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Cascade control for supply air temperature in a variable air volume system

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Abstract. Most supply air temperature in variable air volume systems is typically set at 55F(13℃) that is design value in these systems. However, sometimes the load of cooling varies greatly in different zones, and it means the indoor temperature of low-load zones is lower than comfortable value, even if the supply air damper is at the minimum value that is not closed for minimum outside air requirement. Meanwhile, in transition season, the indoor temperature is also lower due to low outdoor temperature. These factors provided an opportunity to apply higher supply air temperature to reduce air handling unit (AHU) cooling load and box reheating. In this paper, a cascade control method is used to raise the supply air temperature. The external control loop controls the setting value of supply air temperature with the minimum supply air volume as the control target. And the internal control loop controls the supply air temperature by regulating valve. The cascade structure can solve the problem that the time constant of the system is too large. The simulation results show that the quality of control is good and the reheating can be cancelled.

1. Introduction

In recent years, variable air volume (VAV) systems have been widely used in air conditioning systems, since they can conserve energy while maintaining indoor comfort with the technology of variable frequency drives (VFD) and building automation systems (BAS). Different from constant air volume systems where the temperature of supply air is adjusted due to a fixed constant airflow rate, VAV systems can regulate both supply air temperature and supply air flowrate. But in general, the supply air temperature is often fixed at 55F(13℃) typically, since it is often the design value in VAV systems.

However, sometimes the load of cooling varies greatly in different zones, and it means the indoor temperature of low-load zones is lower than comfortable value, even if the supply air damper is at the minimum value that is not closed for minimum outside air requirement. Meanwhile, in transition season, the indoor temperature is also lower due to low outdoor temperature. Thus the reheating in VAVBox is inevitable to ensure the indoor confortable, which means a lot of energy is wasted. These factors provided an opportunity to apply higher supply air temperature (SAT) to reduce air handling unit (AHU) cooling load and box reheating.

To rise SAT during low-load conditions, SAT reset control strategy was applied [1]. At any time when temperature of outdoor air is lower than the set-point value of SAT, compressors are shut down and return air (RA) and the outdoor air dampers adjust to provide the desired SAT. Raising SAT whenever the supply airflow is decreased to a minimum setting of a VAV terminal unit can also decrease reheat at zone level for zones with low cooling loads [2]. However, since the supply air is at a slightly higher temperature, we need more air to satisfy the cooling load and that will result in increasing fan energy [3]. Therefore, SAT reset strategy should be able to minimize overall VAV system energy use. To achieve simultaneous minimization of compressor energy, reheat energy, as well as fan energy several researchers [4-6] have agreed on general principles for balancing the competing issues.

Some strategies had been applied to control SAT. Nassif et al. used genetic algorithm (GA) in an office environment during two summer weeks by incorporating thermal climate and energy for air-handling in the objective function [7]. A similar investigation was presented in [8], and it was found that up to 30% of the energy could be saved by employing GA for SAT control in an educational environment instead of maintaining a constant level. These findings are moreover consistent with the reported results of [9] where genetic fuzzy optimization was used for climate control in an academic building scale model. Compared to maintaining constant SAT levels between 12 and 14 ℃, the strategy yielded energy savings between 54 and 61% during summer and winter ambient conditions, and this range was furthermore assessed as equivalent to savings between 29 and 36% on an annual basis. Wang et al. used an analytical optimization method to seek an optimal supply air temperature setpoint to minimize the energy cost and achieved a raised SAT [10]. Raftery et al. developed a new SAT control strategy that it is simple enough to implement within existing building management systems for multi-zone variable volume systems [11].

In this paper, a cascade control method is used to rise the supply air temperature. It is organized as follows: first, the SAT control strategy is presented. And then followed by the description of the simulation platform with its considered variants and simulated conditions, and finally, the results from the study are presented and discussed.

2. The design of control system

In traditional VAV systems, SAT is fixed at 13℃ as design value, and it causes the indoor temperature too low or requiring reheating, when the load is low. For the purpose of indoor comfort or saving reheating energy, this paper proposed a cascade control method that rises SAT to match the low-load.

2.1. The principle of cascade control method

When the lag of the controlled object is large and the interference is intense and frequent, the simple control systems, such as PID, are often inappropriate, since they often have poor control quality and cannot meet the control requierments. Thus, cascade control method can be considered.

