THERMAL STORAGE PERFORMANCE ANALYSIS OF BUILDING ENVELOPE BASED ON BIG DATA SENSOR NETWORK

by

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In order to understand the thermal storage performance analysis of building envelope, the author proposes a research on thermal storage performance analysis of building envelope based on Big data sensor network. The author first compares and analyzes the thermal storage performance parameter systems of different theoretical methods, and determines the key characterization parameters of thermal storage performance under different working conditions based on the analysis of the thermal storage process. Second, in order to compare and verify the measured and simulated indoor temperature of the building, two groups of buildings with identical exterior wall insulation performance and distinct thermal storage performance were chosen. Three distinct thermal storage levels of the building's exterior walls were used to simulate and analyze the internal surface temperature, heat flux density, and building cooling and heating load. Summer night ventilation was used to investigate the effect of ventilation volume on building cooling loads. In the end, a provincial office building was chosen as the research subject. The structure comprises of two stories, one underground and two over the ground, with a north hub point of 180°. The investigation object is a two-story room. The trial results demonstrate that the deliberate outcomes are in great concurrence with the mimicked results. For the district of the region, under a similar protection execution of the nook structure, the inner surface temperature of the weighty construction outside wall is higher in winter, lower in summer, with a higher intensity load in winter and a lower cooling load in summer. The proper air changes each hour of building night ventilation is 16 ach, and the effect on the cooling heap of weighty structures is huge. Demonstrated the precision of the reproduction technique and model.

Key words: *Big data, building enclosure, thermal storage performance*

Introduction

With the rapid development of IoT technology, large-scale sensor networks have begun to be widely used in various fields, such as urban intelligence, smart factories, environmental monitoring and other fields. The sensor network has the advantages of wide coverage, multi-channel transmission, self-organization*, etc.*, which can realize efficient data acquisition and transmission based on the IoT, which brings us great convenience. However, in practical applications, sensor networks face a series of problems in energy consumption, bandwidth, transmission rate and so on: how to optimize the protocol of sensor networks has become an

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important aspect. Research on final optimization protocol of sensor network based on Big data. It aims to solve the problems in sensor networks by using Big data technology and intelligent algorithm, and improve the performance and service quality of sensor networks. Sensor networks are widely used in urban construction, intelligent manufacturing, agriculture, forestry and fisheries and other fields.

Big data technology can greatly improve the performance and service quality of sensor networks, and its main applications are:

– *Data analysis*: Through big data analysis, we can better analyze the data collected in the sensor network and extract valuable information.
– *Data mining*: Through data mining technology, regularities and patterns hidden in data can be found from massive data to help people better understand and use data.
– *Data processing*: Through big data processing technology, it can better process large-scale data and improve the data processing capacity of sensor networks.
– *Data security*: Through big data analysis, we can analyze the security problems faced by sensor networks, and take corresponding measures to improve the security of sensor networks.

The warm stockpiling execution of building envelope structures is a fundamental pointer for building energy utilization estimation and solace control. There are some distinctions between the design and actual use of comfort and energy consumption in practical engineering. The thermal performance of building envelope structures is influenced by a variety of factors, including the structure, material composition, installation process quality, and indoor and outdoor environments during use of the envelope structure. This is one of the reasons why building envelope structures cannot meet the design requirements. The utilization of environmentally friendly power in building warming is getting expanding consideration. Passive buildings that use direct sunlight to achieve building heating have been widely used, especially in areas with abundant solar energy resources and scarce fossil fuels such as the northwest. However, due to the drastic changes in solar energy over time, building enclosures must have a thermal storage function regulate indoor temperature fluctuations caused by solar energy. There are various types of thermal storage materials for building envelope structures, including those with constant thermal properties that do not change with temperature, as well as those with high latent heat in the phase change temperature range. Combining building thermal storage devices with the enclosure structure to create a thermal storage and temperature regulating enclosure structure cannot only save space but also integrate the design of the thermal storage system with the design of the enclosure structure. The enclosure structure stores heat when the indoor temperature is high, preventing the room temperature from continuing to rise. When the room temperature drops, the stored heat is released to prevent the room temperature from continuing to decrease. Thus, it weakens room temperature fluctuations and improves indoor thermal comfort.

