SIMULATION ON INDOOR THERMAL DYNAMIC PERFORMANCE OF HEATING SYSTEM UNDER THE ON-OFF VALVE ADJUSTING MODEL

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ABSTRACT

In order to solve the unbalance problem and increase the system efficiency of central heating, a new-style adjusting model in the building internal system —on-off valve adjusting system which is composed of by the on-off valve 、controller、 indoor temperature sensor is put forward. According to the heat transfer process, dynamic models of water-flow, radiator, and building are established to solve the indoor temperature variation of individual rooms under different loads and different on-off control strategies, based on which the impacts of different temperature and rate of the water-flow on control strategy are studied, then an on-off control strategy with intelligent feedforward is obtained.

KEYWORDS

Heating system On-off valve adjusting Building thermal characteristic Indoor thermal dynamic performance

INTRODUCTION

In developed countries of northern Europe, heating systems are regulated by the temperature control valves fixed on the radiators. However, it is significantly different about the living style and heating system type in China, so it would be difficult if the adjusting and heat metering methods are copied directly from abroad,and it is urgent to explore a new way to solve the problems based on the living habits of Chinese people. In order to develop a method to working out the problems, a new on-off controlling mode for the heating system is put forward. And a suitable controlling strategy is given out by simulating the indoor thermal dynamic performance under different conditions.

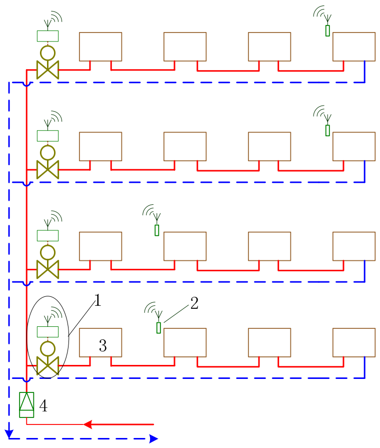
INTRODUCTION OF THE ON-OFF CONTROL SYSTEM AND THE WORKING MODE

As figure 1 shows, the on-off controlling system consists of on-off valves(No.1 in the figure1)and indoor temperature controllers(No.2 in the figure1). The practical operation procedure is as follows. Firstly, the needed indoor temperature is set by the users through the indoor temperature controllers and the wireless signals would be sent to the on-off valves. Then the on-off valves would get the feedback signals of real indoor temperature and work out the difference between the real temperature and the set value. Secondly, the valves would calculate the proportion of on-time to off-time in the next step according to the thermal strategies programmed in the valves'CPU, then the valves would be controlled according to the proportion to maintain the needed indoor temperature. At the same time, controlling system would keep a record of the on-time of the valves automatically.Heat is allocated according to each householder's heating area weighted by their valves' accumulative open time, which is as equation (1) ~(2) shows。.

$$q_j = \frac{\alpha_j * F_j}{\sum_{i=1}^{n} \alpha_i * F_i} Q \qquad (1)$$

$$\alpha_j = \frac{T_{open,j}}{T_O} \qquad (2)$$

q_j—heat allocated of householder j; α_j—valve's accumulative open time proportion of householder j F_j—heating area of householder j; Q—heat metered of the heat meter; $T_{open,j}$—valve's accumulative open time of householder j; T_O—accumulative metering time of the heat meter, n—the householder number of the buliding;



1-on-off valve 2-indoor temperature controller
3-radiators 4-heat meter
Figure1 frame of the on-off control model

MATHEMATIC MODEL AND THE SOLUTION

The mathematic model

To study the dynamic thermal performanceof indoor environment when the heating system is in on-off mode, we establish the mathematic model.

Model for Radiator

As figure 2 illustrates, every single radiator layer is in parallel connection with each other , and we consider the water-flow distribution among the layers is uniform, then we set out the thermal balance equations for the water inside and the radiator shell[1].

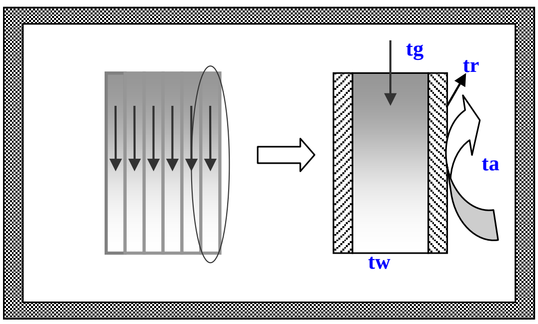


Figure2 the heat transfer model for radiators

(1)thermal balance equations for water inside

The form of heat transfer between the water inside and the shell is convection, and the thermal balance equation is as follows:

$$C_w \rho_w V_w \frac{dt_w}{d\tau} = C_w \rho_w G_w (t_g - t_h) - h_w F_w (t_w - t_r)$$

