A study on the Determination of Minimum Airflow setpoint of Single Duct VAV Terminal Units

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ABSTRACT

The objective of this study was evaluated a control method for the minimum air flow rate of VAV terminal unit. The minimum air flow rate of the VAV terminal unit is the key factor affecting the thermal comfort, indoor air quality (IAQ), stratification and energy consumption, depending on the operating mode of the VAV system. Therefore, selecting the proper minimum air flow is very important. In this study, building simulation was conducted to evaluate the indoor thermal comfort, stratification, IAQ and energy consumption according to the minimum air flow rate of the VAV terminal units. CASE 1 is the minimum air flow that considers sensible load. CASE 2 is the minimum air flow that considers stratification. CASE 3 is the minimum air flow that considers the IAQ. The result of the simulation is that CASE2 satisfies all the conditions of indoor thermal comfort, IAQ and without stratification.

KEYWORDS

Variable air volume system, Minimum airflow, Thermal comfort, Indoor air quality, Energy consumption

INTRODUCTION

The minimum air flow of a VAV terminal unit is the key factor affecting the thermal comfort, indoor air quality (IAQ), stratification and energy consumption. A terminal Unit with conventional control sequences can cause occupant discomfort or waste energy. The terminal Unit will perform simultaneous heating and cooling, and AHUs will consume more fan power if the minimum airflow is higher than required. On the other hand, the air conditioned space will have IAQ problems with less air circulation if the minimum airflow is less than required. Therefore, selecting the proper minimum airflow is a very important element in a VAV system. The existing minimum air flow of a VAV terminal unit generally applies approximately 30~50% of the maximum air flow as a fixed value.

Yao et al. compared three kinds of air conditioning systems (VAV, CAV and fan coil

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system) in a small office building in six different cities in China. Engdahl and Johansson investigated the energy savings potential of a controlled supply air temperature of a VAV based system by a comparison with a constant supply air temperature. Taylor and Stein discussed the minimum airflow setpoint of the terminal units. The actual controllable minimum airflow setpoint is usually different from the unit manufacturer's recommended minimum airflow setpoint for each unit size and for each standard control option. Cho and Liu identified the relationship between supply air temperature and minimum airflow. Besides, the relationship between supply air volume and temperature that minimizes energy consumption was suggested through proper supply temperature, stratification and energy analysis according to load that energy consumption can be minimized.

This paper proposes the minimum air flow of a VAV terminal unit that can resolve the IAQ and stratification problems based on a fixed minimum air flow. The comfort of the indoor heat, indoor air quality, stratification and energy of the VAV terminal unit control method with a fixed minimum airflow was analyzed. The fixed minimum airflow of the VAV terminal unit, which is considered the most appropriate among the existing control methods, was then selected. The simulation method was used to compare with the each minimum airflow.

MINIMUM AIRFLOW OF VAV TERMINAL UNIT

Terminal units are one critical component of the VAV systems. They normally serve both interior zones, which will only have a cooling load and will not require heating, and exterior zones, which will have a cooling and heating load and will require heating. The system consists of a controller, a temperature sensor, an actuator, a modulation damper, a heating coil and a flow station. For spaces requiring heating, a reheat coil can be installed in the discharge.

For the cooling cycle, the inlet damper modulates to maintain the room setpoint between the minimum and maximum airflow setpoint. For the heating cycle, as the temperature in the space drops below the setpoint, the damper begins to close and reduce the flow of air to the space. When the airflow reaches the minimum limit, the valve on the reheat coil begins to open as shown in Figure 1.

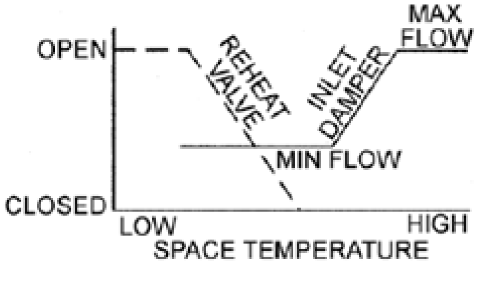


Figure 1. *Control sequence of the VAV terminal unit*†

† ASHRAE Application Handbook, ch.45

The primary considerations for selecting the minimum air flow of the VAV terminal unit are the proper heating demand, amount of ventilation, energy, stratification etc. These factors affect the indoor heat environment and its air quality. On the other hand, currently, the VAV terminal unit control method with the minimum airflow fixed to 30 ~ 50% of its maximum airflow is used when cooling.

SIMULATION CONDITION

The TRNSYS 17 simulation program was used to calculate the minimum air flow of the VAV system. The TRNSYS (transient systems simulation) is a building detailed analysis program and the users perform a simulation by linking the components to each other. In the program, the components that are not in the TRNSYS Library can also be encoded and newly added using FORTRAN. In this respect, TRNSYS is a program with a high possibility of diverse applications. The simulation zone selected was an actual office building. This building is operated as a single duct VAV system and occupies two people. The AHU operate economizer, and zone assumes that it is a closed system.

