SIMULATION DESIGN OF AUTOMATIC CONTROL SYSTEM OF VARIABLE AIR VOLUME AIR CONDITIONING UNDER SIMPLE AIR VOLUME CONTROL ALGORITHM

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Abstract – To solve the shortcomings of traditional proportional integral control algorithm in variable air volume (VAV) air conditioning automatic control system, such as poor control precision, low sensitivity, and system instability, in this study, a simple total air volume control algorithm is proposed to realize automatic control of variable air volume air conditioning. Firstly, the theory of simple total air volume control algorithm and the theory of modified total air volume control algorithm are introduced. Then the initial adjustment of VAV system is introduced. Finally, the traditional total air volume control algorithm, the simple total air volume control algorithm, and the modified total air volume control algorithm are simulated. The results show that the change of the fan performance curve caused by the total air volume control algorithm based on proportional integration (PI) lags behind the change of the air valve opening degree on the pipe network characteristic curve, which is not conducive to energy saving. The simple total air volume control algorithm proposed in this study is improved than the modified total air volume control algorithm in controlling the fluctuation at end air volume. The fluctuation of the end air volume is basically the same as the opening degree of the air valve, so the energy saving effect is good. This research has promoted the application of VAV in the construction industry.

Keywords: Simple Total Air Volume Control Algorithm, Proportional Integral Control Algorithm, Variable Air Volume Air Conditioning System, Automatic Variable Air Volume Control System.

1. Introduction

With the development of economy and science and technology, people pursue higher and higher quality of life. While realizing high efficiency and convenience of life, people are more and more interested in the intelligence of living environment. The development of computer technology and communication technology has provided a good foundation for the intelligentization of people's lives, and the proposal of intelligent buildings has also made people's lives take a bigger step toward intelligentization [1].

Intelligent building refers to the realization of buildings and construction equipment, which focuses more on the realization of construction equipment. At present, the construction equipment mainly includes lighting system, air conditioning system, transportation equipment, health services, and other aspects. The realization of intelligent building is inseparable from control, management, and maintenance of building equipment, and is also the guarantee for the effective use of intelligent building and equipment. However, these can't be achieved without energy consumption [2]. According to relevant statistics, building energy consumption in industrial developed countries is generally 35% to 50%. In China, building energy consumption has reached more than 35%, among which the energy consumption of air conditioning accounts for 50% [3]. Therefore, the need to use energy reasonably and effectively is a trend in the development of intelligent buildings, which requires more energy conservation while ensuring the smooth operation of air conditioning equipment. Variable air volume (VAV) originated in the United States, in 1960s and was quickly introduced to many European countries. More algorithms are proposed for the end control of VAV, which further expands its application field. Under the condition of low energy consumption, in order to meet owners' higher and higher requirements for air-conditioning system, more and more scholars began to study VAV air-conditioning system. Compared with the fixed air volume air-conditioning system, the VAV air-conditioning system has shown advantages in energy saving and control flexibility. On the one hand, when using the traditional PID control method to control the VAV air conditioning system, there are disadvantages such as poor control accuracy, low sensitivity, and system instability. Therefore, it can't achieve the true sense of energy saving, and can't meet the needs of the current social development. On the other hand, the normal operation of the air-conditioning system contains more control subsystems. Each subsystem affects each other in the operation process, resulting in a certain degree of coupling effect, which may lead to the risk of air-conditioning failure [4]. These factors to some extent limit the expansion and development of VAV system in practical engineering. Therefore, in order to promote the large-scale use of VAV in engineering and to find more advanced and effective control strategies, optimizing the control of air-conditioning system is an important technological breakthrough in its development.

To sum up, in order to improve the stability of automatic control system of VAV air conditioning and realize energy saving and emission reduction, a set of automatic control system of VAV air conditioning is designed. The theory of total air volume control algorithm, simple total air volume control algorithm, and modified total air volume control algorithm are analysed. Furthermore, the initial adjustment of the air supply system of VAV is introduced and finally, simulation results based on proportional integral control algorithm, simple total air volume control algorithm, and modified total air volume control algorithm are analysed, which is expected to provide a good idea for the automatic control system of VAV air conditioning.

2. Methods

2.1 Theoretical analysis of total air volume control algorithm

The total air volume control algorithm actually refers to the method to control the fan speed. The sum of the set air volume at each end of the fan is called the fan air volume. In general, Proportional Integral Derivative (PID) control is applied to the control of fan speed. Therefore, the total air volume control can be called PID total air volume control. To realize the control of the total air volume, the fan speed can be calculated according to the fan similarity rate to realize the feedforward control of the fan and then adjust the fan, and timely change air volume at the end, so as to ensure that the air conditioning room temperature is maintained at the set temperature.

