APPLICATION OF SOLAR ENERGY STORAGE SYSTEM IN BUILDING STRUCTURE DESIGN AND ITS THERMAL PROCESS ANALYSIS

by

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In order to understand the application and thermal process of solar energy storage system in building structure design, a research on the application and thermal process analysis of solar energy storage system in building structure design is put forward. This paper will take the outdoor climate conditions of residential buildings in a province as an example to conduct thermal analysis on the heat collection components and heat storage components of urban residential buildings. The building under test is a university teacher's residence located in the university campus of Chengguan District of the city. It is a multi-storey building with a total of five floors, and the building is on the top floor. The experimental results show that the heat storage effect of the thick exterior wall can effectively reduce the temperature fluctuation of the exterior wall. The difference between the maximum and minimum values of the exterior wall surface temperature is 19 °C, and the difference between the maximum and minimum values of the interior surface temperature is 5.4 °C. The difference between the maximum and minimum temperature of the north exterior wall is 4.9 °C, and the difference between the maximum and minimum temperature of the inner surface is 1.6 °C. The work of this paper lays a foundation for the quantitative research on the temperature control of building heat collection and storage components, and provides a theoretical basis for solar heat storage.

Key words*: solar energy, building structure, heat storage system*

Introduction

With the continuous increase in energy demand, traditional energy is gradually unable to meet the needs of society, so people are beginning to explore new RES. Among these RES, solar energy is one of the most outstanding representatives. The application of solar thermal storage systems in buildings is becoming an important research direction, as it can reduce the use of traditional energy, achieve energy conservation and emission reduction, and also provide reliable heating and hot water services for buildings. Solar thermal storage systems can be classified based on their coupling methods and working principles. According to the coupling mode, the solar energy heat storage system can be divided into two categories: independent solar energy heat storage system and networked solar energy hydronics. Independent solar thermal storage systems are generally used in isolated buildings or areas without a power grid, and their thermal energy can be directly converted into hot water or thermal energy from thermal storage. Networked solar thermal storage systems convert solar energy into AC power through inverters and connect it to the power grid. These solar thermal storage systems need to meet

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national standards in terms of power generation and transmission, and have been applied to some large and medium-sized buildings and regions. According to the working principle, solar thermal storage systems can be divided into two categories: direct solar thermal storage system and indirect solar thermal storage system. The direct solar energy storage system collects and converts the solar energy into heat energy through the collector, and directly heats the objects to be heated, such as the hydronics in the building. Indirect solar energy storage systems convert solar energy into thermal energy through collectors, which is transferred to the water heater through a circulating fluid, and then heated and utilized in various objects that need to be heated [1, 2]. The application of solar energy in buildings can be divided into three aspects: hot water supply, air conditioning, and heating:

– *Hot water supply*. One of the most common applications of solar thermal storage systems is to provide hot water for buildings. A standalone solar hot water supply system usually consists of a flat panel collector, water tank, water pump, control system*, etc.*, which can collect, store, and utilize solar energy to achieve the purpose of supplying hot water to buildings. Its advantages are energy conservation, environmental protection, and long service life.
– *Air conditioning*. Solar thermal storage systems can also drive air conditioning systems by utilizing solar energy. Networked solar thermal storage systems can sell unwanted solar energy back to the power grid, thereby reducing its impact on the environment.
– *Heating*. Solar energy thermal storage system can provide indoor heating through hot water movement, especially in winter when heating is required in low temperature areas. Through the solar heating system, we can adjust the indoor temperature to a pleasant range, while also reducing the energy consumption of residential heating, achieving the goal of energy conservation and emission reduction. As shown in fig. 1:

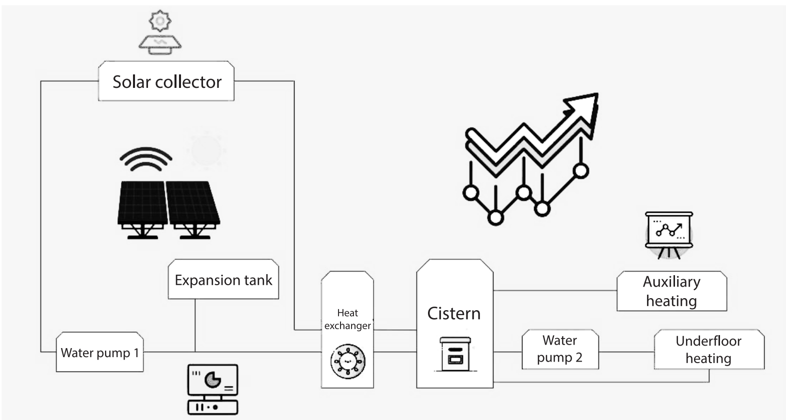

Figure 1. Building structure of solar heat storage system

Literature review

Conducting heat exchange, building and heat storage characteristics have a significant impact on the indoor thermal environment of buildings. With the continuous improvement of people's understanding of building energy efficiency, extensive and in-depth research has been conducted on the thermodynamic performance of building structures. Materials that can store and release energy in buildings can be considered heat storage materials, which are widely present in buildings, such as roofs, floors, exterior walls, interior walls, and other enclosure structures, as well as indoor furniture. The reason why building heat storage units can regulate indoor temperature is because they absorb and store heat during periods of high temperature, and release heat during periods of low temperature. This cycle mainly reflects the regulating effect on indoor temperature by delaying the peak occurrence time of indoor temperature and reducing indoor temperature fluctuations. The influencing factors of the thermal storage characteristics of building structures mainly include the following two aspects:

- Thermal physical parameters of the thermal storage body, such as specific heat capacity, thermal conductivity, density, *etc*.
- The structural parameters of the enclosure structure, such as insulation construction method, insulation layer thickness, building orientation*, etc.*

A large number of scholars have conducted relevant research on improving the stability of the indoor thermal environment in solar heating buildings by optimizing the thermal storage performance of the enclosure.

Olivkar *et al*. [3] used model experiments to study the effects of different heat storage materials, roof materials, and ceiling types on indoor temperature. The experimental data shows that when the maximum outdoor temperature is 35.0 ℃, the maximum indoor temperature of a heavy enclosure structure building is only 25.5 ℃, indicating that heavy materials can effectively reduce indoor temperature. Li *et al*. [4] systematically analyzed the heat storage and release laws of indoor building structures and their regulatory effects on indoor air temperature from both experimental and theoretical perspectives. They also compared and analyzed the differences in the effects of different types of internal heat storage materials (such as partitions, floors, ceilings, and furniture) on indoor temperature changes. The results indicate that: compared with outdoor structures, indoor structures have a greater impact on the delay and attenuation of indoor temperature. Among them, internal structures such as partitions, floors, and ceilings can increase the indoor time constant by about 25%, while internal heat storage materials such as furniture can increase the indoor time constant by about 15%.

With the continuous development of solar energy thermal storage technology, the application of solar energy hydronics in buildings has become increasingly popular, and has become one of the effective means for people to explore and use renewable energy. The technological development and application research of solar thermal storage systems will become increasingly important [5].

Methods

The author takes the outdoor climate conditions of residential buildings in a certain province as an example to conduct thermal analysis on the heat collection and storage components of urban residential buildings, in order to maximize the utilization rate of solar energy storage, improve the indoor thermal environment, and reduce building energy consumption.

Research methods

Literature research. Through extensive literature review, gain an understanding of the research content and existing achievements of domestic and foreign experts and scholars on this topic, gain an overall understanding of the research focus and difficulties of this topic, learn advanced research methods, and expand one's research ideas.

Conduct on-site research. Select the residential buildings in this town for on-site research, measure and record the characteristics, lay-out, building structure, and current status of solar energy utilization of urban residential units, collect first-hand information, and provide factual basis for future research.

