Improved Air Volume Control Logic for VAV Systems

Guanghua Wei
Senior Research Associate
Energy Systems Lab
Texas A&M University
College Station, TX 77843

Mingsheng Liu, Ph.D., P.E.
Associate Professor
Architectural Engineering
University of Nebraska
Omaha, NB 68182

David E. Claridge, Ph.D., P.E.
Professor
Energy Systems Lab
Texas A&M University
College Station, TX 77843

Yasuko Sakurai
Research Assistant
Energy Systems Lab
Texas A&M University
College Station, TX 77843

ABSTRACT

In a VAV (variable air volume) system, the set point of the static pressure (usually measured at 2/3 downstream of the main supply air duct) is maintained by modulating the fan speed or inlet guide vane position. The set point of the static pressure is often set at a constant value, which is adequate to provide design flow to each room. This method consumes more fan power than necessary under partial load conditions. The fan speed or inlet guide vane can also be controlled based on the maximum damper position of the terminal boxes. This method is called air volume control logic. Under this control logic, terminal box airflow requirements are met with reduced static pressure. Fan power consumption is minimized. However, the actual system performance also depends on other factors, such as inaccurate temperature or flow sensors, faulty control valves, unbalanced loads, etc. This paper discusses the existing air volume control logic, its reliability and an improved air volume control logic.

INTRODUCTION

In a VAV (variable air volume) system, supply airflow varies with the building load. Airflow is usually modulated by means of a variable frequency drive, an eddy-current clutch, inlet guide vanes, outlet dampers, or a vane-axial fan with adjustable pitch blades (ASHRAE 1999). These control devices are usually controlled by a static pressure sensor located 2/3 downstream in the main trunk of the supply air duct. The most common control strategy is to maintain a high constant static pressure set point to ensure adequate flow under design conditions. However, this control strategy maintains the static pressure higher than required under partial load conditions.

Several different control strategies take advantage of the DDC (direct digital control) system and integrate the terminal box requirements with the supply air fan control. Hartman (1989) described a new concept called TRAV (terminal regulated air volume) that used advanced control software to control the supply fan based on real-time terminal box airflow requirements rather than meeting a duct static pressure set point. Englander and Norford (1992) proposed two control algorithms that used the primary airflow error signal from one or more zones to modulate the static pressure or fan speed. Warren (1993) presented a control strategy that reset the fan static pressure set point based on terminal box flow requirements. The reset signal increases if a sufficient number of zones are in low airflow alarm. The reset signal decreases if all the zones are satisfied. When the flow sensors function properly, the air volume control logic provides optimal fan power energy consumption and satisfies thermal comfort requirements.

This paper examines a similar air volume control strategy for an AHU (air handling unit) equipped with a VFD (variable frequency drive) on its fan. Fan speed is modulated based on the highest terminal VAV box damper position. Monitoring of the performance of this control logic reveals some practical issues that may cause a fan power consumption penalty. To enhance the control logic reliability, dynamic static pressure high limits are used instead of a constant static pressure high limit to prevent the fan speed from being dominated by such faulty conditions.

CONTROL LOGIC

In this section, we analyze and compare the conventional control method and the improved air volume control logic introduced here.

To illustrate, refer to the following schematic of a single-duct VAV system with terminal reheat and standard static pressure control, as shown in Figure 1. The supply fan is equipped with a VFD. Assume that: 1) There is only one VAV box; 2) The system has a constant static pressure set point of 1.5 inch H_2O; 3) The supply air temperature is constant at 55°F; 4) At maximum cooling load, the terminal box is fully open and the fan is running at 100% speed, and the static pressure is maintained at 1.5 inch H_2O.

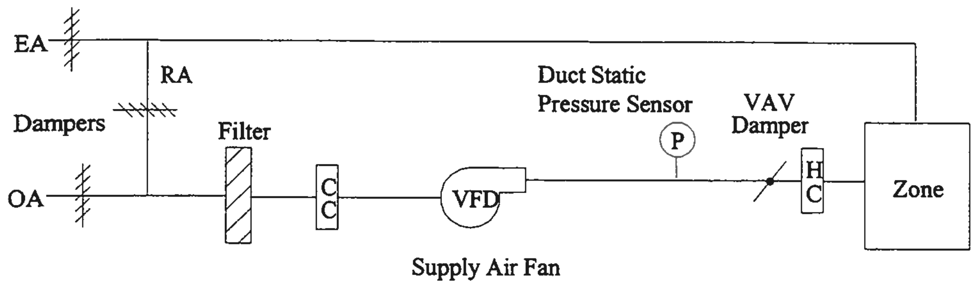

Figure 1. Schematic of a VAV system.