The main control of the fan is to make the airflow at the fan working point to meet the design requirements. The working point of the fan is determined by the intersection of the pipe network characteristic curve and the fan performance curve. When the static pressure difference between the suction tuyere and the outlet of the wind system is not considered, the pipe network characteristic curve of the wind system is a narrow concept [5-7].

The expression of the simple total air volume control algorithm proposed in this research is Eq. 1, that is, the total air volume control algorithm which is not modified by the fan.

$$n_s = \frac{\sum_{j=1}^{n} G_j}{\sum_{i=1}^{n} G_{d,i}} n_d \tag{1}$$

In Eq. 1, n_s represents the fan speed (r/min); n_d represents the fan speed under design condition (r/min); $G_{s,j}$ represents the set air volume at the j[th] end (m^3/h); $G_{d,i}$ represents the set air volume at the i[th] end (m^3/h); n is the number of ends.

According to the relevant experience of previous studies, the total air volume control algorithm needs to be modified, and Eq. 2 is the modified expression [8-9].

$$n_s = \frac{\sum_{i=1}^{n} G_{s,i}}{\sum_{i=1}^{n} G_{d,i}} n_d (1+\sigma K) \tag{2}$$

In Eq. 2, σ represents the mean square deviation of all end relative design air volumes; *K* represents an adaptive parameter.

According to the simple total air volume control algorithm, PID total air volume control algorithm, and the modified total air volume control algorithm mentioned in previous studies, a simulation analysis is conducted on these three methods. which is mainly from the end of the wind fluctuation, valve opening degree influence, size of the fan speed, and energy saving of the fan.

2.2 Initial adjustment of air supply system of variable air volume air conditioning

In design stage of the air conditioning system, the airflow balance in the air system is seldom calculated, which results in the situation that the wind flow at the end branches can't meet the required airflow. Usually, during the initial phase of the system branch, the manual regulator is installed on the end branch pipe to adjust it so that the air volume from the branch reaches the designed air volume. In practical engineering, the adjustment process of manual control valve is a very troublesome work, which needs to be repeated constantly.

The branches affect each other and can't be adjusted quickly. Simulation with Flowmaster software can reduce the workload and calculate valve opening degree through simulation [10-12].

In the design phase of a wind system, the maximum wind volume is calculated based on the maximum load. The initial adjustment process is the maximum amount of air needed to reach the final design. Flowmaster software is used to simulate valve opening degree, that is, adjustment process of manual control valve in actual engineering, as shown in Table 1.

Table 1. The valve opening degree and air volume obtained by initial adjustment simulation

Air-conditioned room number	Valve opening degree /ratio	Air volume/(m^3/h)	Air volume designed/(m^3/h)	Errors/%
1	0.72	942.96	930	1.43
2	0.99	406.65	404	0.94
3	0.94	403.85	405	0.23
4	1	1372.15	1378	-0.27

3. Results

3.1 Analysis of simulation results based on PID total air volume control algorithm

This research adopts Flowmaster software to simulate the total air volume control algorithm based on PID. In the simulation process, it is necessary to reduce the set air volume of room 3 by 500m^3/h. Room 3 is required to undergo an uncancelled change to carry out instantaneous simulation. Figure 1 shows the change of air volume and valve opening degree in room 1 under this circumstance.

According to the changes of room air volume and valve opening degree in Figure 1, when the air volume set in room 3 decreases, the valve span in room no. 1 based on PID total air volume control method changes from 1ratio set before to 0.0872ration. In the simulation process, after the valve opening degree decreases, there is always a small range of fluctuations, so that the air volume in room 1 also keeps a small range of fluctuations. As shown in the figure, the reason for this is that the branch of room 1 is the nearest branch, and the length of the pipe section is short. Therefore, there's less resistance.

The valve resistance is one of the main resistances in the pipe resistance, so the change of valve opening degree and air volume is more obvious. Figure 2 and Figure 3 show the changes of air volume and valve opening degree in room 2 and room 3, respectively. When the speed of the main fan is controlled by PID, the air volume and valve opening degree of room 2 and room 3 are maintained at a constant value after 5s, except for slight deviations at several time points.

The maximum change in air volume is 0.37m^3/h. Therefore, in general, VAV end air volume control of the PID control method is more stable.