Climatic characteristics

The province is located in the southeast of the autonomous region, with geographical co-ordinates of 92.13 °E, 29.68 °N, and an elevation of 3750 m. The air in this area is thin, with low dust and water vapor content, very high transparency, long sunshine time, strong radiation, and hours ranging from 2800-3500. The annual average number of days with sunshine time greater than 7 hours ranges from 276 to 320 days, among them, 9% of the time throughout the year has a total hourly radiation exposure of 317-475 Wh/m^2, and 28% of the time has a total hourly radiation exposure of over 475 Wh/m^2.

The annual average temperature in the region is 10 °C, with a maximum average temperature of 15.9 °C. August is the hottest month of the year, with an average temperature of 15.8 °C, an average maximum temperature of 23.3 °C, and an average minimum temperature of 11.4 °C. February is the coldest month of the year, with an average temperature of –1.8 °C, an average maximum temperature of 8.2 °C, and an average minimum temperature of –10 °C. The annual wind speed in this area is relatively high, with an average wind speed of 1.8 m/s and an average wind speed of around 1.9 m/s in summer, indicating abundant wind resources. At the same time, the higher the altitude, the higher the wind speed. The wind speed in areas such as river valleys and basins is relatively low, and they are divided into VI climate zones according to the climate zone. According to the requirements, buildings in this area should meet the requirements of winter insulation, cold prevention, frost prevention, hail prevention, and wind and sand prevention .

Residential characteristics

The residential buildings in this town basically follow the development model of inland towns, with similar building shapes, unit plans, and per capita area compared to the same period of residential buildings in mainland China. However, in some places, they can also reflect obvious regional characteristics, such as the main spaces such as living rooms and bedrooms facing south with large windows, and the rooms facing north with small windows and mostly double glazed windows.

Structural characteristics of urban residential buildings

The residential buildings in this town are mostly 2-5 floors in shape, with a square and heavy building shape. Each household is equipped with balconies, which can effectively block wind and sand. The external shape of a building is not only an external reflection of the internal space, but also a channel for indoor and outdoor heat exchange in the room. A compact shape is more conducive to reducing indoor heat loss in winter [6].

Roof. The roof of a building, as one of the main components of the building envelope structure, is the uppermost envelope structure of a house. Its unique architectural location maximizes its chances of receiving solar radiation, making it an important channel for energy exchange between the top room of the building and the outside world. The roof form is mainly flat roof, which is due to the lack of rainfall in this area, so drainage factors need not be considered too much. The roof of old-fashioned urban residential buildings does not have an insulation layer. The bottom layer is a 125 mm thick reinforced concrete cast-in-place slab, which is then leveled with 16 mm cement mortar, followed by a waterproof layer, and finally a 25 mm cement mortar protective layer. The roof of new residential buildings has more thermal insulation layers. According to the location of the thermal insulation layer and waterproof layer, it can be divided into two types: upright roof and inverted roof. With strong solar radiation, large temperature difference between day and night, the inverted roof is more reasonable. The structural layers from bottom to top are 125 mm thick reinforced concrete, 35 mm thick cement expanded perlite slope making, 25 mm thick cement mortar leveling, 7 mm waterproof layer, 65 mm insulation layer, and 35 mm cement mortar protective layer.

Doors and windows. According to the investigation, the windows of the old residential buildings in this town are mainly ordinary single glass metal windows, wood windows*, etc.*, with large heat transfer coefficient and poor sealing performance, and most residential windows are not provided with sunshade measures. Severe infiltration of cold air in winter increases heat storage energy consumption. The windows of newly built residential buildings are basically made of plastic steel or colored aluminum hollow double layer windows, and the thermal performance of the windows has been greatly improved. In terms of window to wall ratio, the south facing window to wall area ratio is the largest, with values ranging from 0.5-0.8, while the east west facing window to wall area is relatively small, with values ranging from 0-0.3. In the north direction, only small high windows are opened to meet the requirements of lighting and ventilation.

