Analysis and Calculation of Heating Load for a Residential Building

Zhenpeng Bai, Hengjie Qin, Huaitao Song, Yang Zhang, Haowei Yao, Xiaohan Zhao

***Abstract*— The accuracy of heat load calculation directly affects the effectiveness of the heating system. The design specifications for Heating, Ventilation, and Air Conditioning (HVAC) building load calculations utilized the Tianzheng HVAC software (THS) load calculations and HDY-SMAD software (HSS). A 14-story residential building in Qingdao was taken as an example. The calculation of the heat load was biased and the results were compared with those calculated by the THS and HSS. The results showed that the winter load calculated was 251.3 kW by using HSS. The heat index per unit area in winter was 49.9 W/m^2. The heat index per unit area was 32.6 W/m^2 in summer.**

***Index Terms*—Heating load, Load calculation, HVAC, Building**

I. INTRODUCTION

With the implementation of energy-saving measures in China's buildings, a variety of energy-saving programs have emerged, focusing mainly on the study of heat transfer and thermal insulation properties of building envelopes, as well as the improvement of equipment and system solutions [1]. The aim is to create an optimal room thermal comfort environment under conditions of low or even zero energy consumption .

Computer simulation is one of the most cost-effective methods for predicting and analyzing building energy consumption and performance. Heat loads are essential information for selecting solar equipment, operating procedures, and system evaluation. The magnitude of the heat load directly affects the energy consumption of the heating system and is one of the most important factors that must be considered in building construction. A high building heat load results in high energy consumption. If the building has a low heat load, then the energy consumption is low.

HDY-SMAD software (HSS) is a building simulation and analysis software for HVAC. It could be used for simulation and analysis of building energy consumption and design verification of environmental control systems. And it was an important guide for improving design quality, ensuring design reliability, reducing building and system energy consumption, and ensuring the quality of the built environment.

Since the 20th century, foreign scholars have proposed many load calculation methods in air-conditioning engineering. In 1946, C.O. Mackey and L.T. Wright of the United States proposed the equivalent temperature difference method. This method used the Fourier series expansion of outdoor air temperature and solar radiation as the boundary conditions of the wall heat transfer equation to solve the heat transfer. It used the steady-state heat transfer theory to simplify the calculation to get the equivalent temperature difference, which was substituted into the steady-state heat transfer equation to simplify the calculation of loads [1].

In 1967, D.G. Stephenson and G.P. Mitalas from Canada summarized the reaction coefficient method. The central idea was to define the heat flux output value of the wall as an equal time series of triangular waves of unit isosceles temperature input as a sequence of wall reaction coefficients. The response of the wall thermal system to any outdoor perturbation could be obtained by approximating the change in the integrated outdoor temperature through the superposition of the triangular waves [2-3].

In 1971, Stephenson firstly proposed the method of calculating the instantaneous heat flux of a wall using the derivative transfer function [4]. Later, another scholar analyzed the derivative transfer function method and concluded that the most important feature of the derivative transfer function method was that its inputs and outputs were serial values at equal time intervals. Therefore, It concluded that the hourly recorded values of outdoor temperature and solar radiation intensity as inputs require essentially no preprocessing [5].

In the 1870s, Pivy discovered the correlation between the coefficients of the heat transfer function and the coefficients

Manuscript received May 29, 2023; revised January 6, 2024. This work was supported by the Natural Science Foundation of Henan Province (232300420314), the Key Scientific Research Project Plan of Colleges and Universities in Henan Province (23B560003), Doctor Scientific Research Fund of Zhengzhou University of Light Industry (2021BSJJ048), Key R&D and Promotion Special Project (Science and Technology Research) in Henan Province (232102321094), Key R&D and Promotion Special Project (Science and Technology Research) in Henan Province (232102321021), Zhengzhou University of Light Industry Science and Technology Innovation Team Support Program Project (23XNKJTD0305), Zhengzhou City Collaborative Innovation Special Project (Cultivation of Major Projects) (2021ZDPY0108), Henan Province Key R&D Special Project (231111322200), and Science and Technology Plan Project of Henan Fire Rescue Corps (2021XFYY11).

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of reaction, and arrived at the formula for deriving the heat transfer function from the coefficients of reaction [6].

At present, with the help of computer simulation methods and software such as DOE-2, DesT and Energyplus, it was possible to carry out comprehensive dynamic numerical simulation calculations of buildings under various operating conditions and parameters based on previous theories. Previous studies on tunnel fires were conducted [7-13].

