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A Simple Method of Estimating Air Recirculation in Ventilation Systems

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A method for quantitative measurement of the overall air recirculation in ventilation systems is presented. The air recirculation is calculated from the concentrations of a tracer at three well-defined points, *viz.*, the background concentration in outside air (C_1), the tracer concentration in the recirculated air (C_2), and the tracer concentration in the inlet air after the recirculation system (C_3). The recirculation quotient is calculated according to the following formula: $Q_2/Q_3 = (C_3 - C_1)/(C_2 - C_1)$. Q_2 = recirculated airflow; Q_3 = total inlet airflow including recirculated airflow. Thus, a quotient between flows is identical with a quotient between tracer concentrations. The method allows the usage of both natural tracers (*e.g.*, contaminants, such as CO_2, occurring in the examined building) and artificial tracers (*e.g.*, fluorocarbon 12 or sulfur-hexafluoride). The method has been tested with good results. At these tests, the tracer was CO_2 emitted from exhaled air and indoor activities in the buildings.

Introduction

In temperate and subarctic regions, recirculation of exhaust air is common in order to save energy in buildings. The degree of air recirculation is adjusted with manually or automatically controlled valves. As a rule, intentional air recirculation is usually small or none in summer but considerable in winter. Unintentional air recirculation because of leakage and inappropriate location of air inlets and outlets is common but has been difficult to demonstrate and measure.

There are both technical and medical-hygienic needs for accurate and workable methods to measure the real air recirculation in buildings. In the method described here, carbon dioxide (CO_2) emitted from exhaled air and indoor activities is used as a tracer for quantitative measurement of the overall air recirculation in ventilation systems. Some preliminary results have been presented earlier.[1]

Principle

The principle is demonstrated in Figure 1. Q_1 and Q_5 are inlet and outlet airflows to the building, and Q_3 and Q_4 are inlet and outlet airflows to ventilated rooms in the building. Q_2 is the recirculated airflow, and C represents tracer concentrations. The following balance of airflows (m^3/sec) and mass flows (mg/sec) is presupposed:

$$Q_1 + Q_2 = Q_3 \qquad \text{Flow balance} \qquad (1)$$

$$Q_1C_1 + Q_2C_2 = Q_3C_3 \qquad \text{Mass-flow balance} \qquad (2)$$

The air recirculation is represented by the quotient Q_2/Q_3. From Equations 1 and 2 is derived

$$\frac{Q_2}{Q_3} = \frac{C_3 - C_1}{C_2 - C_1} \qquad (3)$$

Thus, a quotient between flows is identical with a quotient between differences in tracer concentrations.

An application of the principle is demonstrated in Figure 2. It is essential that the test points are properly selected. The three tracer concentrations used in Equation 3 are the background concentration (C_1), the concentration in the recirculation duct before the mixing point (C_2), and the tracer concentration in the inlet air after the mixing point (C_3).

The background concentration (C_1) should be measured either in the inlet duct before the recirculation valve or in the outside air at the vicinity of the air intake.

As a rule, it is not possible to measure the tracer concentration in the recirculation duct (C_2) because this duct usually is very short or totally lacking. In these cases the tracer concentration in the central outlet duct before the mixing point (C_4) or in the duct leading outdoors (C_5) is a good estimation. It is not possible to use the tracer concentrations in the outlet ducts from separate rooms, however, because

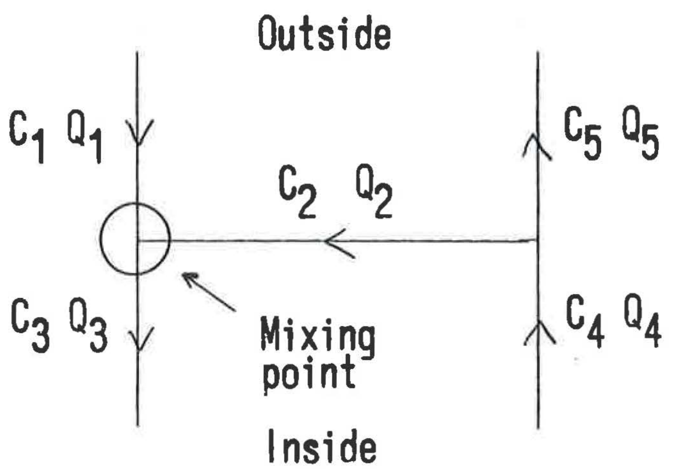

Figure 1 — Skeleton sketch of airflow in ventilation systems with partial air recirculation.

