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A review of Static Pressure Reset Control in Variable Air Volume Air Condition System

Jili Zhang[a], Xiuming Li[a,*], Tianyi Zhao[a], Hao Yu[a], Tingting Chen[a], Chao Liu[a] and Xinwei Yang[b]

[a]*Dalian University of Technology, Dalian, China*
[b]*Center of Buildings Energy Efficiency & Construction Science and Technology, Development of LHCRCD, Shenyang, China*

Abstract

For the sake of energy saving of variable air volume (VAV) system, this paper presents the a review of static pressure control around the optimization problem of static pressure reset in VAV air conditioning system. Then, main control methods of static pressure reset are described, and existing problems are analyzed and concluded. Finally, it is pointed out that the critical technology and the development trend of static pressure reset control. This overview is not intended to be an exhaustive survey on this topic, and any omission of other works is purely unintentional.

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Keywords: Variable air volume, Static pressure reset, Control method, Review;

1. Introduction

Since the contradiction between increasing energy demand and relatively insufficient energy supply is aggravating gradually, energy saving has become into a global issue of common concern in the whole society. Variable air volume (VAV) air conditioning system has been widely adopted due to the better performance than other alternative systems in energy efficiency and thermal comfort [1-3]. Considering the significant energy consumption that the supply fan accounts for in VAV air conditioning system, it becomes an urgent problem to be solved to save fan energy consumption by optimizing fan operation. The most common supply fan control method is to regulate the fan speed with variable frequency drive (VFD) equipped on the fan so as to maintain the measured duct static pressure at its setpoint.

* Corresponding author .Tel: 13080879768; Fax: 0411-84707753
E-mail address: lixiuming@mail.dlut.edu.cn

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The supply fan usually maintains a constant duct static pressure setpoint. Due to the conservative design, the building is usually operated under partial-load conditions, and duct static pressure setpoint should be lower than the design value. Researchers investigate that more than 50% of energy consumption can be saved by static pressure reset control through simulations and experiments [4-7]. Therefore, the study for static pressure reset control becomes an important issue in order to reduce energy consumption and improve thermal comfort in VAV air conditioning system.

2. Basic principle of static pressure reset

For the sake of energy saving, the damper position of terminal box should be kept in the largest opening degree status as far as possible to reduce the terminal resistance loss [8]. A typical schematic diagram of a single duct VAV air conditioning system is shown in Fig. 1. The system mainly consists of AHU, supply and return fans, duct static pressure sensor, terminal boxes and air ducts [9, 10]. Duct static pressure sensor is located on the main duct at 75% to 100% of the distance from the first branch to the most remote branch according to the ASHRAE Application Handbook 2011. To maintain measured duct static pressure at its setpoint, the supply fan speed is regulated according to the deviation between the measured value and the setting value [11].

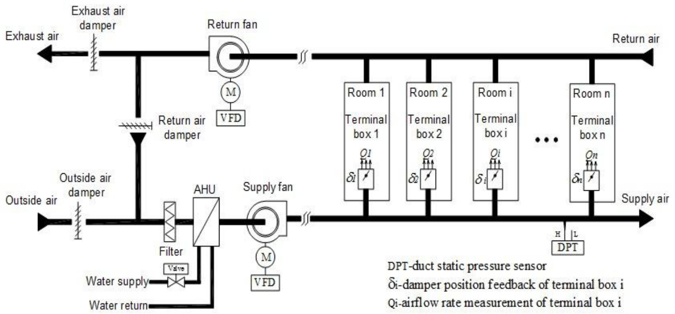

Fig. 1. typical schematic diagram of a single duct VAV air conditioning system

3. Static pressure reset methods

Traditionally, there are mainly three static pressure reset control methods including outside air based control method, airflow based control method and terminal damper position feedback based control method. Besides, intelligent control methods have shown enormous potential with the rapid development of information technology.

