Energy consuming control of building based on fussy temperature control

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Abstract

Energy saving is an hot topic recently as the energy crisis is more and more serious. Among the energy consumer of the world, building is often ignored by many people. Nowadays many researchers noticed that research on the energy saving of building is meaningful, especially the research on the energy saving of air-conditioning. As the energy consuming of air-conditioning is very significant. Traditional control method of air-conditioning is based on PID. In the paper, fussy control is introduced and applied in the air-conditioning control, the result shows that response speed and accuracy of fussy controller are significantly better than PID controller.

Keywords: Energy consuming, Public building, Temperature adjustmen, Air conditioner

1 Introduction

Energy is vital important in the society, as nowadays large amount of energy are consumed everyday. It makes energy become the focus of the world recently. A large number of investigations carried out on energy. One of investigation statistics the energy consumption in different areas. The statics shows that three of the largest energy consumers are industry, transport and agriculture [1]. Table 1 shows the energy index of the world in 1973 and 2012.

TABLE 1 Energy index of world

Parameter	1973	2012	Ratio/%
Population(million)	3938	6352	64.3
GDP(G$ year)	14451	35025	142.4
Per capita income	3670	5514	50.2
Primary energy(Mtoe)	6034	11059	83.3
Final energy(Mtoe)	4606	7644	66.0
Electrical energy(Mtoe)	525	1374	161.8
Per capita Primary energy(toe)	1.53	1.77	15.7
Per capita CO_2 emitions(ton)	3.98	4.18	5.0
Primary energy intensity	418	316	-24.4
Primary energy intensity	319	218	-31.5

With the growth of population and development of the economic, the rate of consumption of fossil fuels increase more and more fast. With the depletion of fossil fuels, energy crisis has become a hot topic recently. So energy saving becoming an important goal of the world now. Among the energy consumer, buildings often is ignored by many people. Actually buildings are one of the largest energy consumers in the world [3].

Due to the increasing use of unitary air-conditioners, there has been a substantial increase in electricity consumption during summer. Therefore, the use of better control techniques for steady temperature control and energy saving has become a major topic in the study of air-conditioning systems [4]. Most research on power savings regarding air conditioners are focused on large/medium-sized chillers as the subject. The control units include; cooling tower, compressor, and fan coils. The amounts of energy savings range from 6% to 13%. While there is little researches focused on unitary systems for energy saving controls. Small-sized shops, offices, laboratories and classrooms generally use 2–3 unitary systems, such as window or split type air-conditioners, for their main air-conditioning devices. Unitary systems are mass-produced by manufacturers, therefore, low production cost, steady performance, low installation fees, and low operational cost, with proper control settings, are the reason unitary systems are now widely used [5]. Unitary systems mainly use the ON/OFF method as temperature control, which causes unstable room temperatures. The changes in room temperatures, from various unitary systems working at the same time, create large surges in energy consumption; therefore, energy crisis related to the buildings is defined with regard to occupant thermal comfort, energy savings and temperature control.

Daily maximum load chillers and pumps of air conditioning systems are selected according to the size of the maximum design load of pipes currently. But the air conditioning system running at full capacity in a relatively short time actually, and most of the time it is at part load. Due to the strong nonlinear characteristics air conditioning systems such as time-varying, large inertia, large lag, strong interference, etc. The classic means of control or PID control can not meet the control demand of air conditioning systems. Considering that the fuzzy control technology is fit for all types of non-linear, strong coupling, uncertainty, variable time-varying complex system. And it has been widely used in various control areas, and achieved good control effect. An air conditioning temperature control system based on fuzzy control is studied in the paper, the result shows that the result is very good.

2 Classic AIR-Conditioner Temperature Adjustment Methods

Air conditioning is a complex system more than just cool down the rooms of building. Actually it includes dehumidifying, cleaning (filtering), and circulating the air. A complete air conditioning system perform all of the functions above, not oily cool down the room. As the air conditioning system is so big, there are a lot of dynamical variables and nonlinear variables [6]. So it very hard to find a simple and fit mathematical model to describe air conditioning, which make design a good control system for air conditioning becomes a challenging work.

Two main classical controllers used in air conditioning control are two-position control (on/off) and PID (proportional-integral-derivative) control.