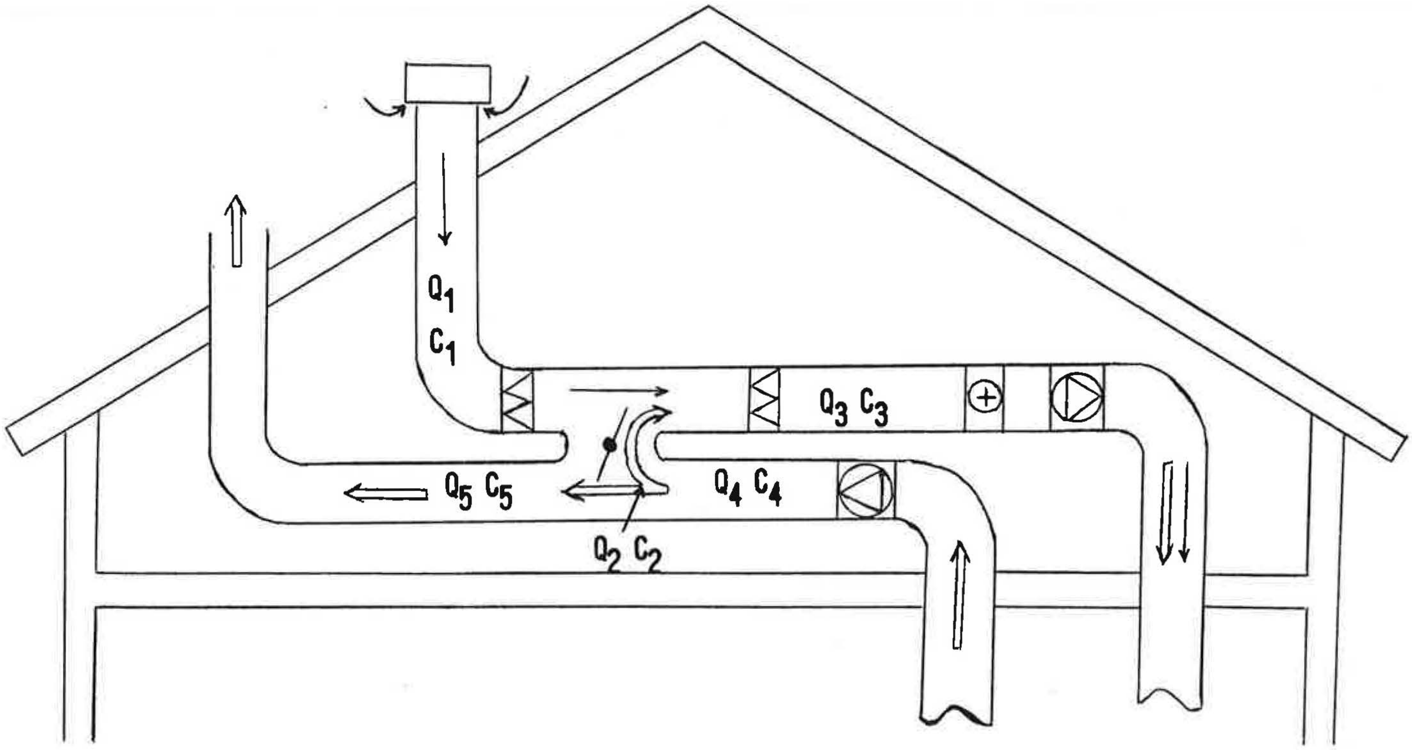

Figure 2 — A ventilation system with partial air recirculation.

these concentrations are not the same as the tracer concentration in the recirculation duct.