As shown in Figure.1, cascade control method has two control loops: one is a internal control loop that also be named secondary loop, and the other is an external control loop that also be named primary loop. The primary variable is the system control variable, e.g. the zone temperature, and the secondary variable is the auxiliary variable, e.g. supply air flowrate through VAVBox, which is chosen for better control of the primary variable. The primary (external) and secondary (internal) controllers are connected in series, and the output of the primary controller is the setpoint of the secondary controller.

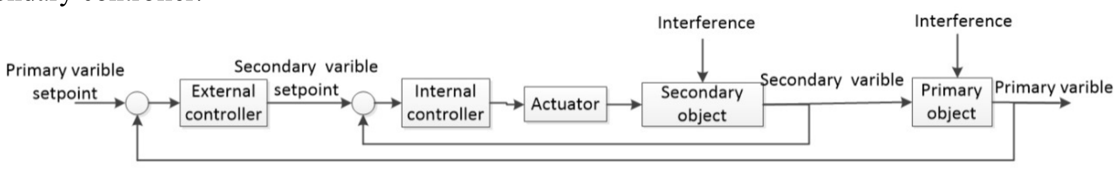

Figure 1. Cascade control system block diagram

2.2. Proposed control design

As for this study, the cascade control method is applied to raise the temperature of SAT. But as shown in Figure 2, the external control target is the supply air flowrate, and the internal control loop target is the SAT. If the SAT is the ultimate control target, the control target is to maintain the SAT at the SAT setpoint that is a fixed value, but this study purpose is to raise the SAT, not fixed. Thus the supply airflow is chosen as the ultimate control target.

This study is to resolve the problem: as one building is put into use, the temperature in some rooms or zones will often lower than comfortable temperature, since the loads of these rooms or zones are lower than the design loads as the result that the design load is according to the area, but few occupants is in these rooms or zones.

Although there are few occupants in these rooms or zones, the supply airflow should be controlled to a minimum airflow that ensures the minimum ventilation air flowrate to meet the indoor comfort, and the minimum airflow is often designed as 20% of the maximum supply airflow in China. So the method of reducing airflow to less than 20% cannot be adopted. Raising SAT then becomes the only option to meet the actual low-load demand.

But the SAT cannot be too high to meet the high-load zones demand. In other words, even the valve is fully opened, some rooms cannot maintain the indoor air temperature setpoint due to the high SAT. Thus the SAT should be raised to a certain value, which can only maintain the indoor temperature setpoint in low-load zones or rooms on the premise of not reducing airflow to less than certain setpoint. In order to keep a control allowance, the supply airflow setpoint is 30% of the maximum supply airflow through the VAVBox, which is 10% higher than the design minimum supply airflow 20%.

In Figure 2, the block “Zone and VAVBox” includes the zone, VAVBox and the control system in VAVBox, which may also be a cascade control system, but is not the content of this paper. To ensure the indoor comfort, the control system in VAVBox will adjust the damper according to the SAT and load in the zone. If the load is low, the damper position will be small, and will lead to a small supply airflow. In general, if the load is becoming smaller, when the airflow reduces to 20% of the the design maximum supply airflow, the damper will not be shut down. And then the reheating will be opened.

In this study, two controllers are designed in addition to the original controller in VAVBox. These controllers can adjust the SAT to maintain the supply airflow at its setpoint.

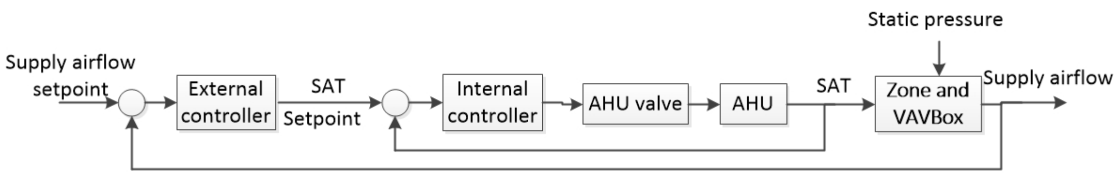

Figure 2. The VAV system control block diagram

2.3. The advantages of cascade control

Cascade control method can achieve good control results for large lag objects. As for this study, the analysis is as follows.

If a simple controller is used, SAT is not detected. After interference affects the system output, and the output deviates from the setpoint, the controller then works. Since the lag of the whole control loop is large, the control effect is not good.