In order to solve an analytical expression for the instability problem of multi-layer walls, F De Monte [14] proposed a simplified method for solving the one-dimensional unsteady problem for multistory walls. Kim Y M et al. [15] investigated the contribution of the double shell (DSE) to the heating energy efficiency due to natural ventilation in an office building. The DSE was applied to the east-facing and west-facing walls of an actual three-story building. Field measurements and computer simulations were carried out in winter. Zhu Y et al. [16] proposed an improved Trombe wall method that it saved nearly 41.3% of the heat load compared to ordinary single glazing.

Wang X et al. [17] proposed that for architectural features, the more rooms there were, the more independent the house was, and the higher the heating energy consumption. In addition, households with higher performance could reduce the electricity consumption for household heating. Liu J et al. [18] proposed various energy utilization systems, analyzed and discussed system capacity confirmation and load demand management control, proposed energy flexibility characteristics with and without energy storage, and introduced load factors to evaluate the impact of case studies on building energy flexibility.

Cai S et al. [19] modeled the system of a typical household in Shanghai and evaluated its performance in winter and summer using the 4E (energy, fire use, environmental and economic) analysis and evaluation methodology. The energy efficiency and CO_2 reduction rates of regulated and unregulated systems were compared. Zhao K et al. [20] defined and compared four typical thermal bridges based on their structure and thermal properties. A new multi-objective optimization method was proposed to determine the best construction solution for thermal bridge retrofit. It used COMSOL, a multi-physics software, to estimate the heat loss through the thermal bridge and used linear thermal transmittance.

The accuracy of the heat load calculation directly affected the effectiveness of the heating system. The use of traditional calculation methods to calculate heating load was an important foundation for the feasibility study, planning, and design of centralized heating. This paper investigated the differences in room heat loads between different heat load calculation software.

II. METHOD

A. Physical Model and Fire Scenario

A floor plan of a residential building is shown in Fig.s 1 and 2. The building was oriented from north to south and consists of 14 floors with 6 units per floor, namely F, G, H and F ', G', H '. The F, G, H and F ', G', H ' were symmetrical to each other. The floor height was 2.90 m. The building height was 40.60 m. The shape coefficient S was 0.30. The total construction area of this residential building was 7702.5 m^2.

The building was located in Qingdao, China. The longitude was 102.2 degrees East. The latitude was 36.04 degrees north.

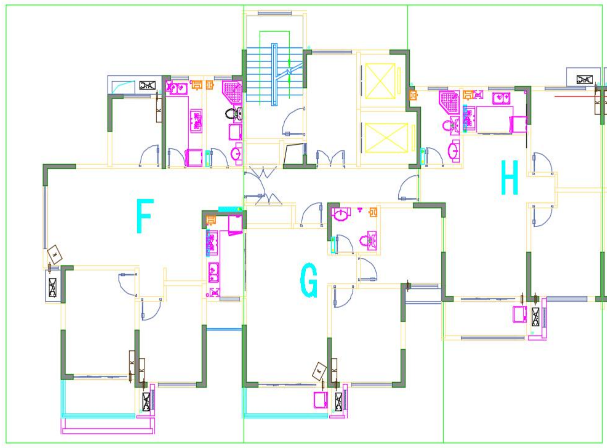

Fig. 1. Left part of a certain floor in a residential building

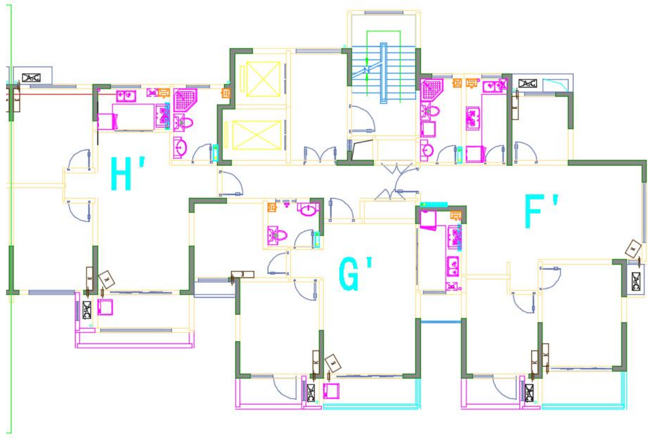

Fig. 2. Right part of a certain floor in a residential building

B. Meteorological parameters of the building location

As shown in Fig. 3, it was the dry bulb temperature in Qingdao, China. The maximum and minimum dry bulb temperatures for 12 months of the year.