China's building consumption has been steadily rising in recent years. Energy consumption in buildings can be effectively reduced through passive building design, which makes use of renewable energy and improves the thermal performance of building envelopes. Building heat capacity, as a latent innovation, has tremendous application possibilities in northern China. Currently, the following aspects are the primary focus of research on building heat storage:

– The affecting elements of the exhibition of intensity stockpiling materials.
– The effect of intensity stockpiling materials on indoor warm climate and building load.
– A tool for thermal design used to construct heat storage [1, 2]. As shown in fig. 1.

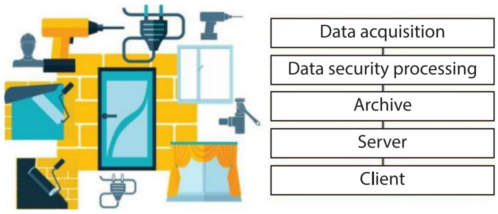

Figure 1. Heat storage performance of building envelope structure

Literature review

The energy consumption of buildings is very high, and they generate a large amount of greenhouse gases. If most of the energy consumption generated by buildings is applied to space heating and cooling, it can create a more comfortable and good thermal environment. The thermal storage performance of winter enclosure structures plays a crucial role in ensuring the thermal stability of buildings. Under the condition of intermittent changes in heat release from heat sources in heating systems, building heat storage suppresses fluctuations in indoor air temperature and improves room thermal stability. The research on the coupling effect of building heat storage and intermittent heating has received attention from scholars. In recent years, with the rise of low energy passive building technology, the issue of building thermal storage design and its quantitative evaluation of its impact on indoor thermal environment and building energy consumption has become increasingly prominent. Heat storage is the core link in solving the intermittent and unstable problems of solar thermal utilization. Loudou *et al.* [3] conducted numerical simulations on the thermal storage and release of different material layers on the exterior walls of residential buildings in urban areas. The study showed that the indoor thermal comfort range of thermal storage buildings in urban areas accounted for 21.8% of the entire year. Diao studied the thermal storage and temperature regulation effects of shaped PCM in passive buildings. The application of shaped PCM with a phase change temperature of 22~24 °C in the *ultra low energy consumption demonstration building* has a good thermal storage and temperature regulation effect, which can ensure that the indoor temperature fluctuation in winter does not exceed 7 °C [4].

The calculation of thermal storage performance should be able to objectively and comprehensively reflect the complex actual building thermal storage and release process affected by many factors. Therefore, it is necessary to first study the unsteady heat transfer process, and then conduct scientific mathematical processing on this basis, so as to obtain the calculation method of thermal storage performance of the enclosure structure. At present, a major problem faced by research on building heat storage is the lack of unified basic theories of unsteady heat transfer, resulting in different parameter systems for heat storage performance. The selection of which parameter system affects the design, performance analysis, and evaluation methods of heat storage components. In view of this, comparative analysis is conducted on the thermal storage performance parameter systems of different theoretical methods, and key characterization parameters of thermal storage performance under different working conditions are determined based on the analysis of the thermal storage process, providing a theoretical basis for the analysis and calculation of building thermal storage process, insulation performance, and thermal stability performance [5, 6].

Methods

Comparison and analysis of thermal storage theory for envelope structures

The process of building heat storage is a non-stationary heat transfer process with multiple factors coupled. Under the dynamic changes of external heat flow or temperature, the heat flow and temperature on the surface and inside of the enclosure structure will fluctuate. The main methods for analyzing unsteady heat transfer in enclosure structures include harmonic analysis, response coefficient method, transfer function method, state space method, and numerical analysis method. The numerical analysis method discretizes the time and space, and can obtain the heat flow and temperature distribution at different positions of the envelope at each time. Compared with other methods, it has the advantage of solving non-linear and multi-dimensional heat transfer problems. However, theoretical analysis methods have more advantages in analyzing the mechanism of unsteady heat transfer. Internationally, a relatively complete thermal storage performance parameter system has been established mainly based on two theoretical analysis methods: harmonic analysis method and transfer function method.

