Application of Intelligent Reverse Regulation in Uniform Heating of Buildings

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The increase in heating building area has led to an upward trend in heating energy consumption. Using automated intelligent equipment to control the heating system has become an important development content to solve the building thermal imbalance and maintain thermal balance. Therefore, the study proposes to achieve temperature regulation through intelligent reverse in uniform heating of buildings, which calculates the energy balance coefficient based on the heat exchange process and the physical model of the heating system. In the control strategy, the focus is to discuss the effects of heating and cooling on time regulation. Subsequently, a heating automatic control system is designed to achieve deviation control and constraint cost function solving using proportional integral control and particle swarm optimization algorithm. Performance testing is conducted on the proposed adjustment method. The parameter controller reduced indoor temperature fluctuations by adjusting the flow rate. Its predicted temperature difference did not exceed 4%, and the flow consumption was relatively low. The study selected a high-rise building in the north of China as the experimental object, and installed heating systems and intelligent temperature and humidity sensors on it. The automatic control results showed that the intelligent directional adjustment mode reduced the heating volume of low floors. The average heating volume of low and high floors was 57.14% and 73.68% of the original level. The indoor temperature adjustment of vertical floors was 2℃-3℃ lower than that of manual adjustment mode. The intelligent regulation method proposed in the study can provide good reference value and significance for the energy-saving and temperature control design of heating systems in northern regions.

Povzetek: Inteligentna povratna regulacija za enakomerno ogrevanje stavb zmanjša nihanja temperature in porabo energije. Model dosega do 4 % boljše rezultate, kar predstavlja prispevek k energetsko učinkovitemu ogrevanju.

1 Introduction

With the continuous increase of construction area, the demand for building heating in northern cities and towns continues to rise. The popularity of building heating equipment ensures the living comfort of northern residents. However, existing research shows that when using traditional building heating equipment, there are problems such as uneven heating temperature and air humidity inside the building, so that the energy loss inside the building accounts for one-fifth of the overall loss. These include hot water loss and leakage, heat loss, and high heat imbalance loss in the horizontal and vertical directions of the building. The uneven heating inside the building includes the uneven internal flow of the heating pipeline and the uneven temperature of the heat source inside the pipeline. Influenced by many factors such as outdoor temperature and heating demand on building heating system, the application method of solving thermal imbalance in a single aspect has little effect. Therefore, it is necessary to start with the causes of temperature imbalance in the heating system and the problems that lead to excessive energy consumption. The design of building heating systems usually relies on predictive models to achieve their temperature control effects, but the lag of indoor and outdoor temperature differences and equipment delays are largely ignored. Therefore, it is difficult to achieve uniform heating in buildings under complex climate change [1]. Therefore, on the basis of this research, it is proposed to use intelligent reverse regulation for uniform building heating. In this study, different connection modes of heating system are used to explore the causes that affect temperature regulation, and to improve them, so as to better improve the application and effectiveness of heating system. The aim of the research is to reduce heating energy cost and waste on the basis of certain thermal comfort. The research mainly analyzes the uniform heating in buildings from four aspects. The first part is the review and discussion of the relevant literature on the current intelligent building heating and heating energy consumption. In the second part, on the basis of analyzing the differences of different heating system design forms, the intelligent commutation regulation method and the heating energy consumption prediction under the intelligent algorithm are proposed. The third part is the performance test and application analysis of the building heating condition under the heating regulation method. The last part is the summary of the full text.

2 Related work

The complexity of current building energy system makes it necessary to improve efficiency in strategy selection. Artificial intelligence algorithm shows good applicability in this field. Scholar Song J proposed an improved long and short-term memory prediction network based on space-time mixing to analyze heating systems. This hybrid model could well describe the heating load, and the absolute percentage error evaluation index was between 3%-4%, which had good thermal adaptability and application [2]. Szul, Tabor, and Pancerz (2021) used feature selection algorithm and rough set theory to design conditional variables, which had high prediction accuracy [3]. Psimopoulos et al. (2019) designed a compact heating system for an independent house to improve the wind speed limit of the original heating. This algorithm reduced the energy cost by more than 5% [4]. Aliferov et al. (2020) designed a sensor that could uniformly heat the end of the steel pipe, and used a Genetic Algorithm (GA) to design an induction heating system [5]. The control accuracy of flow control in common valve-controlled heating systems was low. Zhang, Lei, and Zhang (2019) proposed a reference predictive fuzzy adaptive control method [6]. This method could better realize the room temperature regulator. Sarbu, Mirza, and Crasmareanu (2019) conducted numerical simulation model analysis on the heating system of heat distribution network aiming at the heating problem [7]. Faced with the rapid development of home energy management, Devia, Agbossou, and Cardenas (2020) proposed a distributed co-evolutionary optimization algorithm for heating system design [8]. This system could effectively reduce cost by more than 20%. The energy consumption of residential space heating was an important part of future residential research. The differences in heating systems enabled technological innovation, strategic planning, and other means to achieve energy goals [9].

There is a close relationship between the design of building heating and cooling system and energy consumption, and strengthening the server control ability plays an important role in intelligent buildings. The artificial intelligence algorithm has a significant energy-saving effect (20%-40%) [10]. Esrafilian-Najafabadi and Haghighat (2021) proposed a multi-layer perceptron network for residential building control decision analysis, and added TOPSIS multi-criteria decision method to evaluate temperature sensitivity [11]. This prediction method could better ensure thermal adaptability. With the help of Gaussian mixture model clustering algorithm, Lu et al. (2019) better identified heating load patterns based on time and energy characteristics [12]. Duan et al. (2021) proposed an encoder-decoder model under the attention mechanism to realize temperature detection, thereby achieving long-term spatial factor state information [13]. This model had good temperature detection effects. Accurate heating load prediction plays an important role in the research of intelligent district heating. On the basis of ignoring indoor temperature in traditional prediction methods, Xue et al. (2020) used long and short term memory network to predict heating load, and built a nonlinear prediction model covering multiple factors [14]. The results showed that this method had a prediction accuracy of more than 95%. Based on the demand response problem of heat-supply connected buildings, Salo et al. (2019) proposed an optimal demand response control strategy under case algorithm simulation [15]. The results showed that this method could better achieve peak load balance and save cost. To solve the response time lag of traditional radiant floor heating systems, Chen and Li (2020) used Gaussian process regression algorithm for predictive model control [16]. The study conducted parameter simulation analysis based on various scenarios and configuration conditions. The results showed that this strategy could effectively reduce the response time and ensure better indoor temperature comfort. Vand et al. (2019) proposed a demand response adjustment algorithm under real-time pricing to achieve temperature adjustable settings [17]. Experiments were conducted with the help of dynamic building simulation tools. This method could effectively reduce heating energy consumption and cost. A summary of previous research on building energy consumption and heating related work is presented in Table 1.

Table 1: Summary of building energy consumption and heating related work

Scholar	Methodology	Key results	Limitations
Song et al. [2]	Analyzed heating systems using an improved spatiotemporal mixed long short-term memory prediction network	The absolute error evaluation index of heat load is between 3% and 4%	The prediction network may have generalization issues due to the influence of training data
Szul, Tabor, and Pancerz [3]	Feature selection algorithm and rough set theory for designing energy-saving variable conditions in	High accuracy in predicting building energy consumption after thermal	Affected by changes in conditional variables