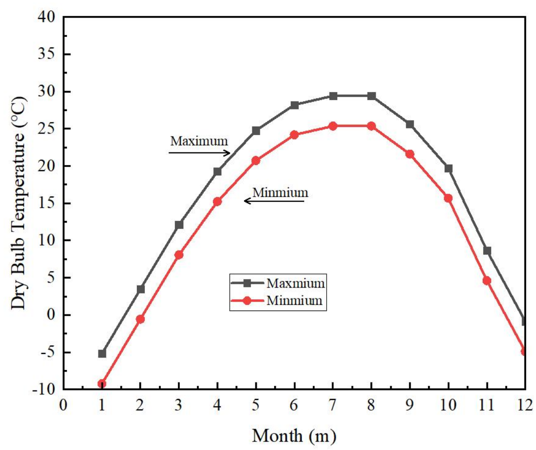

Fig. 3. Dry bulb temperature in Qingdao area of China

Meteorological data from the "Design Code for Heating, Ventilation and Air Conditioning of Civil Buildings (2012)" are used here [2]. The calculated temperature for outdoor heating was -5.0 ℃. The calculated temperature for outdoor air conditioning was -7.2 ℃. The average outdoor wind speed in winter was 5.40 m/s. The outdoor calculated relative humidity was 63.00%. The atmospheric pressure in winter was 101,740 Pa. The indoor heating temperature was 18 ℃, including the study room, the living room, the main (second) bedroom, and the bathroom. The indoor temperature of the kitchen was 15 ℃.

The heat transfer coefficient of the enclosure structure was 0.40 W/(m^2▪K). Roofing was according to the "Energy Saving Design Standard for Residential Buildings in Severe Cold and Cold Areas (JGJ26-2008) " [3]. The exterior wall heat-transfer coefficient was 0.50 W/(m^2▪K). Floor slab heat-transfer coefficient was 0.50 W/(m^2▪K). The door heat-transfer coefficient was 1.5 W/(m^2▪K). The ground heat-transfer coefficient was 1.11 W/(m^2▪K). The external window heat-transfer coefficient was 2.5 W/(m^2▪K).

C. Parameter settings for calculating operating conditions

The THS and the HSS used the same calculated outdoor temperature, the same horizontal radiation intensity, no indoor thermal interference, no indoor or outdoor ventilation. And the room temperature was set to 18 ℃. The THS used the same outdoor temperature as the HSS. The rest were the default parameter settings of the software. In HSS, the indoor convective heat transfer coefficients were all changed to 8.7. And the blackness of the enclosure surface was set to 0. When the blackness was 0, the indoor long-wave radiative heat transfer was 0. It made the convective-radiative heat transfer model of HSS and THS the same. In the HSS, it modified the solar radiation intensity in the east, south, west, and north vertical planes to be the same as the corresponding parameters in the THS [4].

D. Theory of computation

The basic heat consumption formula for the enclosure was as follows:

$$Q_j = \alpha F K(t_n - t_{wn}) \quad (1)$$

where, Q_j was basic heat consumption, W. K was heat transfer coefficient, W/(m^2▪°C). F was calculate the heat transfer area, square meters. t_n was winter indoor design temperature, °C. - t_{wn} was calculated outdoor temperature for heating, °C. α was temperature difference correction coefficient.

The additional heat consumption rate was calculated using the following equation:

$$Q = Q_j(1+\beta_{ch}+\beta_f+\beta_{lang})(1+\beta_{fg})(1+\beta_{jan}) \quad (2)$$

where, Q was the heat consumption of a certain enclosure after considering various additional factors. Q_j was the basic heat consumption of a certain enclosure. β_{ch} was orientation correction. β_f was wind correction. β_{lang} was correction of both exterior walls. β_{fg} was room height surcharge. β_{jan} was intermittent additional rate.

The calculation of cold air infiltration was as follows:

$$Q = 0.28 C_p \rho_{wn} V(t_n - t_{wn}) \quad (3)$$

where, Q was heat dissipation through cold air infiltration through doors and windows, W. C_p was constant pressure mass specific heat capacity of dry air was 1.0056kJ/(kg▪°C). ρ_{wn} was density of air under outdoor heating calculation temperature, kg/m^3. V was permeable cold air volume, m^3/h. t_n was winter indoor design temperature, °C. t_{wn} was calculated outdoor temperature for heating, °C.

