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Optimal Control of Central Air-conditioning Implement Energy-saving

Qiuxin Liu[1, A],Qianjun Lang[2,B] And Fen Chen[3,C]

[1]College of Urban Construction, Wuhan University of Science and Technology, Wuhan, China

[2]Collegeof Urban Construction,Wuhan University of Science and Technology, Wuhan, China

[3]College of Urban Construction, Wuhan University of Science and Technology, Wuhan, China

[a]15671675652@163.com, [b]350704866@qq.com, [c]894034012@qq.com

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Abstract. Establishing the mathematical model of energy consumption of chillers, pump, cooling towers, air conditioning units and coils in the conventional air conditioning system. Analyses energy consumption factors from experiments and simulations to provide the optimized variable flow scheme for the whole central air conditioning system to fit the Load dynamic change. Utilized fuzzy *pid* control and advanced self-adaptive fuzzy *pid* control to maximize energy saving with these more precise and effective control techniques.

Introduction

In the actual *hvac* system, most of the system time is in a partial load state of operation, hot and cold water units, pumps, controllers and other dynamic characteristics in the course of running is also changing, cause the energy consumption of the system in the actual operation of waste, central air conditioning system as the main energy consumption of the building part, it is necessary to find an optimal control method to facilitate the implementation of the centralized air conditioning system in all aspects of the overall optimization of energy-saving control technology that enables the system to adapt to dynamic changes in load, of energy saving. In the optimal control, the performance parameters of the equipment are generally difficult to be set in advance, and the operating parameters of the equipment are mutually influential and mutually restricted, so that it is hard to be optimized by mere experience and simple calculation. which is difficult to be optimized by experience and simple calculation.

This article adopts the method of theory combined with identification method , and in this paper, the most common central air conditioning system is analyzed by the combination of theory and identificationthe establishment of various equipment, establish the energy consumption model of each equipment [1]:chiller model, circulating pump model, cooling tower model, air conditioning unit model , fan coil model and boiler model. The model analyzes the energy consumption from the theoretical and the simulation point of view, puts forward the reasonable control strategy of each link, and coordinates the control strategy of each air conditioning link to realize the overall energy saving of the central air conditioner.

Equipment energy consumption model

Chiller model

The mathematical model of chillers established in this paper is the performance curve model, which consists of cooling capacity curve(*chillercapft*), *eir* and running state relationship curve (*chillereirft*),*eir* and partial load rate curve (*chillereirfplr*).

The cooling capacity curve is the curve of the maximum cooling capacity of the chiller with the temperature of the cooling water and the temperature of the chilled water. This curve is a secondary performance curve. The output of the curve is multiplied by the nominal cooling capacity of the chiller to obtain a full temperature at a given temperature.

$$ChillerCapFT = a_1 + b_1(\mathrm{T}_{e1}) + c_1(T_{e1})^2 + d_1(T_{c1}) + e_1(T_{c1})^2 + f_1(T_{e1})(T_{c1}) \quad (1)$$

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Eir is the reciprocal of *cop*, which represents the ratio of shaft power to cooling capacity. The *eir* and running state relationship curve are defined as the relationship between *eir* and chilled water outlet temperature and cooling water inlet temperature at maximum load, the curve is also a quadratic curve. The result of this curve is multiplied by the chiller *eir* to obtain the maximum load *eir* value at the given temperature of the chiller.

$$ChillerEIRFT = a_2 + b_2(T_{e1}) + c_2(T_{e1})^2 + d_2(T_{c1}) + e_2(T_{c1})^2 + f_2(T_{e1})(T_{c1}) \quad (2)$$

The relationship between *eir* and partial load rate is the curve of *eir* changes with different load changes. The result of this curve is multiplied by the full load energy consumption of the unit in the specific chilled water outlet temperature and the cooling water inlet temperature. Energy consumption at a given part of the load rate.