Here

C_w -specific heat of water, kJ/(kg • ℃）; ρ_w —density of water,kg/m^3; V_w —the volume of water inside,m^3; t_w —average temperature of water, ℃; G_w —water flow rate into the radiator, m^3/s; t_g —entering water temperature of the radiator,℃; t_h —exiting water temperature of the radiator ,℃; t_r —average temperature of the shell,℃; h_w —the convective heat transfer coefficient between water and shell,W/m^2 ; F_w ——the convective heat transfer area between water and inside wall, m^2;

If it is considered that the outlet water temperature is the same as the average water temperature inside the radiator , then the equation is:

$$C_w \rho_w V_w \frac{dt_w}{d\tau} = C_w \rho_w G_w (t_g - t_w) - h_w F_w (t_w - t_r)$$

(2)the thermal balance equation for the radiator shell

The heat conduct and radiation among the single layers is neglected. The inner face of the room is heated by radiation of the radiators and the heat is convected into the air again.,so we consider the heat is convected from the radiator layer directly.

$$C_r \rho_r V_r \frac{dt_r}{d\tau} = h_w F_w (t_w - t_r) - h_r F_r (t_r - t_a)$$

Here:

C_r — specific heat of radiator shell, kJ/(kg • ℃)；ρ_r — density of the radiator shell,kg/m^3; V_r — volume of the radiator shell,m^3; h_r — convective heat transfer coefficient between the shell and the indoor air,W/m^2; F_r—the area of convective heat transfer between the outside wall and the indoor air, m^2; t_a—indoor air temperature, ℃; Other nomenclatures are the same as before

Model for indoor air temperature

According to the state space method[2][3], we set out the mathematic model for the indoor air temperature as follows:

$$t_a(\tau) = \int_{-\infty}^{\tau} \sum_l \sum_k \varphi_{l,k} e^{\lambda_i(\tau-\xi)} u_k(\xi) d\xi$$

In order to analysis the influence of the radiator, We separate the heat gain from the radiator and neglect the influence of heat transfer among the adjacent rooms. Thus :

$$
\begin{aligned}
t_a(\tau) &= t_{base}(\tau) + \sum_i \Delta t_{ai}(\tau) \\
&= t_{base}(\tau) + \int_{-\infty}^{\tau} \sum_i \varphi_i e^{\lambda_i(\tau-\xi)} q(\xi) d\xi \\
&= t_{base}(\tau) + \sum_i e^{\lambda_i \Delta\tau} \Delta t_{ai}(\tau-\Delta\tau) + \int_{\tau-\Delta\tau}^{\tau} \sum_i \varphi_i e^{\lambda_i(\tau-\xi)} q(\xi) d\xi \\
&= t_{base}(\tau) + \sum_i [e^{\lambda_i \Delta\tau} \Delta t_{ai}(\tau-\Delta\tau) + \phi_{1i} q(\tau-\Delta\tau) + \phi_{0i} q(\tau)] \\
&= t_{base}(\tau) + \sum_i e^{\lambda_i \Delta\tau} \Delta t_{ai}(\tau-\Delta\tau) + \Phi_1 q(\tau-\Delta\tau) + \Phi_0 h_r F_r [t_r(\tau) - t_a(\tau)]
\end{aligned}
$$

$$
t_a(\tau) = \frac{1}{1+\Phi_0 h_r F_r}[t_{base}(\tau) + \sum_i e^{\lambda\Delta\tau} \Delta t_{ai}(\tau-\Delta\tau) + \Phi_1 q(\tau-\Delta\tau) + \Phi_0 h_r F_r t_r(\tau)]
$$

Here, t_{base} is the room temperature without the influence of the radiator, as a known process it is called base room temperature; $\phi_{1,i}$, $\phi_{0,i}$, Φ_1, Φ_0 are defined by the building thermal performance. The expressions are as follows:

$$
\phi_{1,i} = \int_0^1 \varphi_i (1-\xi) e^{\lambda_i (1-\xi)\Delta\tau} \Delta\tau d\xi = \frac{\varphi_i}{\lambda_i^2 \Delta\tau}(1 - e^{\lambda_i \Delta\tau} + \lambda_i \Delta\tau e^{\lambda_i \Delta\tau})
$$

$$
\phi_{0,i} = \int_0^1 \varphi_i \xi e^{\lambda_i (1-\xi)\Delta\tau} \Delta\tau d\xi = \frac{\varphi_i}{\lambda_i^2 \Delta\tau}(-\lambda_i \Delta\tau - 1 + e^{\lambda_i \Delta\tau})
$$

$$
\Phi_1 = \sum_i \phi_{1,i} = \sum_i \frac{\varphi_i}{\lambda_i^2 \Delta\tau}(1 - e^{\lambda_i \Delta\tau} + \lambda_i \Delta\tau e^{\lambda_i \Delta\tau})
$$

$$
\Phi_0 = \sum_i \phi_{0,i} = \sum_i \frac{\varphi_i}{\lambda_i^2 \Delta\tau}(-\lambda_i \Delta\tau - 1 + e^{\lambda_i \Delta\tau}))
$$

$q(\tau)$ is the heat flow emanated by the radiator at the time point τ ; φ_i , λ_i denote the thermal characteristics of the building, they are determined by the geometric shape and materials of the building. These parameters are constant for existent buildings, and do not change along with the heat gain. For more details, please refer to the literatures[1].