The formula for calculating the cold air heat consumption when the exterior door was open as follows:

$$Q = Q_j \bullet \beta_{kq} \quad (4)$$

where, Q was heat consumption through cold air intrusion through external doors, W. Q_j was the basic heat consumption of a certain enclosure, W. β_{kq} was the additional rate of heat consumption caused by the opening of the outer door and the charging of cold air.

III. Results And Discussions

A. Typical room

Heat load was calculated and compared. The room area was 12.5 m^2. The load calculated by the THS was 777.73 W. The heat rate of cold air infiltration was 20.6 W, and the heat index per unit area was 62.02 W/m^2. The load calculated using the HSS was 780.56 W. The cold air infiltration heat rate was 20.1 W. And the heat index per unit area was 62.44 W/m^2.

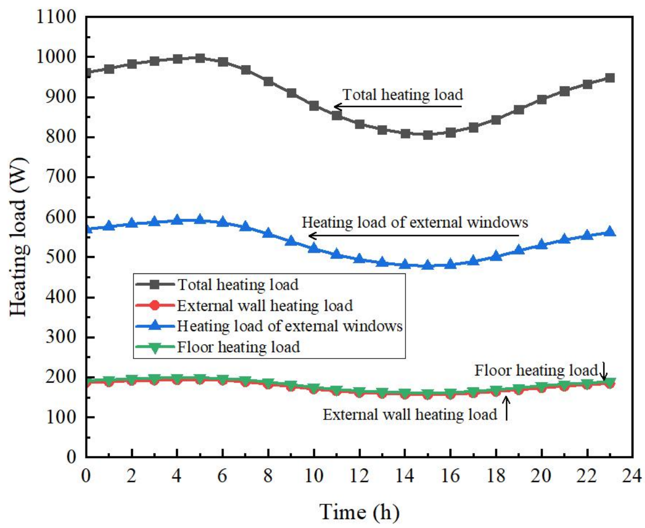

Fig. 4. Hourly data of heat load in a certain room

In Fig. 4, a typical room 1015 was selected as a representative of the heat load calculations to be analyzed and compared. Total heating load was 998 W in 5:00 a.m, and it was 806 W in 15:00 p.m. Heating load of external windows is 592 W in 5:00 a.m., and it was 195 W in 15:00 p.m. Heating load of external wall was 592 W in 5:00 a.m, and it was 157 W in 15:00 p.m. Heating load of floor was 199 W in 5:00 a.m, and it is 161 W in 15:00 p.m.

As shown in Fig. 5, it was the maximum cooling load and maximum heating load for a room throughout the year. From June to September, there was one cooling load and one heating load of 0. From October to May, there was one heating load and one cooling load of 0. The maximum cooling load for this typical room was close to 3 kW, while the maximum heating load was close to 2 kW.

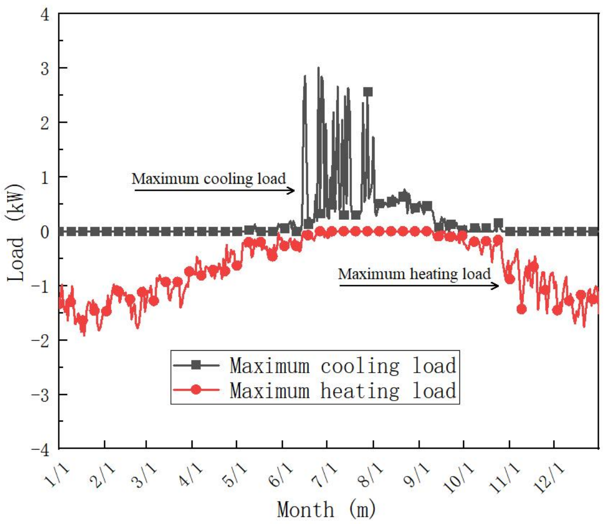

Fig. 5. Maximum cooling load and maximum heating load of a certain room

As shown in Fig. 6, it showed the maximum and minimum outdoor temperatures for a particular room throughout the year. On August 21st, the maximum outdoor temperature was 32.8 ℃. The minimum outdoor temperature was 23.1 ℃ on August 21st . The minimum temperature was -10.1 ℃ on February 22nd. The maximum temperature on February 22nd was 0.6 ℃.