	buildings	renovation	
Psimopoulos et al. [4]	Designed a compact heating system	Reduce user energy costs by over 5%	Restricted algorithm applicability
Aliferov et al. [5]	Designed sensors for uniformly heating the end of steel pipes and solved the heating system using genetic algorithm	The control accuracy of flow control in ordinary valve-controlled heating systems is relatively low	Resource and time consumption issues, and uniform heating design cannot adapt to extreme conditions
Zhang, Lei, and Zhang [6]	Design of flow control for valve-controlled heating system using fuzzy adaptive control method	Significant room temperature regulation effect	Unable to cope with the randomness of traffic fluctuations
Sarbu, Mirza, and Crasmareanu [7]	Application of numerical simulation models and deterministic heuristic optimization techniques to regional heating system distribution networks	This method can better consider the influencing factors of system model objectives	Affected by various operating conditions
Devia, Agbossou, and Cardenas [8]	Numerical simulation of heating network distribution in heating systems	This system can effectively reduce costs by more than 20%	Affected by various operating conditions
Ioakimidis [10]	Introduced artificial intelligence algorithms into intelligent buildings	/	/
Esrafilian-Najafabadi and Haghighat [11]	Analysis of residential buildings using multi-layer perceptron networks and TOPSIS multi-criteria decision methods	This method can achieve good thermal adaptability	Unable to consider all possible diversity and complexity in decision-making problems
Lu et al. [12]	Gaussian mixture model clustering algorithm for identifying heat load patterns	High precision pattern recognition based on time and energy characteristics	The accuracy of load pattern recognition is influenced by the quality and representativeness of input data
Duan et al. [13]	Combined attention mechanism and long short-term memory network to detect temperature models	Good temperature detection performance	The parameter sensitivity characteristics of attention mechanism are more pronounced
Xue et al. [14]	Established nonlinear prediction model for building heat load using long short term memory network	Prediction accuracy exceeds 95%	Poor performance in handling nonlinear problems
Salo et al. [15]	Optimal demand response control strategy for heating connection buildings in case simulation	This method achieves better peak load balancing and saves costs	Over-fitting risk
Chen and Li [16]	Predictive control of traditional floor radiant heating systems using Gaussian process regression algorithm	This method can effectively shorten response time and ensure better indoor temperature comfort	The case algorithms are difficult to ensure comprehensiveness
Vand et al. [17]	Demand response adjustment algorithm under real-time pricing	This method can effectively reduce heating energy consumption and costs	May ignore environmental changes and conditions

In the past, scholars mostly used numerical simulation methods, fuzzy control methods, intelligent algorithms, etc. to study the heating flow rate, load mode, and energy consumption of intelligent heating buildings. Although they have shown good application effects, they ignore the time delay characteristics of internal heating in buildings, and the automatic temperature control effect is poor. Most of the design ideas for some heating systems are limited to specific types and have limited applicability for promotion. Therefore, this study proposes a uniform heating system with intelligent directional regulation. It is designed from the heating system parameter identification and prediction model design. This research method can better consider the differences in heating characteristics of buildings themselves, and improve the automation and intelligence of building heating.

3 Design of uniform building heating system under intelligent reverse regulation

The uneven heat distribution in different heating systems is more prominent, and there is a certain imbalance in building heating heat. Therefore, by analyzing different heating systems, the analysis and identification of energy balance parameters and switching time are proposed. The control method is combined with intelligent methods to achieve predictive analysis of building heating energy consumption [18-19].

3.1 Uniform temperature design of buildings under intelligent reverse regulation

The uniform temperature heating system of the building is to transmit the low-temperature heat carrier to the heat source after being heated, and then to the user through the heating pipe. At the same time, the heat carrier that has been dissipated is transported back to the circulation system at the heat source. Hot water is generally used as heat carrier in civil buildings. Steam is generally used as a heat carrier in industrial buildings. Generally, there are generally three ways to achieve uniform temperature heating: parallel, series, and series-parallel coupling. The parallel building heating system can better solve the uneven building heating, and its specific transmission principle is shown in Figure 1.

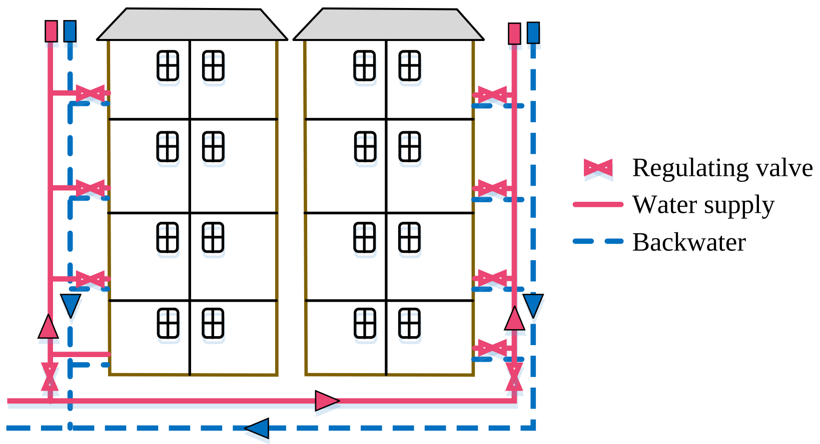
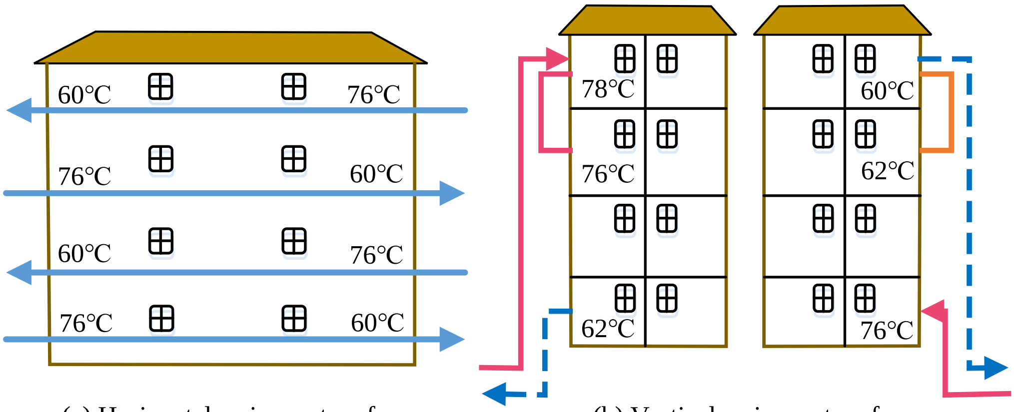


Figure 1: Schematic diagram of parallel system for uniform heating

In Figure 1, hot water from the heat source is distributed to different tributaries, and the flow is controlled by valves to ensure uniform heat transfer. In the upward transmission process, the hot water flow of each layer is controlled to ensure that the upper and lower temperatures are uniform. Finally, the cooled water is returned to the heat source for recycling. In the series heating system, the horizontal single-pipe system ensures a relatively constant temperature between users on the same floor by adjusting the water supply and return time for each floor (Figure 2). The vertical single-pipe system mainly solves the uneven heat dissipation at the upper and lower heat dissipation ends by changing the direction of water supply and return (Figure 2(b)).



(a) Horizontal series system for uniform heating

(b) Vertical series system for uniform heating

Figure 2: Schematic diagram of a uniform heating series system

For indoor temperature control, temperature adjustment can be achieved better by installing reverse device to make the water supply and return directions opposite. During the heating system cycle, the heat Q_g obtained by the heat dissipation terminal equipment transmitted to each household is shown in Equation (1).

$$Q_g = \rho CG(T_1 - T_2) \quad (1)$$

In Equation (1), ρ is the water density. C is the specific heat capacity of water. G is the volume flow of water. T_1 is the water temperature from the heat source. T_2 is the cooled water temperature. Since the heat loss in the transport process is negligible, the approximate indoor temperature can be calculated according to the energy conservation law. On this basis, according to the calculation results, the heat supply is adjusted to ensure that the indoor temperature of the building is relatively constant. Assuming that the indoor temperature is T_n, the indoor heat Q_n is shown in Equation (2).

$$Q_n = B(T_1 + T_2 - 2T_n) = \rho CG(T_1 - T_2) = Q_g \quad (2)$$

In Equation (2), B is the energy balance coefficient. When transferred energy is not balanced, the corresponding energy of the room temperature T_N is Q_N. If $Q_N > Q_g$, the room temperature is higher than the predetermined value. If $Q_N < Q_g$, it means that the room temperature has not reached the predetermined value. The system regulates the flow rate by setting the energy balance coefficient B to ensure a constant indoor temperature. In the parallel heat exchanger uniform heating system, it is necessary to determine the energy balance coefficient B. When building the physical model, considering the diversity of internal floors and the thermal conductivity of different materials, various materials will be set up to verify the stability of the equilibrium coefficient. The specific physical model is shown in Figure 3.

