ANALYSIS OF THERMAL CHARACTERISTICS OF BUILDING ENVELOPE STRUCTURE FOR NIGHT STORAGE HEATING

by

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In order to understand the thermal characteristics analysis of nighttime thermal storage heating, the author proposes a study on the thermal characteristics analysis of nighttime thermal storage heating of building envelope structures. In some places, the writer will use an office room as a research object. The main purpose of the experiment is to measure, compare and analyze the surface temperature and heat flow rate of the room sample volume under two conditions: constant power 24 hour heating and night constant thermal power (12 hours) heating. In order to verify the accuracy of the dynamic thermal process of the heating room, the indoor air time variation will be performed along with the simulation results. Thermal performance parameters and characteristics of building thermal envelope heating effect of storage room were studied. The mathematical model of the thermal dynamic process of the heating room was established using the heat balance method and verified by experiments. According to the experiment, when the heating time increases from 5-12 hours, the additional heating consumption of the building heating system decreases by 500 Wh, and the additional heating consumption decreases to 19.4. In addition, it is important to change the heating time of the night-time packing model and the total heat accumulation. In addition, external wall insulation is useful in reducing additional heating consumption and building heating costs, but all heat transfer between model blocks is low. As the weather changes and the heat transfer coefficient of the external window increases, the additional amount of heat consumption and the additional value of heat consumption for heat storage of the building will increase. In the process of continuous heating operation, the additional heat consumption of the building heating system, the additional heat consumption gradually decreases, the heating equipment changes per hour, and the total heat accumulation of the night packing structure is important.

Key words: *building enclosure, night heat storage, heating*

Introduction

The *energy revolution*, *low carbon energy*, and *clean heatin*g have become important components of the national energy strategy, and promoting revolutionary changes in the energy system is an important orientation of the energy strategy. In recent years, in order to solve the environmental pollution caused by coal-fired heating in northern heating areas, the development of clean energy electric heating has received widespread attention. The traditional cogeneration heating mode in northern heating areas has hindered the development of clean

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wind power, resulting in a serious *abandonment* phenomenon. Regenerative electric heating cannot only meet the heating demand, but also better respond to wind power. Therefore, wind power heating is one of the reasonable measures to solve the winter wind abandonment problem in the three northern regions. As the main enclosure structure of a building, its large area and thermal insulation and storage performance are directly related to the energy efficiency of the building and the economy of the direct supply electric heating system. Utilizing the favorable conditions of electricity heating policies such as *peak valley electricity prices* and building envelope structures for large-scale heat storage, develop a *thermal storage electricity heating building structure* that combines heat storage materials and building envelope structures, it will effectively promote the popularization and development of related technologies such as *building industrialization* and *electric heating*.

Night heat storage is a method of energy storage that utilizes the absorption or release of larger energy generated by PCM during phase change. As a heat storage medium, PCM can reduce the temperature difference between day and night in the room and increase the indoor thermal comfort. In the relevant research on phase change heat storage systems both domestically and internationally, PCM are often placed under the floor to form floor heating systems. There are mainly two types of systems, namely solar air collectors and electric heating. However, regardless of which system is used, a common floor and insulation layer with a thickness of 8-14 cm are usually laid onp of the phase change layer, the heat transfer process from the phase change layer to the indoor air has a high thermal resistance, requiring nighttime ventilation send the stored heat into the room. At present, research on phase change heat storage walls mostly uses plastic pipes encapsulated with PCM, which are fixed horizontally through an iron frame. The hot air outside the pipes is used to heat the PCM and store heat. The principle of thermal storage heating is that during electric heating, materials melt and store latent heat of phase change. When the power supply is stopped and the temperature drops below the freezing point, latent heat of phase change is released to the environment. Heat storage heating is a new intermittent heating method that is superior to ordinary direct supply heating in terms of energy conservation and environmental protection. It not only solves the problem of energy waste, but also plays a role in peak shaving and valley filling of power loads, fully utilizing cheap valley price electricity, and significantly reducing heating costs. So it is very urgent and necessary to study the structure of thermal storage heating buildings [1, 2]. As shown in fig. 1:

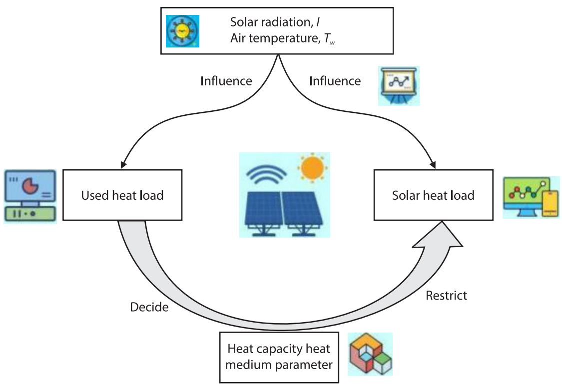

Figure 1. Thermal characteristics of building envelope at night heat storage heating

Literature review

The building envelope plays an important role in separating the interior space from the exterior environment. Indoor and outdoor thermal environments exchange heat through the building envelope. The building and its heating properties have a significant impact on the internal thermal environment of the building. As people's understanding of energy-efficient buildings continues to evolve, extensive and in-depth research has been conducted on the thermodynamic performance of building envelopes:

– *Research on the heat collection and insulation performance of the enclosure structure.*

Lapisa *et al.* [3] conducted a study on the impact of building envelope structure on building energy consumption, and found that the window to wall ratio has a significant impact on building energy consumption. Compared with existing standard designs, reducing the window to wall ratio can significantly reduce the energy consumption of buildings. Li *et al*. [4] and others obtained the architectural design parameters and strategies for each building climate zone based on the magnitude of building energy consumption in different climate regions, providing theoretical guidance for the structural design of building envelopes. Dela *et al.* [5] studied a public building in a certain area and analyzed the effects of window to wall ratio and system coefficient on building energy consumption. The results showed that the effect of window to wall ratio on winter heat load was smaller than that on summer load, and the shape coefficient had no significant impact on building energy consumption. The aforementioned researchers only studied the heat storage and insulation performance of the building structure and gave important recommendations for the good effect of the solar building block. The thermal storage function of the building structure plays an important role in the construction by controlling the indoor air temperature and diurnal differences, and attenuating the temperature, improving the indoor thermal comfort and reducing the energy consumption of the home.

– *Research on thermal storage performance of enclosure structure.*

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 factors affecting the thermal storage characteristics of building envelope 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.*

Therefore, the author utilizes the building envelope structure itself to store heat and heat the room. At night, the heat is stored in the exterior walls, interior walls, and other envelope structures, and during the day, the heat is released. The main research focuses on the room air temperature, changes in the heat storage capacity of the envelope structure, and related influencing factors, in order to achieve comfort and energy conservation.

Methods

Dynamic thermal process model for thermal storage heating rooms

Heating room model

The author selected a north facing room in an office building in a certain area as the research object, located on the fourth floor, with a room size of 3.4 m × 6 m × 3.4 m and a total area of about 20 m^2. The main enclosure structure of the room is: north exterior wall, north exterior window, south interior wall, south interior door, east west interior wall, floor slab, and ground.

Mathematical model of thermal storage heating room

In many office buildings, the heating system is only turned on at certain times of the day, between 10:00 p. m. and 7:00 a. m., known as the heating time, and at other times, known as the heating period.