As for cascade control method, if the interference of the internal loop affects the SAT, the internal controller will adjust the SAT right now, and the control process will be greatly shortened. And if the interference is on the external loop, although the internal loop cannot detect the variable of the external, the closed loop of negative feedback of the internal loop makes the time constant of the

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object, AHU greatly shortened. And then the lag of the whole control loop is shortened, and the control effect is then improved [12].

3. Control platform description

A zonal temperature control platform was established in TRNSYS to realize the system, see Fig. 3, where a simple lumped capacitance single zone model (Type 88) was used to model the space temperature dynamics of the controlled zone. And the rates of energy gain from lights, equipment and people are all set to zeroes. The electric uint heater model (Type 664) was used to control the mixing ratio of return air and outside air. The model has a variable speed fan that was fixed full speed, since the supply airflow is modulated by damper in VAVBox. And the model has a heating device that is fixed off status, since only cooling in summer was studied in this paper. The AHU coil model (Type 32) was used to cool supply air, its inlet water temperature was set 7℃, and its flowrate of water was regulated by the internal controller. The weather data in Beijing was used, and the simulation time starts from 5074 h to 5086 h, a typical summer daytime, with time interval 0.125h. The internal and external controllers are all PID controllers (Type 23), and the two step tuning method was used to adjust the parameters of the two controllers (Bequette 2008). It was found that the internal controller with P=10 and I=0.05, and the external controller with P=0.05 and I=0.1 can control the supply airflow well. Finally, the damper controller is a simple PID controller to simulate the VAVBox.

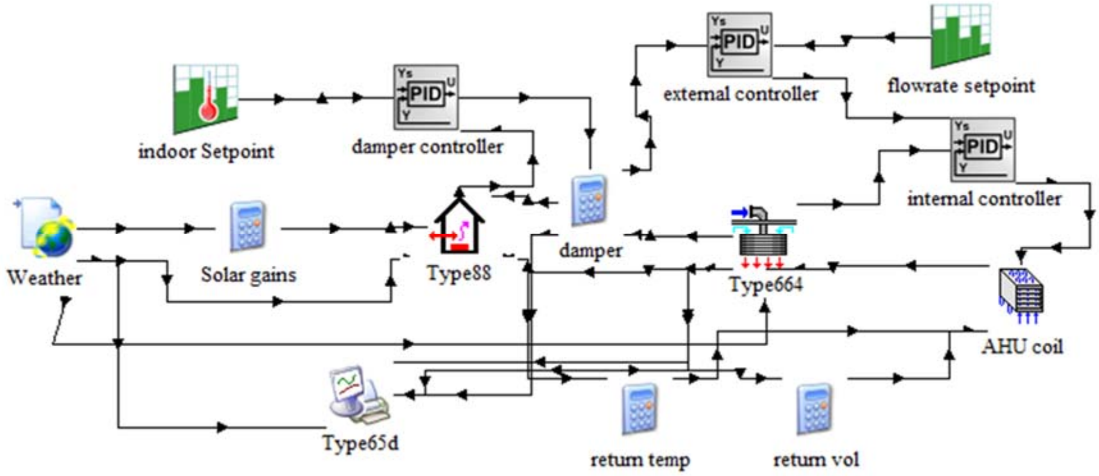

Figure 3. Control platform in TRNSYS

4. Simulation results

The simulation time starts from 5074 h to 5086 h, which is in daytime and avoid the start and stop design in simulation, for the outside temperature is lower than the indoor temperature setpoint 26℃ in night. And the 12 hours of simulation is enough for controller design.