We now examine the sequence of operation under the conventional control strategy as the load changes from maximum cooling to heating. The process is illustrated on the fan curve, as shown in Figure 2. As the cooling load decreases, the terminal box damper will start to modulate towards the minimum position. This causes the static pressure to increase (A→ B) due to increased system resistence. The controller will then slow down the fan speed from N1 to N2 in order to maintain the constant static pressure set point (B→ C). When it settles down at the new speed N2, the static pressure is maintained at the set point of 1.5 inch H_2O. However, the VAV box damper position is partially open at this moment, which means that the unit is operating under increased system resistance. Therefore, the static pressure set point is higher than necessary for this part load operating condition.

To maintain the same airflow rate under the current condition, fan speed can be reduced further down to N3 while opening up the damper, as shown in process C → D. This eliminates the waste of fan power due to the extra pressure head ($P_c - P_d$) that the fan has to overcome. To realize this and minimize the fan power consumption, the control logic can be changed to the following: Modulate the fan speed to maintain the VAV box damper at the fully open position. This control logic, which we will call Air Volume Control (AVC), can be readily applied to a system with multiple terminal VAV boxes. Fan speed will be modulated based on the highest terminal box damper position. By controlling the highest terminal box damper position at or near the fully open position, the fan speed is kept at the minimum and the power consumption is minimized.

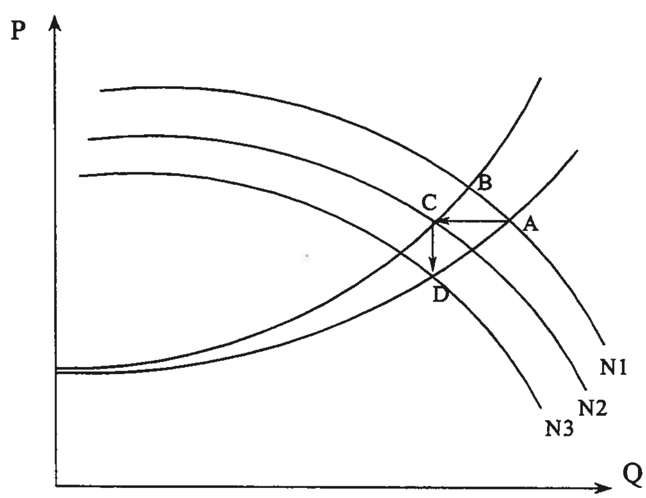

Figure 2. Operating point changes in a VAV system.

Note that a minimum fan speed or a minimum static pressure limit is needed to prevent the fan speed from dropping too low. This control logic can also be applied to a system where the air volume is modulated by other means, such as inlet guide vanes.

IMPROVED AIR VOLUME CONTROL LOGIC

The AVC logic can be applied to a VAV system and optimize energy use regardless the number of the terminal boxes provided none of the following conditions exist in the building:

1. One terminal box reheat control valve is leaking;
2. One terminal box damper is stuck at a partially open position, causing the zone to call for maximum cooling;
3. One terminal box damper actuator is out of calibration;
4. One space temperature sensor reads too high (e.g., sensor reading is 5°F higher than the actual value);
5. One terminal box flow sensor reads too high (higher than the actual value);
6. One section of the flex duct is restricted;
7. One zone does not receive enough airflow due to an air balance problem;
8. One occupant uses a foot heater since the room temperature set point is lower than what he/she wants; or
9. Occupants can adjust the room temperature set point over a wide range.

Unfortunately, a building often has one or more of the problems mentioned above. The AVC logic was implemented in a single-duct VAV system with 5 terminal boxes in a hospital. The highest zone damper position is fed into the fan speed PID (proportional, integral, and derivative) controller, which has a set point of 95%. The output of the PID controller is sent to the VFD. A minimum speed is set for the VFD to provide minimum ventilation. The air volume control logic is shown in Figure 3.