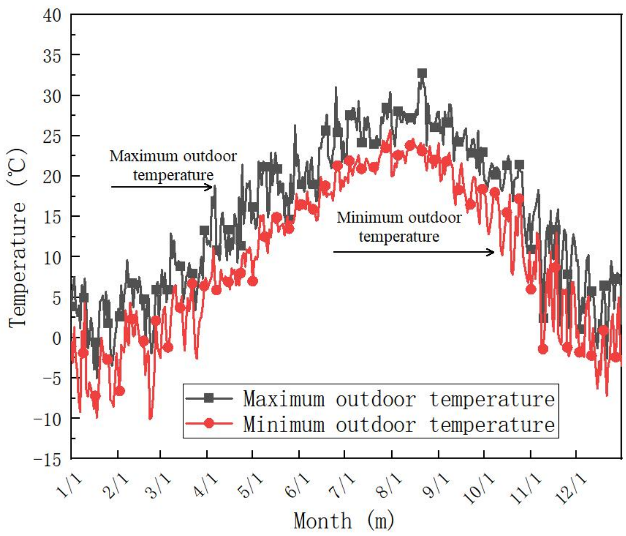

Fig. 6. The highest and lowest outdoor temperatures of a certain room

B. *Energy consumption*

As shown in Fig. 7, it was the annual cooling energy consumption of a particular room. The maximum cooling energy consumption was 9.08 kW▪h on June 25th in summer. The minimum cooling energy consumption was 0 kW▪h in winter.

As shown in Fig. 8, it was the annual heating energy consumption of a room. The maximum cooling energy consumption was 33.0 kW▪h on January 12th in winter. The minimum cooling energy consumption was 0 kW▪h in summer.