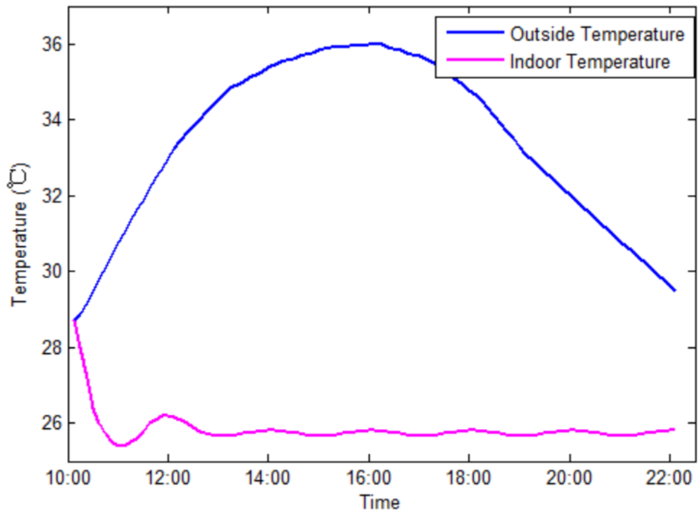

Figure 4. Outside and indoor temperature

Figure 4 shows the outside temperature and the indoor temperature, and it can be seen that the indoor temperature is close to the setpoint 26℃, which means the indoor comfort is satisfied. The SAT is shown in Figure 5, and the supply air flowrate is shown in Figure 6. It can be seen that when the time was from 5076.5 h to 5082.5 h that means from 12:30 to 18:30, the SAT is controlled to the design value, 13℃ that is also the minimum value of the SAT, and the supply air flowrate is higher than 30% of the design maximum flowrate. It means that during this period, the load is high, and the SAT should be the design value. It can also be seen that if outside the period, the SAT is higher than 13℃, and the supply air flowrate is maintained about 30%. Considering Figure 4, and reheating device not designed in the system, the system maintains the indoor comfort by rising the SAT during the low-load period.

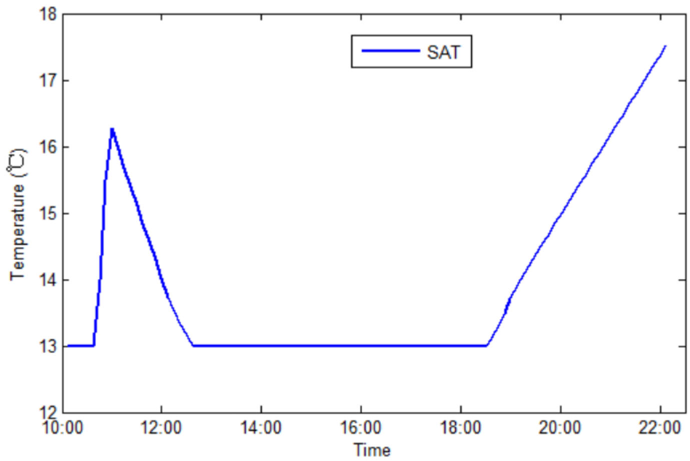

Figure 5. The supply air temperature

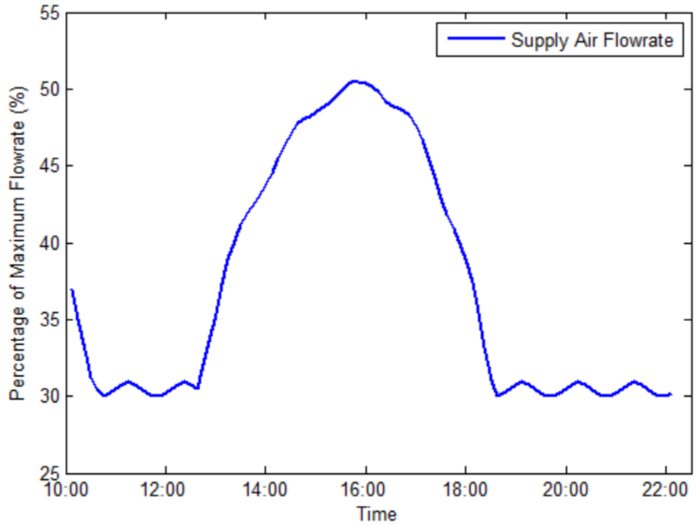

Figure 6. The supply air flowrate

5. Conclusion and future work

In this paper, a cascade control method for raising SAT is proposed. It can resolve the problem of reheating when air condition load is low. The simulation results show that the control precision and the response time are satisfactory.

We will do some further researches to improve the control:

(1) The supply air flowrate and indoor temperature have fluctuations, because only feedback control is used in this study. The control is not applied to the system until the influence from weather condition is reflected on the output. It cause the large lag of the control loop, which means the control is more difficult. Feedforeward control for weather forecasting should be applied to overcome the difficult [13].

(2) In this study, the parameters of controllers are determined by experience mostly, and it requires a lot of luck. So the model of controlled objects should be studied, which will help us to achieve the parameters more theoretically.

(3) The algorithms in controllers can be replaced by more advanced control algorithms, such as MPC, which is widely used in recently years.

(4) The purpose of the simulation is to apply the method to the actual system. In this study, only one zone is studied, and a lot of conditions are idealized. So more complex simulation should be studied. If there are several zones and loads in zones are varing, the lowest-load zone should be found out, and then according to the zone to raise SAT.

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