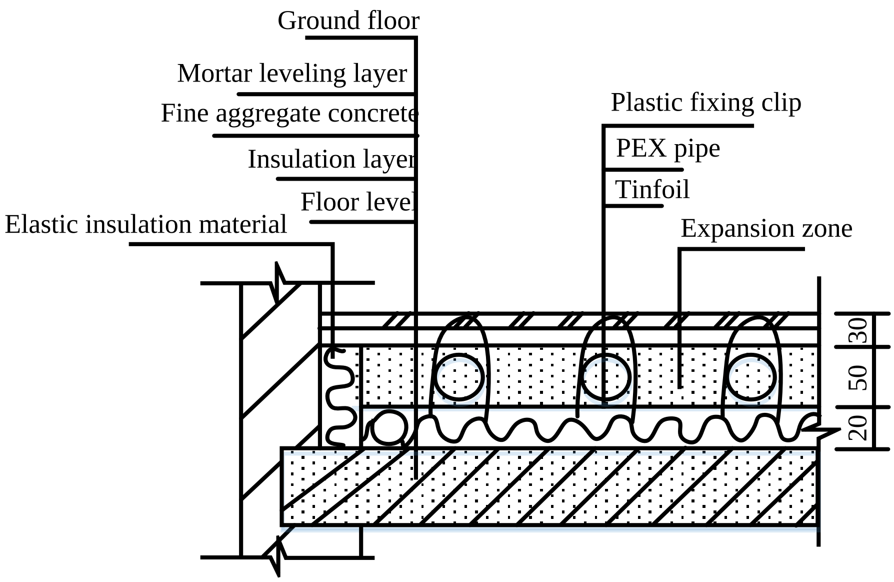


Figure 3: Physical model of series heating system

The surface temperature of the floor layer in the Figure is difficult to be directly related to the indoor temperature because of the coverage of the heat dissipation tube. The whole process can be completed indirectly through the convection heat transfer inside the heat transmission pipe, the heat conduction between the pipe wall and the adjacent floor layer, and the radiation heat transfer of other objects in the room. Therefore, there is a certain heat transfer delay. Based on the heat transfer process, a mathematical model is constructed to calculate the total thermal resistance of the heat source through the floor. Equation (3) displays the final energy balance coefficient B.

$$B = \frac{1}{2R} \tag{3}$$

In Equation (3), R represents the total thermal resistance. It includes the thermal resistance R_1 of convective heat transfer in the tube. The specific equation is shown in Equation (4).

$$R_1 = \frac{1}{h_p A_p} \tag{4}$$

In Equation (4), h_p is the convective heat transfer coefficient between the heat source and the transfer pipeline. A_p denotes the internal surface area of the pipeline. Equation (5) is obtained according to Gnielinski equation and Filonenko equation.

$$R_1 = \frac{8 + 35.92(1.82\lg \mathrm{Re}_f - 1.64)^{-1}(\mathrm{Pr}_f{}^{2/3} - 1)}{(1.82\lg \mathrm{Re}_f - 1.64)^{-2}(\mathrm{Re}_f - 1000)\,\mathrm{Pr}_f\,\lambda_1} A_p \tag{5}$$

In Equation (5), Re is Reynold's coefficient, which is the criterion for judging the fluid flow state. f is the Darcy resistance coefficient of turbulent flow in the pipe. Pr_f is the damping factor of the liquid at the average temperature in the inlet and outlet of the pipeline. λ_1 denotes thermal conductivity corresponding to different materials of the floor layer. The total thermal resistance also includes the thermal resistance of tube wall heat conduction R_2, as shown in Equation (6).

$$R_2 = \frac{\sigma_p}{A_2 \lambda_p} \tag{6}$$

In Equation (6), σ_p is the wall thickness of the tube. A_2 is the surface area of the tube wall. λ_p is the thermal conductivity of the tube wall. In addition, the total thermal resistance also includes the thermal conductivity resistance R_3 of the floor layer and the comprehensive thermal resistance R_4 of the floor heat dissipation surface, as shown in Equation (7).

$$R_3 = \frac{\sigma_i}{A_3 \lambda_i} \tag{7}$$

In Equation (7), σ_i is the thickness corresponding to different floor materials. A_3 is the surface area of the floor. The comprehensive thermal resistance R_4 of the floor heat dissipation surface is calculated in Equation (8).

$$R_4 = \frac{1}{h_c A_3} \tag{8}$$

In Equation (8), h_c is the heat transfer coefficient of the ground surface inside the building. Due to radiation differences in building materials and shapes, temperature distribution is uneven. Therefore, according to previous studies, the mathematical model of Equation (9) is proposed to calculate the radiation heat transfer Q_f inside the building.

$$Q_f = 4.98\left[\left(\frac{T_{pj} + 273}{100}\right)^4 - \left(\frac{T_{s,f} + 273}{100}\right)^4\right] \tag{9}$$

In Equation (9), T_{pj} is the average temperature of the heat dissipation surface. $T_{s,f}$ is the average temperature of a non-radiating surface. When the indoor temperature is constant, it can be seen from Equation (13) that the radiant heat transfer is related to the floor surface temperature. In the actual heating process, the average temperature of the floor surface layer is generally about 25°C within the average supply and return water temperature. Therefore, the comprehensive heat transfer coefficient can be designed, and its mathematical expression is shown in Equation (10).

$$h_c = \frac{q_c}{T_t - T_n} \tag{10}$$

In Equation (10), T_n represents the room temperature. q_c is the comprehensive heat exchange. T_f is the average surface temperature. The thermal conductivity resistance of the northern low-temperature floor radiant heating system is mainly composed of R_3 and R_4. Compared with the former, the values of R_1 and R_2 differ by more than two orders of magnitude. Therefore, the energy balance coefficient B is shown in Equation (11).

$$B = \frac{1}{2(R_3 + R_4)} \tag{11}$$

The energy balance coefficient B per square meter inside the building will be derived from B_m. Then, the relationship between the flow in the heating pipe and the energy balance coefficient B is determined by changing the flow value in the heating pipe. The experimental design is carried out under different working conditions.

3.2 Predictive control analysis of building heating energy consumption under intelligent

reverse regulation

Considering the delay of the indoor heating system in buildings, the time adjustment of heating and cooling variables should be explored when the control strategy is designed. In the series heating system, the heat transfer model of parallel and vertical single pipe systems is shown in Equation (12).

$$K = \alpha \Delta t^{\beta} \tag{12}$$

In Equation (12), K is the heat transmitted by the radiator. α and β are radiator coefficients. Δt is the temperature obtained by subtracting room temperature from the average supply and return water temperatures. The water supply temperature is t_s, the return water temperature is t_r, and the heat allocated to each household is Q_1, Q_2,..., Q_{N-1}, Q_N. The water supply and return temperature of each household in the horizontal and vertical directions can be expressed, as shown in Figure 4.

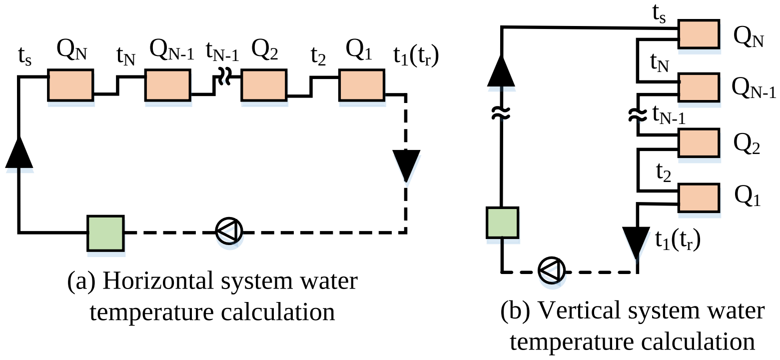


Figure 4: Schematic diagram of heating system with series heat exchanger

In Figure 4, if the heat loss in the pipeline transmission process is ignored, the total heat load of a vertical single pipe can be expressed as Equation (13).

$$\sum_{i=1}^{N} Q_i = Q_1 + Q_2 + \cdots + Q_{N-1} + Q_N \tag{13}$$

In Equation (13), Q_i represents the heat load of the i layer radiator. According to the balance relationship between indoor and outdoor heat in the heating system, the outlet water temperature t_j of each radiator can be obtained, as shown in Equation (14).

$$t_j = t_s - \frac{\sum_{i=j}^{N} Q_i}{\sum_{i=1}^{N} Q_i}(t_s - t_r) \tag{14}$$

