CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 9

Heiselberg, Per Kvols

A Study on the Control Method with Ventilation requirement of VAV System in Multi-Zone

Hyo-Jun Kim[*1], Young-Hum Cho[*2]

[*]*School of Architecture, Yeungnam University, Gyeongsan, Gyeongbuk 38541, Korea*

[1]kimyo@ynu.ac.kr

[2]yhcho@ynu.ac.kr

Abstract

The objective of this study was to propose a control method with ventilation requirement of variable air flow rate (VAV) system in multi-zone. In order to control the VAV system at multi-zone, it is essential to control terminal unit installed in each zone. A VAV terminal unit with conventional control method using fixed minimum air flow can cause indoor air quality (IAQ) issue in winter. This research proposes control method with ventilation requirement of VAV terminal unit in multi-zone. And the conventional and proposed control algorithms were compared through a TRNSYS simulation program. The integrated control method with an air flow increase model in the VAV terminal unit, AHU and outdoor air intake rate increase model in the AHU was based on the indoor CO2 concentration. The proposed VAV terminal unit control method satisfies all the conditions of indoor thermal comfort, IAQ and stratification. An energy comparison with the conventional control method showed that, the method satisfies not only the indoor thermal comfort, IAQ and stratification issue, but also reduces the energy consumption.

Keywords - VAV system; Terminal unit; Control method; Multi-zone; Ventilation requirement

1. Introduction

The building accounts for 25% or higher in the whole amount of domestic energy consumption. Especially, middle and large buildings continue to increase energy consumption. These days, the reduction of green gases by energy saving is highlighted as an important issue. Accordingly, building facility systems should be operated to make sure that energy is used and saved efficiently.

The variable air flow rate system (VAV system) is adopted in many large buildings with increasing interest in energy saving and various studies are performed for its efficient operation. The common air conditioning system is designed to perform air conditioning in a plurality of zones using an air handling unit (AHU). A terminal unit is located in the end terminal that supplies air-conditioning air to each zone, which makes it necessary to control a terminal unit in each zone in order to control a VAV system in a multi-zone.

The systematic use of optimization techniques has been introduced in the heating, ventilation and air conditioning (HVAC) industry in recent years, with a substantial focus on VAV system optimal control.[1] Nassif and Moujaes[2] proposed a new damper control strategy for the outdoor, discharge and recirculation air dampers of the economizer in a VAV system. The strategy controlled the outdoor air by only one damper while keeping the others fully opened. The simulation results showed that the annual energy savings in the supply and return fans of an existing system, compared to the traditional strategy of three-coupled dampers were 12% and 5%, respectively. Cho[3] determined the relationship between supply temperature and minimum air flow rate at the terminal unit and presented a terminal unit air flow rate control method using step control to control indoor load and ventilation requirement. Kang[4] determined the relationship between supply temperature, air flow rate and energy by height and presented a terminal unit air flow rate control method considering stratification and IAQ. Kim[5] presented a method for controlling the supply temperature and air flow rate of a terminal unit to control stratification. However, preceding studies are based on a single zone. Therefore, it is considered to be additionally necessary to study methods for controlling a VAV terminal unit in a multi-zone.

Therefore, the this paper proposed a VAV terminal unit control method in the multi-zone that meets ventilation requirement to control IAQ. The proposed method controls IAQ through air flow rate control in case of the appearance of a space exceeding the IAQ control standard. The minimum outdoor air intake rate was based on the CO2-based model, which is determined depending on the indoor CO2 concentration. Moreover, this study composed a system using Trnsys17, a dynamic energy simulation tool, to make a comparison between the existing and proposed algorithms, and analyzed thermal comfort, IAQ and energy consumption.

2. VAV terminal unit

The selection and control of a VAV terminal unit has a significant influence on energy consumption at the HVAC and indoor comfort. As seen in Figure 1, the single duct VAV terminal unit system consists of a controller, a temperature sensor, an actuator, a damper, a reheating coil, and an air flow sensor.[6]

The air flow sensor controls the damper to meet a required flow rate within the scope of the minimum and maximum air flow rates at the terminal unit according to indoor temperature change. When the air flow rate of the terminal unit reaches minimum and the indoor heating load is high, the reheating coil is operated to enhance supply air flow rate and thus maintain indoor comfortable temperature. Minimum air flow rate is calculated using maximum air flow rate, which is calculated using sensible load, indoor set temperature, and supply temperature.