The tracer concentration of the inlet air after the mixing point (C_3) should be measured in the central inlet duct at a point where the tracer is mixed well with the outdoor air. If the tracer concentration is stable in the air ducts distributing the air to separate rooms, C_3 might be estimated anywhere in these ducts, even in the air inlets to separate rooms.

The principle permits tracers other than CO_2, such as other chemical contaminants occurring in the building and also artificial tracers (fluorocarbon 12, sulfur-hexafluoride, *etc.*). The background concentration for artificial tracers is usually zero. If the temperature differences are large enough, it even is possible to use the air temperature in the ventilation ducts as a "tracer." Temperature differences between the test points, however, are sometimes affected by phenomena other than air recirculation (*e.g.*, supply of heat from heaters and fans or loss of heat because of bad insulation). Thus, calculations of air recirculation from the temperatures could be uncertain.

Method

In the measurements presented here, the CO_2 concentrations were analyzed with an IR-spectrophotometer (Miran 1 A, Foxboro-Wilkes Company, USA) with a cuvette length of 0.75 m and spalt 0.5 mm at the wavelength 4.25 μm. The instrument was calibrated with known concentrations of CO_2. The absolute zero point for CO_2 was determined with air purified from CO_2 by recirculation in a closed circuit through an adsorbent (AGA Monosorb).

The background concentration of CO_2 was measured in outdoor air near the ventilation inlet of the building. In some of the measurements, the reduction of the background was achieved by adjusting the zero-point of the spectrophotometer to this background level which gives the same result.

The airflows in the ventilation ducts were measured both with a pitot tube and with a thermoanemometer (Alnor GGA-65) using a technique recommended by the Nordic Ventilation Group.[2]

The method was tested in two different ventilation systems. The first one was a ventilation system supporting a lecture theater. In this system it was possible to measure the airflows in the inlet duct before the recirculation valve (Q_1), in the recirculation duct (Q_2), and in the inlet duct after the recirculation valve (Q_3). The CO_2 concentrations in the outdoor air (C_1), in the recirculating air (C_2), and in the inlet air after the mixing point (C_3) were measured concomitantly;

TABLE I
Concomitant Measurements of Air Recirculation with Tracer Technique and Determination of Airflows

	Air Recirculation Percent		
	Airflow Measurements		
Valve Adjustment	Pitot Tube	Thermoanemometer	Tracer Technique
25%	23	26	24
50%	53	56	52[A]
75%	75	77	72

[A]Measurement with Freon 12 as tracer gave 54% recirculation.

TABLE II
Measured Recirculation (Percent) at Different Manual Adjustments of the Recirculation Valve in an Office Building

Approximate Recirculation	CO_2 Concentration Inlet	CO_2 Concentration Outlet	Measured Recirculation
0%	359	412	15
	364	430	18
50%	379	409	49
	395	438	51
75%	410	417	90
100%	427	428	99

Note: The CO_2 concentration in outdoor air was 350 ppm during the measurements.

tions were measured concomitantly in the outdoor air near the ventilation inlet of the building (C_1), in the outlet ventilation duct just before the recirculation valve (C_2), and in the inlet ventilation duct after the recirculation valve (C_3).

Results

In the first test the air recirculation was measured with different techniques at the same time. As appears from Table 1, there is good agreement between the results of airflow and tracer measurements, but the latter are considerably easier to erform. Figure 3 shows the results from the measure-·ıent where the intended air recirculation was 75%. The CO_2 concentration in the inlet air was 515 ppm higher than in the outdoor air (C_3 - C_1), and corresponding CO_2 concentration in the recirculated air (C_2 - C_1) was 705 ppm, giving a recirculation quotient about 0.73. Thus, the real recirculation was about 73%.

On another occasion the air recirculation in the lecture theater was followed continuously for some hours (Figure 4). The recirculation valve was adjusted manually to approximately 50% air recirculation. At the first arrow, a group of students began to gather for a lecture in the theater. Between the second and third arrows, there was a pause when most of the students left the theater, and this pause was followed by a second lecture ending at the fourth arrow.

