Improving Heating System Operations Using Water Re-circulation

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Abstract: In order to solve the imbalance problem of a heating system, brought about by consumer demand and regulation, and save the electricity energy consumed by a circulation pump, a water mixing and pressure difference control heating system is proposed. The adjustment formulas of the relative flow rate and temperatures of supply and return water for both primary and secondary circuits of the system are deduced. The corresponding adjustment curves are plotted with calculating examples. Analysis of the curves indicates that consumer- regulated indoor temperature is the primary factor that affects the flow rate and temperature of return water.

Key words: heating system; mixing pump; pressure difference control; adjustment formulas

1. INTRODUCTION

Installing mixing pumps at the heat entrance of each building can increase temperature difference between supply water and return water of heat-supply network and reduce circulation flow rate of heat-supply network by a big margin, so the electricity energy consumed by circulation pump of heat-supply network could be sharply decreased. At the same time, the heat loss caused by overheating of some buildings can be reduced from 20~30% to 7~10%[1]. According to the provisions of the Ministry of Construction P. R. China, the heating systems of new public or residential buildings must have functions of household-based heating metering and indoor temperature regulation. Because the variation of flow rate of household-based heat metering system is more complex than traditional heating system due to consumers' self-determination regulating[2], proper control devices should be adopted at consumer heat

inlet of each building to meet consumers' demands for self-determination regulating and keep balance of heating system. Therefore, a water mixing and pressure difference control heating system, as shown in Figure 1, was proposed in this paper.
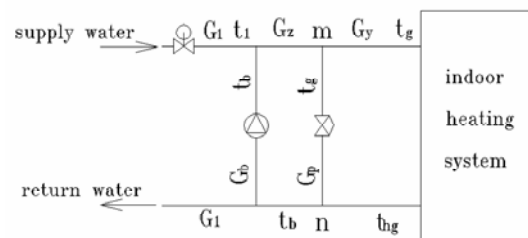

Fig.1 The water mixing and pressure difference control heating system

1- electric control valve   2- mixing pump

3-self-operated pressure difference control valve

Supposing some heat consumers in the building change the target value of indoor temperature, the total flow rate, G_y, of all consumers, and the total heating load of all consumers in the building will be changed. At the same time, the self-operated pressure difference control valve will regulate by-pass flow rate, G_p, to keep the summation of G_y and G_p and the pressure difference ($p_m - p_n$) invariable, and the electric control valve will regulate flow rate, G_1, of primary circuit at consumer heat inlet to adapt to the change of the total heating load of the building.

2. ADJUSTMENT FORMULAS

2.1 Basic Adjustment Formulas

Heating load of buildings are changing with the variations of outdoor conditions (outdoor air temperature, wind velocity, solar radiation and so on) and indoor conditions (indoor temperature, indoor

heat gain and so on), so, strictly speaking, heat-transfer processes of buildings and heating appliances are unsteady state. In order to simplify calculation and the control of heating system, some simplifications were given as follows:

1) Heat-transfer processes of buildings and heating appliances are considered as steady states.

2) Heating load is directly proportional to the temperature difference between indoor and outdoor air.

3) Heat consumers in the building can only set two target values of indoor temperature: design indoor temperature and standby heating temperature.

For radiator heating systems, there are basic heating adjustment formulas as follows according to the simplified conditions (1) and (2) above [2].

$$\overline{Q} = \frac{t_n - t_w}{t'_n - t'_w} = \left(\frac{\Delta t_s}{\Delta t'_s}\right)^{1+b} = \overline{G}\frac{t_g - t_h}{t'_g - t'_h} \tag{1}$$

Where the relative heating load of consumers at actual indoor temperature, $\overline{Q}$, is the ratio, $\overline{Q} = Q/Q'$; Q, and Q' are actual and design heating loads, W; t_n, and t'_n are actual and design indoor temperatures, ℃ ; t_w and t'_w are actual and design outdoor temperatures for heating,℃; Δt_s, and $\Delta t'_s$ are actual and design mean temperature differences between radiators and indoor air,℃; b is radiator constant; the relative flow rate, $\overline{G}$, is the ratio, $\overline{G} = G/G'$; G, and G' are actual and design flow rates of consumers, kg/s; t_g and t'_g are actual and design temperatures of supply water of consumers,℃; t_h, and t'_h are actual and design temperatures of return water of consumers, ℃.