During the heating period, the heating system is turned on, and the constant energy is adjusted to the daily needs to heat the room every hour and raise the air in the house. By using the heat storage function of the building envelope, part of the heat is stored in it. At time n, the heating capacity of the building $HA(n)$ is a constant value, which is equal to the sum of continuous heat supply $HL(n)$ and heat $HS(n)$ of the room at that time. The instructions are:

$$HA(n) = HL(n) + HS(n) \tag{1}$$

where $HA(n)$ [W] is the heating capacity of the thermal storage building at time n, $HL(n)$ [W] – the thermal load of the room in n, and $HS(n)$ – the heat storage load per unit of time n. Among them, the n-time heat accumulation $HS(n)$ is related to the indoor air change, and its value is the heat released or absorbed into the indoor air at time n due to the indoor air temperature change. heat preservation of container samples ahead of time n. Therefore, based on the importance of air changes in the room at time n and earlier, the room heating storage reaction coefficient can be used to obtain the room heating load $HS(s)$ at time n. The instructions are:

$$HS(n) = -\sum_{j=0}^{\infty} RS(j)\Delta t_r(n-j) \tag{2}$$

where $RS(j)$ is the thermal storage reaction coefficient of the room, which is the specific value of the impact on the current and subsequent heating capacity when the room temperature undergoes a 1 °C displacement, n [hour] – the certain moment during the experiment, and j [hour] – the time after the start of the thermal storage reaction.

Dynamic thermal characteristics experiment of thermal storage heating room

Experimental purpose

The main purpose of this experiment is to measure the surface temperature and heat flow rate in a sample volume of the room under two conditions: 24 hour constant heating capacity and night heating storage capacity (12 hours). Comparison and analysis of indoor air time variations with an attempt to clarify the true thermal dynamic process of the storage room. The test item chosen by the author is an office room in some places.

Experimental process and result analysis

Place the convection electric heater in the central position of the room floor, turn on the electric heater at 23:00 p. m. every night, and turn off the electric heater at 7:00 a. m. the next morning, so that the test room can be heated for 10 hours at night, that is, the building's heat storage time is 10 hours. During the heat storage period, the heating power of the electric heater is always maintained at 1500 W, and it is continuously tested in the same way for 5 days. The indoor air temperature and outdoor air temperature are recorded hourly. At the beginning of the testing, the adjacent rooms were not heated, and the temperature of the surrounding rooms was about 20 °C, while the temperature of the corridors was about 18 °C. Throughout the entire testing process, the temperature of the surrounding rooms (including the corridors) changed very little. The calculation results based on the dynamic thermal process model established in the first section are shown in fig. 2 [6].

From fig. 2, it can be seen that the trend of indoor air temperature over time obtained through experimental testing is basically consistent with the trend of indoor air temperature obtained by solving the mathematical model. From the graph, it can be seen that in the first hour after heating on the first and second days, the maximum difference between the experimental and simulated values is 0.8 °C, this is because after 2 hours of heating, the indoor air temperature fluctuates greatly, and the indoor air temperature distribution is uneven. The experimental test results are only local values, and the results obtained by solving the mathematical model represent any temperature in the room. Therefore, the experimental value and the simulated value have the largest difference. At any other time, the difference between the experimental and simulated values remains within 6%, which can verify the accuracy of the mathematical model of the heating room in the first section [7, 8].

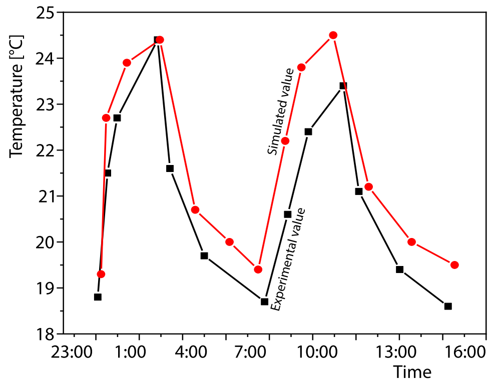

Figure 2. Comparison of simulated and experimental values

Research on the influencing factors of the additional heat consumption rate for lightweight enclosure structure thermal storage heating

Introduction simulation conditions

In the simulation analysis, the typical meteorological days in this area are taken as external disturbance parameters, without considering the interference of solar irradiance, personnel, lighting and equipment heat dissipation, and the convection heat transfer coefficient of the external surface of the wall is 22.9 W/m^2°C. Most new buildings now use lightweight walls as the enclosure structure for rooms. Compared to heavy-duty enclosures, lightweight enclosures have lower density and thermal conductivity.

