DEVELOPMENT OF A DEMAND CONTROL STRATEGY IN BUILDINGS USING RADON AND CARBON DIOXIDE LEVELS

George Y. Chan[1], Christopher Y. Chao[1], Derek C. Lee[1], Samuel W. Chan[2] and H. Lau[2]
[1]Department of Mechanical Engineering
[2]Estate Management Office
The Hong Kong University of Science and Technology, Hong Kong

ABSTRACT

Air change rates, indoor radon and carbon dioxide levels were monitored in a lecture theater in the Hong Kong University of Science and Technology. Two preliminary measurements (Cases 1 and 2) and one series of demand control ventilation simulation (Case 3) were made to investigate the indoor air quality of the lecture theater. Radon and carbon dioxide levels were found to be relatively high in Case 1 and later improved at the expense of operating the system catering for maximum occupancy in Case 2. In Case 3, the average radon and CO_2 levels inside the lecture theater were kept under 200 Bq/m^3 and 1000 ppm during lecture hours, respectively. These results led to the possibility of developing a demand control strategy (Case 4) using radon and carbon dioxide levels as control parameters for fresh air intake. This new demand control ventilation has an estimated energy saving potential of 44%.

KEY WORDS: Demand Control, Carbon Dioxide, Radon, HVAC system, Tracer gas

INTRODUCTION

Traditional demand control ventilation usually makes use of the carbon dioxide (CO_2) level as a signal to control the damper opening for fresh air supply rate on office premises. In some of our studies it was found that this might sometimes lead to high level of radon accumulation during the day. Two preliminary measurements (Cases 1 and 2) and one series of demand control ventilation simulation (Case 3) were made in a lecture theater at the Hong Kong University of Science and Technology. Each of the preliminary measurements lasted for about a week and the simulation lasted for about a month, covering different fresh air supply rate conditions and occupancy levels during the day. As a result, a demand control strategy using both CO_2 and radon gases as control parameters has been proposed in this work. The objective of this demand control strategy was to minimize energy use in the building without sacrificing the health and comfort aspects of the occupants during a dynamic operation sequence while the number of occupants varied with time.

This paper presents the results of three different cases of ventilation control and their effects on indoor radon and CO_2 levels in the lecture theater. The Case 1 study was conducted from December 24 to 31, 1997 and October 13 to 14, 1998. The Case 2 study was conducted from February 16 to 26, 1998. The Case 3 study was conducted from September 17 to October 15, 1998. Based on these measurements, a demand control strategy using both CO_2 and radon as control parameters has been proposed as Case 4, and its potential energy saving estimated.

LECTURE THEATER AND HVAC DESCRIPTION

The test lecture theater is located in the Hong Kong University of Science and Technology, Hong Kong. The lecture theater has a total floor area of about 150 m^2, a volume of approximately 500 m^3, and a maximum capacity of 130 occupants. This lecture theater is on the ground floor of the northern perimeter of the Academic Building, sitting right above the plant room in which the Air Handling Unit (AHU) serving the lecture theater is installed.

The HVAC system in the lecture theater is a single-zone, variable-air-volume (VAV) system that varies the volume of fresh air while keeping that of supply air constant. A duct-mounted temperature sensor measures the supply air temperature, via the control algorithm of the Direct Digital Control (DDC), to modulate the chilled water control valve to maintain the supply air temperature at the desired value. Another duct-mounted temperature sensor measures the return air temperature, which resets the supply air temperature setpoint via the DDC. Static pressure sensors are installed two thirds downstream of the main supply air duct to measure the static pressure and transmit the signal to the DDC. The controller will select the lowest signal, via the control algorithm, to modulate the inlet guide vane actuator to maintain a constant static pressure in the supply air duct. An airflow measuring station with temperature sensor located in the fresh air duct modulates, via the control algorithm of the DDC, the fresh air damper to maintain a constant quantity of supply air.