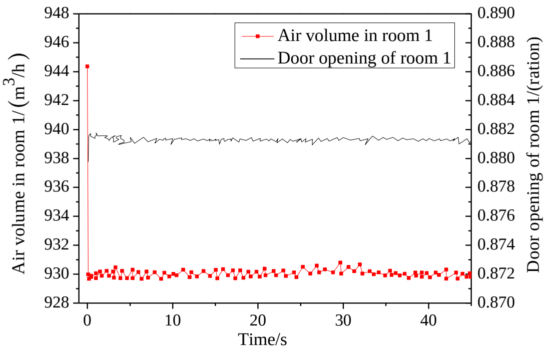

Figure 1: Variation diagram of air volume and valve opening degree in room 1.

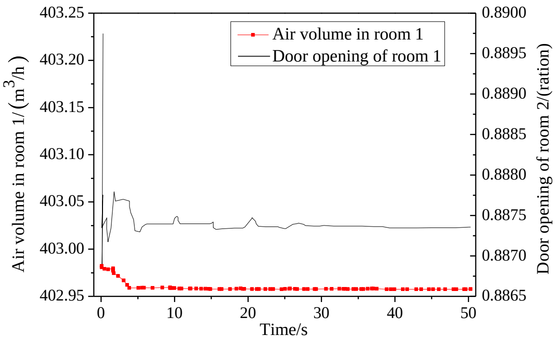

Figure 2: Variation diagram of air volume and valve opening degree in room 2.

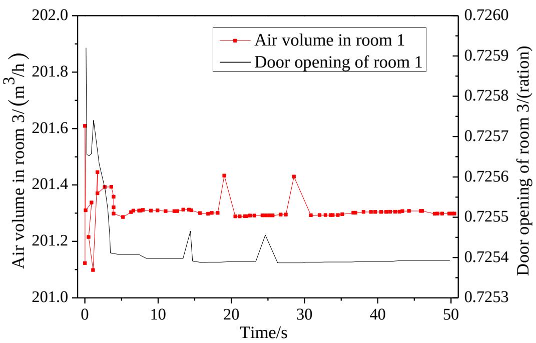

Figure 3: Variation diagram of air volume and valve opening degree in room 3.

Under the control of PID total air volume, the opening degree of the electric air valve at the end of VAV air conditioner decreases by several gradients, from the initial ratio of 1 to 0.87ratio, 0.89tatio, 0.88ratio to the final 0.75rato, that is, the pipe network characteristic curve changes. The output volume of the general fan shall reach the set air volume, which is not only related to the pipe network characteristic curve, but also related to the fan performance curve, ultimately will be affected by the fan speed.

Figure 4 is the speed change diagram of the main fan under the control of PID total air volume. In order to eliminate the chance of parameter setting in the simulation experiment, two groups of experiments are conducted on the data. The two groups show similar trends. Under the control of PID total air volume, the speed decreases first and then increase, and the minimum speed appears at 2s. The speed decreases to 1322r/min and then increases rapidly.

The final speed reaches its maximum value of 1447r/min at 5s, which reaches the rated speed of the main fan. When the air volume is reduced, if the pipe network characteristic curve is constant, the total speed of the fan should be reduced to meet the set air volume. But according to the experimental results, under the total air volume control of PID, the performance curve of fan speed is instigated by the change of air volume. The fan always lags the change in the line characteristic curve caused by the change in the opening degree of the air valve, so that the control system adjusts the air valve at last, and then the speed of the fan.

Therefore, the valve opening degree at the end of the pipe network becomes smaller, the pipe network characteristic curve becomes steeper, and the fan speed becomes larger, which is not conducive to energy saving.

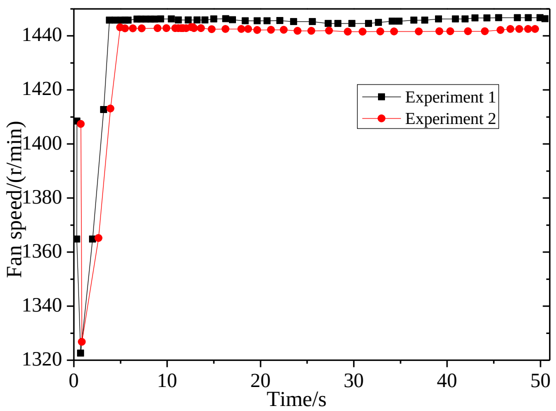

Figure 4: Diagram of fan speed change under PID total air volume control.

