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EVALUATION OF CO_2 DETECTOR TUBES FOR MEASURING AIR RECIRCULATION

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There are both technical and medical hygienic needs for accurate and useful methods to measure air recirculation in ventilation systems. This is possible by analysis of the CO_2-concentrations in outdoor air (C_1) and at two well-defined points before (C_2) and after (C_3) the mixing point for recirculated and fresh air. The percentage of recirculated air in the mixed inlet air is represented by the quotient 100 $(C_3\text{-}C_1)/(C_2\text{-}C_1)$. The accuracy of the method is excellent when the CO_2 concentrations are determined with a sensitive instrument, such as an IR spectrophotometer. However, detector tubes for CO_2-analysis obtainable on the market today are not usable in this situation. Air recirculation in peopled spaces could result in CO_2-concentrations in the inlet air which are considerably higher than 500 µL/L.

INTRODUCTION

Air recirculation is used to an ever increasing extent to save energy. Sometimes more than 80 % of the exhaust air is recirculated in office buildings. In addition, unintentional air recirculation could occur due to inappropriate locations of air inlets and outlets outside the building.

Air recirculation can be determined by measuring the concentration of a suitable tracer, e.g., carbon dioxide emitted from residents and indoor activities. The accuracy of this method is excellent when the tracer is precisely determined with a sensitive instrument, such as an IR spectrophotometer (Bjurström et al. 1986; Göthe et al. 1988). In screening situations

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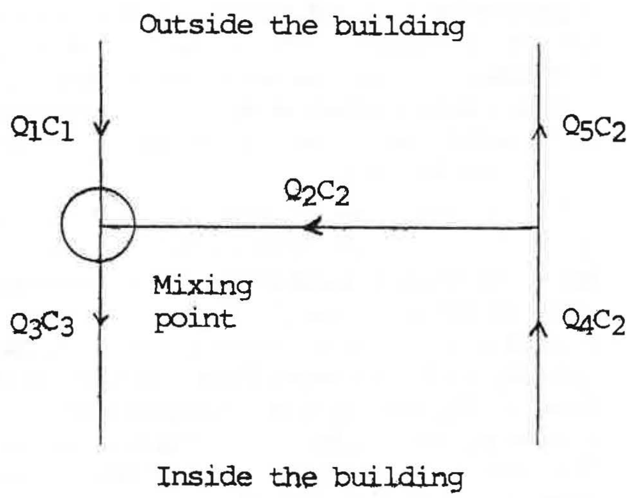

Fig. 1. Airflow in ventilation systems with partial air recirculation. "Q" represents flows and "C" tracer concentrations.

Table 1. Results of CO_2 measurements (μL/L) with an IR spectrophotometer (Miran 1A). The recirculation valve was manually adjusted.

CO_2 Concentrations (μL/L)			Air Recirculation (%)	
Inlet Air (C_1)	Recirculated Air (C_2)	Mixed Air (C_3)	Calculated	Valve Adjustment
350	765	455	25	25
350	885	620	50	50
350	1058	865	73	75

and for routine tests, simpler methods for tracer analysis would be useful. The purpose of the present study is to examine if commercially available detector tubes for CO_2 analysis could be used in such situations.

In a typical air recirculation system, the airflow runs according to the skeleton sketch presented in Fig. 1. If the airflows in different parts of a ventilation system is represented by the designations Q_1 to Q_5, the fraction of recirculated air in the inlet air will be represented by the quotient Q_2/Q_3. If the tracer concentration in corresponding parts of the ventilation system is represented by C_1 to C_3, it can be shown that

$$(Q_2/Q_3) = (C_3-C_1)/(C_2-C_1)$$

when $Q_1+Q_2=Q_3$ and $Q_1C_1+Q_2C_2=Q_3C_3$ (Göthe et al. 1988). Thus, a quotient between flows is identical to a quotient between differences in tracer concentrations (Bjurström et al. 1986; Göthe et al. 1988), and it is possible to calculate the air recirculation from the tracer concentrations in the inlet air from outside (C_1) and in the ventilation ducts before (C_2) and after (C_3) the mixing point.

Suitable tracers are naturally occurring contaminants (e.g., CO_2) or artificial tracers (e.g., fluorocarbon-12 or sulfur-hexafluoride). If the temperature gradients are large enough, it is even possible, at least theoretically, to use the temperatures in corresponding points as a tracer. Often, the most suitable tracer is CO_2, because it is continuously emitted in exhaled air from residents. This results in increased CO_2 concentrations in the outlet air from peopled rooms in the building. This increase is usually large enough for calculating the air recirculation when the carbon dioxide concentration is estimated with a sensitive method, such as IR spectrophotometry (Göthe et al. 1988).

METHOD

The air recirculation was measured in a ventilation system supporting a lecture theater. It was possible to manually adjust the recirculation valve to different recirculation levels and to measure the CO_2 concentration directly in the recirculated airflow. The lever scale was calibrated with direct flow measurements in the ventilation ducts with a technique recommended by the Nordic Ventilation Group (Svensson 1983).