Analysis of factors affecting the thermal storage and heating characteristics of lightweight enclosure structures

Using the mathematical model of dynamic thermal characteristics of heat storage heating room established by the author, the effects of external insulation layer, air changes per hour,

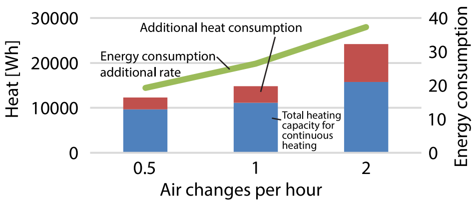

Figure 3. Total heat supply, additional heat consumption, and additional heat consumption rate with external insulation layer

external window heat transfer coefficient and heat storage duration on the heat storage heating capacity of light envelope are explored, respectively. Due to the role of room heat storage and the demand for daytime room temperature, relative to the hourly heat load of continuous heating, it is necessary to increase the constant heating power of building heat storage heating per hour. The additional heat consumption of building heat storage heating is defined as the increase value of building heat storage heating relative to the total heat supply of continuous heating, and the additional heat consumption rate is defined as the ratio of the additional heat consumption the total heat supply of continuous heating. The simulation results are shown in fig. 3.

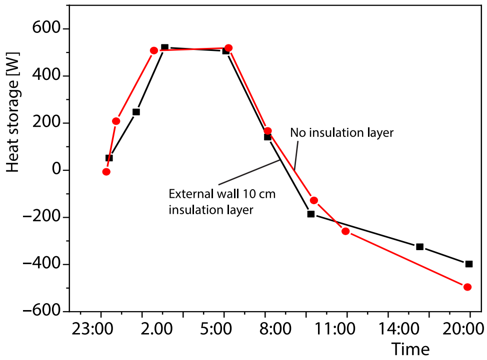

Figure 4. Light enclosure structure with external insulation layer for hourly heat storage

As shown in figs. 3 and 4, when a 12 cm thick insulation layer is placed on the outside of the outer wall of the light shell, the heat transfer coefficient of the outer wall decreases and additional heat consumption is reduced. building heat storage was reduced by 212.9 Wh. Reducing building heat is better than continuous heat, so additional heat consumption will be reduced by 1.4 times [9].

Therefore, the better the external insulation performance of the exterior wall, the lower the additional heat consumption rate. The total heat storage capacity of the enclosure structure is 4020.2 Wh, which is only 6.7 Wh less than the total heat storage capacity without insulation layer. Therefore, after adding insulation layer on the outer surface of the exterior wall, the total heat storage capacity of the enclosure structure is less affected.

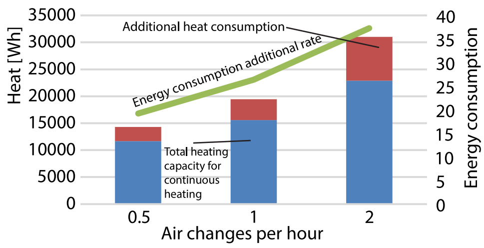

Figure 5. Total heating capacity, additional heat consumption and additional heat consumption rate with different air changes per hour

As shown in fig. 5, the continuous heating cost, the total cost of building heat storage, the increase in heat consumption and the additional cost of heat consumption, and the heat storage capacity of the volume structure increase with the increase of air volume. When the air change in the room increases by 0.6 times per hour and 2.1 times per hour, the additional amount of heat consumption of the heat storage building increases by 6265.8 Wh, and the additional value of heat consumption increases by 18.3 times, and the total heat storage capacity of the packaging model increased by 5181.3 Wh. Therefore, controlling the air pressure in the room can reduce heating costs.