3.2 The simulation results analysis of the simple total air volume control algorithm and the modified total air volume control algorithm

The influence of simple total energy control method and modified total air volume control method on the change of air volume in different rooms is analyzed. In this research, the mixing of primary air and return air at the VAV end is not considered in the simulation experiment. In other words, there is no fan at the VAV end, and the outlet of the VAV end is the indoor environment. In Flowmaster simulation, the outlet of the VAV end device is connected to the pressure source, and the pressure source parameter is set to 101335Pa. Under this setting, the air volume in room 4 is set to change by step for transient simulation.

Figure 5 is the comparison diagram of wind volume fluctuation between the simple total air volume control and the modified total air volume control in room 1. As shown in the figure, the initial air volume under the simple total air volume control fluctuates greatly, fluctuating 215m^3/h and 390m^3/h respectively. Therefore, it indicates that the wind valve at VAV end under the early simple total air volume control method needs to be operated frequently. After comparison with Figure 1, it can be concluded that the effect of wind volume fluctuation control at the end of room 1 under the total air volume control is a simple control method and the effect of the modified total air volume control is good.

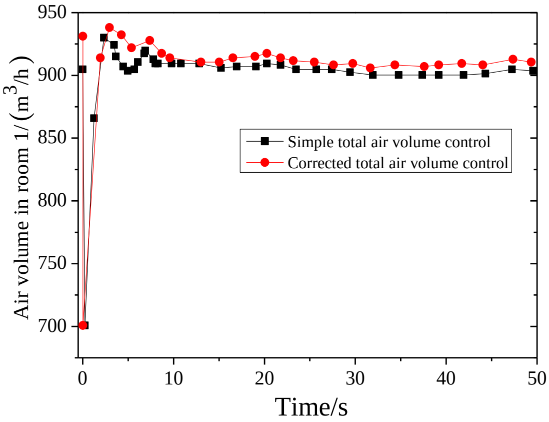

Figure 5: The comparison diagram of wind volume fluctuation between simple total air volume control and modified total air volume control in room 1.

Figure 6 and Figure 7 show the comparison diagram of the wind volume fluctuation between the simple total air volume control and the modified total air volume control in room 2 and room 3, respectively. For the fluctuation control of end air volume, the basic fluctuation is the same whether the simple total air volume control method is adopted, or the modified total air volume control method is adopted.

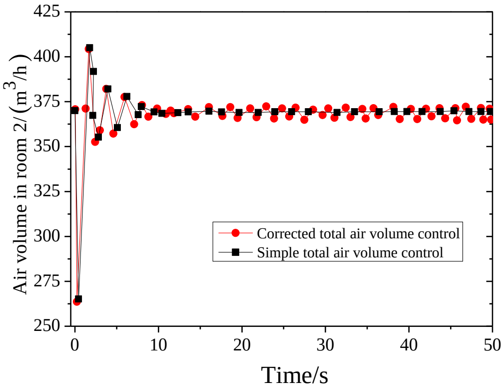

Figure 6: The comparison diagram of wind volume fluctuation between simple total air volume control and modified total air volume control in room 2.

Table 2 shows the opening of the end air valve under the two control methods. The valve opening degree under the PID total air volume control is obviously smaller than the simple total air volume control method and the modified total air volume control method.

It is slightly less than the valve opening degree under the control of modified total air volume and slightly greater than the valve opening degree at the end of VAV under the control of simple total air volume. It can be concluded that under the two control methods, the valve opening degree changes are basically the same.

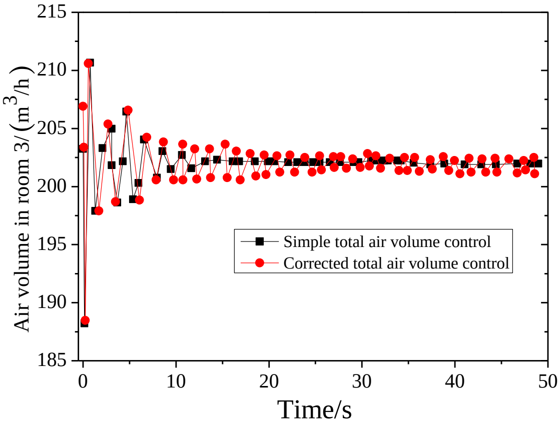

Figure 7: The comparison diagram of wind volume fluctuation between simple total air volume control and modified total air volume control in room 3.

Table 2. The opening degree of the end air valve under both control methods

Room number	Valve opening degree under simple total air volume control/ratio	Valve opening degree under modified total air volume control /ratio
Room 1	1.00	1.00
Room 2	0.9339	0.9360
Room 3	0.9327	0.9338
Room 4	0.7906	0.7830

The above situation considers the situation that there is no fan at the end of the VAV. Then the end control of VAV with fan is analyzed. Figure 8 is the comparison diagram of the change of air volume in room 1 and room 2 controlled by the VAV end with fan. The simulation conditions are the same as those without fan end.