3.1. Control method based on outside temperature

Considering whether the load is influenced by the building envelope or not, the entire building is divided into interior zone and exterior zone. Due to the better building envelope, duct static pressure setpoint of interior zone could be reset based on outside temperature.

In engineering applications, duct static pressure setpoint is reset based on outside temperature using Continuous Commissioning (CC) which is developed by Energy Systems Laboratory University of Nebraska−Lincoln. As a result, the noise level and the energy consumption of the system are reduced. Due to the higher duct static pressure, there are some problems including airflow measurement, terminal noise and air leakage in existing constant air volume air conditioning system. For this reason, Dong presents an improved static pressure reset method based on outside temperature and the supply fan speed in the transformation process of an office building for energy saving [12]. The typical control rule is as below: when outside temperature is higher than 70 °F, duct static pressure setpoint is reset based on the supply fan speed; when outside temperature is lower than 70 °F, duct static pressure setpoint is reset based on outside temperature. In order to obtain the appropriate maximum and minimum values of duct static pressure setpoint, Napper presents a selection method of duct static pressure setpoint based on the airflow rate measurement in the transformation process of public schools in Texas. The airflow demand of all terminals, which is under the maximum load condition, is simulated by making the damper position of the farthest terminal to be 100% opening. Then, the maximum and minimum values of duct static pressure setpoint are decided by judging whether the airflow measured value meets the design value [13]. According to the characteristic that the system is composed of multiple AHUs, Martinez and Zeig present a rule schedule for static pressure reset control based on the measurement of outside temperature in the transformation process of a medical research facility [14].

In the field of the theoretical research, the building load is assumed as a line function of outside temperature, and duct static pressure setpoint could be considered as a line function of outside temperature approximately. The relationship is shown in Fig. 2. Where, P_{MAX} and P_{MIN} represent the maximum and minimum value of duct static pressure setpoint, respectively; t_{down} and t_{up} represent the upper limit and lower limit of outside temperature, respectively; Ps represent duct static pressure setpoint. On the basis of Continuous Commissioning, static pressure reset control, which is based on outside temperature, is widely used in the transformation process of VAV systems for energy saving.

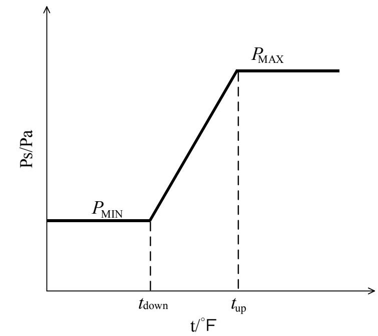

Fig. 2. basic principle of static pressure reset control based on outside temperature

3.2. Control method based on measured value of airflow rate

In the early 1990s, many scholars, at home or abroad, have focused on the study of the control method of the supply fan airflow [15, 16]. In China, Tsinghua University develops a total air volume control method in 1998, and the supply airflow is regarded as the controlled variable based on the pressure independent VAV terminal. The effect of static pressure reset control is compared with that of constant static pressure using the HVACSIM+ software, and experimental results show the presented method has the better control performance and the higher reliability [17]. Essentially, the total air volume control method is a supply fan control method based on the pressure independent VAV terminal. Compared with the total airflow measurement results of all terminals, the total airflow demand is regarded as the target value to regulate the supply fan speed with variable frequency drive.

In order to improve airflow measurement accuracy, David develops the second and third order theoretical models for the flow station using fan speed and fan head as inputs. The theoretical model has been experimentally tested, and experimental results show the second order model was within 1.71% of the experimental values, and the third order model was within 1.52%. The second order model, which is much simpler, is considered adequate for use in buildings [18]. In addition, Liu develops an airflow control method named variable speed drive volumetric tracking (VSDVT) instead of the flow stations, and its performance is studied and compared with the fan tracking (FT) method using model simulations, and experimental results show VSDVT, which maintains a constant building pressure and the required outside airflow, reduces the annual return air fan and supply air fan energy by up to 50% and 30%, respectively [19]. Then, Liu presents a supply fan speed control method using the fan airflow station (FAS), and the supply fan speed is controlled to maintain the duct static pressure setpoint, which is reset based on the airflow ratio measurement using the FAS. The result shows that the control method can significantly save supply fan power and improve the energy efficiency [20].