Solutions

We can get the solutions based on the former mathematic models. For every single room, we discrete the differential equations by implicit expressions. Then we can get the equations as follows.

$$
C_w \rho_w V_w \frac{t_w(\tau) - t_w(\tau-\Delta\tau)}{\Delta\tau} = C_w \rho_w G_w(\tau)(t_g(\tau) - t_w(\tau)) - h_w F_w (t_w(\tau) - t_r(\tau))
$$

$$
C_r \rho_r V_r \frac{t_r(\tau) - t_r(\tau-\Delta\tau)}{\Delta\tau} = h_w F_w (t_w(\tau) - t_r(\tau)) - h_r F_r (t_r(\tau) - t_a(\tau))
$$

$$
t_a(\tau) = \frac{1}{1+\Phi_0 h_r F_r}[t_{base}(\tau) + \sum_i e^{\lambda\Delta\tau} \Delta t_{ai}(\tau-\Delta\tau) + \Phi_1 q(\tau-\Delta\tau) + \Phi_0 h_r F_r t_r(\tau)]
$$

Every single room can be worked out separately; the outlet water temperature of the former room is the inlet temperature of the next room, so we can get all of the rooms' state parameters.Assume the number of the room is n, so we can get n balance equations for water inside, n balance equations for the shells and n balance equations for room temperature. There are 3n equations and 3n unknown parameters in all. It is easy to know that the equation group has only one set of solutions.

In order to make it easier for the program to work out, we separate the parameters for the equations, and get the expressions in form of $AT = B$,

$$
A = \begin{bmatrix} A_1 & & & & \\ & \cdots & & & \\ & & A_i & & \\ & & & \cdots & \\ & & & & A_n \end{bmatrix}
$$

$$
T = \begin{pmatrix} T_1 \\ \cdots \\ T_i \\ \cdots \\ T_n \end{pmatrix} \qquad B = \begin{pmatrix} B_1 \\ \cdots \\ B_i \\ \cdots \\ B_n \end{pmatrix}
$$

Here A_i 、 B_i 、 T_i stand for:

$$
A_i = \begin{pmatrix} (\frac{C_{wi}\rho_{wi}V_{wi}}{\Delta\tau} + C_{wi}\rho_{wi}G_{wi}(\tau) + h_{wi}F_{wi}) & -h_{wi}F_{wi} & 0 \\ -h_{wi}F_{wi} & (\frac{C_r\rho_r V_r}{\Delta\tau} + h_{wi}F_{wi} + h_{ri}F_{ri}) & -h_{ri}F_{ri} \\ 0 & -\Phi_{0,i}h_{ri}F_{ri} & (1+\Phi_{0,i}h_{ri}F_{ri}) \end{pmatrix}
$$

$$
B_i = \begin{pmatrix} \frac{C_{wi}\rho_{wi}V_{wi}}{\Delta\tau} t_{wi}(\tau-\Delta\tau) + C_{wi}\rho_{wi}G_{wi}(\tau) t_{gi}(\tau) \\ \frac{C_{ri}\rho_{ri}V_{ri}}{\Delta\tau} t_{ri}(\tau-\Delta\tau) \\ t_{base,i}(\tau) + \sum_j e^{\lambda_{j,i}\Delta\tau} \Delta t_{aj,i}(\tau-\Delta\tau) + \Phi_{1,i} q_i(\tau-\Delta\tau) \end{pmatrix}
$$

$$
T_i = \begin{pmatrix} t_{wi}(\tau) \\ t_{ri}(\tau) \\ t_{ai}(\tau) \end{pmatrix}
$$

Here: N is the number of room

After working out the equations, we can get the solutions of water temperature, average temperature of the shells and each temperature of the rooms.

EXAMPLE FOR CALCULATION

Conditions

(1)The model for calculation

Here a building in Changchun city is taken as a calculating model. It is a T shaped, 7-storeyed building with four apartments on each floor. The indoor heating system is a cascaded single-pipe system and each apartment has a household circle connecting to the main pipe. The 2d pictures of the building is as figure 3 illustrate. The household on the third floor of the east wing are selected as the calculating objectives. The heating water flows anticlockwise, starting from room1 and coming out from room4.

