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Research on Optimized Energy Saving Control System of VAV Air Conditioning System

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Abstract: VAV air conditioning system has complex structure, huge scale, many variables, strong coupling and various uncertainties. The traditional automatic control methods adopt the method that the controlled parameters of the system are fixed, which can satisfy the stable operation of the system, but it will bring a great waste of energy. In this paper, the optimization objectives and constraints to minimize energy consumption are proposed, and the optimization model of central air conditioning system is established. The optimization objective of VAV is minimum energy consumption.It can meet the comfort and stability, reduce the energy consumption of the system and achieve the best energy-saving effect.

1. VAV air conditioning description

Variable air volume (VAV) air conditioning system is a kind of all-air conditioning system, which is widely used at home and abroad. It can adjust the air supply according to the actual needs of the system. It can change the air condition parameters in the building by changing the air flow into the air conditioning area to maintain indoor comfort. Variable air volume air conditioning system has complex structure, huge scale, many variables, strong coupling and various uncertainties. The traditional automatic control methods adopt the method that the controlled parameters of the system are fixed, which can satisfy the stable operation of the system, but it will bring a great waste of energy.There are many controllers in the system, and they are independent and dispersed. So, it is difficult to achieve global optimization control.[1]-[3]. This paper designs a control method to minimize the energy consumption of VAV air conditioning system as the optimization objective, so that it can meet the comfort and stability, while reducing the energy consumption of the system to achieve the best energy-saving .

2. Working principle of VAV air conditioning system

VAV air conditioning system mainly includes cooling towers, chillers, air handling units and terminal areas. It can be divided into three interrelated parts: the water system, the wind system and the terminal system. The end system adjusts the temperature of the environment by changing the amount of air which sending to the air conditioning area. The air system including filtration, temperature and humidity treatment, and also provides the motive power for air circulation. The chilled water system transfers the cooling capacity to the air treatment system, transfers the heat in the chiller, transfers the heat to the cooling water, and eventually releases the heat of the cooling water into the atmosphere

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through the cooling tower.Its working principle is shown in Figure 1.

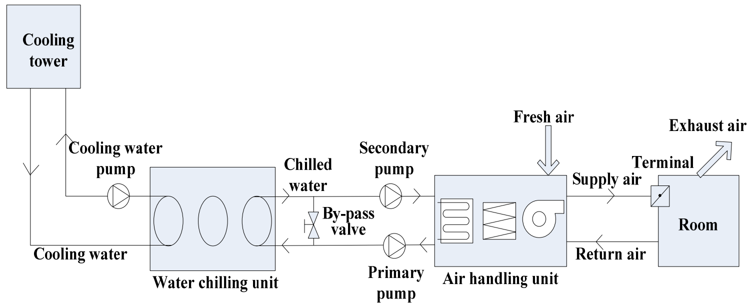

Fig. 1 Schematic diagram of VAV air conditioning system

3. Energy saving optimization of VAV air conditioning system

Steady-state optimization of air conditioning system is to find the optimal combination of dynamic parameters under the condition of satisfying process constraints, so that the desired objectives (energy consumption, air quality, comfort) can be optimized[4]-[6].

3.1. Optimization goal

The optimization objective of the air conditioning system is to minimize the energy consumption of all the equipment on the comfort requirements of the system[7]-[9].

$$\min P = P_{ch} + P_{chwp1} + P_{chwp2} + P_{fan} + P_{cw} + P_{ctf} \tag{1}$$

Among them P 、P_{ch} 、P_{chwp1} 、P_{chwp2} 、P_{fan} 、P_{cw} and P_{ctf} respectively, the total energy consumption of the system, chiller energy consumption, chilled water primary pump energy consumption, chilled water secondary pump energy consumption, air treatment unit fan energy consumption, cooling tower fan energy consumption and cooling water pump energy consumption. Because the system does not use frequency conversion control for cooling tower fan and cooling water pump, the sum of energy consumption $P_{cw}+P_{ctf}$ is considered to be a fixed value, which can not be considered in optimization.

When the chiller is running, if the change of cooling water temperature is neglected, the energy consumption of the chiller can be expressed as follows:

$$P_{ch} = Q_{nom} \cdot COP_{nom} \cdot (a_0 + a_1 \frac{Q_{ch}}{Q_{nom}} + a_2 \frac{Q_{ch}^2}{Q_{nom}^2}) \cdot (b_0 + b_1 T_{chws} + b_2 T_{chws}^2) \tag{2}$$

Among them, Q_{nom} and COP_{nom} are the nominal refrigeration capacity of a unit and the energy efficiency ratio under full load, which Q_{ch} is the actual refrigeration capacity of the unit and T_{chws} is the return water temperature of the chilled water of the unit. a_i and b_i ($i = 0,1,2$) are constant coefficients.

For variable frequency refrigeration pump and air supply fan, the output power of the pump is monotonic with the refrigerated water mass flow, and the output power of the air supply fan is monotonic with the air mass flow, so the model structure is the same.