The measurements were done with an IR spectrophotometer (Miran 1A, Wilks, Foxboro Co, USA) at the cuvette length of 0.75 m, slit 0.5 mm and wave length 4.25 μm. Calibration was performed with known concentrations of CO_2. The probes were inserted into the ventilation ducts through drilled holes at such a distance from the mixing point that the airstreams were mixed as indicated by constant CO_2 concentrations during the measuring period. The results were compared with concomitant measurements performed with the following types of CO_2 detector tubes: Auer PR 817 (Auergesellschaft GmbH, Berlin), Dräger CH 30801 (Drägerwerk AG, Lübeck) and Kitagawa 126 B (Komyo Rikagaku Kogyo K.K., Japan). The detector tubes were inserted into the ventilation ducts through the same holes as the spectrophotometer probe, and air was sucked through the tubes with standard pumps delivered by the tube manufacturers.

In the detector tubes, color reactions occur which are proportionate to the CO_2 concentration. At low CO_2 levels, the length of the colored part of the tube is short, the color reaction is weak and the borderline next to uncolored parts could be rather diffuse. To eliminate a possible reader's bias, three persons, independently of each other, read off the tubes at one of the experiments. In another experiment, two consecutive CO_2 measurements were performed, and the two sets of reactor tubes were read by one person.

RESULTS

As appears from Table 1 there is a good agreement between the valve adjustments based on direct flow estimations and the calculated air recirculations when the CO_2 concentrations are determined with an IR spectrophotometer. Air recirculation resulted in high concentrations of CO_2 in the mixed air distributed to the lecture theater.

It is obvious from Table 2 and Table 3 that the air recirculations calculated from detector tube readings not only demonstrate large spread and unsatisfactory precision, but the results could even be preposterous with values below 0% and above 100% when the air recirculation is calculated from the medians or means of the detector tube recordings.

DISCUSSION

It is possible to estimate the extent of air recirculation in ventilation systems by accurate analysis of the CO_2 concentrations in outdoor air and at two well-defined points in the ventilation ducts (Göthe et al. 1988).

IR spectrophotometers have a high precision for analysis of CO_2, and their sensitivity is sufficient for the CO_2 concentrations occurring in the background atmosphere and ventilation ducts. It is important to calibrate the instrument for CO_2 concentrations around

Table 2. Comparison between CO_2 measurements with an IR spectrophotometer (Miran 1A) and three types of reactor tubes. The midpoint of the total variation width of reactor tube readings performed independently by three persons is accounted.

	CO_2 Concentrations (μL/L)			Air Recirculation (%)	
Method	Inlet Air (C_1)	Recirculated Air (C_2)	Mixed Air (C_3)	Calculated	Valve Adjustment
Miran	386	596	464	37	33
Auer	250-700 300	200-700 450	200-800 400	67*	33
Dräger	300-350 325	350-450 400	300-450 375	67*	33
Kitagawa	250-260 260	470-500 470	370-390 390	62*	33

*Calculated from the medians.

Table 3. Comparison between CO_2 measurements with an IR spectrophotometer and three types of reactor tubes. The mean of the midpoints of the variation widths of detector tube recordings read by one person on two sets of reactor tubes.

	CO_2 Concentrations (μL/L)			Air Recirculation (%)	
Method	Inlet Air (C_1)	Recirculated Air (C_2)	Mixed Air (C_3)	Calculated	Valve Adjustment
Miran	410	513	479	67	66
Auer	0-500 225	350-1000 575	0-700 375	43	66
Dräger	300-400 325	350-450 380	200-400 290	<0*	66
Kitagawa	300-300 300	350-400 375	375-400 390	>100*	66

*Calculated from the means.

350 to 1500 µL/L, because the calibration curve for CO_2 is curvilinear at these concentration levels. The IR spectrophotometer reacts rapidly to minor fluctuations in the CO_2 concentration. Therefore, it is important to avoid contamination of the analyzed air with exhaled air from the operator.

When the CO_2 concentrations are not stabilized, as, for example, when people are gathering in a lecture theater or a cinema, the recirculation quotient (Q_2/Q_3) is constant irrespective of the CO_2 level (Göthe et al. 1988). In such situations, however, it is essential to measure the tracer concentrations simultaneously at the different measuring points. In large office buildings, the CO_2 concentration in the outlet air increases in the morning when people come to work and decreases in the afternoon when they leave their workplaces, but during the day the concentration is more stable.

The CO_2 concentrations in atmosphere and ventilation ducts are usually lower than 1000 µL/L. Two manufacturers of the examined detector tubes do not recommend them for detection of CO_2 concentrations below 0.1% (1000 µL/L), but the measuring range for one of the tubes is specified from 100 to 1500 µL/L. However, it is obvious that none of the examined detector tubes is suitable for measuring air recirculation in ventilation systems.

On a global basis, the atmospheric CO_2 concentration demonstrates a slow long-term increase (Gammon et al. 1986). There are seasonal variations with lower concentrations during the winter; in the northern hemisphere, they usually fluctuate between 335 to 340 µL/L in winter and between 340 to 345 µL/L in summer (Keeling et al. 1984). In densely populated areas, large local variations can occur, and it is recommended that the background CO_2 concentration is estimated as a standard procedure.

According to the Swedish Building Code (1983) the concentration of CO_2 in the inlet air to rooms "where people permanently stay" ought not to exceed 500 µL/L. Air recirculation can result in CO_2 concentrations in the inlet air to populated rooms which are considerably higher than this recommended limit value.

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