On/off control is one of the oldest techniques that is practiced in buildings for the purpose of energy saving and occupant thermal comfort. It's diagram is shown in Figure 1. As is shown in Figure 1. On/off control is a simple, fast and inexpensive feedback controller that accepts only binary inputs which is also known as bang-bang control and hysteretic control [7]. This control technique is still being using in domestic and commercial buildings effectively, as the well known thermostat, humidity and pressure switch. It is based on cutting of the power supply. The method is very simple and the cost of controller is very cheap. While its performance is so bad that it can't meet the demand of air conditioning now.

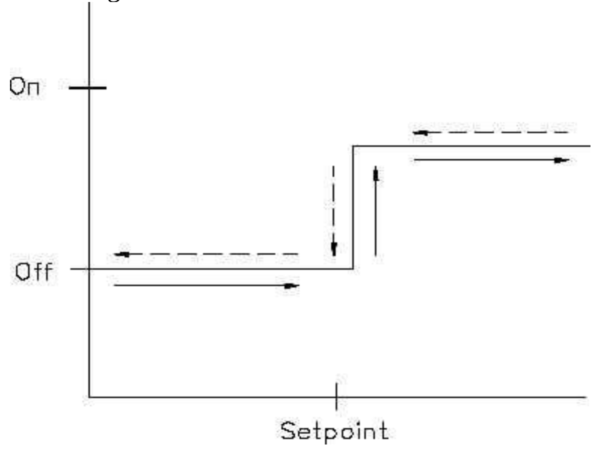

FIGURE 1 Diagram of two-position control

The most important and popular controller in industrial process is Proportional Integral Derivative (PID) as it is easy to understand and to be used as a controller. So Proportional integral derivative control (PID control) is another control method that use in the air conditioning control. Its diagram is shown in Figure 2.

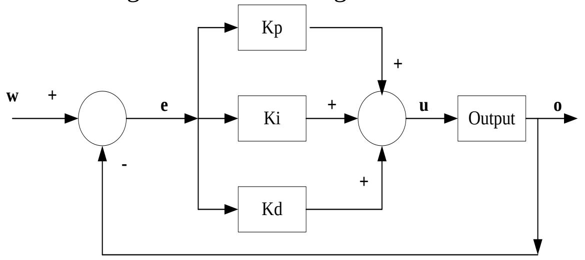

FIGURE 2 Diagram of PID control

But there are major problems that occur when using the PID controller which cause disturbance and environmental condition on the structural of the system. However when it compared to other controller, the PID are better and simple structure. To the controlled object in air condition system, the traditional PID control can be applied, but it has some disadvantages such as inconvenient tuning parameters, faint anti-interference and large overshoot. The traditional PID control method has the characteristics of simple construction, good stability, and mature theories. But the PID method excessively depends on the model parameters, and the robustness is poor. From a mathematical viewpoint, the PID control works to push the error e to zero, where

$$e = o - w, \tag{1}$$

where w is the target of the PID control system and o is the output of the PID control system.

The change of output can be expressed as:

$$\Delta o = K_p e(t) + K_i \int e(t)dt + K_d \frac{\partial e(t)}{\partial t}, \tag{2}$$

where K_p , K_i and K_d are the scale factors for the proportional, integral and differential terms respectively.

There are three separate control techniques used in the PID control algorithm:

1. proportional term relates to the present offset;
2. integral term depends on the accumulation of past errors;
3. derivative term predicts the future offsets based on the current rate of change of the process.

A control signal is delivered based on a weighted sum of these three actions. The distinct effect of these three terms causes the most important stimulus for the survival of the PID control mechanism, and it also committed to the evolution of modern control approaches. It could be beneficial for certain applications to apply only one or two actions out of the three by setting the other parameters to zero. P control and PI control are two mostly used control algorithms. Thermal process dynamics in a building is usually a slow responding process. Therefore, proportional control can be engaged in building temperature control with a good stability and a reasonable small offset. Also, it is good in building humidity control. Derivative term also contributes to combat the sudden load changes encountered in the system. Still, small amounts of measurement and process noise can cause large variations in the output due to the derivative term present in the PID control.