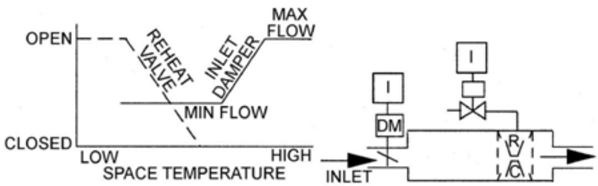

Figure 1. Control sequence of the VAV terminal units (from ASHRAE Application Handbook Ch. 45)

3. Proposed Control Method of VAV Terminal Unit

3.1 Simulation Conditions

This study used TRNSYS 17,a dynamic energy simulation program to propose a method for controlling the VAV terminal unit. The building was modelled using the Google Sketch Up, and its detailed information was entered using TRNBuild. The building's HVAC system was modelled using Simulation Studio.

The building was located in Lincoln, State of Nebraska, and an AHU was selected that controlled 8 target spaces in which occupants resided. The spaces are used for office work and equipped with single duct VAV systems. The VAV system is operated 24 hours around the year and indoor temperature is set at 24˚C. This study selected an AHU controlling 8 indoor spaces to calculate the minimum air flow rate of the VAV system in a multi-zone. The terminal unit controls a supply damper and supplies air flow rate on the basis of the set values of indoor temperature and minimum and maximum air flow rates. Minimum air flow rate is set at approximately 30 % of maximum air flow rate.

3.2 Proposed control method for multi-zone VAV terminal unit

If an AHU controls a plurality of zones, the minimum air flow rate of a terminal unit is very important, and the terminal unit should be controlled in accordance with the circumstances in each zone. For the control for the terminal unit, air flow rate is controlled according to change in absolute temperature. At the existing terminal unit, air flow rate is controlled for indoor temperature alone, not for IAQ. In this case, IAQ is based on CO2 concentration. The existing CO2-DCV controls only the outdoor air flow rate of the AHU to control indoor CO2 concentration. But if outdoor air flow rate is increased to control indoor CO2 concentration, an excessive AHU coil energy will be used according to outdoor air. Therefore, this study aims to propose a method for controlling the air flow rates of a terminal unit and an AHU, delaying outdoor air inlet time, and reducing outdoor air flow rate, in order to control indoor CO2 concentration.If there appears a zone in which indoor CO2 concentration is higher than 1000ppm:

(1) Control indoor CO2 concentration by increasing the air flow rate of a terminal unit in the zone concerned.Do not increase outdoor air flow rate.

(2) If ventilation CO2 concentration is low, control indoor CO2 concentration by increasing the inflow of ventilation air flow rate. Do not increase outdoor air flow rate.

(3) Control indoor CO2 concentration by increasing outdoor air flow rate from the AHU.

Therefore, this study proposed an integral control algorithm after making a simulation comparison between air flow rate increase models at the terminal unit and the AHU.

For a terminal unit and AHU, a method for increasing air flow rate was established in view of minimum fresh outdoor air flow rate and outdoor air flow rate for operating an economizer. But when controlling indoor CO2 concentration using the air flow rate increase of the terminal unit and the AHU, return CO2 concentration may be increased by increase in occupants, which increases supply CO2 concentration, making it impossible to control indoor CO2 concentration. In this case, indoor CO2 concentration should be controlled by increasing outdoor air flow rate.

Calculated with the air flow rate increase method, air flow rate is greater than that to eliminate indoor load and may consume air-conditioning and heating energy too much without controlling indoor temperature. To solve this problem, this study proposed a VAV terminal unit CO_2 integration control method that reset outdoor air flow rate and supply temperature on the basis of the above-mentioned air flow rate increase method. When increasing air flow rate to control CO_2 concentration, air flow rate is supplied more than required and air-conditioning and heating energy is waste.

Therefore, when a VAV terminal unit system works in a ventilation mode due to the non-control of CO_2 concentration, supply temperature should be reset using Equations (1) and (2) to make sure that set indoor temperature is maintained:

$$Q_h = \rho \dot{V} C_p (T_s - T_r) \qquad (1)$$

$$T_s = \frac{Q_h}{\rho \dot{V} C_p} \qquad (2)$$

Where,Q_h= Indoor heating load, $\dot{V}$= Supply air flow rate, ρ=Air density, C_p=Air specific heat, T_s=Supply air temperature,T_s=Indoor air temperature.

4. Results and discussion

The indoor thermal comfort, IAQ, and stratification issue wereestimated to evaluate the proposed control method of the VAVterminal unit. An analysis of the indoor thermal comfort was conductedusing the standards of the indoor set temperature (24 ˚C).