In Equation (14), t_s is the water supply temperature. t_r is the return water temperature. In the heating process, the heat from the source end of hot water is continuously lost during the supply process to users, which leads to uneven heating at both ends of the building. In the cascade system, the heat imbalance is alleviated by changing the flow direction, which often ignores the heat loss caused by the mixed water in the pipe and the thermal inertia of the building. Therefore, by changing the ratio of forward time and reverse time, that is, the commutation time ratio Ra, the corresponding forward and reverse heating cycle is adjusted to ensure that the whole building achieves a relative temperature constant state. In the vertical series single-pipe heating system, the commutation time ratio of each floor is calculated, as shown in Equation (15).

$$Ra_i = \frac{a_i}{b_i} \tag{15}$$

In Equation (15), i represents layer i. a_i represents the thermal cycle time of each layer in the up-supply and down-cycle mode. b_i denotes the heat cycle time of each layer in the down-feed up-return mode. The commutation time ratio is related to the commutation time and the misalignment of the system. Temperature, heat dissipation area and flow rate all affect this variable. During the experiment, it should be taken into account that the heat and load conditions located in the middle floor under the two heating systems are similar, so the value should be excluded to reduce the experimental error. In the design scheme, the research combines the water system and the electric system to form a floor radiant heating system with air source heat pump inside the building. The internal structure is shown in Figure 5. Among them, the water system includes air source heat pump, flow meter, thermometer, etc. The electric system is composed of electric regulating valve and air source heat pump unit.

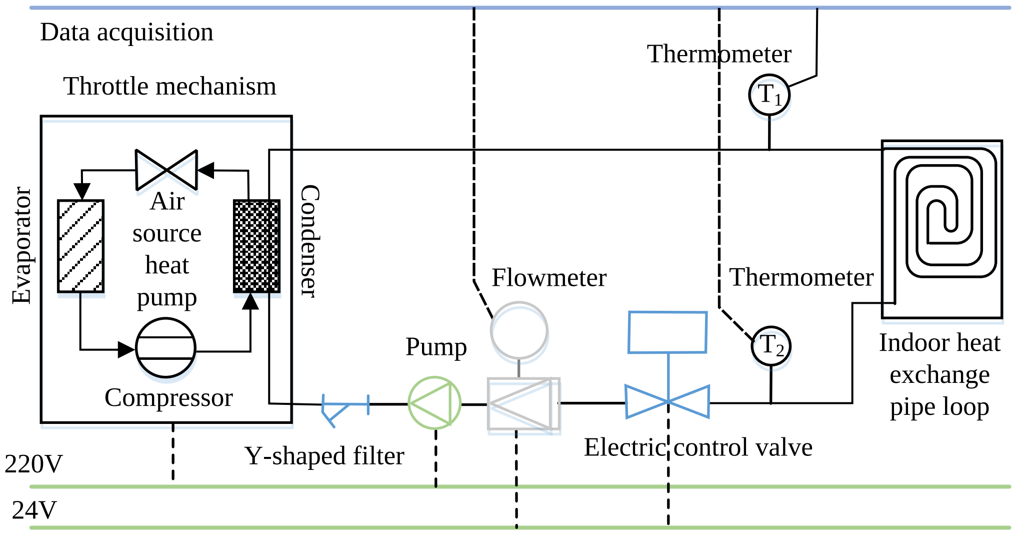


Figure 5: Air source heat pump floor radiation heating system

In Figure 5, the heating system can obtain low temperature heat source by air energy storage, and form high temperature heat source through system heat collection and integration, thus providing heating. The heat balance is maintained by adjusting coefficient and commutation time ratio in series and parallel to achieve uniform heating effect. In addition, this study also designs a heating automatic control system to collect information and complete valve control under flow regulation. The adjusting hardware system includes temperature sensor, single chip microcomputer and connection system. In the part of connection system design, the system control of energy balance method is studied. The traditional Proportional Integral-Differential (PID) controller will inevitably lead to deviation signal after factor stabilization and system adjustment. Therefore, the research uses Proportional Integral (PI) control to design the system. The PI control module adjusts the valve position to achieve the output value. In addition, it maintains the circulation flow in the system to the required flow value. No matter how the external pipeline network changes, increasing or decreasing flow, PI control only requires fewer parameter variables to effectively avoid oscillation situations. When the input deviation step occurs, the proportional part of PI control acts in a timely manner, first performing coarse tuning to suppress the influence of disturbances. Then, the integration adjustment effect gradually accumulates and enhances, and fine adjustments are made to gradually eliminate residual errors. This control method can effectively ensure the rapid response and steady-state accuracy of building heating problems, which is suitable for heating systems with rapid dynamic changes. When the room temperature, temperature deviation and circulation flow are set, the four-way valve opening can be calculated by PI control, and then intelligent adjustment can be achieved. The output result of the controller is shown in Equation (16).

$$u(t) = K_p\left[e(t) + T_d\frac{de(t)}{dt} + \frac{1}{T_i}\int e(t)dt\right] \quad (16)$$

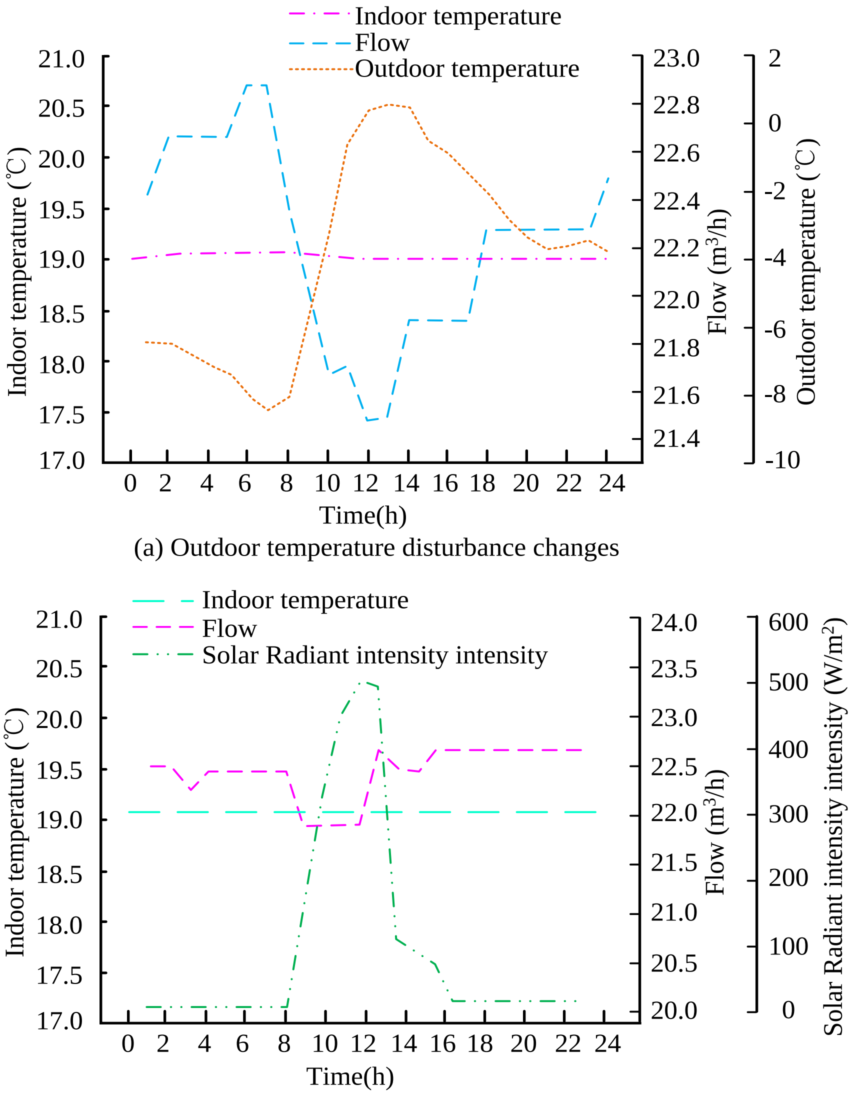
In Equation (16), t represents the set temperature. $e(t)$ indicates input deviation. K_p is a proportional factor. T_i is the integral time constant. T_d is the differential time constant. Particle Swarm Optimization (PSO) is used to solve the constrained cost function in predictive control. As an intelligent algorithm to simulate predation behavior, PSO achieves the optimal solution through fitness update and algorithm iteration. The PSO is applied to the intelligent regulation of building heating to find the optimal value at the corresponding time and avoid sudden changes in system flow during the temperature regulation process. The PSO has strong global search ability, which can effectively search for the global optimal solution in the solution space. It has significant advantages for multi-variable and multi-constraint optimization problems in building heating systems. Compared with other optimization algorithms such as GA and simulated annealing, the concept of PSO is simple, easy to program and implement, with less parameter adjustment, which reduces the difficulty of algorithm implementation. This algorithm can be adjusted according to specific heating systems and needs, adapting to different constraint conditions and cost functions, which has good adaptability and parallel processing ability. The mathematical expression of the fitness function is shown in Equation (17).