2.2 Adjustment Formulas at the Heat Entrance

The total heating load of the building contains two parts: one is the heating load of consumers regulating indoor temperature; the other is that of consumers keeping indoor temperature. Similar to definition of the relative heating load of consumers at actual indoor temperature, the ratio of actual heating load to design heating load of the building may be defined as total relative heat load $\overline{Q}_s$. Supposing the ratio of consumers regulating indoor temperature to all consumers in the building is a, the following formulas will be derived according to the simplified

conditions (2) and (3).

$$\overline{Q}_s = \overline{Q}_d(1-a) + \overline{Q}_r a = \frac{t'_n - t_w}{t'_n - t'_w}(1-a) + \frac{t_{nr} - t_w}{t'_n - t'_w}a \tag{2}$$

Where $\overline{Q}_d$ is relative heating load at indoor design temperature t'_n, $\overline{Q}_r$ is relative heating load at standby heating temperature t_{nr}.

Therefore, adjustment formulas at consumer heat inlet of buildings can be obtained from relations of heat equilibrium:

$$\overline{Q}_s = \overline{G}_1\frac{t_1 - t_b}{t'_1 - t'_b} = \overline{G}_z\frac{t_g - t_b}{t'_g - t'_b} \tag{3}$$

Where $\overline{G}_1$, and $\overline{G}_z$ are relative flow rates of primary circuit and secondary circuit at consumer heat inlet; t_1, and t'_1 are actual and design temperatures of supply water of the heat-supply network, ℃; t_b, and t'_b are actual and design temperatures of return water of primary circuit at consumer heat inlet, ℃.

3. SELECTION OF CONTROL PARAMETERS

If the constant flow control mode were adopted, the supply water temperature of consumers would be changed with the variation of outdoor air temperature, but the flow rate would not. For consumers keeping design indoor temperature, if temperature of supply water were the same as the above temperature of supply water, the flow rate would be the same as design flow rate, but if temperature of supply water were lower or higher than the above temperature, the flow rate would be increased or decreased. In order to maintain the stability of the flow rates of consumers keeping design indoor temperature, the supply water temperature of consumers under the constant flow control mode should be selected as the target value of supply water temperature of all consumers in the building.

In order to adapt to the variation of heating load and save electricity energy consumed by circulation pump of heat-supply network, variable flow heating system which have the function of self-determination regulating should adopt the control mode combining the constant flow control mode with the variable flow control mode, i.e., the supply water temperature of network should be changed with the variation of outdoor temperature, and the circulation pump of heat-supply network should adopt the method of frequency control of speed to adapt to the flow rate

variation of networks caused by consumers' regulating[3]. So the supply water temperatures of network under the constant flow control mode in the whole heating season should be selected as the target values of supply water temperatures of network.

The supply water temperature of consumers under the constant flow control mode can be expressed as [2]:

$$t_g = t_n + \Delta t_s' \overline{Q}_d^{\frac{1}{1+b}} + 0.5\overline{Q}_d(t_g' - t_h') \qquad (4)$$

The temperatures, t_g, are the target values of supply water temperature of consumers.

There are several relations under the constant flow control mode as follows:

$$\overline{Q}_s = \overline{Q}_d \qquad (5)$$

$$\overline{G}_1 = \overline{G}_z = 1 \qquad (6)$$

From Equations (3), (5), and (6), the temperature t_1 is giving by

$$t_1 = t_g + \overline{Q}_d(t_1' - t_g') \qquad (7)$$

Substituting for the temperatures t_g from Equation (4) gives

$$t_1 = t_n + \Delta t_s' \overline{Q}_d^{\frac{1}{1+b}} + 0.5\overline{Q}_d(t_g' - t_h') + \overline{Q}_d(t_1' - t_g') \qquad (8)$$

From Equations (8), the target values of supply water temperature of network can be attained.