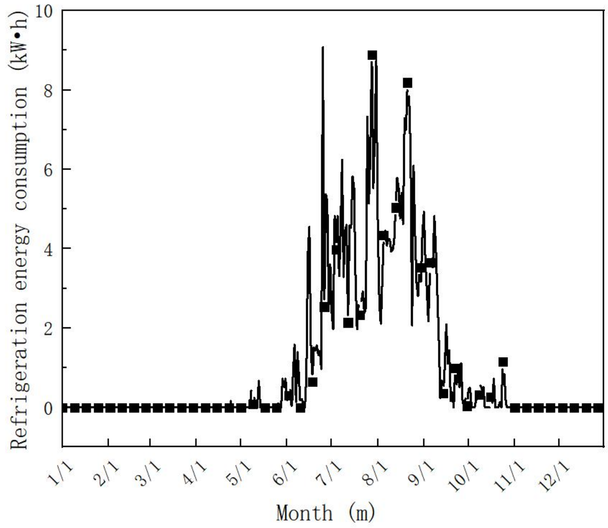

Fig. 7. Cooling energy consumption of a certain room

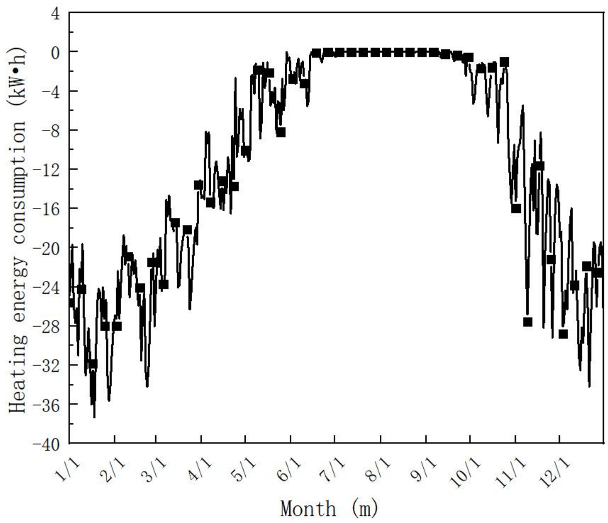

Fig. 8. Heating energy consumption of a certain room

C. *Typical floor*

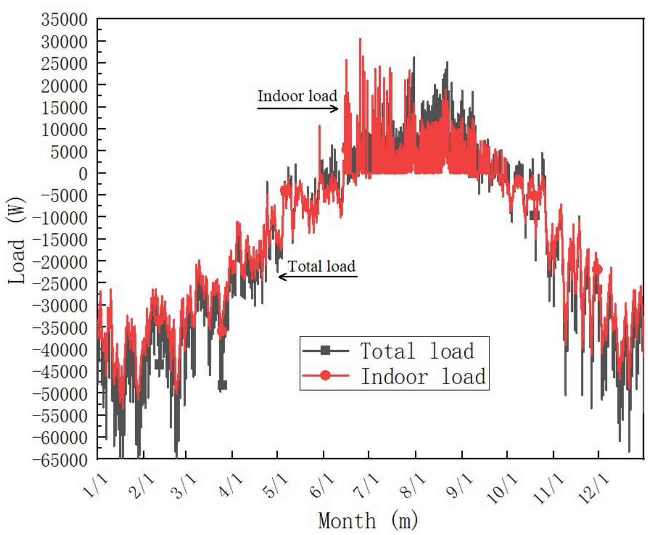

Fig. 9. Annual load diagram of a building on a certain floor

As shown in Fig. 9, it was an annual load map for a floor building. The typical maximum total heat load on the floor was 60413 W. On January 7th in winter, the typical maximum total heat load for the floor was 45623 W. On June 16th in the summer, the typical maximum total heat load on the floor was 25682 W. On June 16th in the summer, the typical maximum indoor heat load on the floor was 25682 W.

D. The entire building

As shown in Fig. 10, it was an annual load diagram for the whole building. In winter on January 16th, the maximum total heating load for the whole building was 906129 W. On the winter of January 16th, the maximum indoor heating load for the whole building was 702843 W. In summer on June 30th, the maximum total heating load for the whole building is 83326 W. In summer on June 16th, the maximum indoor heating load for the whole building was 74071 W.

The whole building was selected for heat load calculation, analysis and comparison with a heating area of 5037.5 m^2. The biggest advantage of the load calculation software was that it could calculate the load variation for 8760 hours in a year for a building. The load calculated by using THS was 245.7 kW, the heat consumption of cold air infiltration was 144.5 kW, and the heat index per unit area was 31.9 W/m^2. The load calculated by using HSS was 251.3 kW, the heat consumption of cold air infiltration was 14,501.9 W, and the heat index per unit area was 32.6 W/m^2. The two are very close to each other, and they were in line with the specified requirements and could be verified with each other.

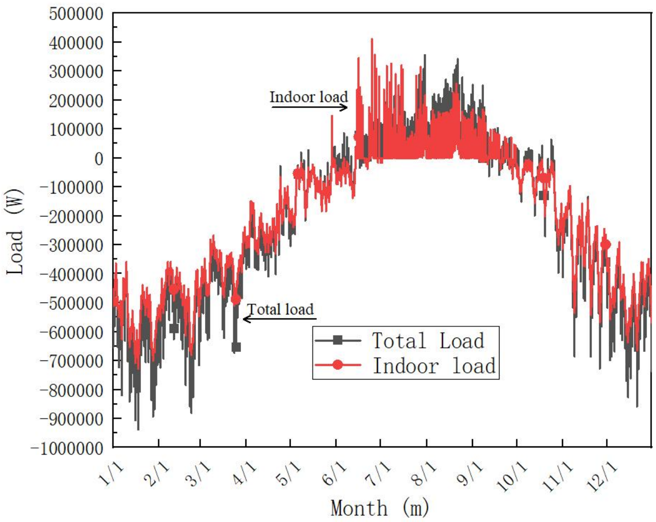

Fig. 10. Annual load diagram of the entire building

IV. Conclusions

In this paper, two types of load calculation software were used to calculate heat loads of typical rooms, floors, and entire buildings in a residential building. The results of the calculations were compared and analyzed. The main conclusions are as follows:

The load calculated using HSS for this residential building was 5.6 kW higher than the total heat load calculated using THS. The heating index was 0.7 higher, but the error was within the permissible range. It could meet the requirements of the design code. In addition, the HSS could calculate the dynamic load change of the building in one year, which provided further reference for building energy efficiency.

The heating area of the building was 5037.5 m^2. The winter load calculated by using HSS was 251.3 kW. The heat index per unit area in winter was 49.9 W/m^2. The heat consumption of cold air infiltration in summer was 14.5 kW, and the heat index per unit area was 32.6 W/m^2.

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