Zhang studies the existing methods of the supply fan control, and puts forward a static pressure reset control method based on the airflow rate measurement in the main supply air duct. Test results are compared between constant static pressure and static pressure reset in a small VAV system laboratory. Considering the limitation of laboratory study, a series of simulation tests are performed on a simulation platform, and the performance of the presented method is evaluated from aspects of the system stability, the energy saving potential and the application range [21].

For running and commissioning engineers, a simple and useful measurement method of supply fan airflow directly affects the commissioning difficult level of the system. Liu develops a simplified in-situ fan curve measurement procedure using the manufacturers fan curve and one point (air flow and fan head) measurement. Background theory, methodology, error analysis and the step-by-step procedure developed for the practitioners are presented. Both error analysis and experimental results show that the generated in-situ fan curve with the least system resistance closely matches the measured in-situ curve, and the difference of the fan head predicted by the fan curve is within the error range [22].

3.3. Control method based on terminal damper position feedback

In order to meet the indoor load change and the requirement of temperature and humidity, the indoor supply airflow is regulated by the damper position of terminal box, which is equipped with the pressure independent VAV terminal. Duct static pressure setpoint is reset by judging the on-off state and the quantity of 100% opening of terminal dampers in traditional supply fan control method based on the terminal damper position feedback. Though these methods is easy to implement, it could not consider whether the supply airflow meets the load demand of all terminals or not.

With the development of building automation technology, electric damper, which is equipped with the damper positon feedback, is widely used in VAV air conditioning system. The basic principle of static pressure reset control based on the terminal damper position feedback is described in Fig. 3, and it is shown that the regulated goal is to adjust the damper position of the maximum damper position terminal into a target damper position domain. If the damper position of the maximum damper position terminal is bigger than the upper limit of the target damper position domain, duct static pressure setpoint is increased by improving the supply fan speed and vice versa [2].

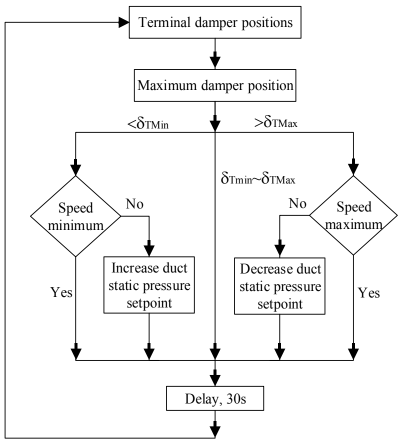

Fig. 3. basic principle of static pressure reset based on terminal damper position feedback

Wei and Liu present an integrated damper and pressure reset (IDPR) method for VAV system supply fan control. IDPR method regulates the static pressure at a minimum required level while maintaining at least one terminal box damper at 100% opening. When the entire system is flawless, the fan speed is controlled in a way similar to the terminal regulated air volume (TRAV) method. When the system fault exists, the control effect of IDPR method is better than that of TRAV method. IDPR method can be implemented in both full DDC (direct digital control) systems and hybrid systems, where only the space temperature readings are communicated to the DDC controller at the air-handler level and terminal boxes are controlled by pneumatic controllers [23].

With the development of direct digital control, each control loop of VAV air conditioning system could be directly regulated according to input and output signals of all terminals, especially static pressure reset control. Compared with PID logic, Taylor presents a Trim & Respond logic which saves the fan energy consumption and is the more effective approach [24]. Furthermore, Zheng presents an optimal cascade control method for static pressure reset based on the terminal damper position feedback using wireless sensor networks. Wu and Cao (Chinese architectural academy of sciences) apply existing foreign determination methods, and present an improved method which identifies the index circuit firstly and then figures out duct static pressure setpoint. This method could find suitable duct static pressure setpoint and is useful for the system commissioning in VAV air conditioning system [25].