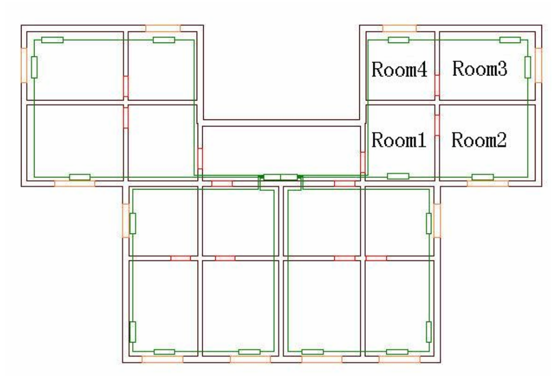


Figure3 2d chart of the building

(2)The radiator type and layer quantities in each room

The TZ2-5-5(M-132) radiators are adopted. The number of layers in each room is as table 1 shows.

Table1 Number of layers in each room

Room Number	No. of layers	Room Number	No. of layers
Room1	5	Room2	9
Room3	12	Room4	12

(3)Initial parameters

The initial parameters are as table 2 shows.

Table 2 initial parameters[4]

Parameter Name	Units	Value
Specific Heat of Water	kJ/kg • ℃	4.19
Density of Water	kg/m^3	1000
Specific Heat of Cast Iron	kJ/kg • ℃	0.42
Density of Cast Iron	kg/m^3	7272
Heat Radiating Area of a Single Layer	m^2/layer	0.24
Water Capacity of a Single Layer	L/layer	1.32
Mass of a Single Layer	kg/layer	7
The Convective Heat Transfer Coefficient between the Water and Inside Wall When Valve is Open	W/m^2 • ℃	1000
The Convective Heat Transfer Coefficient between the Water and Inside Wall When Valve is Closed	W/m^2 • ℃	70
The Convective Heat Transfer Coefficient between the Outside Wall and the Air	W/m^2 • ℃	8.5
Initial Circulating Flow Rate	m^3/s	0.000106

(4)Base room temperature

Based on the simulation results of the software DEST(a software for simulating the thermal process of a building and air conditioning system) developed by the Department of Building Science and Technology of Tsinghua University, we get the base room temperature curves of all the rooms from Mar.8th to Mar.15th as figure 5 illustrates.

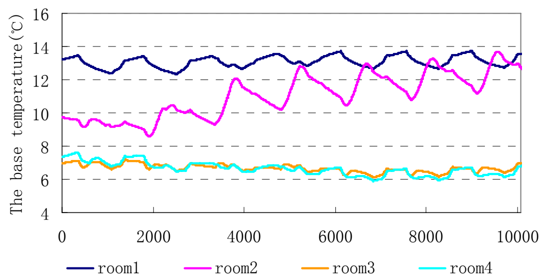


Figure 5 the base room temperature curves of each room

The scheme of the simulation and the result

Introduction of the controlling methods in heating sysytem

There are mainly two controlling methods in automaticly adjusting heating system normally:

(1) radiator thermostats continuously change flow rate : the volume of the liquid in the temperature sensing element in the valve will change along with the temperature, which leads to the up and down motion of the valve handle, and the hot water flow rate into the radiator can be changed continuously in a range controlled by the valve handle. The flow rate controlling mode is recommended in the Literature[5], as equation (3) shows.

$$\begin{cases} T_{in} > T_{set} + 1.93 & G = 0 \\ T_{set} + 1.93 \ge T_{in} \ge T_{set} & G = \dfrac{T_{set} + 2 - T_{in}}{2} G_{max} \\ T_{in} < T_{set} & G = G_{max} \end{cases} \qquad (3)$$

T_{set} —temperature set by users，℃； T_{in} —real room temperature，℃； G — real flow rate，m^3/s； G_{max} —flow rate when valve is fully open，m^3/s；

(2) step-changed flow rate based on temperature deviation : set a differential range around the set value of the room temperature and control the water flow rate by on-off valve, the flow rate will change in step. The controlling model is as equation (4) shows. The deviation is ±0.5℃. In order to prevent the valves from opening and closing too frequently and

to avoid the delay of controllers, we set the cycling period to be 10 minutes. That is to say, the valve will judge according to the deviation of the room temperature every 10 minutes .

$$\begin{cases} T_{in} \geq T_{set} + 0.5 & G = 0 \\ T_{set} - 0.5 < T_{in} < T_{set} + 0.5 & G = G_{pre} \\ T_{in} \leq T_{set} - 0.5 & G = G_{max} \end{cases} \quad (4)$$

T_{set} —temperature set by users，℃； T_{in} —real room temperature，℃； G —room flow rate，m^3/s； G_{max} —flow rate when valve is fully open，m^3/s； G_{pre} —the flow rate in last period，m^3/s.