4. CALCULATION OF TEMPERATURES AND RELATIVE FLOW RATES

4.1 Temperatures of Return Water and Relative Flow Rates of Different Consumers

According to the simplified conditions (1) and (2), whether consumers in building regulate indoor temperature or not, the temperatures of supply and return water, and the flow rate, etc. of consumers still conform to the basic adjustment formulas (1). But for consumers regulating indoor temperature, using the arithmetic mean temperature difference in the basic adjustment formulas would lead to big error, so the logarithmic mean temperature difference should be adopted [4].

$$\Delta t_s = \frac{t_g - t_h}{\ln \dfrac{t_g - t_n}{t_h - t_n}} \qquad (9)$$

For consumers regulating indoor temperature, the following equations can be obtained from

Equation (1) and (9):

$$\frac{t_g - t_{hr}}{\ln \dfrac{t_g - t_{nr}}{t_h - t_{nr}}} = \frac{t_g' - t_h'}{\ln \dfrac{t_g' - t_n'}{t_h' - t_n'}} \left(\frac{t_{nr} - t_w}{t_n' - t_w'} \right)^{1/(1+b)} \qquad (10)$$

$$\overline{G} = \overline{G}_r = \frac{t_{nr} - t_w}{t_n' - t_w'} \frac{t_g' - t_h'}{t_g - t_{hr}} \qquad (11)$$

Where t_{hr}, and $\overline{G}_r$ are temperature of return water and relative flow rate of consumers regulating indoor temperature.

Similarly, for consumers keeping design indoor temperature:

$$\frac{t_g - t_{hu}}{\ln \dfrac{t_g - t_n'}{t_h - t_n'}} = \frac{t_g' - t_h'}{\ln \dfrac{t_g' - t_n'}{t_h' - t_n'}} \left(\frac{t_n' - t_w}{t_n' - t_w'} \right)^{1/(1+b)} \qquad (12)$$

$$\overline{G} = \overline{G}_u = \frac{t_n' - t_w}{t_n' - t_w'} \frac{t_g' - t_h'}{t_g - t_{hu}} \qquad (13)$$

Where t_{hu}, and $\overline{G}_u$ are temperature of return water and relative flow rate of consumers keeping design indoor temperature.

Assuming that $t_n' = 18℃$, $t_{nr} = 8℃$, $b=0.3$, $t_g' = 60℃$ and $t_h' = 50℃$, it is possible to derive a series of temperature values of t_g at different outdoor temperatures from Equation (4). Substituting them into Equations (10) and (11) or Equations (12) and (13), the values of $\overline{G}_r$ and t_{hr} or $\overline{G}_u$ and t_{hu} could be obtained.

Tab. 1 Temperatures of supply and return water and relative flow rates of different consumers

$t_w/℃$	$t_g/℃$	$t_{hu}/℃$	$\overline{G}_u$	$t_{hr}/℃$	$\overline{G}_r$
-12	60.00	50.00	1.00	19.58	0.165
-8	55.47	46.81	1.00	16.51	0.137
-4	50.81	43.47	1.00	13.48	0.107
0	45.97	39.97	1.00	10.67	0.076
5	39.60	35.27	1.00	8.21	0.032

From Table 1, it is seen that the temperatures of return water and relative flow rates of consumers regulating indoor temperature are lower much than those of consumers keeping design indoor temperature.

4.2 Temperatures of Mixing Return Water and Total Relative Flow Rates of Consumers

For mixing process of return water from consumers regulating indoor temperature and keeping design indoor temperature, the heat equilibrium

equation is

$$cG_r t_{hr} + cG_u t_{hu} = cG_y t_{hg} \qquad (14)$$

Where $G_y = G_r + G_u$.

In the design working condition, there are

$$G'_y = G'_r + G'_u \qquad (15)$$

$$G'_r = aG'_y \qquad (16)$$

$$G'_u = (1-a)G'_y \qquad (17)$$

From Equations (14) to (17), it follows that

$$t_{hg} = \frac{a\overline{G}_r t_{hr} + (1-a)\overline{G}_u t_{hu}}{a\overline{G}_r + (1-a)\overline{G}_u} \qquad (18)$$

$$\overline{G}_y = a\overline{G}_r + (1-a)\overline{G}_u \qquad (19)$$

Where t_{hg} is the temperature of mixing return water from consumers regulating indoor temperature and consumers keeping design indoor temperature, ℃; $\overline{G}_y$ is the total relative flow rate of all consumers in the building, $\overline{G}_y = G_y / G'_y$.