The energy consumption of chilled water primary pump is as follows:

$$P_{chw1} = P_{chw1,nom} \cdot (c_0 + c_1 \frac{m_{chw}}{m_{chw1,nom}} + c_2 \frac{m_{chw}^2}{m_{chw1,nom}^2}) \tag{3}$$

The energy consumption of the secondary pump of chilled water is as follows:

$$P_{chw2} = P_{chw2,nom} \cdot (d_0 + d_1 \frac{m_{chw}}{m_{chw2,nom}} + d_2 \frac{m_{chw}^2}{m_{chw2,nom}^2}) \tag{4}$$

Among them, $P_{chw1,nom}$, $P_{chw2,nom}$ and $m_{chw1,nom}$, $m_{chw2,nom}$ are the theoretical power consumption value of the primary and secondary pumps and the theoretical flow value of the frozen water at full load. m_{chw} is the actual flow for chilled water. c_i and d_i ($i = 0,1,2$)are constant coefficients.

The energy consumption of the air supply fan is expressed as:

$$P_{fan} = P_{fan,nom} \cdot (e_0 + e_1 \frac{m_a}{m_{a,nom}} + e_2 \frac{m_a^2}{m_{a,nom}^2}) \tag{5}$$

Among them, $P_{fan,nom}$ and $m_{ah,nom}$ are the theoretical power consumption and the theoretical flow value of the air supply fan under full load condition are respectively. m_a is the actual discharge value for the air. e_i ($i = 0,1,2$)is a constant coefficient.

3.2. constraint conditions

In the process of energy-saving optimization of central air-conditioning system, some physical constraints of the system itself and the relationship between energy, mass and pressure balance of the system should be considered. The central air-conditioning system optimization constraints are:

(1) The cooling water flow rate of the refrigerator, the air flow rate of the air supply fan and the air flow rate of the terminal room should satisfy the following restrictions:

$$m_{chw,\min} \le m_{chw} \le m_{chw,\max}, \quad m_{a,\min} \le m_a \le m_{a,\max}, \quad m_{ar,\min} \le m_{ari} \le m_{ar,\max} \ (i = 1,2,3,4)$$

Among them, $m_{chw,\max}$ 、 $m_{chw,\min}$ are the maximum and minimum value of chilled water flow. m_a 、 $m_{a,\max}$ 、 $m_{a,\min}$ are the supply air volume and its maximum and minimum. m_{ari} 、 $m_{ari,\max}$ 、 $m_{ari,\min}$ are the end room air flow and its maximum and minimum.

(2) The relationship between cold mechanism cooling capacity and chilled water flow rate is:

$$Q_{ch} = m_{chw} \cdot C_{ahw} \cdot (T_{chws} - T_{chwr}) \tag{6}$$

Among them m_{chw} 、 C_{ahw} and T_{chwr} are chilled water flow, chilled water specific heat capacity and cooling water supply temperature.

(3) The return water temperature and the air supply temperature of the refrigerator should be satisfied:

$$T_{chws,\min} \le T_{chws} \le T_{chws,\max}; \quad T_{a,\min} \le T_a \le T_{a,\max} \tag{7}$$

(4) The minimum air flow in the terminal room is satisfied:

$$m_{ari,\min} = \frac{W_i}{C_a \cdot (T - T_a)} \tag{8}$$

Among them, W_i 、 T 、 C_a are room load, room setting temperature and air specific heat.

(5) According to the principle of mass conservation, the air supply volume is approximately satisfied:

$$m_a = \sum_{i=1}^{4} m_{ari} \tag{9}$$

(6) According to the principle of energy conservation of surface cooler, the heat loss of air and the heat gain of cold water are approximately equal.

$$m_a \cdot (h_2 - h_1) = m_{chw} \cdot C_{ahw} \cdot (T_{chws} - T_{chwr}) \tag{10}$$

Among them, h_2 and h_1 are the enthalpy of air before and after passing through the surface cooler.

(7) According to the law of conservation of energy, the total air flow rate after mixing should be equal to the sum of the two air flows before mixing; according to the principle of heat balance, the total air heat after mixing should be equal to the sum of the heat of the two air before mixing.

$$h_2 = (1\text{-}\alpha) \cdot h_r + \alpha \cdot h_o \tag{11}$$

Among them, h_r 、 h_o and α are the air return enthalpy value, the fresh air enthalpy value and the fresh air volume accounted for the percentage of air supply volume.