Most residential entrance doors mainly consider safety factors, with a high proportion of anti-theft doors. Some residents install two entrance doors, which is beneficial for reducing the heat transfer of the entire room enclosure structure. However, the heat transfer coefficient of indoor doors of residential buildings varies greatly, and the heat transfer coefficient of indoor doors of most residential buildings cannot meet the standard requirements. For residential buildings with partial intermittent heating, the heat transfer between rooms is large, which is not conducive to heating and energy saving in winter.

Experiments

Thermal testing of urban buildings and residential buildings

Overview of the tested object

The tested building is a residence for university teachers, located within the university campus of Chengguan District in the city. It is a multi-story building with a total of five floors, and is located on the top floor of the building. The building area is 86 m^2 in total, facing north and south. The thickness of the exterior wall of the building is 310 mm, without an insulation layer. The thickness of the interior wall is 245 mm, and both the interior and exterior walls are constructed of solid concrete blocks with double-sided plastering. The roof is composed of a 250 mm reinforced concrete slab and an asphalt membrane waterproof layer, with a 25 mm cement mortar protective layer onp of the waterproof layer and no insulation layer.

Test plan

Test time. The test was conducted on December 25, 2012, during which the weather was clear, with strong sunlight and a slight breeze, indicating a typical winter weather.

Test content:

- Indoor air temperature and humidity: Measure the indoor air temperature and humidity of the balcony, living room, master bedroom, and secondary bedroom, with the measurement point located one meter above the ground and without any heat sources around.
- Outdoor air temperature and humidity: Measure the temperature and humidity of the outdoor air, with the measuring point located outside the bedroom facing north and not exposed to sunlight.

Analysis of test results

Outdoor air temperature and humidity. Figure 2 shows the variation curve of outdoor air temperature and relative humidity on December 22nd. Overall, the winter climate is cold

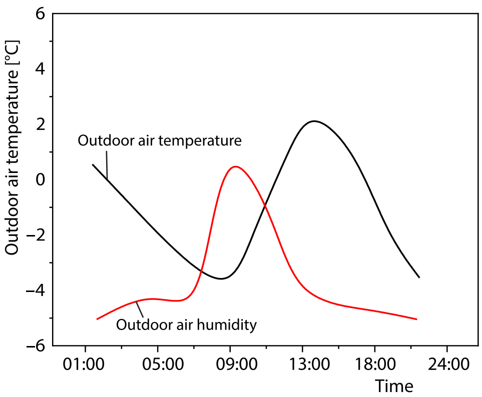

Figure 2. Outdoor air and outdoor RH

with a large temperature difference between day and night. The average outdoor air temperature is –1.78 °C, with a maximum value of 2.4 °C and a minimum value of –5.8 °C. The temperature fluctuation is 7.8 °C, and the average outdoor relative humidity is 16%. The overall outdoor relative humidity is relatively low, with a maximum relative humidity of only 30% [7].

Outdoor solar radiation. As shown in fig. 3, the effective sunshine time recorded during the testing period was from 8:00 a. m. to 18:00 p. m., totaling 10 hours. During the sunshine time, the average intensity of the total radiation on the solar horizontal plane is about 345.6 W/m^2, the average intensity of the scattered radiation is 123.8 W/m^2, and the direct radiant intensity accounts for 65% of the total radiant intensity. The maximum value of the total solar radiation intensity occurs around 13:00 p. m. at noon, about 789 W/m^2.

As shown in fig. 4, among the four orientations, the average intensity of the east facing sun is 208.8 W/m^2, the south facing sun is 498.1 W/m^2, the west facing Sun is 313.8 W/m^2, and the north facing sun is 117.0 W/m^2. The average radiant intensity intensity of the Sun in the south direction is much higher than that in other directions, and its peak value is 1082 W/m^2, which is suitable for arranging heat collection and storage components. The average radiant intensity intensity of the north sun is the smallest, and the maximum is only 254.6 W/m^2.