$$ChillerEIRFPLR = a_3 + b_3(PLR) + c_3(PLR)^2 \quad (3)$$

Mathematical model of power consumption of chiller:

$$\begin{aligned} P_{chiller} &= (\frac{Q_{avail}}{COP})(ChillerEIRFT)(ChillerEIRPLR) \\ &= \frac{Q_{ref}}{COP_{ref}}(ChillerCapFT)(ChillerEIRFT)(ChillerEIRPLR) \end{aligned} \quad (4)$$

Where $P_{Chiller}$ - chiller power, kW;

C_{OPref} - chillers nominal *cop* value;

Q_{ref} - chillers nominal cooling capacity, kW;

Q_{avail} - chillers maximum cooling capacity, kW;

T_{e1} - chilled water outlet temperature, ℃;

T_{c1} - cooling water inlet temperature, ℃;

a, b, c, d, e, f - model coefficients.

Circulating pump model

A model of power of pump variable flow:

$$N = c_0 + c_1 V + c_2 V^2 + c_3 V^3 \quad (5)$$

Where N - the pump after the flow of power, kW;

V - pump flow, m^3/s;

c_0, c_1, c_2, c_3 - pump model factor.

Cooling tower model

The mathematical model of cooling tower energy consumption model [2] is:

$$P_t = \frac{k_c h c \Delta t}{e_a \Delta h} \quad (6)$$

Where k_c - cooling tower fan operating coefficient.

In order to simplify the calculation and guarantee the higher model accuracy, the mathematical expression of the energy consumption model of the cooling tower is obtained. The quadratic polynomial of the cooling tower power and the cooling water pump flow is expressed as follows:

$$P_t = 0.1554 + 83.7279 V_c + 69.8978 V_c^2 \quad (7)$$

Air conditioning unit model

The mathematical expression of the energy consumption model of the air conditioning unit is shown in the following equation [2]:

$$P_k = F_x + F_h = Q f_k = 0.051Q \quad (8)$$

Where Q - the actual energy consumption of chillers;

F_k - air conditioning unit integrated unit of cold power consumption;

F_x - energy consumption of new air units;

F_h - energy consumption of return air unit.

Fan coil model

The energy model of the fan coil is expressed as follows:

$$P_{fan} = f_{fan}Q = 0.016Q \tag{9}$$

Where f_{fan} - fan coil unit of the cold power consumption;

Q - actual cooling capacity of chillers.

Boiler model

The relationship between boiler energy consumption and heat load can be expressed by the following equation:

$$P_g = g_0 + g_1Q_r + g_2Q_r^2 + \cdots + g_nQ_r^n \tag{10}$$

Where Q_r - boiler heat load, kW;

P_g - boiler energy consumption or fuel consumption, kW;

g_0, g_1, g_2, ..., g_n - boiler model coefficients.

Model experiment analysis

For the more complex chillers and pump energy consumption model, this paper is also through the experimental fitting energy consumption analysis.

Energy consumption analysis of chiller model

This paper selects GeLi LH series screw water chillers (R22), model LSBLG HR 780.

Table 1 Parameter table of chiller performance

chilled water outlet temperature (℃)	cooling water inlet temperature (℃)								
	25			28			30		
	cooling capacity	input power	*eir*	cooling capacity	input power	*eir*	cooling capacity	input power	*eir*
5	0.998	0.897	0.899	0.954	0.950	0.996	0.931	0.987	1.060
6	1.031	0.903	0.876	0.992	0.958	0.966	0.965	0.992	1.028
7	1.074	0.911	0.848	1.030	0.963	0.935	1.000	1.000	1.000
8	1.118	0.918	0.821	1.068	0.971	0.909	1.035	1.008	0.974
9	1.163	0.926	0.796	1.108	0.982	0.886	1.071	1.016	0.949