As shown in figs. 6 and 7, with the increase of heat storage duration, the additional heat consumption and rate of building heat storage heating gradually decrease, and the hourly and total heat storage of the enclosure structure also decrease. When the heat storage duration is 5 hours, compared to the continuous heating capacity, the additional heat consumption rate of building heat storage heating is 24%. When the heat storage duration increases from 5 hours to 12 hours, the additional heat consumption of building heat storage heating decreases by 500 Wh, and the additional heat consumption rate decreases to 19.4%. Therefore, when using building heat storage heating at night, it is necessary to control the length of heat storage time by combining the constant power of the heating equipment, in order to reduce the additional heat consumption rate, and the envelope structure has a significant fluctuation in hourly and total heat storage [10].

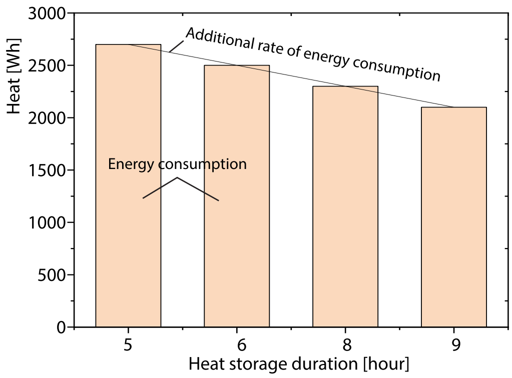

Figure 6. Total heat consumption additional amount and heat consumption additional rate for different heat storage durations

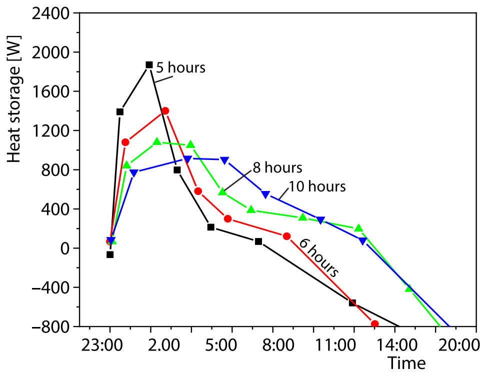

Figure 7. Hourly heat storage of lightweight enclosure structures with different heat storage durations

Conclusions

The author takes light envelope structure office buildings as the research object, explores the dynamic thermal characteristics and related influencing factors of rooms using envelope structure thermal storage heating, and establishes a dynamic thermal process mathematical model and experimental verification based on this. The conclusions are as follows.

- By increasing the external wall insulation layer, the additional heat consumption and additional heat consumption rate of thermal storage heating will decrease accordingly. When a 10 cm insulation layer is added to the exterior wall, the additional heat consumption for building thermal storage heating decreases by 212.9 Wh, and the additional heat consumption rate decreases by 1.5%. However, the total heat storage of the enclosure structure is less affected by the insulation layer.
- With the increase of air changes per hour, the additional amount and rate of heat consumption for building heat storage heating also increase. When the air changes per hour of the room increases from 0.6 times per hour to 2.1 times per hour, the additional heat consumption of building thermal storage heating increases by 6265.8 Wh, the additional heat consumption rate increases by 18.3%, and the total heat storage of the enclosure structure increases by 5181.3 Wh. Therefore, in order to reduce the additional heat consumption rate, the room should maintain good air tightness.
- With the extension of heat storage time, the additional heat consumption and rate of building heat storage heating gradually decrease, and the hourly and total heat storage of the enclosure structure also decreases. When the heat storage duration increases from 5-12 hours, the additional heat consumption of building heat storage heating decreases by 500 Wh, and the

additional heat consumption rate decreases to 19.4%. Moreover, the fluctuation of hourly heat storage and total heat storage of the night enclosure structure is significant.

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