$$\begin{gathered} J = Min\left\{\left[q(T_{seti} - T_i\right]^2 + (r \cdot dG)^2\right\} \\ (G_{\min} < G < G_{\max}) \end{gathered} \quad (17)$$

In Equation (17), q represents the weight coefficient affecting the response speed of the control system. r represents the weight factor affecting the stability of the control system. T_{seti} indicates the set temperature. T_i indicates the room temperature. G, dG are the flow rate and the flow increment. G_{max}, G_{min} and G_{max}, G_{min} indicate the maximum and minimum values of the set flow. The control device designed by PI has less control, and its connection with the sensor can better control the temperature, the difference of water supply and return pressure, and the valve operation.

4 Application effect of uniform building heating under the regulation method

The thermal comfort inside the building is an important index to ensure the residential comfort. The heating system under intelligent reverse regulation is designed through the system program design to achieve uniform heating effect. Firstly, the performance of the proposed regulation method is tested, including the change of energy consumption and uniform heating. The hardware equipment involved in the research mainly includes intelligent heating equipment (valves, four-way directional valves, ultrasonic flow meters, and temperature sensors). The temperature sensors is mainly installed on the water supply and return pipelines in the hot well. The study uses MATLAB software to calculate the actual operating data of the building heating system, with a data sampling interval of 1 hour. A total of 24 data points are collected within a day and combined with the corresponding meteorological temperature at that time. The collected normal operation data of the heating system is used as training and testing data for predicting the heating load of the heating system. The design parameters of heating data include primary return water temperature, instantaneous load, primary supply and return water flow rate, and cumulative load. After that, the identification results of changed energy balance coefficient and commutation time ratio are analyzed, and then the parameter sensitivity under the model predictive control is analyzed. The result is shown in Figure 6.



(a) Outdoor temperature disturbance changes

(b) Disturbance changes in solar radiation

Figure 6: Parameters under the change of outdoor temperature and solar radiant intensity

In Figure 6, there is a negative correlation between the variation curve of system flow and outdoor temperature. When the temperature difference is larger, the heat loss rate is accelerated, and the parameter controller can adjust the flow rate according to the change. The solar radiation intensity from 7:00 to 18:00 first increased and then decreased. The controller can better adjust the flow rate to achieve indoor temperature regulation. Then, the temperature regulation effect of the proposed predictive control method is analyzed, and the results are shown in Figure 7.

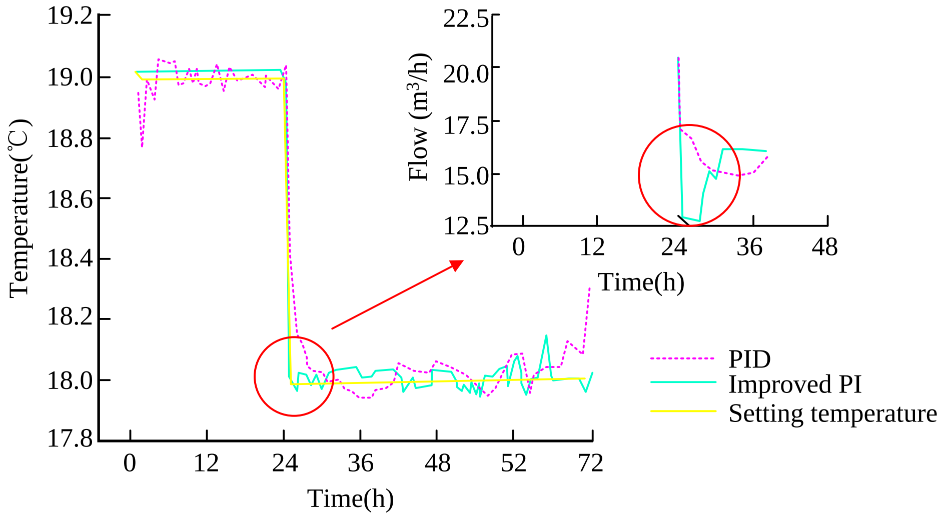
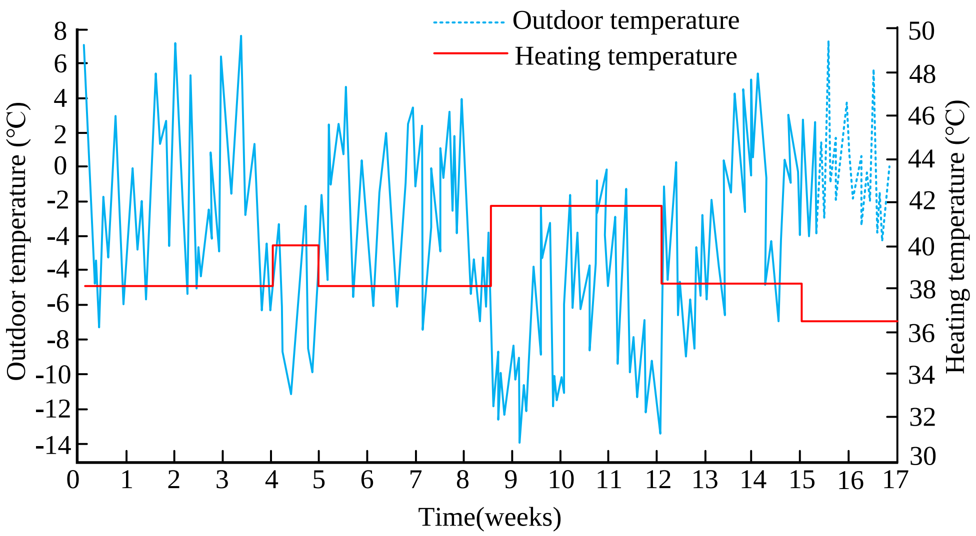


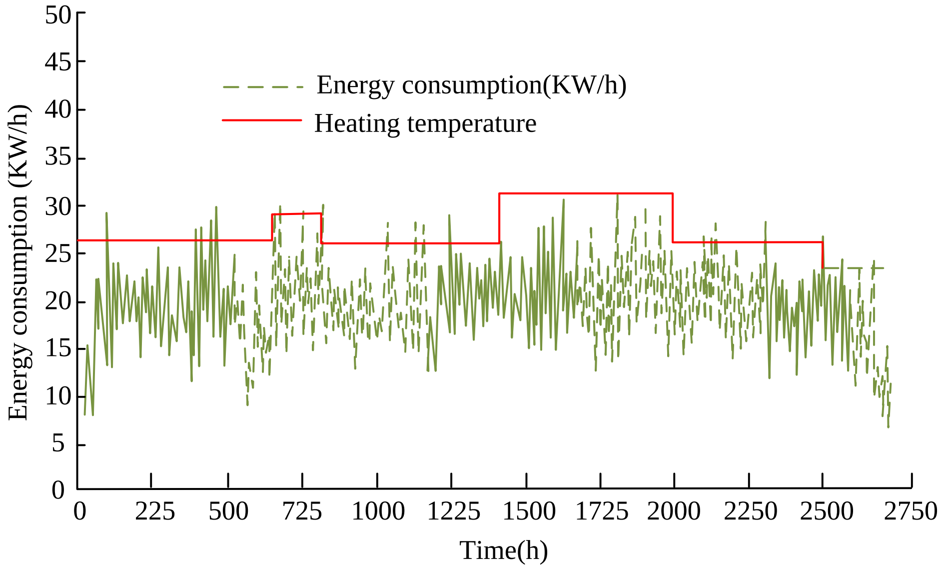
Figure 7: Adjustment effects of different methods at set temperatures

In Figure 7, the predictive control method adopted in the study showed a lower temperature difference with the limited temperature. The maximum temperature difference between 0-24 hours and 24-72 hours was 1.25% and 3.24%. However, the difference between the traditional PID algorithm and the limit temperature varied greatly, and the maximum error reached 7.38%. The improved PI algorithm had lower traffic consumption than PID algorithm under the flow variation. When the time was 27 hours, the flow rate was 12.6m3/h, which had a good response time and anti-interference.