3.4. Intelligent control method

To adopt the building load change and save building energy consumption, the study of static pressure reset control method has been developed in the direction of intelligent control recently. In many studies, intelligent control algorithms such as model predictive control [26], generalized predictive control, robust PID control and fuzzy control [27] have been widely applied in VAV air conditioning system. These methods, which partly improve the control parameter accuracy and the control system stability, reduce the energy consumption of VAV air conditioning system.

Andrew (the University of Iowa) applies the evolutionary computation algorithm to solve a multi-objective predictive model about supply air temperature and humidity. The results show that the control method saves energy consumption by optimizing operations of an HVAC system while maintaining the corresponding indoor air quality within a user-defined range [28]. Furthermore, Andrew also applies the multi-objective particle swarm optimization algorithm to solve a multi-objective predictive model, and the optimization model and the multi-objective algorithm are implemented in an existing HVAC system. The test results, which are performed in the existing environment, demonstrate significant improvement of the system. Compared to the traditional control method, the proposed model saves up to 30% of the energy consumption [29].

Considering of the nonlinear, the time-varying feature and difficulties in modeling controlled object, Bai and Ren (Xi'an University of Architecture and Technology) design a generalized predictive self-tuning algorithm and apply the algorithm in the process of static pressure reset control. Simulation and experimental results indicate that the algorithm has the better performance of tracking and anti-interference as well as the greater energy saving potential [5]. In order to further improve the stability of static pressure reset control, Yang and Ren design a linear matrix inequality-based robust PID controller with polytypic system models and optimize PID parameters with the covariance constraint method, and the stability of the system is improved in the practical application. Experimental results show that the robust control algorithm for PID controller can overcome the model uncertainty and realize the stable control of static pressure reset in VAV air conditioning system with the better dynamic and static indexes [30].

Chen (Hunan University) presents a sum flow rate-damper signal and highest load ratio-minimum flow rate to optimize the supply air static pressure and the temperature of VAV air conditioning system. The system model is established, and the energy consumption before and after the optimization is simulated on typical days using TRNSYS software. Compared with constant static pressure and constant air temperature control scheme, simulation results show that the optimal scheme can save the energy consumption and improve the indoor thermal comfort, especially in part load conditions [31].

4. Conclusion

For the sake of energy saving of VAV air conditioning system, this paper presents the basic principle and the a review of static pressure reset control, which includes outside air based control method, airflow based control method, terminal damper position feedback based control method and intelligent control method, on the basis of constant static pressure control. Although lots of achievements have been made on the aspect of static pressure reset control, there are still several problems that need to be solved.

- Due to characteristics of nonlinear, multivariable and long delay time, it is difficult to set up an exact mathematics model about static pressure reset. Therefore, the change direction of static pressure reset could be obtained directly, but the variable quantity of static pressure reset could not be obtained accurately.

- Generally, duct static pressure setpoint is obtained according to design parameters and the empirical analysis. However, there is a big difference between operating parameters and design parameters under the operating condition, and design parameters do not reflect actual load characteristics. These will result in that duct static pressure setpoint cannot meet the load demand and increase the commissioning difficulty.

- Inaccurate airflow rate measurement is always there due to measuring error and sensor fault. Jin (Shanghai Jiao Tong University) presents the strategy and the tool of the robust fault detection and diagnosis to ensure the energy efficiency of the system [32, 33].

As a result, factors such as measuring error, sensor fault and parameter uncertainty, directly affect the accuracy of traditional control method of static pressure reset, which reduces the robust and the stability of the system. With the development of information technology, it is promising for static pressure reset to select reasonable intelligent control method in order to remove the dependence on accurate mathematical model and supply a novel way for the nonlinear problem in VAV air conditioning system.

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