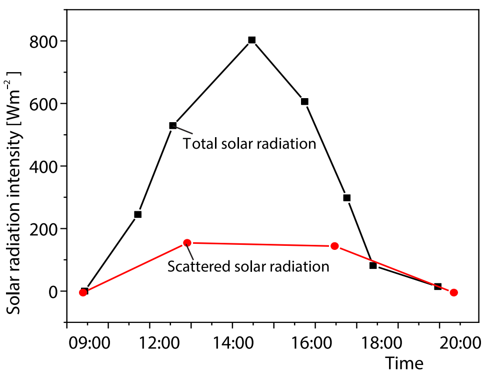

Figure 3. Curve of solar radiant intensity on outdoor horizontal plane in winter

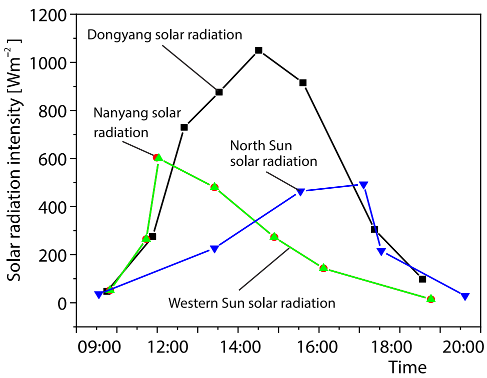

Figure 4. Curve of outdoor radiant intensity in four directions in winter

Indoor air temperature. As shown in fig. 5, the air temperature in the living room fluctuates between 11.4 °C and 13.8 °C, with an average value of 12.3 °C. The lowest value of the balcony air temperature is 10.8 °C, the highest value is 28 °C, and the average value is 15.3 °C. The change trend of the balcony temperature is consistent with the change trend of the southern radiant intensity intensity of the Sun, indicating that the transmission of sunlight has a relatively important impact on the indoor thermal environment. The air temperature in the master bedroom fluctuates between 12.2 °C and 15.2 °C, with an average value of 13.2 °C. The air temperature of the secondary bedroom fluctuates between 7.8~11 °C, with an average value of 9.7 °C. The average temperature of the north facing secondary bedroom is 3.6 °C lower than that of the south facing main bedroom.

Using evaluation indicators to evaluate the indoor thermal environment, the uncomfortable hours of the balcony on December 25th were 25.9 °C per hour, including 14.4 °C per hour for subcooling and 11.6 °C per hour for superheat. The uncomfortable hours in the living room are 16.8 °C per hour. The discomfort duration of the master bedroom is 5.17 °C per hour. The uncomfortable duration of the second lie is 78.6 °C per hour. The discomfort hours in the living room, master bedroom, and secondary bedroom are all caused by overcooling [8-10].