These two methods are considered to be limited in some aspects. In radiator thermostats continuously changed flow rate method, the controlling action may be delayed by the thermal inertia. And the flow rate is too low, which may lead to maladjustment in cascaded heating system, the valve is easy to be blocked, too; In step-changed flow rate based on temperature deviation method, if the offset is too big, the fluctuation extent will be too large and the accuracy is not satisfactory. On the contrary, if the offset is too small, a good stability can not be ensured, especially at lower heating load, the valves are easy to open and close very frequently. So here we will introduce an intelligent step-changed flow rate method.

(3) step-changed flow rate intelligent: by predicting the proportion of on-time to off-time of the valves in the next period, we can control the water flowing time and meet the thermal users' demand. And because there are only two states for the water flow, on and off, it is not easy to lead to maladjustment or block in the valves. The problem generated from thermal inertia can also be eliminated by predicting the variation of the room temperature, and the valves will act once at most in one period,so it also avodes the vavle acting frequently.

Further details will be given out by simulating indoor thermal dynamic performance under the same condition. Then the advantage and disadvantage of three methods will be compared and analyzed.

For the convenience of depiction, we call the former three methods as Method 1, Method 2 and Method 3 for short. all the controlling methods will be implemented

Indoor dynamic thermal performance at different heating load

The base temperature curve shows the influence of all the inner and outer heat gains (including outside air temperature, solar radiation, and inner heat gains from lights, equipments and people)except the radiators. Different base temperatures indicate different demand for heating load if the set value of indoor air temperature is the same. The base temperature in the four rooms of figure 5 varied significantly. In order to study the adaptability of the three methods when imposed on the base temperature, we set the supply water temperature to be constant 60 ℃,set the indoor air temperature to be 18℃ and the period of method 3 to be 30 minutes. The variations of indoor air temperature under different controlling methods are as figure 6 to figure 8 illustrate. Figure9,10 individual shows the mean temperatures of rooms and its mean square deviation.It can be seen from the results:

(1)Method 1: Only the room temperature is above the set value ,the flow rate can be adjusted automaticly, so the controlling accuracy is not satisfactory. From figure9 we can see that the mean temperatures exceed the set value for 0.7~1.5℃ and it is greatly affected by the base room temperature.On the other hand, the variation characters are similar to the base temperatures, which indicate that the base temperature has a great effect on the indoor air temperature.

(2)Method 2: the offset of room temperature from set value is ±0.7℃, bigger than the set value ±0.5℃. The valve takes one action per 10minutes and the room temperature fluctuates between the up and down extreme(18±0.7℃) very frequently, which may affect the thermal comfort of users. Though the variation of base temperature will not affect the controlling accuracy greatly, its application may be limited in real engineering if the valve acts too frequently.

(3)Method 3: for the rooms with more smooth variation of base temperature, the room temperature deviation is basically within ±0.5℃, and amplitude of variation is relatively small; for the rooms with more acute variation of base temperature, because the period is 30 minutes, which is relatively long, the room temperature deviation becomes larger some time, however the mean square deviation is the lest of the three methods ,and the overall effect is satisfactory.

