Ventilation Rate Measurement

#4920

Occupant-Generated CO_2 as a tracer gas in a field of study of ventilation rate
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Introduction

Some guidelines[1] on indoor-air quality specify a maximum allowable exposure to CO_2. In a room ventilated by a mechanical extract system a control program on the CO_2 concentration may, by an appropriate sampling strategy, supply information about the exhausted flowrate. This paper briefly outlines a simple analytical model for estimating the exhausted flowrate by measuring the CO_2 concentration and keeping a record of the occupancy of the room. The CO_2-data from a field study is applied to the model and the estimated flowrate is compared to the flowrate obtained by a well established tracer gas technique.

The Analytical Model

In a room a tracer gas is released at a rate m(t) and the volume of the room is denoted V. At time t let the flowrate of exhausted air be denoted Q(t). Assuming the homogenously mixed gas concentration of the room is C(t), and the gas concentration of the supply air is $C_s(t)$, the continuity equation gives the following well known expression for the tracer gas content of the room:

$$V \frac{dC(t)}{dt} = M(t) - [C(t) - C_s(t)]\,Q(t) \qquad [1]$$

If it is assumed that Q is time-independent Q can be obtained after integrating Equation [1] from t0 to t1:

$$Q = \frac{\int_{t0}^{t1} M(t)\,dt - \int_{C(t0)}^{C(t1)} V\,dc}{\int_{t0}^{t1} [C(t) - C_s(t)]\,dt} \qquad [2]$$

It is assumed that C(t) is continuously recorded and by selecting t0 and t1 so that C(t0) = C(t1) the rate of exhausted air may be conveniently calculated[2] by:

$$Q = \frac{\int_{t0}^{t1} M(t)\,dt}{\int_{t0}^{t1} [C(t) - C_s(t)]\,dt} \qquad [3]$$

The tracer gas considered may be occupant-generated CO_2. For the period t0 – t1 let the dose of CO_2 above the fresh air level be denoted D(t0 – t1). Let the number of occupants at time t be denoted N(t) and the average CO_2 generation rate per occupant be denoted G(t). If it is assumed that G is time independent Q is obtained from Equation [3]:

$$Q = \frac{G \int_{t0}^{t1} N(t)\,dt}{D\,[t0 - t1]} \qquad [4]$$

where

$$D\,[t0 - t1] = \int_{t0}^{t1} [C(t) - C_s(t)]\,dt \qquad [5]$$

The rate of exhausted air, Q, can be estimated by integrating the occupancy and concentration functions over the chosen time period using the appropriate CO_2 generation rate G. Alternatively Q may be estimated by integrating Equation [1] from t0 to t assuming m(t) = 0 and $C_s(t) = 0$, i.e:

$$C(t) = C(t0)\,e^{-\left(\frac{tQ}{V}\right)} \qquad [6]$$

From the tracer decay relationship (Equation (6)) the air change rate is readily estimated by observations of C(t) vs t. In practice it may be appropriate to justify the assumed spatial homogenous mixing of the tracer in a decay test by estimating the air exchange efficiency $\langle \epsilon_a \rangle$. If the mean-age of air in the room is denoted $\langle \tau \rangle$ then[3]:

$$\langle \tau \rangle = \frac{\int_{t0}^{\infty} t\,C_e(t)\,dt}{\int_{t0}^{\infty} C_e(t)\,dt} \qquad [7]$$

and

$$\langle \epsilon_a \rangle = \frac{[V/Q]}{2\langle \tau \rangle} = \frac{\left[\int_{t0}^{\infty} C_e(t)\,dt\right]^2}{2\,C_e(t0)\int_{t0}^{\infty} t\,C_e(t)\,dt} \qquad [8]$$

In Equations [7] and [8] the subscript e indicates the concentration in the exhaust air, and it is noted that $\langle \epsilon_a \rangle$ = 0.50 in case of complete mixing.

