Q_c + Q_\lambda \tag{1}$$

The three basic reconstructions specified in the guidelines are based on the analysis of various heating energy sources. The heating energy consumption, W, of the building using a central heating system:

$$W = P + \left(Q + C_1 A + C_2 A\right) C_3 \tag{2}$$

Reconstruction of the insulation performance of the outer building envelope: by deforming the actual heat demand equation of the building in the model and the heat demand per unit volume of the building can be derived:

$$q = \frac{Q}{V} = \frac{KF\Delta t}{V} = K\varepsilon\Delta t \tag{3}$$

where q [Wm^{-3}] is the heat demand per unit volume of the building, V [m^3] – the building volume, and ε [m^{-1}] – the building shape coefficient. Reconstruction of heat source and pipe network heat balance: for large-scale urban heat networks and the heat loss caused by uneven ends can reach 20%.

The imbalance rate of the pipe network:

$$\delta = \frac{\Delta t_p - t_r}{\Delta t_p} \times 100\% \tag{4}$$

The calculation for the heat distribution of the pipe network and the energy-saving effect of the heating pipe network after reconstruction:

$$\begin{gathered} L = \Delta t c G \\ M_2 = \left(L' - L\right)\sigma_2 \end{gathered} \tag{5}$$

The comprehensive energy-saving effect of the reconstruction plan:

$$M_3 = \frac{\left(E' - E\right)\sigma_3}{\xi\eta} \tag{6}$$

$$M = \max\left(M_1 + M_2 + M_3,\ M_1 + M_3,\ M_2 + M_3,\ M_3\right) \tag{7}$$

Under steady-state heat transfer conditions, the heat flow through the non-transparent building envelope is equal to the heat flow through all parts of the building envelope:

$$\frac{I}{R_0}\left(t_i - t_e\right) = \frac{I}{R_i}\left(t_i - \theta_i\right) \tag{8}$$

Therefore, the inner surface temperature of the building envelope:

$$\theta_i = t_i - \frac{R_i}{R_0}\left(t_i - t_e\right) \tag{9}$$

By combining the indoor and outdoor air temperature of each room, the temperature of the inner wall surface of each room orientation can be obtained.

Heat transfer is the comprehensive effect of three modes of heat conduction, heat convection, and heat radiation. The comprehensive effect can be regarded as a 3-D steady-state heat transfer problem without an internal heat source. The specific control equation of its numerical simulation in a rectangular co-ordinate system is:

– The continuity equation:

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \tag{10}$$

– The momentum equations:

$$\frac{\partial(\rho uu)}{\partial x}+\frac{\partial(\rho uv)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}=\frac{\partial}{\partial x}\left(u\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(u\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(u\frac{\partial u}{\partial z}\right)-\frac{\partial \rho}{\partial x} \tag{11}$$

$$\frac{\partial(\rho wu)}{\partial x}+\frac{\partial(w)}{\partial y}+\frac{\partial(\rho ww)}{\partial z}=\frac{\partial}{\partial x}\left(u\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(u\frac{\partial w}{\partial y}\right)+\frac{\partial}{\partial z}\left(u\frac{\partial w}{\partial z}\right)-\frac{\partial \rho}{\partial z} \tag{12}$$

$$\frac{\partial(\rho wu)}{\partial x}+\frac{\partial(\rho wv)}{\partial y}+\frac{\partial(\rho ww)}{\partial z}=\frac{\partial}{\partial x}\left(u\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(u\frac{\partial w}{\partial y}\right)+\frac{\partial}{\partial \mathrm{z}}\left(u\frac{\partial w}{\partial z}\right)-\frac{\partial \rho}{\partial \mathrm{z}} \tag{13}$$

– The energy equation:

$$\frac{\partial(\rho Tu)}{\partial x}+\frac{\partial(\rho Tv)}{\partial y}+\frac{\partial(\rho Tw)}{\partial z}=\frac{\partial}{\partial x}\left(\frac{k}{c_p}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{k}{c_p}\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{k}{c_p}\frac{\partial T}{\partial z}\right) \tag{14}$$