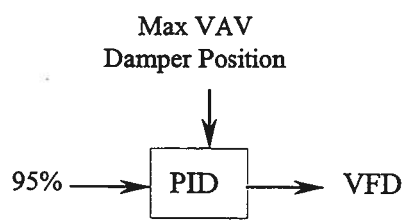

Figure 3. Control logic for the fan speed.

The performance of the AVC logic was observed over a one-year period. Every week, the fan speed and damper position were recorded and analyzed. During the summer months, it was functioning well. No system hardware breakdown, such as leaky reheat valve or stuck VAV dampers, was observed. During the winter months, the fan was found to be running at a high speed. A control system check indicated that the space temperature in one zone was 2°F higher than the set point, causing its zone damper to go to the full open position. Field investigation revealed that the occupant of that zone was using an electric heater! The fan was doing the exact right thing. However, it did not know that the occupant wanted a higher room temperature.

Realistically speaking, it is impossible to avoid all of the problems mentioned above. Especially for systems with a large number of terminal boxes, where the chances of failure increase. The actual fan power energy savings can be significantly less than the expected value due to these problems. To improve the reliability of the air volume control logic, a static pressure high limit was recommended (Englander and Norford 1992). Since the high limit is often based on the maximum airflow, a significant amount of fan energy can still be wasted when any one of the problems occurs. The above incident clearly shows that a constant duct static pressure high limit in conjunction with AVC is not adequate to prevent the fan speed from running unnecessarily high.

The required duct static pressure decreases with the total airflow rate. The set point can be reset based on the total airflow, outside air temperature, or fan speed (Liu et al., 1997). The reliability of AVC logic can be improved by using a static pressure reset schedule. When the static pressure is higher than the set point, thermal comfort problems are likely to be caused by one or more of the mechanical or man-made problems mentioned above. A repair or a correction is required. When there are no mechanical or man-made problems, the AVC logic maximizes the fan power savings while providing adequate comfort.

In our case study, the static pressure set point is reset based on outside air temperature since the heating/cooling load are dominated by the weather for each zone. The improved AVC logic is presented in Figure 4. The reset schedule is in parallel with the AVC logic. Output based on the highest zone damper position and the static pressure control are compared, and the lower output signal is selected and sent to the VFD controller. The reset schedule is acting as a dynamic high static pressure limit. With this safety measure, we eliminate the possibility of high speed operation of the fan due to faulty conditions like a leaky reheat control valve, drifted space temperature sensors, relative load changes among the terminal boxes, a stuck VAV damper, or other problems.

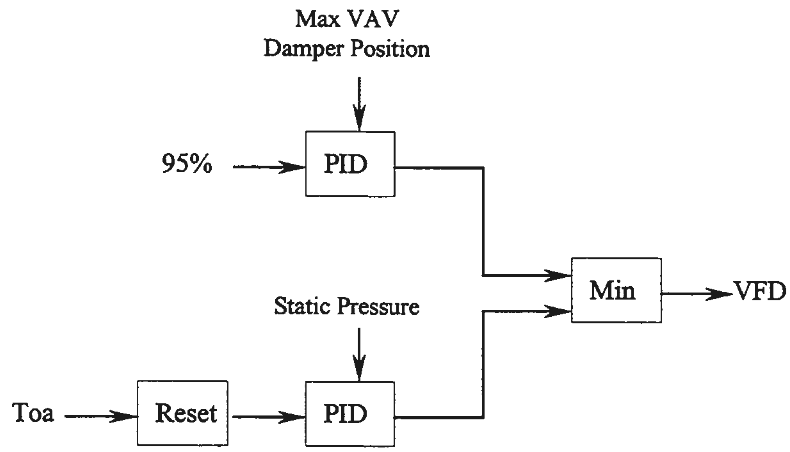

Figure 4. Control logic of fan speed with changing high limits.

The static pressure reset schedule can be developed based on historical data if it is available. The relationship between duct static pressure and outside air temperature is a good reference when developing such reset schedules for use with AVC.

CONCLUSIONS

An improved air volume control logic scheme is introduced in this paper. The potential savings of the air volume control logic are often much smaller than the ideal value due to operating problems. To improve the reliability and achieve optimal fan power savings, a good reset schedule is required. The static pressure can be reset based on the airflow, fan speed, or outside air temperature in combination with air volume control.

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