For a=0, 0.3, 0.5, 0.7, and 1, the following values, as shown in Figures 2 and 3, can be obtained from Equations (18) and (19).
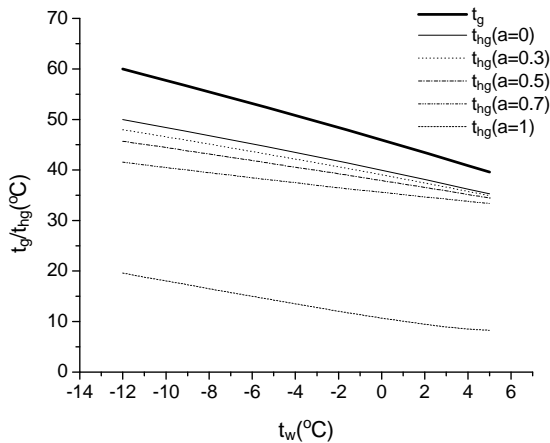

Fig.2 Temperature adjustment curves of supply and return water of consumers regulating indoor temperature
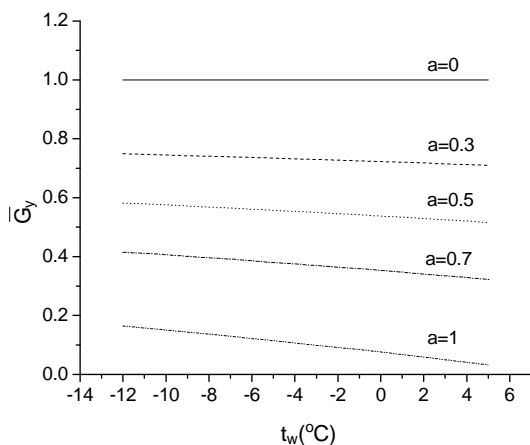

Fig. 3 Flow adjustment curves of consumers regulating indoor temperature

From Figures 2 and 3, it is seen that temperature of supply water, temperature of mixing return water and total relative flow rate of all consumers in the building are all decreased with decreasing of the outdoor temperature. Temperature of supply water at the same outdoor temperature is exclusive, but the temperature of mixing return water and the total relative flow rate decreased sharply with increasing of the proportion of consumers regulating indoor temperature, so the proportion of consumers regulating indoor temperature is the primary factor which affects the temperature of mixing return water and the total flow rate. The variable range of consumers' theoretical flow rate is 3.2 to 100%

4.3 Temperatures of Return Water and Relative Flow Rates of Primary Circuit at Consumer Heat Inlet

For mixing process of return water and by-pass water in the design working condition, the heat equilibrium equation is

$$cG'_p t'_g + cG'_y t'_h = c(G'_p + G'_y)t'_b \qquad (20)$$

Rearranging, the Equation (20) can be written as

$$t'_b = t'_g - (t'_g - t'_h)/(1 + u'_2) \qquad (21)$$

Where $u'_2 = G'_p / G'_y$

For $u'_2 = 0.2$, $t'_b = 51.7$℃ is obtained.

G_1 was changed with the regulating of consumers in the building, but because of the action of the self-operated pressure difference control valve, the mixing pump's flow rate, G_b, did not change, i.e., $G_b = G'_b$, therefore,

$$G_z = G'_z - (1 - \overline{G}_1)G'_1 \qquad (22)$$

In the design working condition, there are following heat equilibrium equation and flow rate equation:

$$G'_1(t'_1 - t'_b) = G'_y(t'_g - t'_h) \qquad (23)$$

$$G'_z = G'_y + G'_p \qquad (24)$$

Combining Equations (22), (23), and (24) gives

$$\overline{G}_z = 1 - \frac{1 - \overline{G}_1}{1 + u'_2}\frac{t'_1 - t'_b}{t'_g - t'_h} \qquad (25)$$

Substituting t_g, t_1 obtained from Equations (4) and (8), and the other known parameters into Equations (2), (3) and (25), the return water temperature of primary circuit at consumer heat inlet, t_b, and relative flow rate, $\overline{G}_1$, can be obtained. The results are shown in Figures 4 and 5.