Table 1. *Simulation condition*

List		Contents
Zone	Location	Omaha, Nebraska, USA
	Use	Office
	Size	6.3m *2.7m*3.35m (L*W*H)
System		VAV with reheat system
People		2 people
Operating conditions	Schedule	24hour
	Set point temperature	24°C
Load conditions	Occupant	- Seated, Light work, typing : 150W - Occupants : 2
	Light	$13W/m^2$
	Equipment	$16W/m^2$

CASE STUDY OF MINIMUM AIRFLOW

The most widely used single maximum control logic was selected as an existing control method of the VAV terminal unit. An evaluation by comparison was conducted with three different measures. CASE 1 is the minimum air flow that considers sensible heat. The minimum air flow calculated with the largest heating load was applied to CASE 1. CASE 2 is the minimum air flow that considers stratification. This is the case that increases the minimum air flow without inducing stratification. CASE 3 is the minimum air flow that considers the IAQ. In this case, the air flow that can maintain the indoor CO_2 concentration at less than 1,000ppm is selected as the minimum air flow. The standard for the CO_2 concentration was 1,000ppm based on the IAQ maintenance standards of ‘Indoor Air Quality Control in Public Use Facilities, Etc. Act’. Table 2 lists the minimum air flow of each CASE.

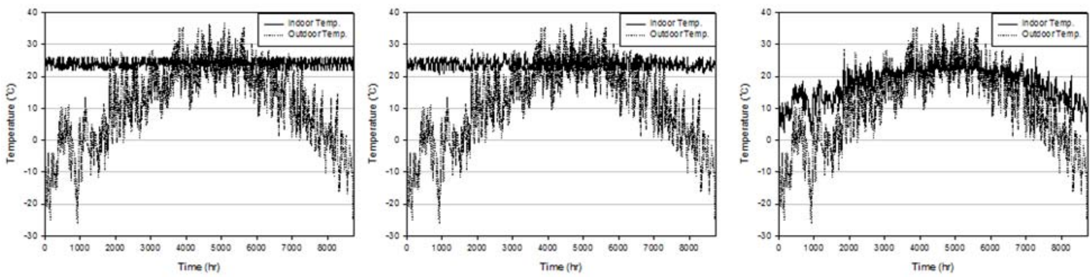
Table 2. *Simulation CASE*

CASE	Classification	Minimum airflow
CASE1	Minimum air flow considering sensible load	150cfm
CASE2	Minimum air flow considering stratification	170cfm
CASE3	Minimum air flow considering IAQ	30cfm

ANALYSIS OF SIMULATION RESULTS

Analysis of the Indoor Thermal Comfort

Figure 2 describes the changes in the annual indoor temperature in CASES 1, 2, and 3. CASES 1 and 2 are cases that control the annual indoor temperature to 24°C. In CASE 3, the minimum air flow is so low that the indoor temperature cannot be maintained at a set temperature.



(a) CASE 1 (b) CASE 2 (c) CASE 3

Figure 2. *Thermal comfort analysis*

Analysis of the Indoor Air Quality

An analysis of the IAQ was conducted based on the indoor CO_2 concentration. The standard of the indoor CO_2 concentration was set to 1,000ppm according to the IAQ criterion in ‘Indoor Air Quality Control in Public Use Facilities, Etc. Act’.

In CASE 1 and CASE 2, the indoor CO_2 concentrations were approximately 400ppm ~ 600ppm. This figure is lower than the standard. The concentration in CASE 3 was approximately 400ppm ~ 1,000 ppm, which meets the IAQ criterion.

Stratification Analysis

The spread of indoor vertical temperature was analyzed according to the load condition in each case to determine the stratification. CASE 3 was excluded from stratification analysis because it did not satisfy the indoor temperature. Both CASES 1 and 2 meet the set temperature at the measurement point of the indoor temperature (1.1m) when the load is 500~1000kJ. The temperature difference between 0.1m from the floor and 1.1m from the floor was no higher than 3°C. In other words, there was no stratification. CASE 1 and 2 satisfied the indoor temperature at the measurement point (1.1m) under all load conditions when the load is 1500~4500kJ. On the other hand, stratification occurred when the temperature difference between 0.1m from the floor and 1.1m from the floor of CASE 1 exceeded 3°C at indoor loads of 2,500kJ, 3,000kJ, and 4,000kJ.

Energy Analysis

The heating coil in the AHU showed the largest energy consumption in CASE 3. If the indoor load is small, the minimum necessary outdoor air intake rate is supplied to the room, which increases the heating coil energy. This occurs in CASE 3, which has a relatively low minimum air flow. The cooling coil energy and fan energy were highest in CASE 2, which has a high minimum air flow. The AHU energy consumption was approximately 42,000MJ, 52,000MJ and 61,000MJ in CASES 1, 2 and 3, respectively. In other words, CASE 3 had the largest energy consumption.

The reheating coil energy consumption of the VAV terminal unit was approximately 120,000MJ, 140,000MJ and 20,000MJ in CASES 1, 2 and 3, respectively. These are related to the size of the minimum air flow.

The total energy consumption was approximately 160,000MJ, 200,000MJ and 88,000MJ in CASES 1, 2 and 3, respectively. CASE 2 and 3 had the largest and smallest energy consumption, respectively.

CONCLUSION

This study examined the minimum airflow of the VAV terminal unit at an office building. The minimum air flow of the VAV terminal unit is an essential part of the indoor thermal comfort, IAQ, stratification, and energy. Therefore, selecting the proper minimum air flow is very important. In this study, the minimum airflows that consider the load, stratification, and IAQ were selected after a comparison of the existing minimum air flow control algorithm. Comparison analysis of the indoor thermal comfort, IAQ, stratification, and energy was conducted. The minimum airflow consider of the IAQ was not satisfied indoor set temperature. The minimum airflow consider of the load was occurred stratification. The minimum airflow consider of the stratification had the largest energy consumption but satisfied Indoor temperature and IAQ. As a result, the minimum air flow considering stratification was the most appropriate.

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