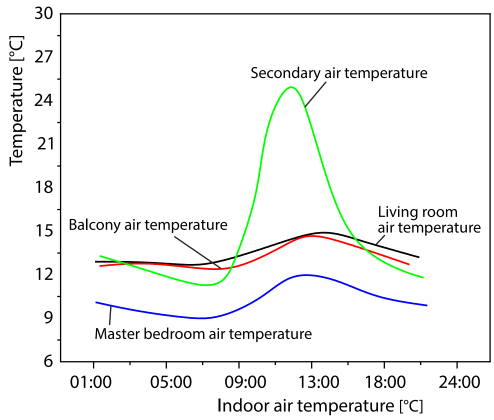

Figure 5. Indoor air temperature

Wall temperature. As shown in fig. 6, the overall trend of the inner and outer surface temperature of the southbound wall first decreases, then increases, and then decreases. Starting from 0:00, the temperature on the outer surface of the south wall continued to decrease, reaching a minimum value of 5 °C at 8:40 a. m. Afterwards, the temperature rapidly increased, reaching a maximum value of 22.5 °C at 15:40 p. m., and then decreased again. The trend of temperature change on the inner surface is similar to that on the outer surface, but the fluctuation amplitude is relatively small compared to the outer surface temperature. At 10:30 a. m., the inner surface temperature drops to the lowest value of 10.2 °C, and at 18:30 p. m., the inner surface temperature rises to the maximum value of 15.5 °C. Among them, between 12:00 a. m. and 16:30 p. m., the outer surface temperature is greater than the inner surface temperature. The delay in heat transfer caused by the thermal inertia of the wall can be clearly seen from the time when the maximum and minimum values of the internal and external surface temperatures appear, tab. 1.

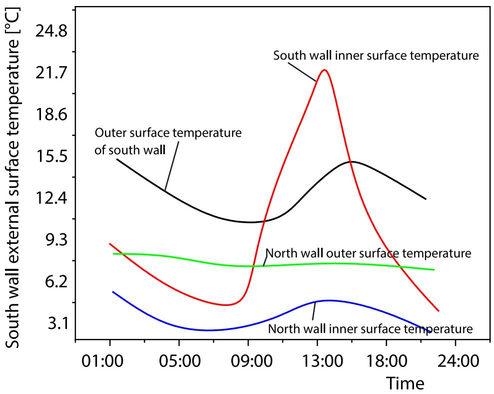

Figure 6. Wall temperature

Table 1. Statistical table of wall surface temperature

Parameter	Maximum value	Minimum value	Average value	Standard deviation
Surface temperature inside the south facing wall [°C]	15.6	10.2	12.8	1.8
Surface temperature outside the south facing wall [°C]	22.5	4.1	9.3	5.6
Surface temperature inside the north facing wall [°C]	8.6	7.1	7.8	1.5
Outer surface temperature of the north facing wall [°C]	6.7	1.8	3.8	1.4

Conclusions

On the basis of analyzing the thermal process of the heat storage component of the solar energy collection component, the author summarizes the main factors that affect the heat storage effect of the solar energy collection component, and evaluates the heat storage effect of the solar energy urban residential buildings, this indicator can reflect the indoor thermal environment characteristics under the comprehensive effect of building heat collection and storage, which is helpful for balancing heat collection and storage in solar energy design. The main conclusions are:

The utilization of solar energy has been taken into account in the construction of existing urban residential buildings. The size coefficient of urban residential buildings is relatively small, with few convexities. The area of windows and walls facing south is relatively large, while those facing north have small or no windows, resulting in very thick walls. Some residential buildings have specially set up sunlight rooms. Through testing, it was found that the average air temperature in the living room is 12.3 °C, with a maximum value of 13.9 °C and a minimum value of 11.3 °C. The average air temperature in the master bedroom is 13.2 °C, with a minimum value of 12.1 °C and a maximum value of 15.1 °C. The average temperature of the secondary air is only 9.7 °C, with a maximum value of 12 °C and a minimum value of 7.7 °C. The sunlight room can serve as a buffer space indoors to prevent significant fluctuations in indoor air temperature. However, the temperature fluctuation of the sunlight room itself is very large, with a maximum temperature of 28.1 °C, a minimum temperature of 10.8 °C, and a temperature fluctuation of 16.1 °C, which can easily cause overheating at noon. The discomfort hours for the living room are 16.8 °C per hour, 25.9 °C per hour for the balcony, 5.17 °C per hour for the master bedroom, and 78.6 °C per hour for the secondary bedroom.

The heat storage effect of a thick exterior wall can effectively reduce temperature fluctuations on the inner and outer surfaces of the exterior wall. The difference between the maximum and minimum surface temperatures of the exterior wall facing south is 19 °C, and the difference between the maximum and minimum surface temperatures of the interior wall is 5.4 °C. The difference between the maximum and minimum surface temperatures of the north facing exterior wall is 4.9 °C, while the difference between the maximum and minimum surface temperatures of the interior wall is 1.6 °C.

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