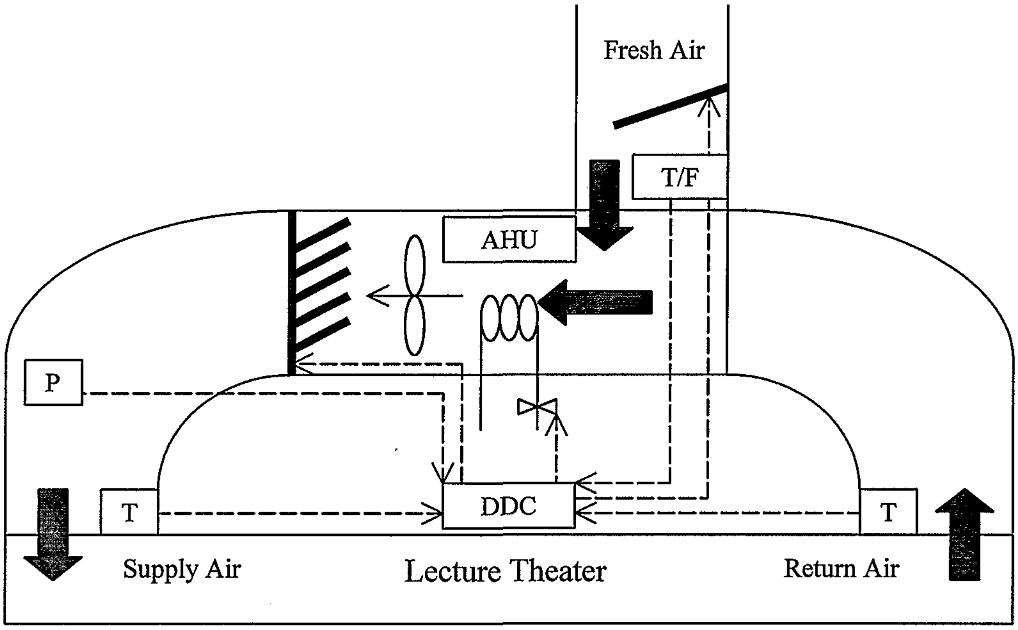

Figure1. Schematic diagram of the HVAC system serving the lecture theater

METHODS AND INSTRUMENTATION

An INNOVA 1312 Photo-acoustic Multi-gas Monitor was connected with an INNOVA 1303 Multi-points Sampler and Doser unit so that two sampling points could be monitored inside the lecture theater. Four other sampling points were located outside the lecture theater: the corridor adjacent to the front doors, the stairway in the back, the AHU plant room and the fresh air louver. This system was able to collect information on CO_2 levels, as well as sulfur hexafluoride (SF_6) for the tracer gas decay tests conducted on selected periods of time during the air change rate measurements. The two sampling points were placed in the front and back rows of the lecture theater at an elevation comparable to the breathing zone (right underneath the handles of the seats). The sampling intervals for CO_2 and SF_6 levels were about nine minutes. Temperature and relative humidity were measured by the corresponding data loggers. Standard calibration procedures were conducted in the laboratory before the measurements were performed.

Radon level was measured by a solid state radon detector, Niton Rad7. The detector pulls samples of air through a fine inlet filter into a chamber for analysis. The filtered air decays inside the chamber producing detectable alpha emitting progeny, particularly the polonium isotopes. The solid state detector converts α radiation directly to an electrical signal using the alpha spectrometry technique that is able to distinguish radon from thoron and signal from noise. The detector is sent back to manufacturer for calibration twice every year. The calibration procedure is carried out in a well-controlled environmental chamber and the reading is compared to a master instrument. The detector was put inside the hose reel compartment inside the lecture theater to minimize disturbance to the occupants and was used for continuous monitoring of the indoor radon level.

The above descriptions are true for Cases 1 to 3. However, the fresh air supply rate for Case 3 varied from class to class while that for Cases 1 and 2 was fixed by the Building Management System (BMS) at 236 L/s (0.236 m^3/s) and 1300 L/s (1.298 m^3/s), respectively. For Case 3, a series of demand control ventilation simulation were conducted, where frequent adjustments were made to the fresh air supply rate of the AHU, depending on the number of occupants present at different lecture hours. According to ASHRAE Standard 62-1989 [1] for light office work environment, a fresh air supply rate of 10 L/s/person (0.01 $m^3/s/person$) was used for this simulation. The fresh air supply rate was manually keyed into the BMS as setpoint, approximately ten minutes after performing a head-count in the lecture theater in the beginning of each class.

