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A QUANTITATIVE METHOD FOR MEASURING AIR RECIRCULATION

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Abstract

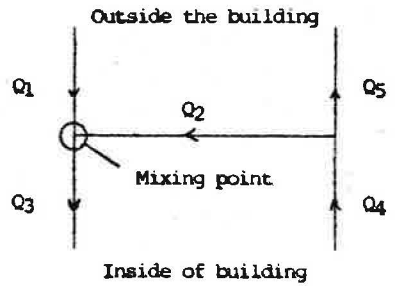
There are both technical and medical-hygienic needs of accurate and useful methods to measure air recirculation in ventilation systems. This is possible by analysis of the CO_2-concentrations in outdoor air (C_1) and at two well-defined points before (C_2) and after (C_3) the mixing point for recirculated and fresh air. The percentage of recirculated air in the mixed inlet air to the interior of the building is represented by the quotient $100 \times (C_3 - C_1)/(C_2 - C_1)$. 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 ppm.

Introduction

Air recirculation is used to an ever increasing extent to save energy. In the Scandinavian countries during wintertime, up to 80 percent of the exhaust air could be recirculated in office buildings. In addition, non-intentional air recirculation could occur due to unappropriate locations of air inlets and outlets.

Air recirculation can be determined by measuring the concentration of a suitable tracer, e.g., carbon dioxide (CO_2) 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 (1,2). In screening situations and for routine tests, more simple methods for tracer analysis would be useful. The purpose of the present study has been to examine if commercially available detector tubes for CO_2-analysis could be used in such situations.

Method



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In an air recirculation system, the airflow runs according to the skeleton sketch on the preceding page.

If the airflows in different parts of a ventilation system are 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 are represented by C_1 to C_5, it can be shown that the following equation is valid when $Q_1 + Q_2 = Q_3$ and $Q_1C_1 + Q_2C_2 = Q_3C_3$.

$$\frac{Q_2}{Q_3} = \frac{C_3 - C_1}{C_2 - C_1}$$

Thus, a quotient between flows is identical with a quotient between differences in tracer concentration (1,2).

Often, it is not possible to measure the tracer concentration in the recirculation duct (C_2), because this duct usually is too short or totally lacking. In these cases the tracer concentration in the outlet duct (C_4 or C_5) is a good estimation.

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 temperature in the ventilation ducts as a "tracer". As a rule, the most suitable tracer is CO_2, which is emitted in exhaled air and from different indoor activities. This results in increased CO_2-concentrations in the outlet air from peopled rooms in the building.

At the examinations reported here, the air recirculation was measured in a ventilation system supporting a lecture theater. In this system, 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 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 wavelength 4.25 µm. The IR-spectrophotometer was calibrated with known concentrations of CO_2. The results were compared with concomitantly measurements performed with detector tubes for CO_2 of types Auer PR 817 (Auergesellschaft GmbH, Berlin), Dräger CH 30801 (Drägerwerk AG, Lübeck) and Kitagawa 126 B (Komyo Rikagaku Kogyo K.K., Japan).

In the detector tubes a colour reaction occurs which is proportionate to the CO_2-concentration. At low CO_2-levels this colour reaction is weak, and the borderline against uncoloured parts of the tube could be rather diffuse. For elimination of a possible "reader's bias" three persons read off the tubes independently of each other at one of the experiments (table 2), and at another experiment (table 3) two CO_2-measurements were performed immediately after each other, and the two sets of reactor tubes were read off by one and the same person.

Results

Table 1: Results of CO_2-measurements (ppm) with an IR-spectrophotometer (Miran 1A). The recirculation valve was manually adjusted.

CO_2-concentrations (ppm)			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

As appears from table 1 there is a good agreement between the valve adjustments and the calculated recirculations, when the CO_2-concentrations are determined with an IR-spectrophotometer. It is also notable that air recirculation could result in high concentrations of CO_2 in the mixed inlet air, if the building or ventilation segment is densely peopled.

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 are acconuted.

	CO_2-concentrations (ppm)			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.

Tabel 3: As tabel 2. The mean of the midpoints of the variation widths of detector tube recordings read by one and the same person on two sets of reactor tubes.

Method	CO_2-concentrations (ppm) Inlet air (C_1)	Recirculated air (C_2)	Mixed air (C_3)	Air recirculation (%) Measured	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.

It is obvious from table 2 and table 3 that the air recirculations calculated from detector tube reading not only demonstrate large spread and unsatisfactory precision, but the results could even be preposterous with values below 0% and above 100%.

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.

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 350 to 1500 ppm, because the calibration curve for CO_2 is curvilinear at this concentration level. A simple and convenient method to reduce the background level of CO_2 is to adjust the zero-point of the spectrophotometer to the CO_2-level in inlet air.

The IR-spectrophotometer reacts rapidly to minor fluctuations in the CO_2-concentration. This is important when the CO_2-concentrations are unstable and rapidly fluctuating, such as the situation could be when people are gathering in a lecture theater or a cinema. 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 situation is usually stable.

Two of the producers of the examined detector tubes do not recommend them for detection of CO_2-concentrations below 0.1% (1000 ppm), but the third one sets out the measuring range for their product to 100 to 1500 ppm. The CO_2-concentrations in atmosphere and ventilation ducts are usually lower than 1000 ppm. However, it is obvious that all examined detector tubes are unsuitable for control of air recirculation in ventilation systems. At the current CO_2-concentration both the resolution and reproducibility of the examined detector tubes are unsatisfactory.

The atmospheric CO_2-concentration is relatively stable but demonstrates some seasonal variations with lower concentrations during the cold than the warm season. In the northern hemisphere, it usually fluctuates between 335 to 340 ppm in wintertime and between 340 to 345 ppm in summertime (3). In densely populated areas, however, large local variations could occur, and it is recommended that the background CO_2-concentration is controlled as a standard procedure.

According to the Swedish Building Code (4) the concentration of CO_2 in the inlet air to rooms "where people permanently stay" ought not to exceed 500 ppm. In the tables this limit value refers to the CO_2-concentration in mixed inlet air. It is obvious that air recirculation could result in CO_2-concentrations in the mixed inlet air which are considerably higher than this recommended limit value.

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