The data of the two quadratic complete regression models were obtained by *matlab*, the cooling capacity curve (*chillercapft*) relationship is:

$$\begin{aligned} ChillerCapFT &= 0.945 + 0.0737(T_{e1}) + 0.000557(T_{e1})^2 - 0.00659(T_{c1}) \\ &+ 0.0000415(T_{c1})^2 - 0.00157 f_1(T_{e1})(T_{c1}) \end{aligned} \tag{11}$$

The relationship between *eir* and running state curve (*chillereirft*):

$$\begin{aligned} ChillerEIRFT &= 0.641 - 0.0394(T_{e1}) + 0.000729(T_{e1})^2 + 0.00639(T_{c1}) \\ &+ 0.000434(T_{c1})^2 + 0.0000845(T_{e1})(T_{c1}) \end{aligned} \tag{12}$$

The relationship between *eir* and partial load rate curve (*chillereirfplr*):

$$ChillerEIRFPLR = 0.189 + 0.357(PLR) + 0.454(PLR)^2 \tag{13}$$

Using *matlab* programming can draw the performance curve of the input and output relationship of the three-dimensional map.

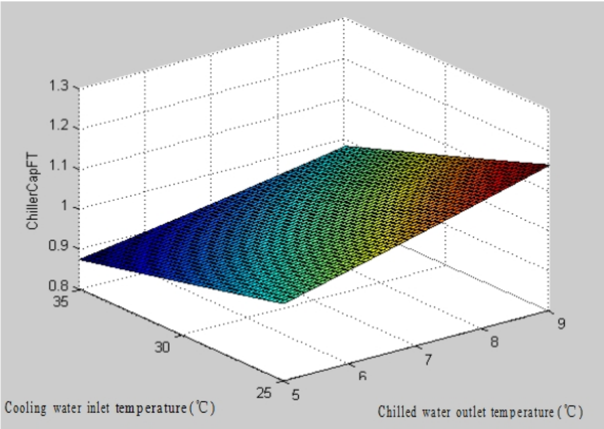

Fig.1. The relation between the cooling water inlet temperature and the water inlet temperature of cooling water is the relative maximum refrigerating quantity

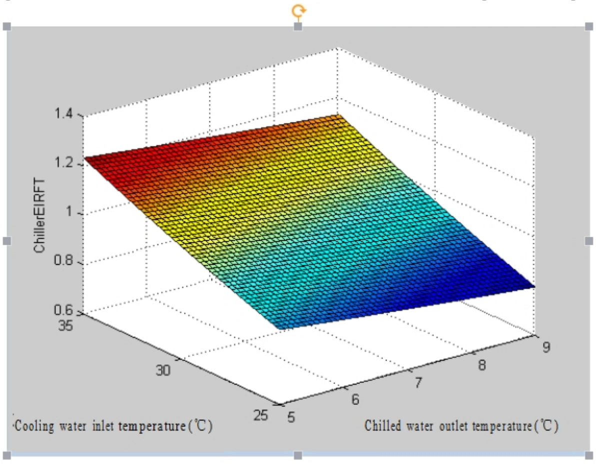

Fig.2. The relationship of *eir* with water inlet temperature of chilled water and cooling water inlet temperature (*chillereirft*)

Fig.1 shows the relationship between the maximum cooling capacity and the temperature of the chilled water and the water temperature of the cooling water when the chilled water unit is in the maximum cooling capacity. It can be seen from the figure that the relative maximum cooling capacity increases with the decrease of the cooling water temperature and the increase of the freezing water temperature. Through this performance curve, the chilled water temperature and the cooling water temperature can be completely corrected according to the system demand, The final choice of the appropriate chillers, to avoid the election of chillers is too large, the occurrence of "big mara trolleys" situation, resulting in a waste of energy.

In Fig.2, the *eir* decreases with the increase of the temperature of the chilled water and the *eir* of the cooling water decreases at the maximum cooling capacity. The *cop* is the reciprocal of the *eir*, and the *cop* is gradually increased;also else.