Both the setpoint and the feedback values of fresh air supply rate were recorded, to account for the differences. The set and the actual percentages at which the fresh air damper was opened were also recorded, which altered according to the setpoint of fresh air supply rate. The reaction or response time of the HVAC system was monitored, in order to determine suitable control parameters for the future controller. With the aid of the BMS trend log and the instrumentation mentioned earlier, the operation condition of the HVAC system and the concentrations of the indoor radon and CO_2 levels can be correlated.

RESULTS AND DISCUSSIONS

Originally, the fresh air supply rate for the lecture theater was fixed at 0.236 m^3/s in Case 1. According to HKEPD guideline [2] and ASHRAE Standard 62-1989, indoor radon and CO_2 levels should not exceed 200 Bq/m^3 and 1000 ppm, respectively. The measurements showed that this fresh air supply rate was insufficient and posed health risks to the occupants, resulting in high CO_2 concentrations and radon level very close to 200 Bq/m^3 when occupants were present. In Case 2, the fresh air supply rate at the lecture theater was then constantly set at its maximum capacity catering for 130 occupants; however, not every single lecture held in the lecture theater has 130 occupants. This inflexible fresh air supply rate of 1.274 m^3/s gave rise to over-ventilation, resulting in the waste of energy [3].

During the period of demand control strategy simulation in Case 3, in which the fresh air supply rate was no longer fixed and varied depending on the number of occupants present at different lecture hours. The average radon and CO_2 levels inside the lecture theater were kept under 200 Bq/m^3 and 1000 ppm during lecture hours, respectively.

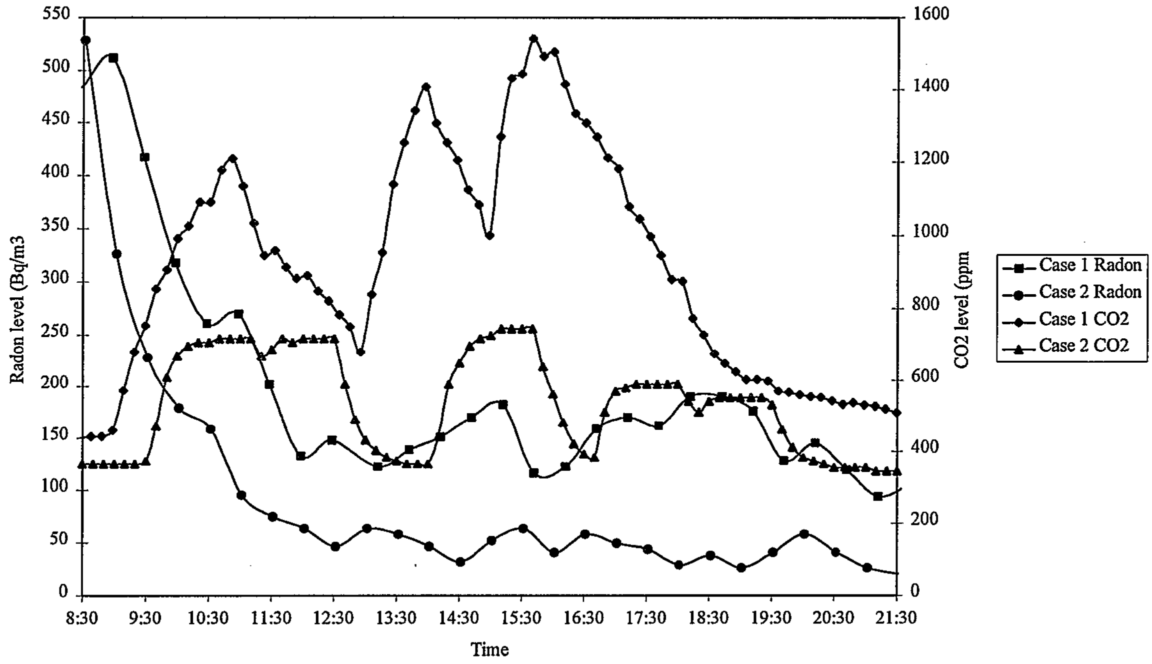

Figure 2. Typical Case 1 and Case 2 indoor radon and CO_2 levels during lecture hours