Even though there are a number of advantages in using PID control such as simplicity of implementation, it may not be the most suitable controller for building control due to several reasons. It requires three parameters to be trained for each building zone after the installation. This is quite a time consuming task and re-tuning after the commissioning may be inconvenient. They are unable to handle random disturbances, and therefore large deviations from the set point can occur. In buildings, thermal interaction between the zones leads to multi-variable behavior. However, standard PID controller assumes a single input single-output (SISO) system during the analysis which may cause unacceptable deviations. Since these controllers operate at low energy deficiencies they may not be suitable in the long run. Smart temperature control technique for energy.

3 Consuming control

3.1 ALGORITHM OF FUSSY CONTROL

With the development of fussy mathematic, a new control algorithm - Fussy Logic Control is developed. Fussy Logic Control is based on the fussy logic [9]. Fussy Logic Control is a mathematical method that ake on continuous values between 0 and 1. The fussy logic simulate fuzziness of human information processing.

Fuzzy Logic Control is one of the intelligent control systems that are a successful solution to many control problems. The fuzzy models can represent the highly nonlinear processes and can smoothly integrate a prior knowledge with information obtained from process data. Many control solution need the mathematical model of the system to be controlled, but the Fussy Logic Control only need the measurement of input and output signals of the system to be controlled.

This controller consists of fuzzy membership function, fuzzy rules and defuzzification. Fuzzy membership rules are used to set the input and output range in several level such as low, medium and high. The fuzzy rules are used to relate and combine the input and output of Fussy Logic Control. Commonly, the relation of input and output are using "OR" and "AND" logic. Defuzzification is used to convert the rules output to appropriate value which is to be used by plant. This controller is widely used in air conditioner [10].

Fuzzy Logic Controller has three successive blocks through which the control signal is generated in Figure 3.The first block fuzzification the input, this fuzzification input is sent through an inference block where decisions are made by firing certain rules. The Fussy Logic Control system is based on the theory of fuzzy sets and fuzzy logic. Previously a large number of fuzzy inference systems and defuzzification techniques were reported.The output of the inference engine is a set of fuzzification knowledge which is converted to a crisp control signal through a technique of defuzzification. This crisp output is applied to the plant to be controlled.

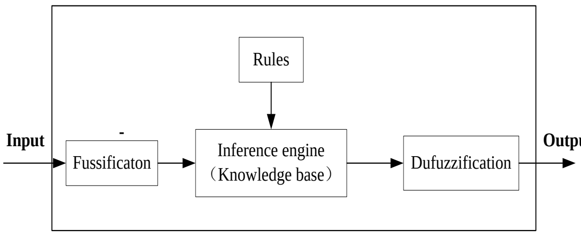

FIGURE 3 Structure of Fussy Block

The Fussy Logic Control can overcome some short-comings of traditional PID. The fuzzy controller is a language controller. The algorithm of Fussy Logic Control can be obtained from experience and optimized from the operation, which has advantages such as powerful anti-interference, faster response and strong robust. Fussy control is appied in the control of air conditioning in the paper, so as to improve the temperature control of the air conditioning.

3.2 DIAGRAM OF THE FUSSY CONTROL SYSTEM

Air conditioning Fussy Logic Control system is shown in Figure 4. Temperature is measured by the indoor temperature sensor. Then A / D converted the measured temperature value into the digital value T. The set temperature S is compared with T. The digital temperature deviation and temperature change rate δT. And e as a controlled amount of input look-up table obtained after the fuzzy control output U_1 and U_2 is the system of cooling air volume increment increment. Changing the cooling capacity is adjusted by the electric proportional valve regulating water flow rate is achieved, then the fan flow by adjusting the fan speed regulator circuit.