3.3. optimization process

The flow chart of real-time optimization is shown in Figure 2

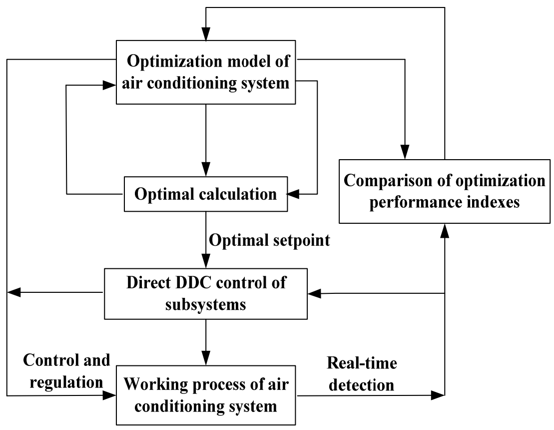

Fig. 2 Real-time optimization flow chart of VAV air conditioning system

As can be seen from the flow chart, for the optimal control of VAV air conditioning system, the optimization model of the system should be determined firstly, including the determination of optimization objectives, optimization constraints and so on. According to the optimization model, the setting values of each control loop can be obtained. For each subsystem, adaptive control can be done according to the optimized setpoint. The system adopts different adaptive methods according to different control loops, and adds the control to the actual system, and then measures the actual parameters through sensors. These parameters are fed back into the optimization model and compared with the performance indicators of the optimization objectives to see if the optimization objectives are met. This optimization process is repeated, every once in a while to optimize, this time is called an optimization cycle[10].Because each optimization will produce new settings and add them to the control loops, in order to prevent strong oscillations and even instability of the system, it is required to gradually add the settings to the VAV air conditioning control system.

4. Simulation and experimental analysis

The energy consumption of the central air-conditioning system is simulated and experimented to verify the energy-saving effect of optimizing the dynamic parameters of the system. According to the objective function of system optimization, the variables to be optimized are chilled water flow, chilled water temperature and air flow. The constant values of the optimization equation are fitted by experiments. The equality constraints and inequality constraints are written as standard form. The upper and lower limits of inequality constraints are determined by the device itself. Set the initial point and iterate, repeat the above iteration until the optimal solution is obtained.

The water supply temperature of the refrigerator and the room temperature were set at 7.5℃ and 26℃, respectively, from 8:00~20:00 in summer. According to the indoor comfort requirement, the minimum fresh air percentage is 15%. During the one-day operation of air-conditioning, the cooling load in the air-conditioning area is constantly changing due to the changes of indoor personnel flow, outdoor temperature and indoor heat source, so the optimized variable values are also different. Because the working point of dynamic parameters changes too frequently, the stability of the system will be affected, so set 60 minutes as a single optimization process, get a set of optimization variables. Because the optimized variables are controlled by dynamic parameters such as the pressure difference between refrigerated water supply and return water and the static pressure of air supply pipeline , a set of dynamic parameters are obtained after each optimization. The optimized dynamic parameters can vary with the load. Therefore, the optimized central air-conditioning system can be adjusted with the change of load, not only the air supply can be adjusted by variable air volume, but also the refrigerated water can be adjusted by variable air flow.The optimization parameters of air conditioning system are shown in Table 1.

Tab.1 The optimization parameters of air conditioning system

	Time(h)												
	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
Tchws(°C)	12	12	12	12.5	12	12	12	13	13	13.5	13	12	12
DP(MPa)	0.036	0.046	0.0563	0.0598	0.0621	0.065	0.066	0.069	0.066	0.063	0.059	0.046	0.041
SP(Pa)	125.1	160.1	196.55	208.55	216.74	227.5	231.6	241.1	231.1	219.7	206.1	160.9	141.5

The energy consumption of the air conditioning system optimized by the optimization algorithm is compared with that of the fixed flow method as shown in Figure 3.

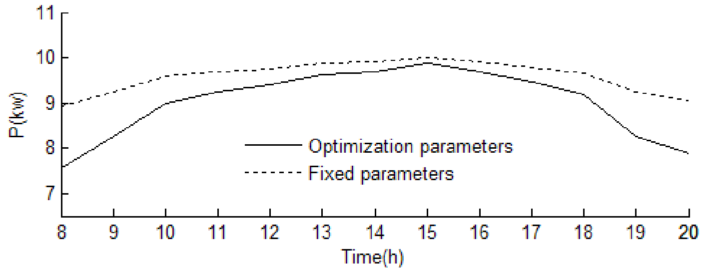

Fig. 3 Comparison diagram of air conditioning system energy consumption

From Figure 3, we can see that the total energy consumption of the optimized parameter algorithm is 117.06kw.h. If the fixed parameter method is adopted, the total energy consumption is 124.568kw.h. It can save 6.41% of the system energy consumption.

5. Conclusion

By analyzing the composition and characteristics of the actual central air-conditioning system, this paper presents the optimization and constraints to minimize energy consumption, and establishes the optimization model of the air-conditioning system. The optimal operating condition of the air conditioning system is found by optimizing calculation, and the optimal dynamic parameter operating value is obtained to minimize the energy consumption of the air conditioning system. Through automatic adjustment, the central air-conditioning system can achieve energy saving optimization. Simulation and experiment show that this method can effectively reduce the operation energy consumption of the VAV air conditioning system.

Acknowledgments

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