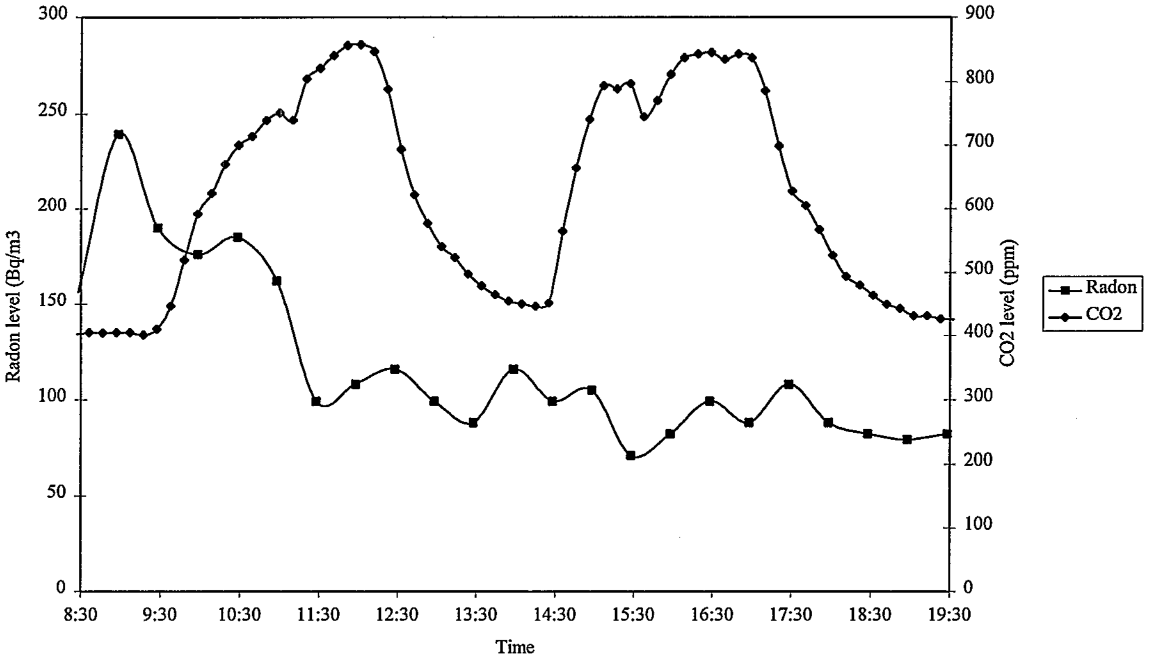

Figure 3. Typical Case 3 indoor radon and CO_2 levels during lecture hours

The air change rates were measured using the tracer gas decay technique. The SF_6 concentrations at the front and back rows of the single-zone lecture theater differed no more than 10%. This satisfied the ASTM requirement that the tracer gas concentration within the building be uniform within 10% [4,5]. It was found that the BMS pitot tube measurement, when compared against the tracer gas decay test, overestimated the air change rates by 25% with fresh air supply rate in the range of 0.236 m^3/s and by as much as 100% with fresh air supply rate in the range of 0.944 m^3/s. The relationship between these two methods must be further studied in order to generate a reference database for the future demand controller.

In order to meet the criteria of both HKEPD and ASHRAE guidelines and achieve energy saving at the same time, the next step will be the development of a demand control ventilation using both radon and CO_2 levels as control parameters for fresh air intake in Case 4. The data have shown that there are still rooms for reducing the fresh air supply without putting the indoor radon level over the limit of 200 Bq/m^3. Since most lectures last no more than 80 minutes, this implies the assumption of indoor CO_2 concentration at equilibrium of the ASHRAE 62-1989 10 L/s/person may not be valid in this study [4].

The aim of the demand control ventilation is to keep both radon and CO_2 levels just below 200 Bq/m^3 and 1000 ppm, respectively, while operating the air-conditioning system at an optimum fresh air supply rate. The demand control ventilation will give an enormous potential for energy saving without compromising the health and comfort aspects of the occupants during a dynamic operation sequence while the number of occupants varied with time. A simple estimation on how much energy can be saved based on the equilibrium analysis approach is presented below.

