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Development of a dual-mode demand control ventilation strategy for indoor air quality control and energy saving

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Abstract

A dual-mode demand control ventilation strategy was established targeting at use in buildings where the number of occupants varies frequently. The first contaminant chosen for sensor control is CO_2 and the second is a non-occupant-related indoor pollutant which indicates the demand of fresh air to dilute the non-occupant-related indoor contaminants. Experiments were conducted to verify the performance of this control strategy. The experimental results showed that an acceptable indoor air quality could be obtained. More than 90% of the occupants thought that the indoor air quality was acceptable. Comparing with the original fixed-rate ventilation control strategy, about 8.3–28.3% of the daily electrical energy could be saved.

Keywords: Indoor air quality; Demand control ventilation; Carbon dioxide; Radon; Purging

1. Introduction

Ventilation is one method to maintain good indoor air quality. The more fresh air is brought into the indoor environment, the better the indoor air quality can be achieved if the fresh air comes from non-polluted ambient source. However, conditioning fresh air can consume a lot of energy, especially in Asian cities where humidity is high in summer. It has been noticed that 30% or more of the annual heating and cooling cost is spent in handling the fresh air in a typical office building [1,2]. Over-ventilation may lead to a significant waste of energy. Therefore, an operationally cost-effective ventilation control system is very important in buildings. Ventilation control strategies such as sensible temperature-based air-side economizer, enthalpy-based air-side economizer and demand control ventilation (DCV) have been demonstrated in many buildings all over the world. The sensible temperature-based air-side economizer uses the outdoor air temperature (dry-bulb temperature) as the control signal to adjust the fresh air supply to the prescribed supply rate. It usually can reduce the annual cooling energy by around 30% in moderate climates such as in Columbia, MO, US [3,4]. The enthalpy-based air-side economizer considers the total heat of the outside, re-circulated and mixed air to determine the fresh air supply rate. It can have a better performance than the sensible temperature-based air-side economizer in terms of energy saving because it traces both the sensible and latent heat of the dry-air and moisture, especially in highly humid climates. However, the enthalpy sensor is much more expensive and it usually needs a semi-annual calibration. While using these two kinds of ventilation control strategy, fresh air is brought in at the prescribed rate and does not directly correspond to the variation in occupancy. So if these two ventilation control strategies are used in institutional or similar buildings where the number of occupants varies frequently, they may not be able to maintain a good indoor air quality and avoid over-ventilation at the same time. Demand control ventilation makes use of some methods to estimate the actual number of occupants and adjusts the fresh air supply rate to meet the demand of fresh air per person. This approach is more suitable for buildings with varying occupancy during the day such as auditoriums, libraries, classrooms and theatres. In recent years, CO_2 concentration has been widely used to measure the occupancy for the demand control ventilation system as it is an excellent surrogate gas for the concentrations of occupant-related contaminants [1,5–7]. By using the dynamic CO_2 detection method, the occupancy can be determined accurately and the change

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Nomenclature

A	Area of the material that emits radon (m^2)
C_i	Indoor radon concentration (Bq m^{-3})
C_{i0}	Indoor radon concentration at the beginning of the purging sequence (Bq m^{-3})
C_o	Outdoor radon concentration (Bq m^{-3})
C_{p2}	Radon level after Purging sequence 2 (Bq m^{-3})
C_{sco2}	CO_2 set point (ppm)
C_{oco2}	Outdoor CO_2 concentration (ppm)
E	Radon emanation rate of building material (Bq (m^{-2} h^{-1}))
Q	Ventilation rate of the premises (m^3 h^{-1})
K_d	Differential parameter of the PID controller
K_i	Integral parameter of the PID controller
K_p	Proportional parameter of the PID controller
N	CO_2 generation rate per person (l min^{-1})
t_{pg}	Purging duration (h)
V	Effective volume of the premise (m^3)
V_o	The outdoor air flow rate per person (l s^{-1})
X	Damper position, which is carried out by the PID controller (%)
$\Delta y(k)$	Difference between the CO_2/radon setpoint and the kth sampled CO_2/radon level
λ	^{222}Radon decay constant (7.553585×10^{-3} h^{-1})

of occupancy can be detected with a fast response time [8]. Based on the actual occupancy, the outdoor air supply rate per person recommended in the industrial standards such as ASHRAE 62-1999 [9] can be met and over-ventilation can be avoided. Rock and Wu's work [1] shows that CO_2 based demand control ventilation could offer better performance on energy saving than fixed-rate and economizer ventilation in hot and humid climate.

In Hong Kong, where such climate is normal from May to September as the average temperature and relative humidity during this period are as high as 27.6°C and 81%, respectively. CO_2 based demand control ventilation may be a good way to provide indoor air quality and energy saving. However, CO_2 is only an indicator for occupant-related indoor pollutant sources. The CO_2 based DCV can only guarantee that the fresh air intake is enough to dilute the occupant-related pollutants. Whether the levels of the non-occupant-related pollutants are acceptable or not is not considered. ASHRAE 62-1999 [9] points out that using CO_2 as the indicator of bio-effluents does not eliminate the need to consider other contaminants, a number of which have received increasing attention in recent years such as radon and VOCs.

Since the end of 1997, in order to study the performance of the CO_2 based demand control ventilation strategy, a series of site measurements had been conducted in a typical lecture theatre at the Hong Kong University of Science and Technology (HKUST). During the experiments, the major indoor pollutants such as CO_2, radon, TVOC, and formaldehyde were measured in detail, among which CO_2 and part of the VOCs are occupant-related and radon, formaldehyde and part of the VOCs are non-occupant-related. The results showed that by using only CO_2 based demand control ventilation, the non-occupant-related indoor pollutants such as radon might not be maintained at acceptable levels under some circumstances. Based on the findings from the experiments, a new dual-mode demand control ventilation strategy, which aims at maintaining some of the occupant-related and non-occupant-related indoor air pollutants at acceptable levels was developed. Experiments were conducted in a medium-sized lecture theatre at HKUST to verify the performance of this new demand control ventilation strategy. During the experimental study, both the indoor air quality and the energy consumption while using the developed dual-mode demand control ventilation strategy were studied.

2. Experimental setup and methods

Both the site measurements on some of the indoor air quality parameters and the verification of the dual-mode demand control ventilation strategy performance were conducted in a lecture theatre at the Hong Kong University of Science and Technology. The lecture theatre is on the ground floor of the northern perimeter of the Academic Building. It has a total floor area of about 150 m^2, a volume of about 500 m^3, and a maximum capacity of 130 occupants. As there is variable occupancy, the venue is very suitable for the study of demand control ventilation. A HVAC system was used to serve only this lecture theatre. It is a single-zone, variable-air-volume (VAV) system. A direct digital controller (DDC) is used in this system to control the chilled water valve and the supply air inlet guide vane actuator to maintain the desired supply air temperature and static pressure. A fresh air damper is