As shown in Figure 8, whether room 1 or room 2, the air volume fluctuation of VAV air conditioning based on simple total air volume control is less than the modified total air volume control in the initial stage, which indicates that the simple total air volume control method is better than the modified total air volume control method when the VAV air conditioner is equipped with a fan. In addition, it can be concluded that the VAV end control with fan can reduce the fluctuation of the end air volume.

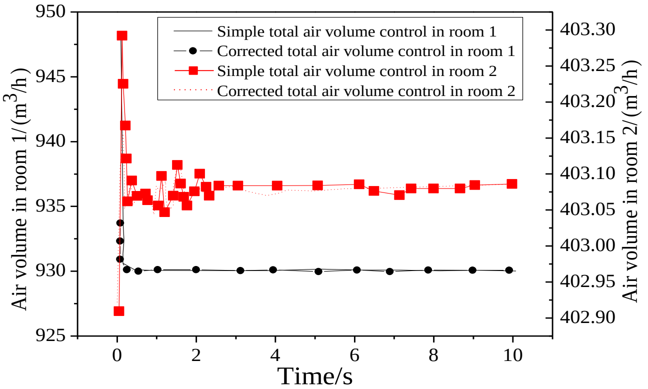

Figure 8: The change of the air volume in room 1 and room 2 controlled by the variable air volume end of the fan.

4. Discussion

With the national slogan of energy conservation, emission reduction, and environmental protection sounding, air conditioning systems in the construction industry account for a large proportion of energy consumption, thus more and more researchers began to study VAV air conditioning systems. Hu et al. (2017) introduced the automatic control of VAV air conditioning under five different control strategies. The five strategies are automatic control based on building load rate, optimal circulation flow control, optimal on/off control of variable speed heat pump unit, variable flow control at regulating valve position, and variable flow control through variable speed pump. The results show that the variable flow control effect of variable speed pump is the best. By comparing the original operation with the best case, it is found that during the cooling and heating seasons, the system exergy efficiency increases from 9.0% to 10.4%, exergy loss decreases by 31% and 51%, and energy consumption decreases by 37% and 60%, respectively [13-14].

This research refers to his research ideas, after evaluating the traditional control strategy, the new control strategy is simulated. Ghahramani et al. (2017) introduced model-free control strategy to optimize the energy use of VAV systems. The control strategy is an adaptive hybrid heuristic algorithm, which uses real-time data stored in building automation systems to find and control optimal set-points at the building level. The strategy uses intelligent selection of daily set points as the basis for its control, considering the design wind volume at each end of the control strategy, so that the control scheme can complement the traditional building management system. The results show that the algorithm can save 31.17% energy [15-16].

According to the previous experience, it is necessary to take the difference of design air volume at each end into consideration in the total air volume control method and the modified total air volume control method. Some studies calculate the mean square deviation of all ends relative to the set air volume according to the set air volume, so as to modify the main fan. Only the modified method is mentioned in the literature, but the unmodified and non-modified control methods are not compared. In this research, the two algorithms are compared.

5. Conclusions

In order to save energy in the control process of VAV air conditioning and not affect the stability of the air conditioning system, a simple total air volume control algorithm based on the total air volume control algorithm is proposed.

Firstly, the automatic control system of VAV air conditioning is designed and the total air volume control theory is introduced, including the total air volume control method modified by the simple total air volume control algorithm. Then the initial adjustment of the air supply system of VAV air conditioning is introduced. Finally, the total air volume control algorithm based on PID, simple total air volume control algorithm, and the revised total air volume control algorithm are simulated and analyzed.

Through the analysis based on the PID total air volume control algorithm, it is concluded that although the PID total air volume control algorithm can meet the initial design air volume requirements, and the wind volume fluctuation control of the end is better, the change of the fan performance curve is later than the change of the wind valve opening degree on the pipe network characteristic curve, which is not conducive to the requirement of energy saving. The simulation results of the simple total air volume control algorithm and the modified total air volume control algorithm show that the correction factor has little influence on the pipe network characteristic curve. On the contrary, the simple total air volume control algorithm is simpler, and the control effect of the simple total air volume control algorithm is better with the fan equipment.

The research promotes the large-scale application of VAV in the construction industry to achieve the goal of energy saving. However, there are still some limitations in this study. In this research, although Flowmaster is used to realize the modeling of the model, there are still errors between the model and the actual situation. Therefore, it is hoped that the follow-up research can carry out engineering test to expand the depth of this paper.

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