In Figure 8, when the outdoor temperature fluctuated greatly and had obvious node fluctuation, the water supply temperature of the heating system was always kept between 36°C and 42°C. The overall change appeared stages, the volatility was small. The proposed heating system had obvious low energy consumption. Then, the indoor temperature and water supply temperature of the heating system proposed in the study are analyzed, and the results are shown in Figure 8.



(a) Water temperature variation under heating system



(b) Energy consumption under heating system

Figure 8: Water temperature change and energy consumption in hydronics

In Figure 8, the outdoor temperature was higher than the indoor temperature on the whole, and its fluctuation was relatively large. Under different solar radiation intensity, the overall temperature change of the heating system was relatively small when the temperature was adjusted. The prediction method proposed in the study is analyzed, and the results are shown in the Figure 9.

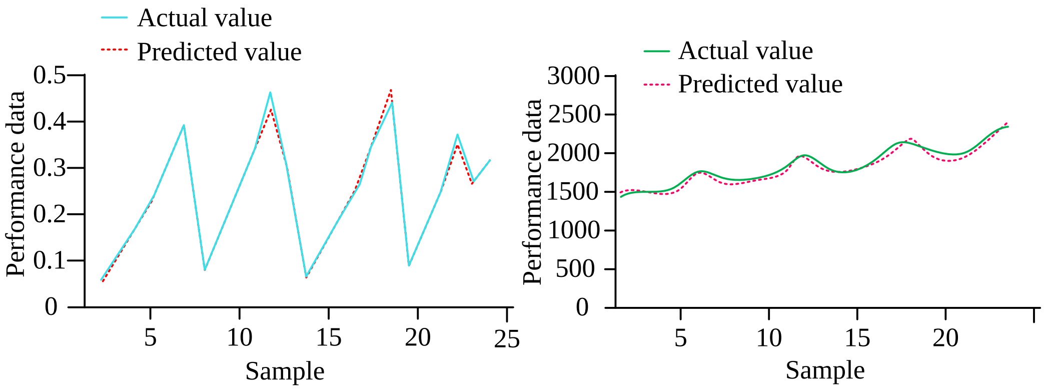


Figure 9: Predicted values for temperature measurement and energy consumption analysis

From Figure 9, the prediction method proposed in the study showed that the predicted result curve was basically consistent with the actual result curve during temperature measurement and energy consumption analysis, with an overall small deviation. Therefore, the method proposed in the study can effectively monitor changing temperatures, which is highly feasible. The heat load of the building heating system is analyzed and compared with algorithms such as Back Propagation Neural Network (BPNN), GA, and extreme vector machine. The Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE) are shown in the Table 2.

Table 2: Heating system heat load calculation

Algorithm	Mean absolute error	Mean squared error	Root mean square error	Mean absolute percentage error/%
BPNN	0.532	0.415	0.637	1.543
GA	0.643	0.463	0.596	1.261
Extreme vector machine	0.579	0.377	0.584	1.126

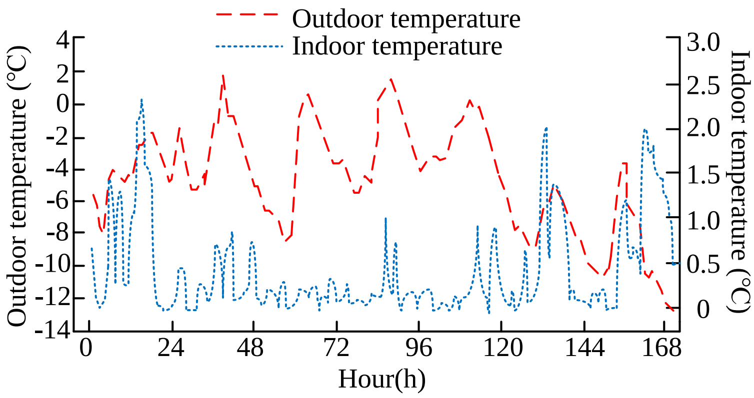
Research algorithm	0.376	0.205	0.432	0.817

The results in Table 2 indicated that the proposed prediction method exhibited lower error results, with significantly lower values than other comparative algorithms in MAE (0.376), MSE (0.205), RMSE (0.432), and MAPE (0.817) metrics. Among them, the GA exceeded 0.6 in all four indicators, with a maximum value of 1.453. The above results indicate that the prediction method proposed in the study can effectively analyze the thermal load conditions of buildings. The thickness of the external wall and roof insulation layer is replaced by the external wall heat transfer coefficient and the roof heat transfer coefficient, respectively. The external window is replaced by its corresponding heat transfer coefficient and solar thermal gain coefficient. The processed data is subjected to multiple regression analysis, as shown in Table 3.

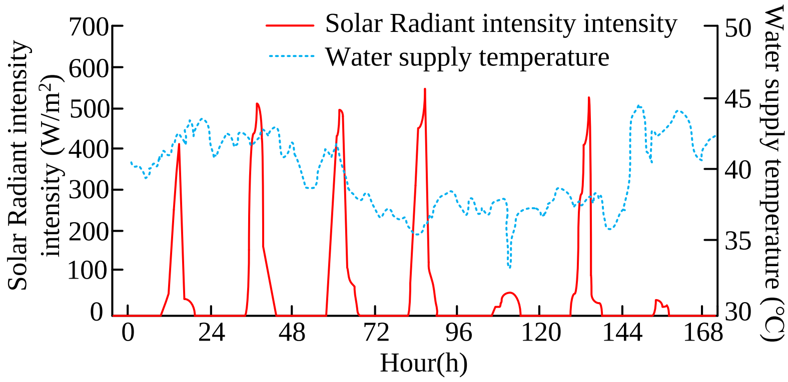
Table 3: Multiple regression results

Variable	Standard error	t	Sig
Aspect ratio	0.135	4.032	0.000
Facing	0.253	10.261	0.000
External window heat transfer coefficient	0.002	17.134	0.000
The external wall receives sparse heat from the sun	0.072	-8.564	0.000
External wall heat transfer coefficient	0.431	14.302	0.000
Roof heat transfer coefficient	0.396	21.365	0.000

The variables in Table 3 all had obvious significance. The fitting effect was good when the table was adjusted and calculated. The above results indicate that the proposed method has good effectiveness. Then, a high-rise building in the north is selected as the experimental object. The building covers an area of more than 8,000m2, with a total of 20 floors (including one underground). The building load ranges from 190 to 210KW. The heating system of the building is low temperature floor radiant heating system, according to the low zone and high zone heating. In this study, six households in two districts are selected to install water supply and return temperature measurement points and heating equipment. The heating system is placed in the pipeline well in the form of household installation. At the same time, in order to ensure the normal heating demand under the adjustment effect, a smart temperature and humidity sensor is installed in the user's home to observe the temperature change. In the results of building intelligent management, the test is carried out in two forms: manual control and automatic control. The test time is the end of the heating time in the area (about 120 days). The application results of the heating system are shown in Figure 10.