An evaluation of the IAQ was conducted based on the indoor CO2concentration. The standard of the indoor CO2 concentration was1000 ppm. Stratification was considered to have occurredwhen the temperature difference between 0.1 m and 1.1 m fromthe floor was more than 3 ˚C.

4.1 Indoor environment comfort

Thermal comfort

In every zone, indoor temperatures are 23-25°C, which meets 24±1̊C, an indoor set temperature.

Indoor CO2 concentration

Indoor CO2 concentration was higher in winter than in summer. If outdoor air temperature falls below a specific temperature with the operation of the economizer, the AHU minimizes outdoor air flow rate, thus increasing indoor CO2 concentration in winter. If outdoor air temperature rises above a specific temperature, the AHU minimizes outdoor air flow rate, but indoor CO2 concentration is considered to be kept low due to high air flow rate at the terminal unit.

Indoor vertical temperature difference

Stratification was considered to have occurred when the temperature difference between 0.1 m and 1.1 m from the floor was more than 3°C. The proposed algorithm satisfied the indoor set temperature without stratification in any zone.

4.2 Energy Consumption

The existing VAV terminal unit control method selected a minimum air flow rate control which fixes air flow rate to 30 % of its maximum.

The total energy consumption amount at the reheating coil of the terminal unit showed approximately 118,000 MJ according to the existing terminal unit control method, but decreased by approximately 68 % according to the proposed terminal unit control method. This result was caused by the reset of minimum air flow rate and supply temperature. The zone-specific supply air flow rate was decreased by the application of floating minimum air flow rate, and energy was saved by lower supply temperature than fixed one.

Total energy consumption amounts were approximately 228,000 MJ and 135,000 MJ at CASE 1 and CASE 2, respectively. Energy consumption amount was decreased by approximately 41 % by the proposed terminal unit control method, as compared to the existing one.

5. Conclusions

Figures and tables must be centred. Graphics may be full color. All colors will be retained on a digital medium. Graphics must not use stipple fill patterns because they may not be reproduced properly. The minimum air flow rate of the VAV terminal unit is a chief factor that has a direct influence on indoor heat comfort, IAQ, and energy consumption amount. This makes it very important to select optimum minimum air flow rate. According to the existing VAV terminal unit control, indoor temperature alone is controlled using fixed minimum air flow rate, and IAQ can be affected by change in the number of occupants. Therefore, this study proposed a VAV terminal unit control method considering indoor ventilation requirement in a multi-zone, and evaluated a terminal unit control method proposed in comparison with the existing one.

This study proposed a VAV terminal unit CO2 integration control method for increasing outdoor air flow rate according to increase in air flow rate at terminal unit and AHU on the basis of indoor CO2 concentration. Any CO2 problem led to the operation of ventilation mode, which increased air flow rate and solved IAQ. Indoor thermal comfort was also stable, even when air flow rate was increased with the reset of supply temperature by increase in air flow rate.The proposed VAV terminal unit control method satisfies all the conditions of indoor thermal comfort, IAQ and stratification. An energy comparison with the existing control method showed that, the method not only satisfies the indoor thermal comfort, IAQ and stratification but also reduces the energy consumption.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology. (NRF-2014R1A1A2058912)

References

[1] G.Wang, L.Song, “Air handling unit supply air temperature optimal control during economizer cycles”, Energy and Buildings 49 (2012) 310-316

[2] N. Nassif, S. Moujaes, “A new operating strategy for economizer dampers of VAV system”, Energy and Buildings 40 (3) (2008) 289–299

[3] Cho, Y., Liu, M, "Correlation between minimum airflow and discharge air temperature", Building and Environment 45 (2010) 1601-1611

[4] Kang, S., Kim, H., Cho, Y. "A Study on the control method of single duct VAV terminal unit through the determination of proper minimum air flow", Energy and Buildings 69 (2014) 464-472

[5] Kim, H., Kang, S., Cho, Y. “A study on the control method without stratification of single duct VAV terminal units

[6] ASHRAE, ASHRAE applications handbook. Chapter 45. Design and application of controls, 2004.

[7] California Energy Commission (CEC), 2008 Building Energy Efficiency Standards for Residential and Non-residential Buildings. California Code of Regulations Title 24, Part 1, CEC.400.2008.001.CMF, 2008

[8] ASHRAE, ASHRAE Standard 90.1-2010 "Energy Standard for Buildings Except Low-Rise Residential Buildings”, 2010

[9] ASHRAE, ASHRAE Standard 62.1-2010 "Ventilation for acceptable indoor air quality (IAQ)", 2010.

[10] ASHRAE, ASHRAE Standard 55-2010 “Thermal environmental conditions forhuman occupancy”, 2010.