– The heat balance equation of convection heat transfer:

$$-\lambda_s\left(\frac{\partial t}{\partial n}\right)_w=h\left(t_w-t_f\right) \tag{15}$$

The heat balance equation of radiation heat transfer on the outer surface of windows:

$$\varPhi=\varepsilon\sigma_b\left(T_1^4-T_2^4\right)A \tag{16}$$

The calculation of outdoor comprehensive temperature:

$$t_{sa}=t_e+\frac{q_s+q_R}{\alpha_a}-\frac{q_e}{\alpha_a} \tag{17}$$

For the internal heat retainer, the effective plate and plane integral expression method is adopted. Then, the heat transfer process of the heat retainer is considered as 1-D unstable heat transfer. The 1-D unstable thermal conductivity differential equation and Fourier's law analytical equation for the temperature distribution of the heat retainer:

$$\frac{\partial T}{\partial t}=a\frac{\partial^2 T}{\partial x^2} \tag{18}$$

$$q(x,t)=-\lambda\frac{\partial T(\mathrm{x},t)}{\partial x} \tag{19}$$

For an ideal model, its initial condition is assumed that the temperature of the internal heat retainer at the initial time is the same as the average indoor air temperature. The boundary conditions:

$$\begin{aligned} -\lambda_i \left(\frac{\partial T}{\partial x} \right)_{x=0} &= h_i \left(T_i - T_{x=0} \right) \\ -\lambda_i \left(\frac{\partial T}{\partial x} \right)_{x=\delta} &= h_i \left(T_i - T_{x=\delta} \right) \end{aligned} \tag{20}$$

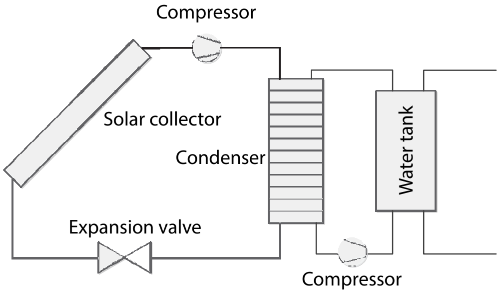

Figure 6. Direct expansion solar heat pump system

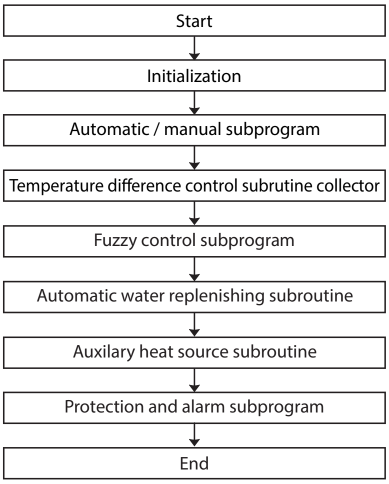

Figure 7. The main program flowchart

when analyzing the placement, the density, the volumetric heat capacity and different material changes of the internal heat retainer, the dynamic change of the indoor thermal environment occurs. The direct expansion solar heat pump system is shown in fig. 6.

Current research on energy consumption characteristics of solar heating buildings

The main program flowchart is shown in fig. 7. The thermal insulation performance of the building envelope is poor. The thermal insulation of building envelopes and the air-tightness of doors and windows are the main internal factors affecting building energy consumption. The heat loss of the heat transfer of the building envelope accounts for about 70-80% of the total heat loss of the building. The heat loss caused by air penetration in the gaps between doors and windows accounts for about 20-30%. Therefore, these two aspects are also the main points for energy-saving reconstruction.