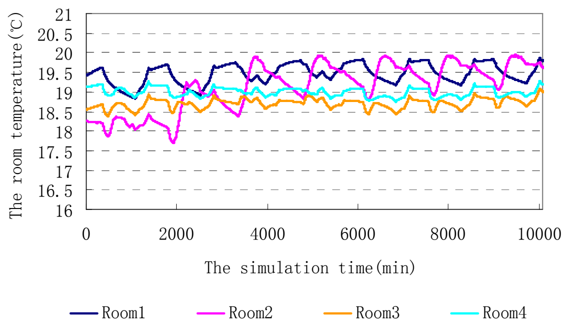


Figure 6 the simulation results of the method 1 in different base temperatures

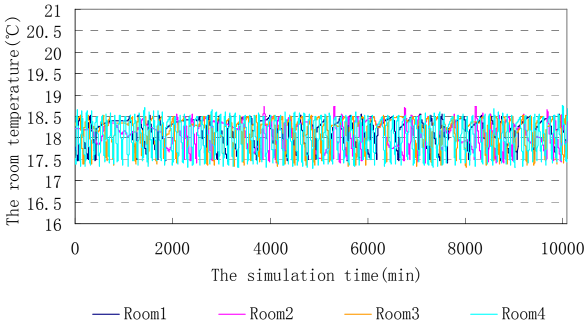


Figure 7 the simulation results of the method 2 in different base temperatures

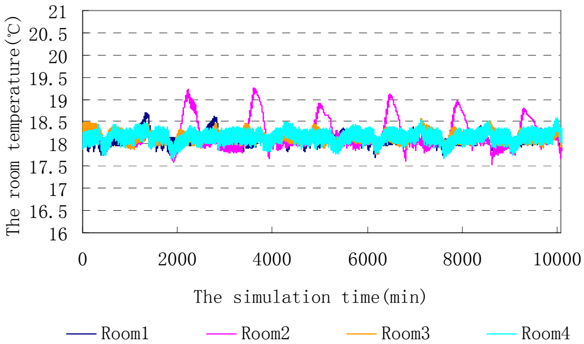


Figure 8 the simulation results of the method 3 in different base temperatures

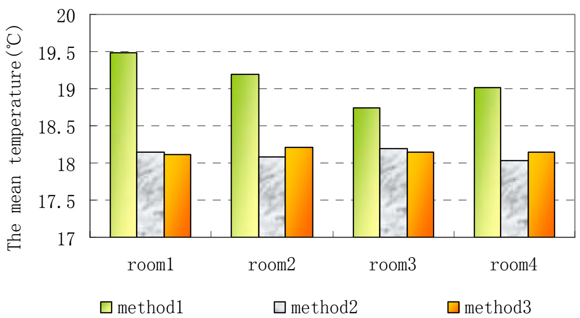


Figure9 the mean temperature of the room

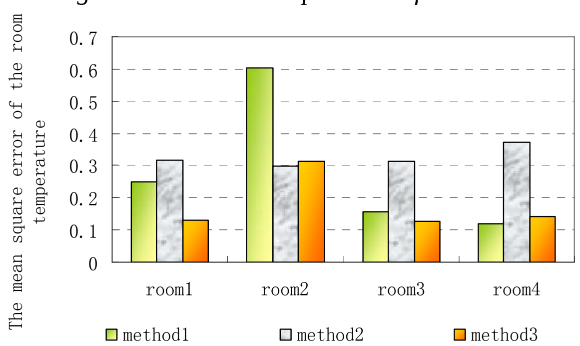


Figure10 the mean square deviation of the room temperature

The indoor dynamic thermal performance under different supply water temperature.

The supply water temperature from the heat source is the same in heating system, but the buildings are different significantly, and the demand for supply temperature varies too. It needs to be considered how much the variation of the supply water temperature will affect the controlling effect when the former three methods are supplemented on the buildings. Figure 11 to 13 illustrate the dynamic thermal performance when the supply water temperature is 55℃、60℃、65℃ and 70℃. Figure14,15 individually shows the mean temperatures and its square deviation in different supply water temperature.The results indicate that: the controlling effect of Method 1 will be greatly affected by the supply water temperature.At a lower heating load in the example, the room temperature deviation becomes larger if the supply water temperature is lower. For method 2, the offset of room temperature is bigger than set value because of the thermal inertia as mentioned before;Method 3 shows rather good robustness, and the supply water temperature has little impact on the controlling effect.

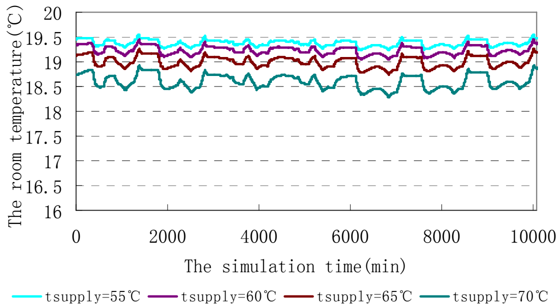


Figure 11 the simulation results of the method 1 in different supply temperatures