Harmonic analysis method

The harmonic analysis method regards the complex non-simple harmonic motion temperature fluctuations as simple harmonic waves. Using Fourier transform, the periodic function is expressed in the form of series of cosine function.

Transfer function method

The transfer function method transforms the input of temperature and heat flux on one side of the building component into the output of temperature and heat flux on the other side using a coefficient matrix that identifies the thermal physical properties of the building components. The coefficient lattice is gotten through a Laplace change of a one-layered warm conductivity differential condition.

Comparison between harmonic analysis method and transfer function method

Both harmonic analysis method and transfer function method can calculate the thermal response characteristics of the enclosure structure under different wave periods. For multi order harmonic waves, they can be calculated separately and stacked according to different periods. The key problem to be solved by two methods is to obtain the thermal response characteristics of the enclosure structure to disturbances. The harmonic analysis method is solved through the separation of variables method, while the transfer function method is obtained through the Laplace transform. The harmonic analysis method is more intuitive in expressing periodic non-stationary heat transfer processes and has a clear physical meaning. The exact solution of the harmonic analysis method utilizes complex operations. In order to facilitate practical application, approximate calculations were made for parameters such as surface heat storage coefficient, attenuation factor, and delay time. The transfer function method has higher accuracy in calculating results, but its calculation process is more complex, and the physical meaning of parameters is relatively difficult to understand, which is limited in practical applications.

Influence of heat storage performance of envelope structure on building load

The capability of the structure envelope structure is to oppose or use warm impacts to make an agreeable and controllable warm condition in the room. The open air temperature and sun powered radiation display intermittent changes among constantly, and the structure envelope bears the impact of occasional and unsteady intensity stream waves. During the course of intensity stream waves arriving at the inside surface of a room through the structure nook structure, the constriction of wave plentifulness and stage defer peculiarity happen because of the intensity limit and warm opposition of the fenced in area structure. The enclosure structure regulates the climate outside, and the effects of various materials and construction techniques on the thermal flow waves outside are significantly different. Three distinct thermal storage levels of the building exterior walls, namely light, medium, and heavy, were chosen in order to analyze the effect that the enclosure structure's thermal storage performance has on the load that the building experiences.

In order to compare and analyze the thermal storage performance of three different types of exterior walls with different thermal storage levels, and to control the same thermal resistance of the three types of structural exterior walls, two sets of exterior wall structures with different thermal storage levels were determined through 1-D stable heat transfer calculation of flat walls, as shown in tab. 1. At the same time, the 2-D heat transfer calculation heat bridge software PSI developed by the Chinese Academy of Building Sciences was used for verification. Set the air temperature inside the outer wall to 22 ℃, and the surface convective heat transfer coefficient to 8.9 W/m^2°C. The air temperature outside the exterior wall is 0 ℃, and the surface convective heat transfer coefficient is 24 W/m^2°C. According to software PSI calculation, when the heat transfer error of two different types of exterior walls is 0.2%, the heat transfer resistance is 4.09 and 2.28 m^2°C/W, respectively.

Table 1. Construction of exterior walls for buildings with three levels of heat storage

Group	Heat storage level	Structure	Thermal resistance [m^2°CW^{-1}]
Group 1	light	119 mm Molded polystyrene board + 210 mm aerated concrete	4.09
	Secondary	145 mm Molded polystyrene board + 210 mm hollow brick	
	Heavy quality	148 mm Molded polystyrene board + 210 mm reinforced concrete	
Group 2	Light	49 mm Molded polystyrene board + 210 mm aerated concrete	2.28
	Secondary	72 mm Molded polystyrene board + 210 mm hollow brick	
	Heavy quality	80 mm Molded polystyrene board + 210 mm reinforced concrete	

The thermophysical properties of building materials can be divided into three categories, namely:

- Basic thermophysical quantities, including specific heat, thermal conductivity, and radiation coefficient.
- Derive thermal physical quantities, including thermal storage coefficient and thermal conductivity coefficient.
- Other thermophysical quantities, including steam permeability coefficient, air permeability coefficient, and water transfer coefficient. The heat transfer equation of the building envelope structure can be expressed:

$$\frac{\partial T}{\partial \tau} = a\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) \tag{1}$$

$$a = \frac{\lambda}{c\rho} \tag{2}$$

The heat transfer control equation can be solved under certain boundary conditions and initial conditions. The enclosure structure's temperature and heat flux density are related to the material's thermal storage coefficient, *S*, and thermal resistance, *R*, when using unstable heat transfer to calculate them. This means taking into account the enclosure structure's insulation and thermal storage capabilities. The enclosure structure's temperature and heat flux density are only related to the thermal resistance, *R*, when stable heat transfer is used in the calculation. The enclosure structure's thermal storage performance is not taken into account. The warm stockpiling impact of the nook structure absolutely affects the indoor warm climate and energy utilization of the structure. However, actual buildings are subject to periodic unstable outdoor thermal effects, and the building materials that make up the enclosure structure have certain thermal storage performance. Therefore, the actual heat transfer process of the building is unstable heat transfer [7].

Experiments

Building model

The energy utilization recreation programming EnergyPlus depends on the Warm balance technique to compute the indoor air temperature and indoor burden. The intensity move estimation of the envelope embraces unsound intensity move. Taking into account the intensity stockpiling qualities of the structure, EnergyPlus is utilized for Building execution reproduction. The typical annual meteorological data (CSWD meteorological file) supplied by EnergyPlus serve as the hourly meteorological data. Choose an office building in a particular province as the subject of your research. The building is two stories tall, has two floors above ground and one below, and has a 160° north axis angle. The investigation object is a two-story room. Indoor thermal disturbance is ignored in order to accurately evaluate the impact of external wall thermal storage performance on building thermal performance and energy consumption performance.

Model and method validation

The author conducted thermal environment testing on buildings with moderate thermal storage level in Group 1, and established a numerical simulation model based on actual buildings. The numerical simulation results were compared and verified with the measured results. In order to verify the accuracy of analog verification and eliminate errors caused by human activities and other factors, the building test is conducted without internal heat sources such as personnel, lighting and equipment. The simulation also does not consider the impact of indoor thermal disturbance. The test building is located within the campus of the Provincial University of Architecture and Technology, surrounded by the teaching building of the School of Architecture on three sides: east, west, and south,. The testing is divided into outdoor and indoor parts, and the lay-out of testing instruments is based on the *Standard for Testing Methods of Building Thermal Environment*. The outdoor test parameters are outdoor air dry-bulb temperature, relative humidity, solar radiation, wind speed, and the test instrument is a small meteorological station. Indoor test parameters are indoor air dry-bulb temperature and relative humidity. The test instrument is a self recording temperature block. The testing period is from October 29 to November 12, 2021, and the testing is recorded every 30 minutes. During the test period of the simulation, the corresponding data in the original meteorological file will be replaced by the outdoor meteorological data dry-bulb temperature and solar radiation. The impact of building envelope structures on open air environment has a specific timeframe, that is to say, the indoor temperature on that day is likewise impacted by the complete impacts of earlier days. To guarantee the precision of similar investigation, November 8-11 is chosen as the exploration object. The correlation between indoor air temperature recreation and genuine estimation is displayed in fig. 2.

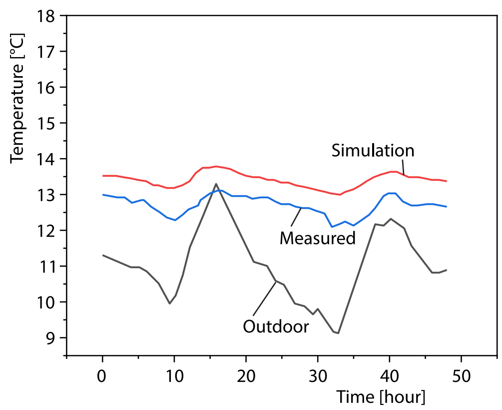

Figure 2. Comparison between simulated and measured indoor air temperature on the second floor