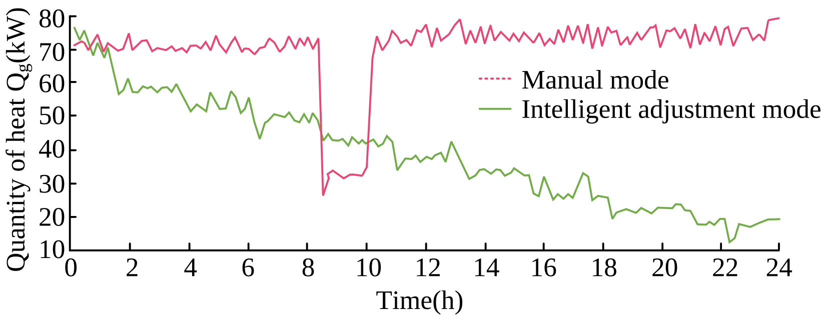


(a) Outdoor temperature and indoor temperature changes

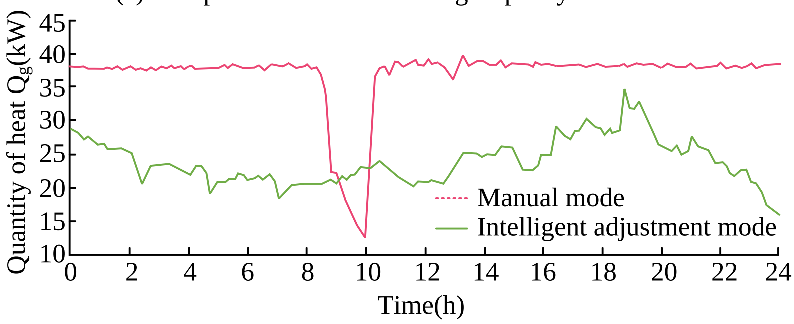


(b) Change of water supply temperature under Radiant intensity intensity

Figure 10 Indoor and outdoor temperature changes



(a) Comparison Chart of Heating Capacity in Low Area



(b) Comparison Chart of Heating Capacity in High Area

Figure 11: Changes in heating capacity of two zones under different modes

In Figure 11, the heat supply of high floors was obviously less than that of low floors. Under manual control mode, the heat supply of low and high floors was basically maintained between 70kW and 80kW and between 35kW and 40kW. Under the intelligent reverse regulation mode, the overall heat supply of the low floor showed a decreasing trend from 80kW to 10kW. The heating capacity of high floors was basically maintained between 20kW and 35kW. Whether on high or low floors, the intelligent reverse adjustment mode saved heating for over 80% of the time. After the improvement, the average heating capacity of the lower and upper floors was 40kW and 28kW, which was 57.14% and 73.68% of the energy consumption before the improvement, effectively realizing the indoor temperature control in the state of energy saving. Then, the change of the room temperature inside the building under the two heating modes is statistically analyzed. The average temperature change is expressed, as shown in Figure 12.

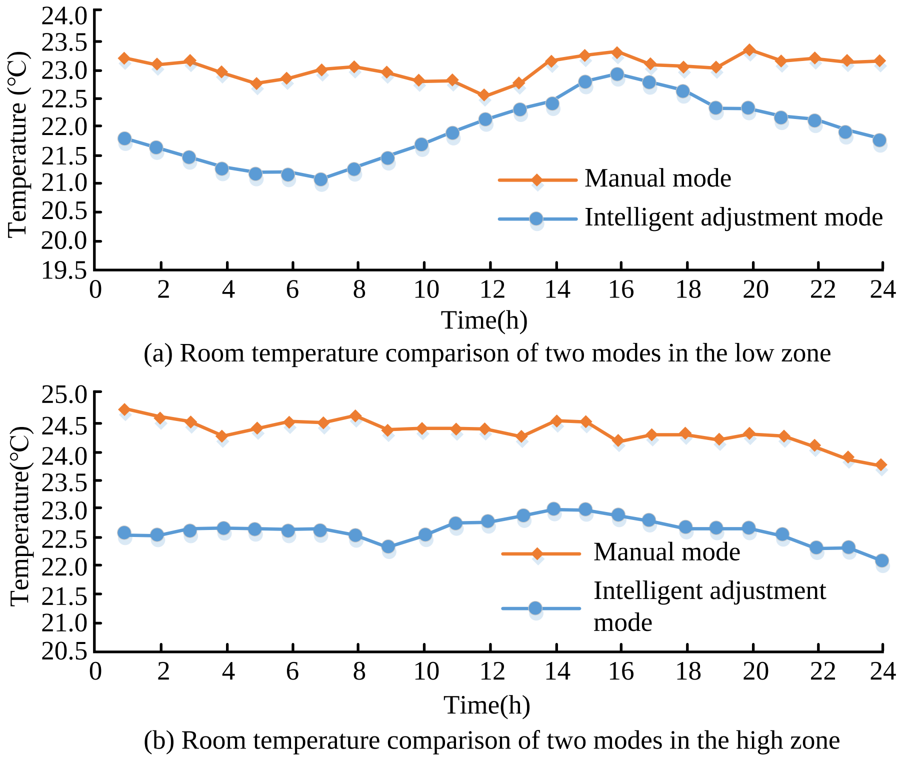
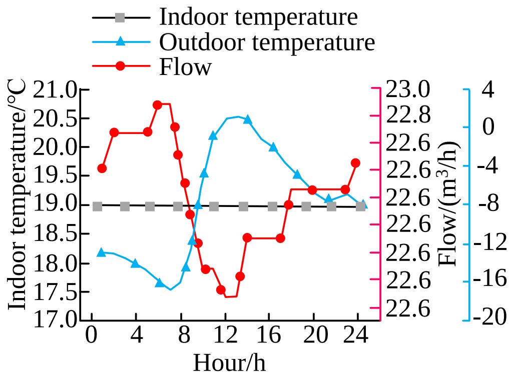
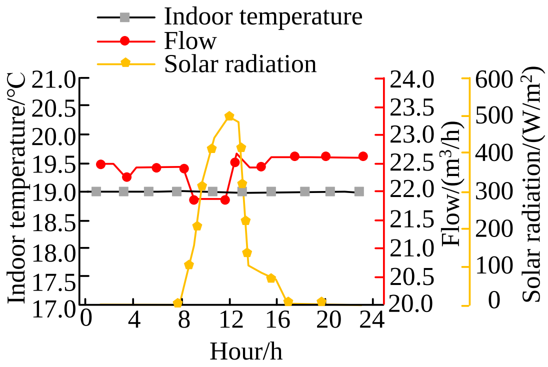


Figure 12: Room temperature changes under different control modes

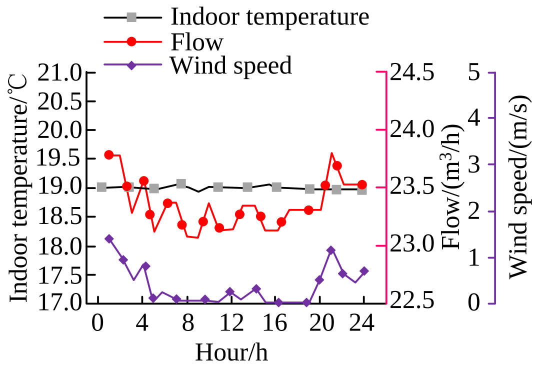
In Figure 12, the average indoor temperature in the manual control mode was high, and the low floor was between 22.5°C and 23.5°C. The high floor was between 23.5°C and 24.5°C, which was significantly higher than the indoor heating standard temperature stipulated by the state. The average temperature of the low floor in the rear of the intelligent reverse control system was between 21°C and 23°C. The temperature of the high floor was between 22°C and 23°C. On the whole, the temperature was 2°C to 3°C lower than the manual adjustment mode. In addition, the day and night temperature changes in the manual adjustment mode were more volatile, which increased the power consumption of the internal heating system to a certain extent. Subsequently, the parameters under different disturbances are analyzed to further understand the heating system. The results are shown in the Figure 13.