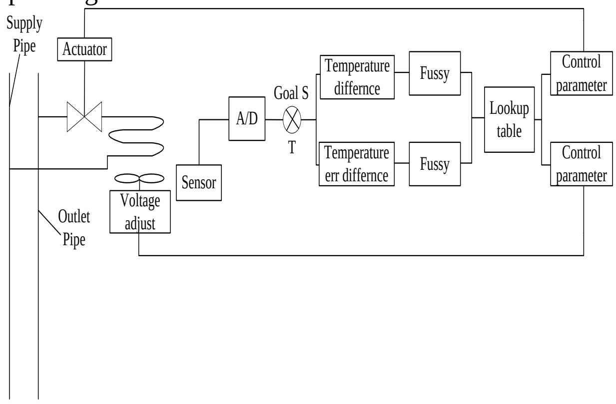

FIGURE 4 Diagram of the fussy control system of air conditioning system

3.3 FUSSY OF THE INPUT AND OUTPUT OF THE CONTROL SYSTEM

Basic domain of temperature change ΔT is [-2,2] ºC in the paper. And the corresponding linguistic variables E of ΔT is divided into 8 files: Negative Big change(NB), Negative Middle change(NM), Negative Little change(NL), Negative Zero(NZ), Positive Zero(PZ), Positive Small change(PS), Positive Middle change(PL) and Positive Big change(PB)[8]. And divide ΔT into 12 levels: -5,-4,-3,-2,-1, -0,+0,1,2,3,4,5. The quantization factor K_t of ΔT is:

$$K_t = 2 \tag{1}$$

Temperature change ΔT is transfer into a number ranges from -2 to 2 by appropriate variation.

Basic domain of temperature change rate δT is [-0.25,0.25] ºC the paper. And the corresponding linguistic variables δT is divided into 7 files: NB, NM, NL, Z, PS, PM, and PZ. And divide δT into 12 levels: -5,-4,-3,-2,-1,0,1,2,3,4,5. The quantization factor K_t of ΔT is:

$$K_T = 5/0.25 = 20 \tag{2}$$

Temperature change rate δT is transfer into a number ranges from -0.25 to 0.25 with the same variation above.

Output of the control system is defined as U_1. Basic domain of U_1 is [U_{1min},U_{1max}]. U_1 is divided into 7 files: NB, NM, NL, Z, PS, PM, and PZ. And divide U_1 into 7 levels: -3,-2,-1,0,1,2,3. The quantization factors of U_1 and U_2 are shown below:

$$K_{u1} = \frac{3}{U_{1\max}} \tag{3}$$

Also, U_1 is transfer into numbers ranges from -3 to 3.

3.4 DESIGN AND SIMULATION OF FUZZY SYNTHESIS ALGORITHM

After summarizing the above-mentioned principles, the fussy control structure of air-conditioning can be concluded as below:

$IF \quad E$

$THEN \quad U_{1k} \quad and \quad U_{2l}$

in which $k = 1, 2, 3; \quad l = 1, 2, 3.$

And the fussy rule of the air-condition control system is:

$$\begin{cases} R_{U_k} = R_{U_{1k}} \cup R_{U_{2k}} \cup \ldots \cup R_{U_{52k}} \\ R_{U_l} = R_{U_{1l}} \cup R_{U_{2l}} \cup \ldots \cup R_{U_{52l}} \end{cases} \quad (5)$$

After the iterative calculation of equation 5, R_{n1} and R_{n2} can be obtained. Depending on the fuzzy subset affiliations of temperature ΔT and the temperature change rate deviation δT, the corresponding U_1 and U_2 is calculated in accordance with the rules of control fuzzy decision. But it is a blur amount can not directly control the controlled object. A reasonable approach need to taken the amount of blur into a precise amount. In order to play the best decisions effect the fuzzy inference result, the principle of maximum membership degree of actual control in the paper, as long as the sampled values to calculate the temperature deviation ΔT and temperature change rate δT.

After conclude, there are 56 fussy rules in the fussy control system. The rules are shown in Table 2.

TABLE 2 Rule table of fussy control

δT / ΔT	NB	NM	NL	Z	PS	PM	PB
	Output of the fussy control system						
NB	PB	PS	Z	NM	NM	NB	NB
NM	PB	PM	PS	NS	NM	NB	NB
NL	PB	PM	PM	NS	NS	NB	NB
NZ	PB	PB	PB	Z	NS	NM	NB
PZ	PB	PB	PB	Z	NS	NM	NB
PS	PB	PB	PB	PM	NM	NS	NB
PM	PB	PB	PB	PB	NM	Z	NB
PB	PB	PB	PB	PB	NS	PS	NB

According to the purpose of the corresponding affiliation, precise control of the amount charged is realized. At the end of the fussy control system, the control for freezing water to establish the simulation model shown in Figure 5. In which, Gain, Gain1 and Gain2 are constant gains. Derivative is the differential link, MinMax is seeking the best value. Fuzzy Logic Control is fuzzy logic controller block. Matlab Function is Matlab functions. Switch and Switch1 is to convert the block. Transport Delay is the input signal at a given time to do the delay. The selected scale factors of the fuzzy controller are $K_E = 3.2$, $K_F = 0.8$, $K_{U_{1k}} = 0.85$.