Without considering indoor thermal disturbance, the trend of changes in indoor air temperature between simulated and measured values is basically consistent, with no significant difference, with an average error of 0.68 °C. The simulated values are higher than the measured values, with significant relative errors between 10:10 a. m. and 14:10 p. m., indicating that some of the errors were caused by the simulation not fully considering the actual impact of external environmental obstructions and other factors. During the nighttime period without solar radiation, the simulated values higher than the measured values are caused by differences in actual testing and simulation methods. The difference between the simulated and measured values is 3.89~8.38%, with an average relative error of 5.45%. The good agreement between the two proves the accuracy of the simulation method and model [8].

Analysis of the impact of thermal storage performance on building load

The heat storage performance affects the heat transfer of the building envelope structure, which in turn affects the load of the building. The monthly load of exterior wall buildings with moderate heat storage level and the annual heat and cooling load of two groups of exterior wall rooms with different heat storage levels are shown in figs. 3 and 4, respectively.

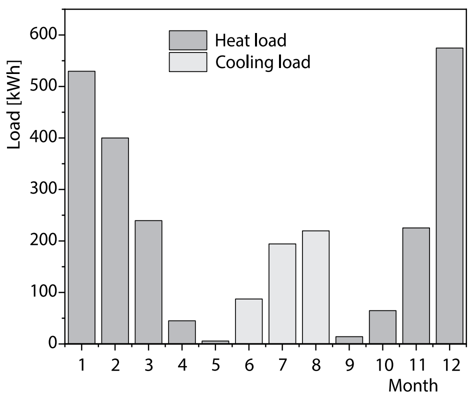

Figure 3. Monthly load of moderate heat storage buildings in Group 1

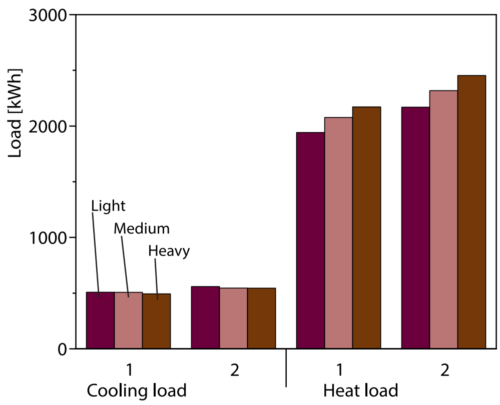

Figure 4. Cooling and heating loads of buildings with three different levels of heat storage

For cold districts, the intensity load in winter is a lot more prominent than the cooling load in summer, with a higher intensity load from November to April of the next year and a higher cooling load from July to August. For winter, the protection execution of building envelopes, for example warm opposition, fundamentally affects warm burden. Thermal resistance, or the insulation performance of building envelopes, has a significant impact on thermal load during the winter. For summer, the protection and intensity stockpiling execution of structures positively affect the cooling heap of structures. The heavy enclosure structure has a higher thermal load and a lower cooling load when the exterior wall's thermal resistance is the same. This is on the grounds that in winter, the open air temperature is moderately low, and the weighty walled in area structure stores more cool energy, ceaselessly delivering it inside, bringing about an expansion in indoor intensity load. The heat storage effect makes it difficult for heat from the outside to enter an indoor space during the summer, when the cooling load is relatively low. The warm stockpiling execution fundamentally affects the warm heap of outside walls with low warm obstruction, and a critical effect on the cooling heap of outside walls with high warm opposition. At the point when the warm opposition of the outside wall is 4.09 m^2°C/W, the warm heap of weighty outside wall structures is 92.32 kWh higher than that of medium and 222.23 kWh higher than that of light structures. At the point when the warm opposition of the outside wall is 2.28 m^2°C/W, the warm heap of weighty outside wall structures is 122.15 kWh higher than that of medium and 284.86 kWh higher than that of lightweight structures. When the exterior wall's thermal resistance is 4.09 m^2°C/W, the cold load ratio of buildings with heavy exterior walls is 7.58 kWh lower than that of buildings with lighter exterior walls and 16.05 kWh lower than that of buildings with lighter exterior walls. When the exterior wall has a thermal resistance of 2.28 m^2°C/W, the warm burden proportion of weighty outside wall structures is 7.201 kWh lower than that of lightweight structures, and 15.44 kWh lower [9].