Measurements

All the reported tests were performed as part of a field study of a kindergarten with previously reported complaints about indoor-air quality. The room selected for the tests was ventilated by a mechanical extract system with an outlet in the ceiling (see Fig 1, Position 1). The net volume of the room, which contained only a few tables, was 290 m^3. The intake of fresh air was provided by grills under the windows. During the initial test period the CO_2-concentration vs time throughout the room (See Fig 1, Positions 1-6) and incoming fresh air were sequentially recorded (45 second intervals) by a portable computer controlled unit (Fig. 2). In the same test the occupancy was recorded every fifteenth minute, and the occupant motion through the door was unrestricted. Following the initial test a tracer gas (SF_6) was injected and homogeneously mixed in the now unoccupied room. The tracer decay was measured by the portable unit using the previously outlined experimental setup modified to only one sampling point (No. 1), and the door was closed throughout the test period.

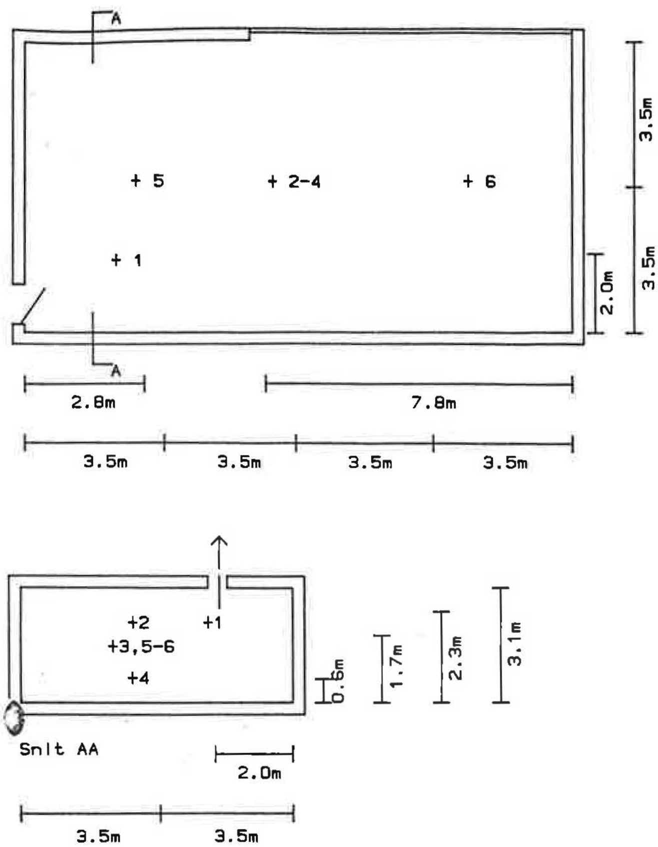

Figure 1: The test room in the kindergarten

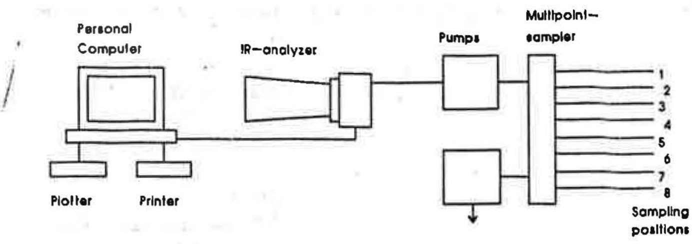

Figure 2: Portable computer controlled tracer sampling unit

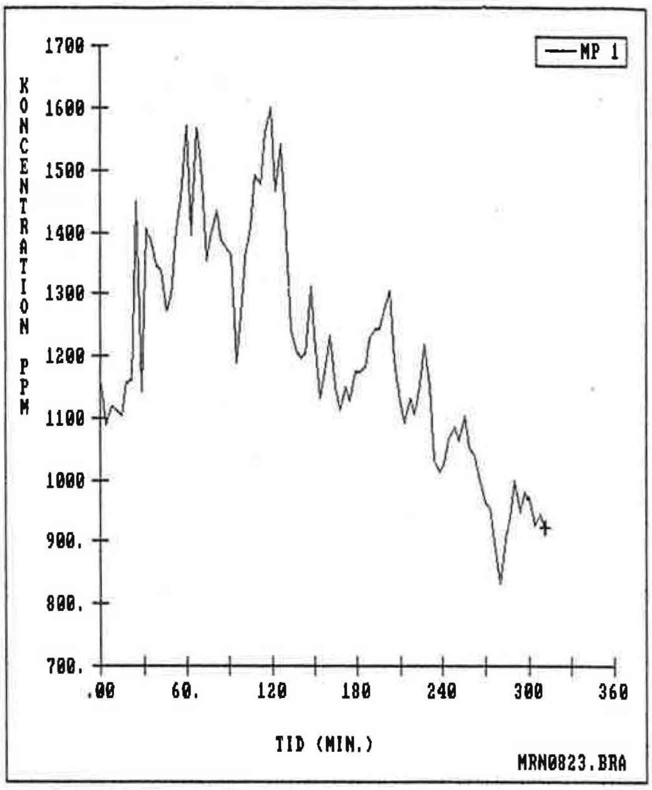

Figure 3: CO_2 concentration vs time for Position 1 in Figure 1

Results

The initial test period lasted 315 minutes, and an example of the measured CO_2 concentration vs time at Position 1 is shown in Fig 3. The time-weighted average concentration of the test period at the six positions considered ranged between 1210-1390 ppm indicating a basically spatial homogeneous concentration. The average CO_2-concentration in fresh air was 360 ppm. Selecting the CO_2 data from Position No. 1 for estimating the exhausted air flow a detailed analysis of the data indicated that $C(t0) = C(t1)$ for $t0 = 0$ and $t1 = 231$ minutes. The estimated dose above the fresh air level of that period is listed in Table 1. Also shown