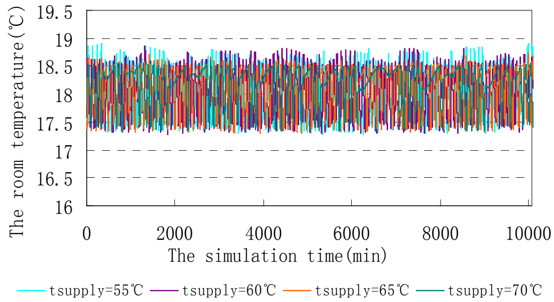


Figure 12 the simulation results of the method2 in different supply temperatures

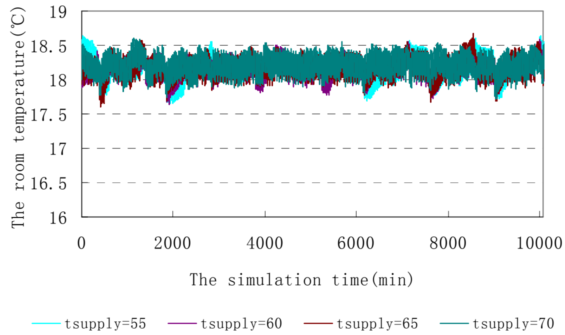


Figure 13 the simulation results of the method3 in different supply temperatures

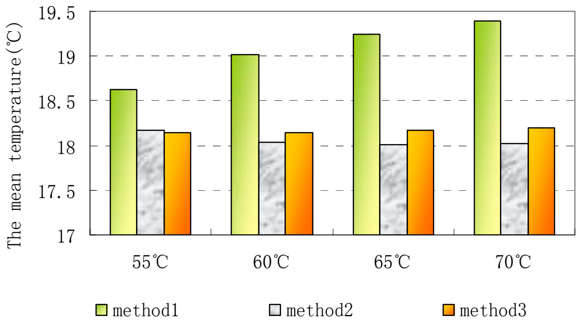


Figure 14 the mean temperature of the room in different supply temperatures

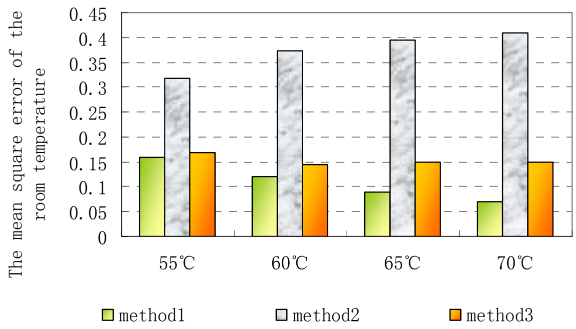


Figure15 the mean square deviation ot the room temperature in different supply temperatures

The indoor dynamic thermal performance in different supply water flow rate.

The distribution of water flow is coupling among multiusers in the heating system,so when one user's flow rate is adjusted, the adjacent user's flow rate will change too. In order to study how much the variation of flow rate will affect the controlling effect, we simulate all the cases under three methods in which the flow rate is 0.5 times, 1 times and 2 times of the original flow rate. The results are as figure 16 to 20 illustrate, and it indicates that:

(1)Since the principle of Method 1 is to adjust the flow rate in proportion to the offset of room temperature, the controlling effect will be greatly affected by the supply water flow rate. At the lower heating load, the offset of room temperature becomes bigger if the supply flow rate is bigger.

(2)From figure 20,we can see that the mean square deviation of the room temperature is largest for Method 2,and it indicates that the temperature fluctuates greatly. In addition ,the offset of the room temperature becomes bigger if the supply water flow rate is bigger.

(3)For Method 3 ,it shows good robustness, and the controlling effect is not greatly affected by the supply flow rate.

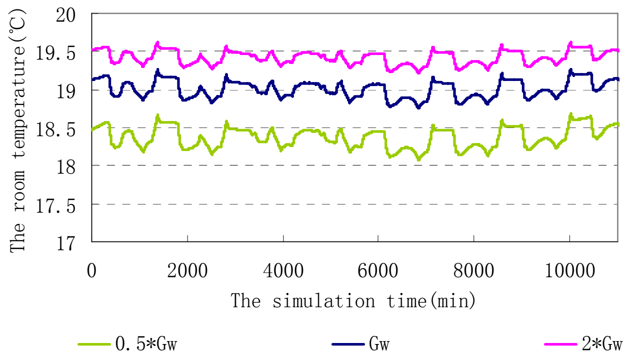


Figure16 the simulation results of the method1 in different supply water flow rate

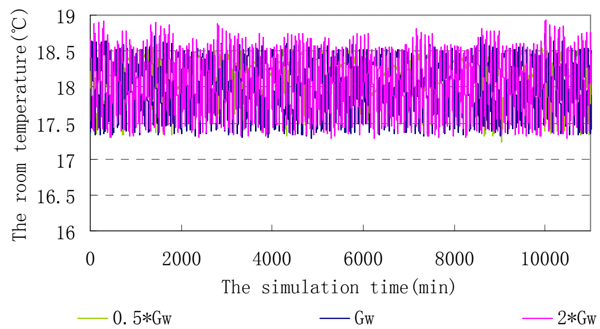


Figure17 the simulation results of the method2 in different supply water flow rate

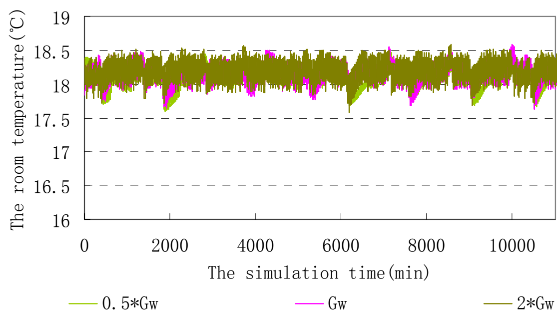


Figure18 the simulation results of the method3at different supply water flow rate