It is well known that the capacity of the chiller is determined by the load on the design conditions. In fact, most of the chillers run under partial loads and rarely run at full capacity, so we are more concerned with partial loads Performance of chillers.

It can be seen from Fig.3 with the part of the load factor increases, the relative power consumption of the chiller gradually increased.

It can be seen from Fig.4 that under the high load rate, the *cop* value is not very large, and the lower the load rate is less than 70%, the faster the *cop* decreases. The cold water chiller has the largest *cop* value when the load factor is 70%. The *cop* of the chiller is relatively high at 40% ~ 100% of the load.

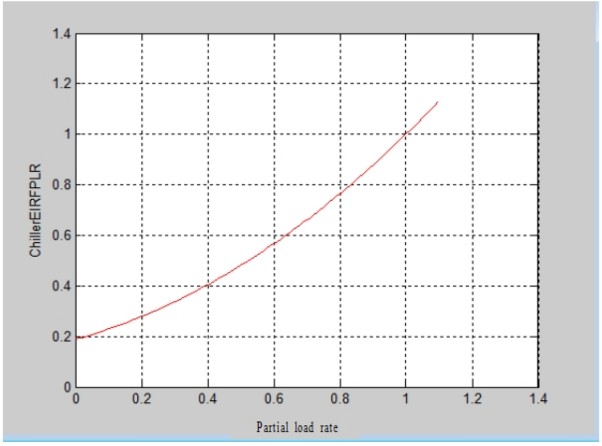

Fig.3.The graph of the relationship between *eir* and partial load

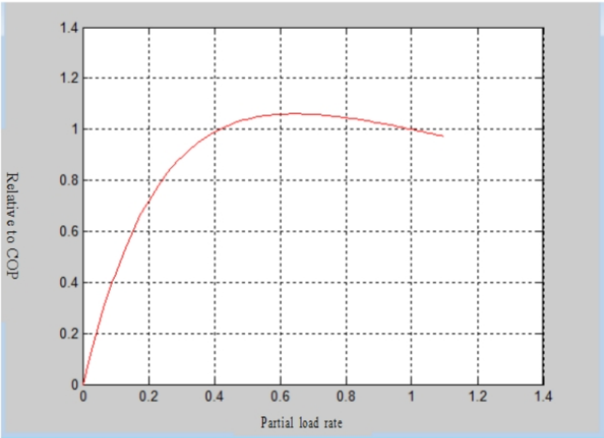

Fig.4. The graph of the relationship between relative *cop* and partial load rate

Pump model energy consumption analysis

This paper chooses the KTB125-100-260 type pump produced by Changsha Canon Pump Limited Company, and uses the interpolation function in *matlab* to fit and obtain the model expression of the cooling water pump as follows:

$$N_c = -0.6589 + 0.3041V_c - 0.0069V_c^2 + 0.0002V_c^3 \quad (14)$$

The measured value of the cooling water pump is compared with that of the three polynomials of P valued by the proposed curve. The two have high degree of overlap, and the fitting curve is more accurate, as shown in Fig.5.

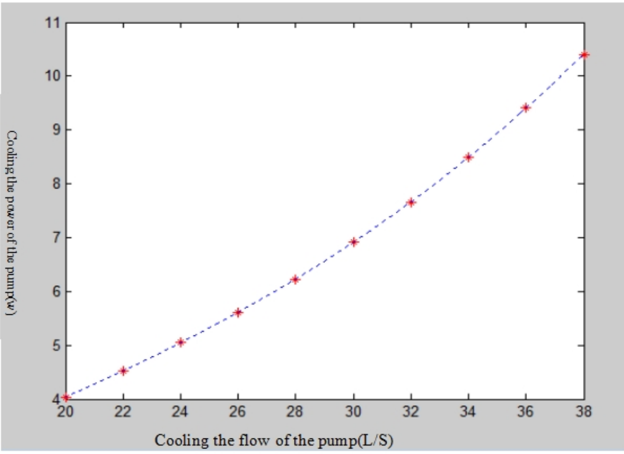

Fig.5.The performance curve of the cooling water pump frequency regulation

From the cooling pump frequency adjustment performance diagram shows that with the pump flow increases, the power also increases, and vice versa; by the slope of the curve is growing, we can see that when the flow is reduced, the power reduction rate is greater , Energy-saving effect is more obvious, therefore, the pump frequency conversion energy by the great potential.