Analysis of the impact of building heat storage combined with nighttime ventilation

The following is a comparative analysis of the impact of different ventilation rates at night on the indoor cooling load of two sets of light, medium, and heavy exterior walls with different heat storage levels. From the aforementioned analysis, it can be seen that the cooling load of buildings is relatively high from July to August, and the heat flow from indoor to outdoor during the period from 19:35 p. m. to 09:30 a. m., that is, the outdoor temperature is lower than the indoor air temperature. Therefore, the ventilation period from 21:30 p. m. to 07:30 a. m. on June 2 to August 30 is selected, the ventilation volume is 1 ach, 5 ach, 10 ach, 15 ach, 20 ach, 25 ach, and 30 ach in sequence. The influence of air changes per hour on indoor cooling load is shown in fig. 5. Analysis of the impact of building heat storage combined with nighttime ventilation on the outdoor air temperature during summer is relatively low. If appropriate ventilation can be used, the heat stored in the indoor and surrounding structures can be taken away in a timely manner, effectively reducing the indoor cooling load in summer.

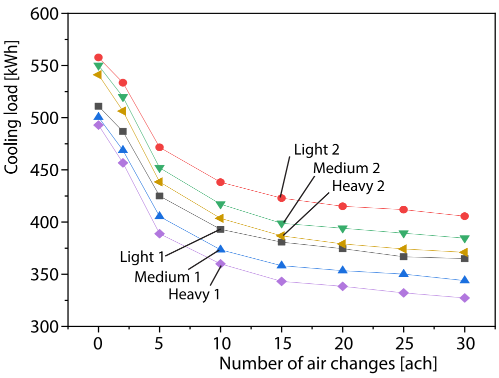

Figure 5. Influence of air changes per hour of buildings with different heat storage levels on cooling load

Under the condition of no indoor heat disturbance, the effect of nighttime ventilation in summer on the cooling load of heavy enclosure structures is relatively significant. The air changes per hour increases from 0-16 ach. When the thermal resistance of the external wall is 4.09 m^2°C/W, the cooling load of heavy external wall buildings decreases by 148.42 kWh, or 30.08%, and the cooling load of light external wall buildings decreases by 127.96 kWh, or 25.13%. When the thermal resistance of the exterior wall is 2.28 m^2°C/W, the cooling load of the heavy exterior wall building is reduced by 154.43 kWh, a decrease of 28.54%, and the cooling load of the light exterior wall building is reduced by 133.56 kWh, a decrease of 23.98%. When there is a certain heat disturbance in the room during the day, the influence of air changes per hour rate of night ventilation on the building cooling load is similar to that under the condition of no indoor heat disturbance, but the overall building cooling load increases, increasing the air changes per hour will reduce the building cooling load more significantly, especially for heavy envelope structures. With the increase of air changes per hour, the reduction of building cooling load gradually decreases. When the air changes per hour increases to 16 ach, the indoor cooling load changes little. The appropriate air changes per hour rate of building ventilation is 16 ach [10] .

Conclusions

The author used EnergyPlus software to establish a numerical model of an office building in a certain province and region. The accuracy of the numerical model was verified by comparing the measured and simulated indoor thermal environment results of the building. Using simulation methods to analyze the impact of two sets of external walls with different heat storage levels on the thermal performance of the enclosure structure and building energy consumption performance, the research results show that, are as follows.

- When the thermal resistance of the enclosure structure is the same, the inner surface temperature of the heavy enclosure structure building is higher in winter and lower in summer.
- For this area, in the absence of ventilation and with the same thermal resistance of the enclosure structure, heavy structural buildings have a higher heat load and a lower cooling load.
- The influence of nighttime ventilation on the indoor cooling load of heavy structure buildings is more significant in summer, and the appropriate air changes per hour of nighttime ventilation is 16 ach.

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