(a) Parameter changes under outdoor temperature disturbances



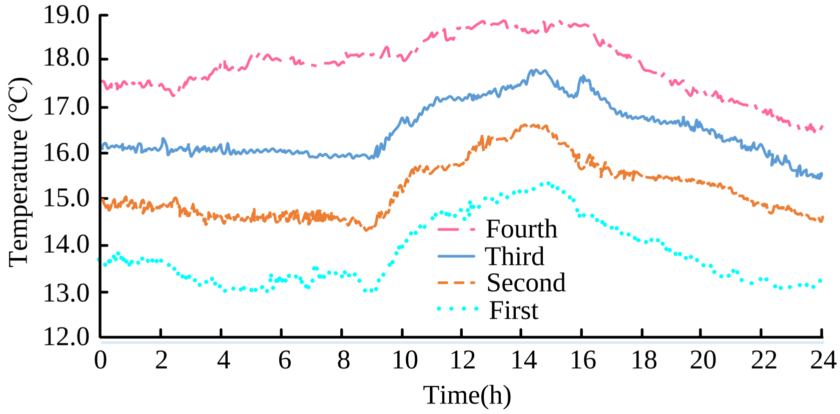
(b) Parameter changes under solar radiation disturbance



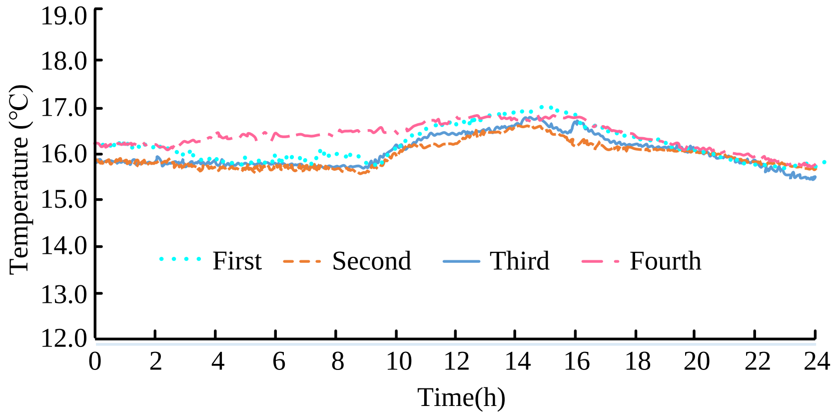
(c) Parameter changes under wind speed disturbance

Figure 13: Parameters under disturbance changes of different factors

Figures 13 (a), (b), and (c) show the disturbance changes of outdoor temperature, solar radiation, and wind speed factors, respectively. Specifically, the system flow rate was negatively correlated with outdoor temperature. From the perspective of heat transfer theory, the larger the temperature difference between indoor and outdoor buildings, the faster the heat loss. Therefore, when the outdoor temperature drops, the controller will adjust to increase flow. When the outdoor temperature rises, the controller will adjust to reduce flow. From the indoor temperature and flow rate changes, when the solar radiation intensity undergoes drastic changes, the thermal intelligent controller can predict the indoor temperature changes in advance and make adjustments. Overall, there is a negative correlation between system flow and solar radiation intensity. When calculating the thermal load of a building, wind energy consumption is usually added to the enclosure structure. When controlling constant solar radiation, outdoor temperature, and water supply temperature, the system flow rate in building thermal intelligent control is positively correlated with wind speed. In order to further explore the temperature regulation under the intelligent commutation adjustment method, the study conducts experimental observation on the low floor. The continuous changes in room temperature for five days are shown in Figure 14.



(a) Original mode room temperature distribution map



(b) Room temperature distribution map in intelligent adjustment mode

Figure 14: Room temperature distribution map before and after intelligent adjustment

In Figure 14, the temperature difference between the three floors was large under the positive room temperature condition. When the time was less than 10 hours, the average temperature of floors 1-4 was 13.8°C, 14.9°C, 16.2°C and 17.9°C, respectively. The four floors all showed a fluctuation rise and a slight decline within 12-16 hours. After more than 18 hours, the average temperature of the floor showed a downward trend, and the maximum floor temperature difference exceeded 4°C. After the commutation temperature adjustment, the temperature imbalance between the four floors is obviously alleviated. Although there are still temperature fluctuations, the overall temperature difference tends to be stable, which effectively realizes temperature regulation.

5 Discussion

On the basis of considering the complexity of building energy systems and the variability of heating influencing factors, this study proposes a design concept for a uniform heating system based on intelligent directional control and regulation. It is implemented based on key parameter identification, series parallel control system design, and algorithm design. Performance testing analysis is conducted on the research method. According to the results, there was a negative correlation between the system flow rate change curve and outdoor temperature. The parameter controller could adjust the flow rate based on changes in solar radiation intensity to achieve indoor temperature control. The method proposed in the study predicted a maximum temperature difference of 1.25% and 3.24% within 0-24 hours and 24-72 hours, which was significantly better than comparison algorithms. The improved PI algorithm showed lower flow consumption compared with the PID algorithm, with a flow rate of 12.6m3/h within 27 hours, and had better time response and anti-interference performance. Accurate parameter identification can effectively grasp various response conditions changes inside and outside the building, thereby improving identification accuracy. The designed water supply system designed has obvious advantages of low energy consumption. The energy balance coefficient can effectively consider the impact of heat exchangers and material thermal conductivity on building heating heat. Compared with the literature [2] using an improved long short-term memory prediction network, the literature [2] may have some shortcomings in reading and adapting to real-time changes, while the intelligent directional adjustment proposed in the study can adjust heating parameters in real-time and better maintain temperature balance. Compared with the literature [8] that uses the distributed co-evolutionary optimization algorithm, the improved approach proposed in the study focuses more on real-time control performance, which is different from the focus on structural efficiency in the literature [8].

The application performance results showed that under the intelligent directional control mode, the overall heating supply of low floors showed a decreasing trend from 80kW to 10kW, while the heating supply of high floors basically remained between 20kW and 35kW. More than 80% of the time, the intelligent directional adjustment mode saved more heat supply. The average heat supply of the low and high floors in the building after improvement was 40kW and 28kW, which was 57.14% and 73.68% of the energy consumption before improvement. Reverse temperature regulation can effectively alleviate temperature imbalance on different floors, and the overall temperature regulation effect is relatively obvious. The reason for this result is that during the design of control strategies, the study explores the time adjustment of heating and heat dissipation variables, effectively considering the delay of indoor heating systems in buildings. Compared with the approach proposed in literature [14] that combined attention mechanism and long short-term memory network to predict heating load, the proposed method combines the water and electricity system to observe the internal air source heat situation of buildings. PI control can calculate the opening of four-way valves, which can be better connected to sensors. Therefore, it has higher sensitivity and adaptability to data reflection. Although literature [14] can maintain indoor temperature stability well, its approach using algorithmic calculations is difficult to timely examine the dynamic response of the system. The literature [11] utilizes TOPSIS multi-criteria decision-making to evaluate building temperature sensitivity issues. Although it can effectively ensure thermal adaptability, compared with research methods, its impact on the heating system itself is not sufficiently considered.

6 Conclusion

Aiming at the temperature imbalance in building heating system, the intelligent reverse regulation equipment was introduced into the heating system. The intelligent uniform regulation system was constructed to achieve uniform heating. When the indoor temperature remained unchanged, the flow curve of the heating system was negatively correlated with the outdoor temperature. The designed parameter controller had obvious effects in temperature regulation. When the flow rate changed, the flow rate of the improved PI algorithm was 12.6m3/h at 27 hours, which had better response time and anti-interference. The application results showed that the intelligent reverse adjustment mode was better than the traditional manual adjustment mode. Its low floor (80kW to 10kW) and high floor heating capacity (20kW to 35kW) was much lower than the manual control mode between 70kW to 80kW and 35kW to 40kW. The overall indoor temperature adjustment was 2°C~3°C lower than the manual adjustment mode, which effectively improved the temperature imbalance on the floor. The intelligent control method for uniform heating in buildings is applicable to all heating systems. The intelligent control method for uniform heating in buildings can effectively avoid overheating and achieve relatively uniform heating distribution in building spaces, which has a positive impact on the intelligent temperature regulation and energy control of buildings. Intelligent temperature regulation can be achieved by installing sensors and four-way valves. The architectural layout, orientation, body shape coefficient, enclosure structure, shading method, ventilation, noise, lighting, and other aspects all have impacts on the indoor thermal environment of residential buildings before and after the heating period. In the actual installation process, design values should be considered based on on-site conditions. The difference between the deployment range of temperature sensors and the selected type will to some extent affect the calculation cost. This study proposes a building uniform heating system based on intelligent directional adjustment, which can effectively regulate temperature and improve thermal imbalance. However, there are still certain shortcomings in the research, among which the energy regulation coefficient in the energy balance method still needs to consider the comprehensive factors such as temperature and flow rate, and strengthen the study for temperature distribution under different commutation time ratios. At the same time, the coupling relationship between the energy balance method and the reverse process should be comprehensively considered to optimize the system heating.

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