The CO_2 concentrations varied between a level slightly above the background level when the theater was empty and considerably higher CO_2 levels which occurred during the lectures. Irrespective of the absolute CO_2 levels, however, the ratio between the simultaneous CO_2 elevations above background in the inlet airstream (C_3) and in the recirculation airstream (C_2) was about 0.57 all of the time, indicating a constant air recirculation of about 57%.

In the test of the air recirculation in an office building (Table II), there was an unintended air recirculation around 17% when the recirculation valve was closed and the recirculation was supposed to be zero. When the valve scale indicated 75% air recirculation, the air recirculation measured with the tracer technique was found to be 90%.

Discussion

Measurements of airflows in recirculation ducts are often difficult to perform, and sometimes the recirculation duct is replaced by a valve. There are great possibilities for error in such measurements because of turbulence phenomena and varying flow velocities in different parts of the ducts. Concentrations of well-mixed tracers are considerably less affected by turbulence than by airflows. Chemical tracers are often utilized when examining different ventilation parameters. Monitoring of airflows,[3] CO_2,[3-6] and temperature[3,4,6] often are used for automatic adjustment of recirculation valves. Here tracers have been used for quantitative measurements of air recirculation in ventilation systems.

The difference in CO_2 concentrations must be measured with acceptable accuracy. Sensitive IR-spectrophotometers demonstrate small differences in CO_2 concentration, and the CO_2 emanation, even in almost unpopulated localities, is usually enough for recirculation measurements. A small candle produces more CO_2 per unit of time than an adult.[7] Thus, if necessary, it is simple to produce sufficient amounts of CO_2 for measuring the air recirculation with IR-spectrophotometers. If the airflows are not too large, some burning candles placed near a ventilation outlet in one of the rooms in the building emit enough CO_2 for spectrophotometrical detection in the ventilations ducts. In other cases, artificial tracers could be used.

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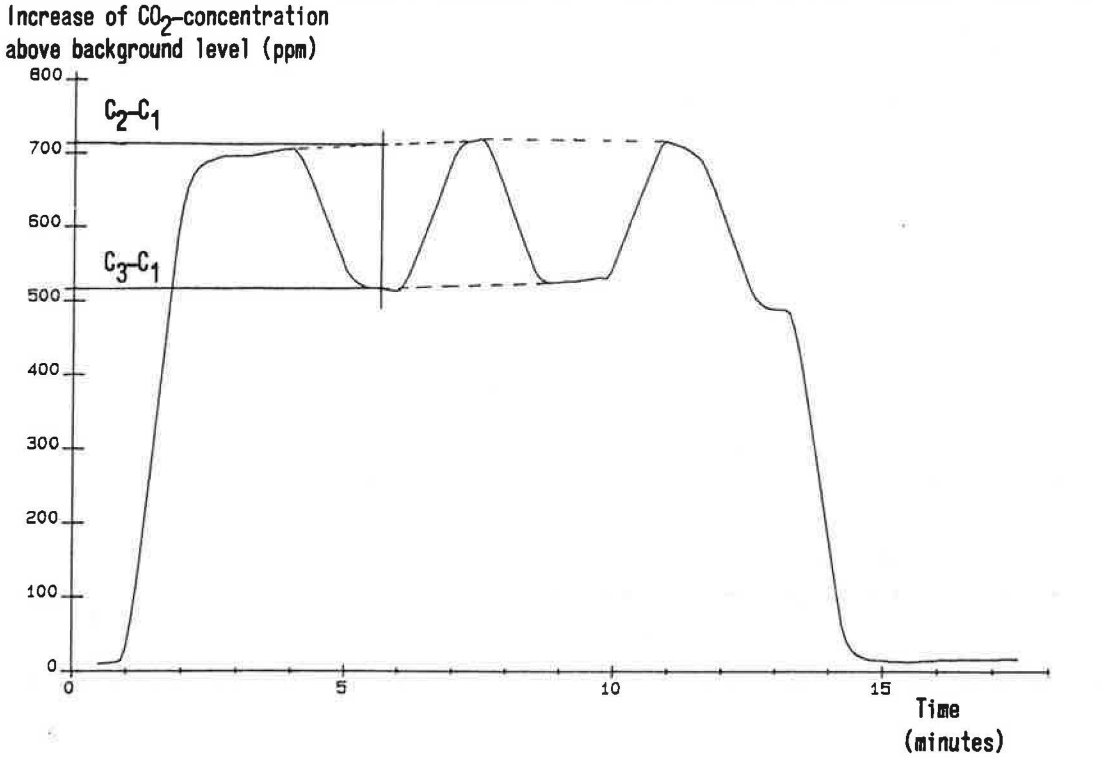