The chilled water model is similar to the cooling water model, and the pump power decreases with the decrease of the flow rate, and the energy saving potential of the variable flow operation is remarkable.

Simulink simulation

Simulated by the Simulink model simulation[3], and then the establishment of the chiller energy consumption simulation module, chilled water system simulation module, cooling water simulation module and the wind system simulation module in accordance with the law linked to the establishment of the central air conditioning system Simulation module, the energy consumption of air conditioning system under different variables is obtained.

The simulation results are shown in Fig.6. In the simulation results, there are the central air conditioning system total energy consumption, chiller energy consumption and air conditioning load curve. Then the following conclusions are:

(1) The air conditioning load of the building is changing with time, and the central air conditioning energy consumption and air conditioning load is closely related to the air conditioning load increases, the system energy consumption increases, air conditioning load decreases, thesystemenergy consumption also of the reduction, indicating that the role of variable flow, the system can be a very good energy consumption with the load changes.

(2) The central air conditioning system, the chiller energy consumption accounts for about60% of the total energy consumption of the system, consistent with the actual system.

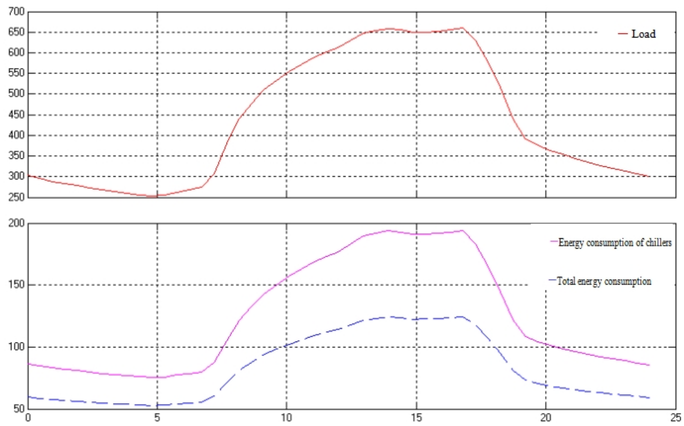

Fig.6. Global energy consumption simulation curve of central air-conditioning

In the conventional flow rate of the water system, the cooling water pump, the chilled water pump and the cooling tower are basically operated at the rated flow rate, and the energy consumption of the three is basically the same. Fig.7 compares the energy consumption of the fixed flow rate and the variable flow rate of the water system Figure.

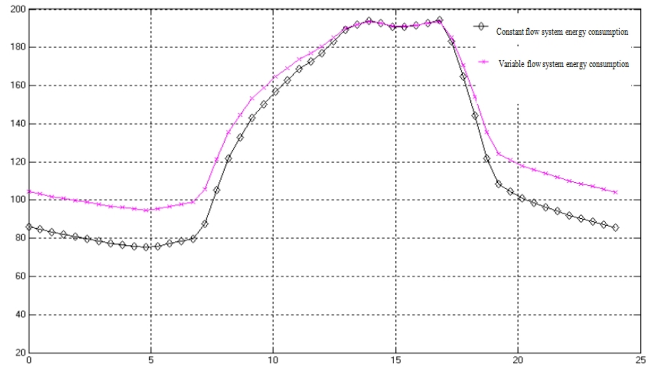

Fig.7. The energy consumption comparison diagram of the steady flow system and variable flow system

Analysis of the above chart can draw the following conclusions:

(1) By adopting variable flow energy-saving technology and optimize the control of air-conditioning energy consumption significantly better than the fixed-flow system of air-conditioning energy consumption is small, about 10% energy saving.