From Figures 4 and 5, it reveals that the

proportion of consumers regulating indoor temperature is still the primary factor which affect return water temperatures and flow rates of primary circuit at consumer heat inlet, but outdoor temperature has smaller affection to them than the proportion a. The variable range of primary circuit' theoretical flow rate is 26.8 to 100%.
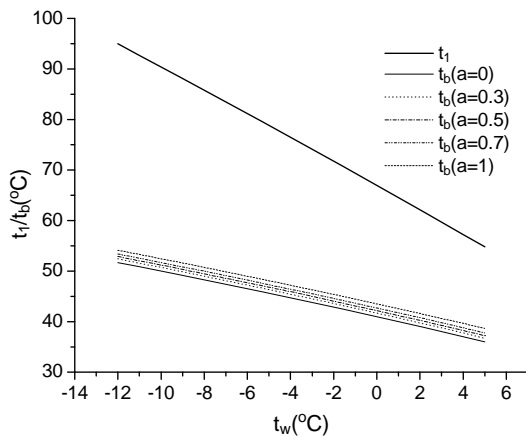

**Fig. 4 Temperature adjustment curves of
supply and return water of primary
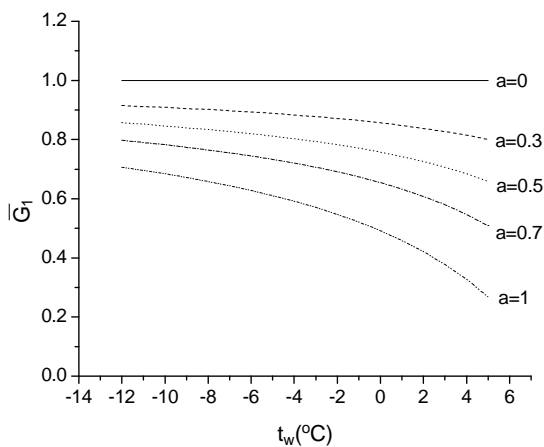circuit at consumer heat inlet**

**Fig. 5 Flow rate adjustment curves of primary
circuit at consumer heat inlet**

5. CONCLUSIONS

1) Adopting water mixing and pressure difference control heating system make the heat-supply network operating in condition of "small circulation flow rate with large temperature difference". Compared with the mode of simple direct connection, this method could save more energy. And the lower the temperature of return water is, the better effect it has.

2) The supply water temperature of consumers

should be changed with the variation of outdoor air temperature by regulating of the electric control valve in order to meet the all consumers' demands for heating in the building. Variation of the outdoor temperature is only the secondary factor that affects the temperature of mixing return water from different consumers, but the change of the proportion of consumers regulating indoor temperature is the primary factor.

3) Supply water temperature of heat-supply network should be changed with the variation of outdoor air temperature in order to meet the all buildings' demand for heating. Change of return water temperature of network not only relates to the outdoor temperature but also to the proportion of consumers regulating indoor temperature.

4) For water mixing and pressure difference control heating system, the proportion of consumers regulating indoor temperature is the primary factor that affects network's flow rate and consumers' total flow rate, and the outdoor temperature is the secondary factor.

5) Water mixing and pressure difference control heating system can keep the total pressure difference of all consumers in the building invariable, and so hydraulic stability of consumers in the building can be improved.

REFERENCES

[1] Yi Jiang. Problems in improvement of central heating systems in China and possible solutions[J]. Heating Ventilating & Air Conditioning, 2006, 36(3): 37-41.

[2] Ping He and Gang Sun. Heating Engineering[M]. Beijing: China Architecture & Building Press. 1993, 140-143.

[3] Guobing Zhou et al.. Adjustment of indirect variable-flow heating systems[J]. Heating Ventilating & Air Conditioning, 2004, 34(7): 43-47.

[4] Jianxing Li, Guangbei Tu and Yi Wang. Employment of flow adjustment formulas in heat metering systems[J]. Heating Ventilating & Air Conditioning, 2001, 31(6):112-114.