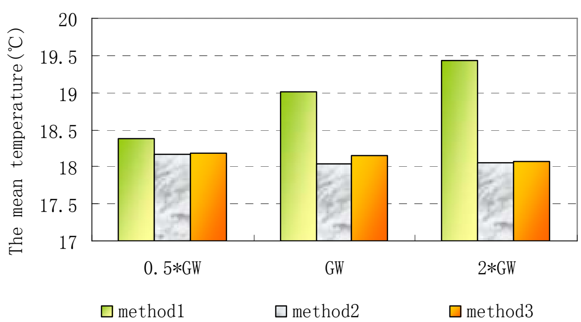


Figure19 the mean temperature of the room in different supply water flow rate

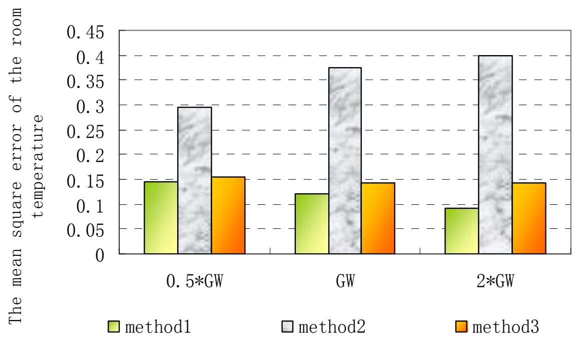


Figure20 the mean square deviation of the room temperature in different supply water flow rate

Result of experiment

During the heating season (2006~2007)，room temperature of certain building in Changchun is controlled by Method 3, and the result is shown in Fig 21. It represent that the deviation of room temperature is on the whole confined at within ±0.5 ℃， which is in good accordance with simulated result.

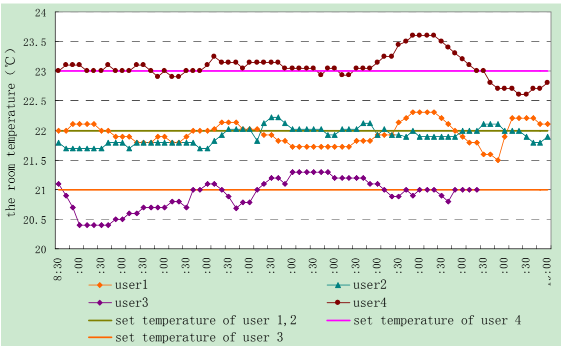


Figure21 the measure room temperature of the method 3

CONCLUSION

(1) A new heating system, which can achieve the function of controlling room temperature and heat metering at the same time, is presented. The dynamic heat transfer models of water-flow, radiator, and building are established to solve the indoor temperature variation of individual rooms under different loads and different on-off controlling strategies.

(2) Especially for the on-off valve system as mentioned, an intelligent controlling strategy is put forward. The method is to predict the duty cycle of the vavle in the next period and control the on-time of the vavle based on the intelligent strategies. Then the indoor temperature variation of individual rooms is simulated by the three methods which are radiator thermostats continuously changed flow rate(method 1), step-changed flow rate based on temperature deviation (method2) and step-changed flow rate intelligent(method 3) in different base room temperatures(different heating loads), different supply water temperatures and different supply water flow rates, From the simulation results it can be seen that:

Method 1: Only when the room temperature is above the set value ,the flow rate can be adjusted automaticly, so the controlling accuracy is not satisfactory. The mean temperature is all above the set value and it is greatly affected by the base room temperature (heating load), supply water temperature and water flow rate.

Method 2: the controlling action is delayed by the thermal inertia, and room temperature fluctuates between the up and down extent and the deviation is sometimes larger than the set value. Meanwhile, the valves take actions too frequently ,so application of this method may be limited in real engineering .

Method 3: for the rooms with more smooth variation of base temperature, the room temperature deviation is basically within ±0.5 ℃ , and amplitude of variation is relatively small; for the rooms with more acute variation of base temperature, because the period is 30 minutes, which is relatively long, the room temperature deviation becomes larger some time. The method shows good robustness and adaptability and it is the best control strategie of the three methods.

References

[1] Zhang Ximin, Ren Zepei.2001.“Heat Trasfrer”. Beijing: China Architecture and Building Press.(in Chinese)

[2] Xie X N,Song F T,Yan D, Jiang Y. 2004. “Building environment design simulation software DeST(2):dynamic thermal process of buildings”. Heating Ventilating & Air Conditioning. 34(8): 35-47. (in Chinese)

[3] Zhang X L, Xie X N, YAN D.2004. “Building environment design simulation software DeST (3) : Validation of dynamic simulation results of building thermal progress”.Heating Ventilating & Air Conditioning. 34 (9) :37-50. (in Chinese)

[4] He Ping, Sun Gang.1993.“Heat supply Engineering”. Beijing: China Architecture and Building Press.(in Chinese)

[5] Tian Yongzheng.2006. “Users-group dynamic simulation of thermal circulate condition in heating systems with metering”, Master thesis. Harbin Institute of Technology (China).26 pages.