in Table 1 are the summarized data of the occupancy and the CO_2-generation rate. Assuming a respiratory quotient (RQ) of 0.83 and a metabolic rate of 1.8 met the CO_2-generation rate per adult was estimated to be 0.027 m^3/h and per child the rate was estimated to be 0.010 m^3/h. By data from Table 1 and using Equation [4] the estimated exhausted airflow was 230 m^3/h.

Table 1: CO_2 Data from Kindergarten Field Study

Period min	No. of adults	Amount of generated CO_2 m^3	No. of children	Amount of generated CO_2 m^3	Dose above the fresh air level min m^3/m^3
0–75	5	0.168	18	0.225	
75–105	7	0.094	18	0.090	
105–150	1	0.020	11	0.083	
150–165	3	0.020	11	0.028	
165–180	4	0.027	0	0	
180–195	0	0	0	0	
195–210	3	0.020	0	0	
210–231	2	0.019	0	0	
Total		0.368		0.426	0.206

The measured SF_6-tracer decay of the non-occupied room was analyzed by logarithmic regression and the estimated air change rate was $1.1h^{-1}$ ($r^2 = 0.99$) i.e. the estimated exhausted airflow was 320 m^3/h. By Equation [7] the estimated mean-age of air in the room was 57 minutes and by Equation [8] the estimated air exchange efficiency was 53%.

Discussion

Occupant generated CO^2 has previously[4] been used as a tracer for characterizing the ventilation process of a room. It is well recognised, however, that the generation rate per occupant depends on the respiratory quotient and the activity level of the individual[1]. The respiratory quotient is the volumetric ratio of carbon dioxide to the oxygen consumed. It varies from 0.71 for a diet of 100% fat to 0.80 for a diet of 100% protein and 1.0 for a diet of 100% carbohydrates. In the present study a value of RQ = 0.83 was applied assuming the diet being a normal mix of fat, protein and carbohydrates. A graph on the relationship between the CO_2 generation rate and the activity level is available,[1] and in the present study a metabolic rate of 1.8 met on average (light physical activity) was applied. The CO_2 generation rate per child was estimated from a previously reported[5] kindergarten study.