(2) When the air conditioning load reaches the maximum value, and the equipment selection is reasonable, the variable flow system and the constant flow system energy consumption difference is not, the system is running at full capacity. In some of the load when the variable flow system energy saving is more obvious.

Optimize the control strategy

By establishing and analyzing the model of energy consumption, combining with the variable flow technology, the variable flow control scheme of the central air conditioning system is put forward. At the same time, the control mode of the variable air volume is used to adapt to the dynamic change of the load and the control form of every step is optimized in order to obtain the maximum efficiency of energy. Of the control form, so as to achieve maximum energy efficiency.

For the chilled water system using temperature control [4], the use of "feedback control", "feedforward control", "adaptive control" combined with the control mode, with the load to achieve energy-saving operation control. "Feedback control" determines whether the chiller is loaded or unloaded, "feedforward control" determineswhether the chiller loading or unloading amplitude, "adaptive control" can effectively prevent chillers frequent shutdown.

The joint use of cooling water flow control and cooling tower fan frequency control joint, the cooling tower not only guarantees the unit's cooling water inlet temperature, but also ensures that the cooling water flow control when the import and export temperature unchanged. This achieves the maximum potential of saving energyfor water pumps and fans and reduces the energy consumption of cooling water system. The maximum energy savings potential, reducing the cooling water system energy consumption.

Cooling tower of the frequency control method is to control the cooling water inlet temperature, usually set to 32℃. When the cooling water inlet temperature is greater than the set value, the heat transfer and the speed of the cooling tower fan, heat transfer increased. The water temperature gradually decreases to the set value and a new equilibrium state is established. When the cooling water inlet temperature is less than the set value, the control system reduces the cooling tower fan speed, decreases heat transfer; the cooling water temperature gradually rises to the set value, and then re-establish a new balance. When the load is small to a certain value, the cooling water flow decreases, the cooling water inlet temperature is lower than the set value and continued to decline, when the cooling tower fan speed is very low as 20Hz, the direct stop cooling tower fan, When the water temperature rises to the set value, the fan starts again. As the cooling tower energy consumption compared with the pump is relatively small, generally more than one cooling tower fan only need to configure a frequency converter, which can ensure that the fan are running at the same frequency, cooling effect is good, and will not increase the investment of many inverters cost.

Also in the central air conditioning system using pumps and fans frequency adjustment, in saving a lot of energy, can also significantly reduce the motor running noise, no special requirements without special noise reduction measures.

In this paper, an improved method based on fuzzy *pid* control[5] and improved adaptive fuzzy *pid* control is proposed, which makes it possible to control the fuzzy control rules in the control process. In this paper, we propose a new method to improve the fuzzy *pid* control. Automatic adjustment and improvement, the system control performance can also continue to be improved to achieve precise control results.

Conclusion

In this paper, energy consumption is analyzed by experiment and simulation, and the control strategy of variable flow control and end variable air volume control scheme of central air conditioning system is put forward to realize the operation and energy saving of air conditioning.

1. Chilled water system. Chilled water using temperature control, the integrated use of "feedback control", "feedforward control", "adaptive control" combination of control methods to achieve chilled water system energy efficiency and stable operation.

2.Cooling water system. The use of cooling water flow control and cooling tower fan frequency control in combination with the way to achieve the maximum energy saving potential of pumps and fans to reduce the cooling system energy consumption.

3.End variable air volume control. The principle of air volume regulation is that the air volume can follow the load changes and change, so as to achieve energy saving.

4. The entire control system uses fuzzy *pid* control and improved adaptive fuzzy *pid* control, to achieve more accurate and effective control, in order to achieve energy efficiency.

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