Figure 3 — CO_2 concentrations in a ventilation system with an intended air recirculation of about 75%. The real air recirculation was about 73%.

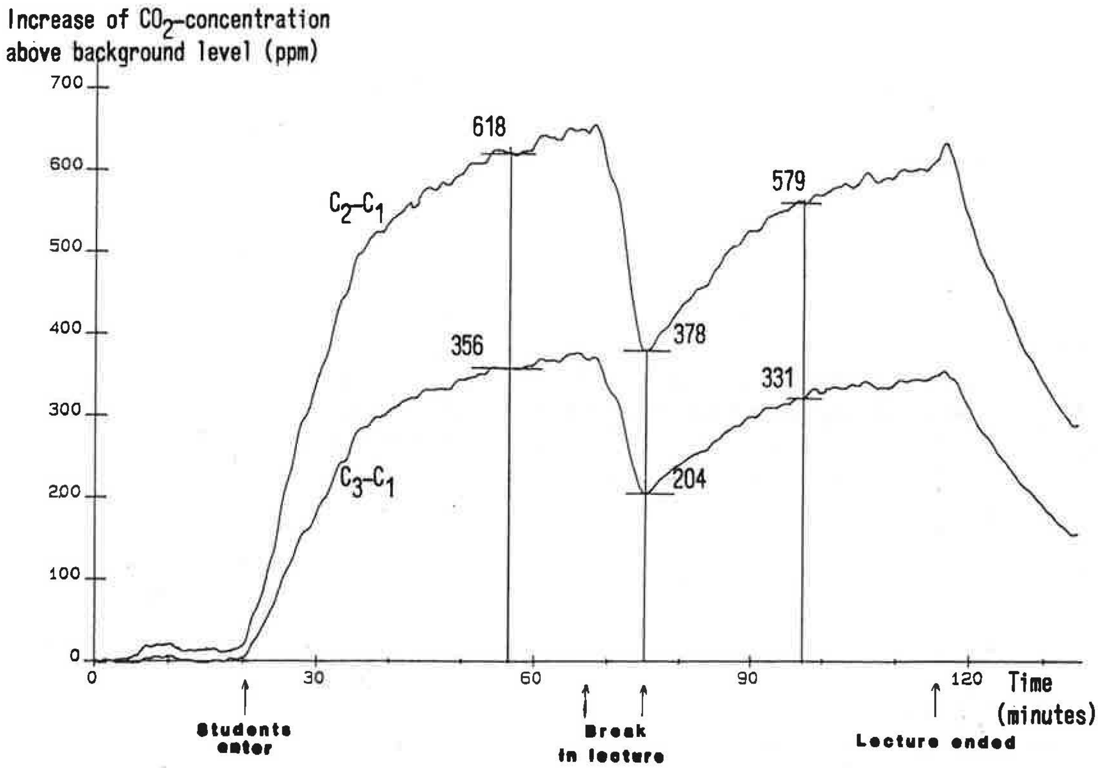

Figure 4 — CO_2 concentrations in the ventilation system of a lecture theater. The air recirculation is constant about 57%.

the recirculation quotient calculated from the tracer concentrations was estimated from Equation 3.

The second test was made in a building with central distribution of inlet and outlet air. The air recirculation was adjusted manually with a valve operating from closed (0% recirculation) to fully open (100% recirculation). This valve was adjusted to different recirculation levels, and the resulting air recirculations were measured. The CO_2 concentra-