Results and discussion

The study of energy-saving structural design in solar heating buildings is shown in fig. 8. After the energy-saving reconstruction of solar heating buildings, the indoor temperature of the solar heating buildings has been greatly increased, with an average growth rate of 6 °C. This paper analyzes six rooms in different directions in the building, to make a more comprehensive judgment and research on the effect of energy-saving structural design in solar heating buildings. The reconstruction not only improves the utilization efficiency of solar heating but also reduces the environmental pollution caused by traditional heating. The

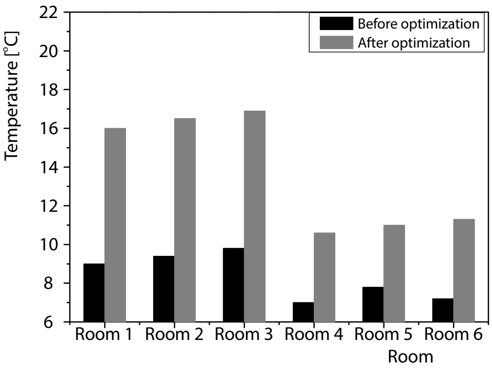

Figure 8. Research on energy-saving structural design in solar heating buildings

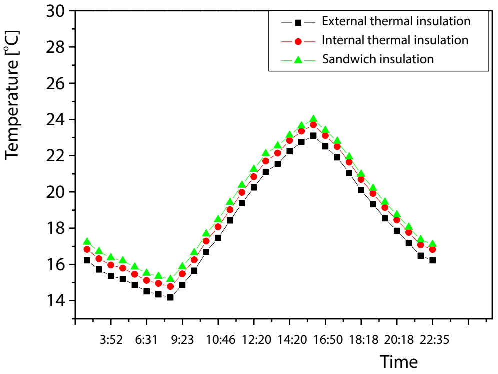

Figure 9. The instantaneous temperature of each room indoor under different insulation construction

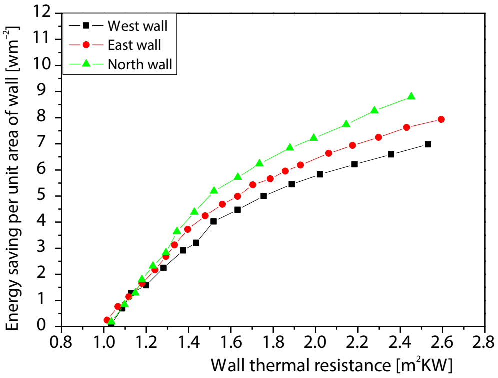

Figure 10. The change of the wall thermal resistance and the energy-saving per unit area of the outer wall

energy-saving reconstruction of solar heating buildings is very effective for improving the environment.

The instantaneous temperature of each room indoor under different thermal insulation construction is shown in fig. 9. Compared with the building heating situation before the energy-saving structural design, this paper mainly studies the effect of solar heating buildings under the methods of internal insulation, external insulation, and sandwich insulation. Also, compared with the external and internal insulation modes, the sandwich insulation mode has the best effect, and the room temperature increases the most. Therefore, the sandwich insulation mode has a great effect and significance for the energy-saving structural design of solar heating buildings under numerical simulation. Such solar heating building design can save social resources to the greatest extent.

The change of the wall thermal resistance and the energy-saving per unit area of the outer wall is shown in fig. 10. The energy-saving per unit area of the east wall, west wall and north wall is increasing, with the increase of the wall thermal resistance. The difference is that the growth rate of the north wall has significant advantages over the east wall and west wall. The average growth temperature of eight solar heating buildings randomly selected in this paper is 6 °C. The method greatly improves the utilization efficiency of solar energy and reduces waste of resources. Therefore, the energy-saving structural design of the numerical simulation has a significant role in solar heating buildings, which brings great benefits to people and society.

Conclusion

This paper mainly performs the energy-saving structural design for solar heating buildings. The effects of measures such as expanding the window area, increasing the heat retainer, using energy-saving walls, and improving the building envelope were studied by constructing a numerical simulation. The results show that reconstruction can significantly improve the utilization efficiency of solar energy, and reduce environmental pollution, forming a good social effect. With the tension and rising prices of traditional fossil energy, the energy-saving structural design for solar heating buildings has become popular and received widespread support and recognition from society. There are also some deficiencies in the research process of this paper. The conclusions are more based on surveys and information. Actual conditions and data cannot be obtained due to objective factors. Therefore, there are many interference factors.

This paper ignores many external factors, and the results are less convincing. However, the research provides a valuable reference for the subsequent research on the energy-saving structural design of solar heating buildings from a qualitative perspective.

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