C	indoor CO_2 concentration [ppm]
C_o	outdoor CO_2 concentration = 400 ppm
C_1	occupants-present average CO_2 concentration [ppm]
C_2	desired CO_2 concentration for demand control strategy =1000 ppm
Q	fresh air supply rate [m^3h^{-1}]
Q_1	existing fresh air supply rate [m^3h^{-1}]
Q_2	new fresh air supply rate for demand control ventilation [m^3h^{-1}]
G	CO_2 generation rate per person [m^3h^{-1}]
N	number of occupants
t	time unit [h]
V	effective volume of the office [m^3]
ES	percentage energy saving [%]

$$\frac{dCV}{dt} = Q(C_o - C) + GN \tag{1}$$

Assuming that *GN* is a constant at equilibrium and that a linear relationship exists between fresh air supply rate and energy cost, the steady-solution becomes:

$$ES = \frac{Q_1 - Q_2}{Q_1} \times 100\% \tag{2}$$

$$ES = \left(1 - \frac{C_1 - C_o}{C_2 - C_o}\right) \times 100\% \tag{3}$$

For the lecture theater, daily average C_1 is about 734 ppm from Case 3 simulation period.

$$ES = \left(1 - \frac{734 - 400}{600}\right) \times 100\% = 44\% \tag{4}$$

The estimation includes cooling load energy saving only; fan energy saving is not included. It is based on equilibrium analysis that yields results on the conservative side. The real scenario is non-equilibrium and a factor is needed for adjustment [4]. The linear relationship between the cooling load and the fresh air supply rate is difficult to confirm experimentally due to system measurement challenges. This assumption may need further study since the capability of the chilled water units will influence this assumption. Also, the ratio of sensible cooling load to the latent load may not be a constant, which in turns influences the assumption. Detailed analysis and metering are required to verify this point.

Due to financial feasibility of the future demand controller, it is natural that one radon monitor and one CO_2 sensor to be located at the return air side of the HVAC system. This calls for the choice of appropriate radon and CO_2 setpoints [6], making sure that the instrument readings at the return air side are correlated and clearly reflect the condition of the occupants' zone. There is also a damper response delay for demand control ventilation and the optimum condition must be verified on site. This mechanical and control signal response time needs to be carefully characterized, which will be used as an important parameter when developing the demand control algorithm. The same piece of information is also crucial in determining the relationship between air change rate and fresh air damper opening [7].

ACKNOWLEDGEMENTS

This work was supported by the Honeywell Technology Center, Minnesota, USA (research grant number HTC97/98.EG01). Sincere thanks to the EMO staff, Kelvin K. Wong, Samuel C. Ip, Steven S. Chui, Rosie M. Ma and Susanna C. Cheung for their assistance.

REFERENCES

1. ASHRAE. 1989. *ANSI/ASHRAE Standard 62-1989*, Ventilation for Acceptable Indoor Air Quality, Atlanta: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc.

2. HKEPD. 1984. *Interim Indoor Air Quality Guidelines for Hong Kong*, Hong Kong: Hong Kong Environmental Protection Department.

3. Warren, B F. 1982. Energy saving in buildings by control of ventilation as a function of indoor carbon dioxide concentration. *Building Services Engineering Research & Technology*. Vol. 3 (1), pp 4-12.

4. Nabinger, S J, Persily, A K, and Dols, W S. 1994. A study of ventilation and carbon dioxide in an office building. *ASHRAE Transactions*. Vol. 100 (2), pp 1264-1274.

5. ASTM. 1993. *ASTM Standard E741-93*, Standard Test Methods for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution, Philadelphia: American Society for Testing and Materials.

6. Schultz, K J and Kraftherfer, B C. 1993. CO_2-based ventilation control: choice of CO_2 setpoint. *ASHRAE Transactions*. Vol. 99 (1), pp 1548-1553.

7. Reardon, J T, Shaw, C, and Vaculik, F. 1994. Air change rates and carbon dioxide concentrations in a high-rise building. *ASHRAE Transactions*. Vol. 100 (2), pp 1251-1263.