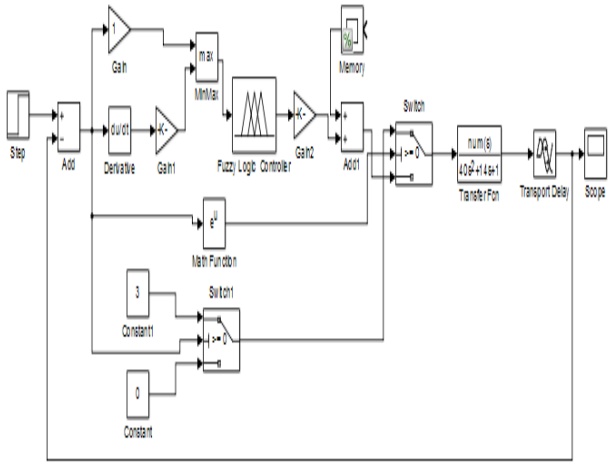

FIGURE 5 Simulation model of fussy control system for air conditioning

Assumed that indoor temperature variation is 1.4ºC, the simulation curve of fussy logic controller is shown in Figure 6.

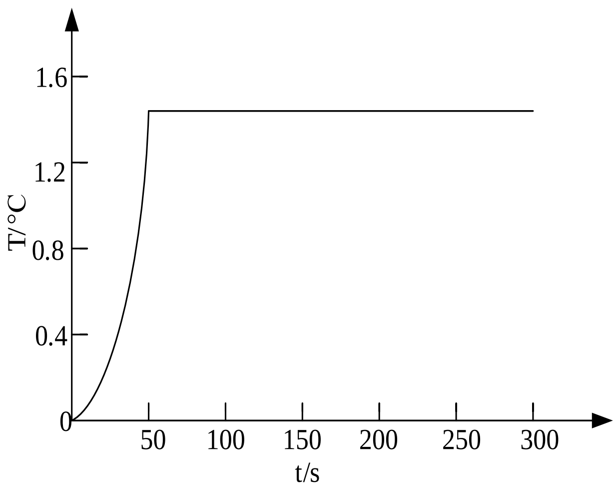

FIGURE 6 Temperature adjustment performance of fussy controller

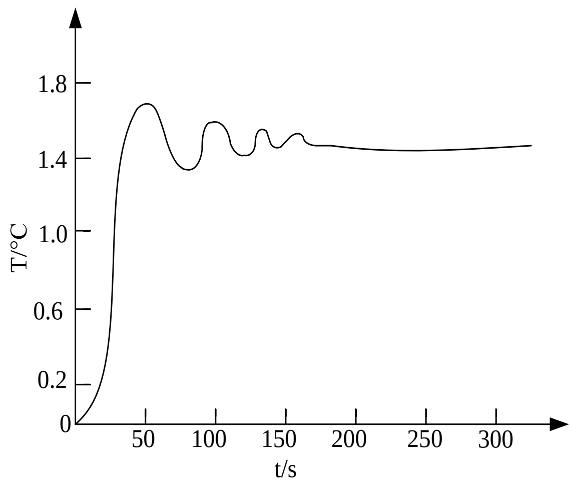

FIGURE 7 Temperature adjustment performance of PID controller

From the simulation curves, it can be seen when the temperature change of the stable room is less than 0.1, the response time of the fuzzy controller is 60 s. Its response speed and accuracy are significantly better than PID controller. Thus the temperature adjustment performance of air-conditioning with fuzzy controller better than that with PID controller. Good temperature regulation will be able to significantly reduce the energy consumption of air conditioning. So the fuzzy control system developed in the paper is significant for building energy saving.

4 Conclusion

An air-conditioning controller based on fussy control for air-conditioning is developed in the paper. In order to evaluation the performance of the fussy controller, a simulation model is set up with the help of Matlab. After simulation, the temperature adjustment performance of fussy controller and PID controller are obtained. The simulation results shows that response speed and accuracy of fussy controller are significantly better than PID controller. And the fuzzy control system developed in the paper is significant for building energy saving.

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