

AN INDIRECT METHOD FOR MEASURING VENTILATION RATES

LADISLAV OPPL and VLADIMÍR VAŠÁK

Ústav hygieny práce a chorob z povolání, Praha II, Karlovo Nám. 33, Czechoslovakia

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Abstract—The paper describes an indirect method for determining the rate of air change in ventilated spaces by means of carbon monoxide. The concentration of carbon monoxide was found by an infra-red analyser which proved to be very precise and sensitive and made it possible to carry out analyses in a short time. The paper concludes with a discussion of the natural ventilation of rooms, based on the measurements.

In ventilation we often come across cases where the rate of air change in a ventilated space cannot be determined directly by measuring the amount of inlet air and outlet air. As a rule this occurs in rooms ventilated naturally. In direct determinations we get the average rate of air change I in the whole space v by the equation

$$I = \frac{V}{v} \text{ air changes/hr,} \quad (1)$$

where V is the volume of air flowing through the room per hour. In different parts of the ventilated space the rates of air-change are generally different, and may vary from the mean values or even be considerably different. Thus the direct method does not make it possible to determine local intensities of exchange, and where we cannot measure the amount of air V the method does not ascertain even the mean intensity of exchange. In such cases it is possible to use the indirect method, whereby we measure the rate of decrease of concentration of a definite, easily determined gas, which we let into the room in a convenient amount (DICK, 1950). This method may seem simple, but requires careful selection of a suitable gas and a sufficiently sensitive, accurate and rapid analytical method for determining the gas concentration.

The added gas should be of approximately the same density as air to promote good mixing with the air, so that there does not arise any accumulation of gas in a particular zone during the time of measurement. The gas must be used furthermore in concentrations which, in short-time operations, are neither harmful nor explosive. It is difficult to find a gas which would satisfy all these requirements. Some authors have used carbon dioxide, which is heavier than air, and the methods for its determination are not sensitive and accurate enough. Nitrous oxide has been used successfully (HIGGINS and SHUTTLEWORTH, 1958; LEACH and WALKER, 1959). Hydrogen and helium are considerably lighter than air, so that it is questionable to assume an even distribution of concentration in the space. Apart from this, hydrogen becomes explosive in a 4 per cent concentration, and helium is a very expensive gas. The attempt to find a sensitive method of detection of a substance

added in a small amount resulted in the use of radioactive substances such as xenon (WILLAX and MAIER-LEIBNITZ, 1955). With these a short half-life is necessary.

Having compared different substances and methods for their determination in air, we decided to use carbon monoxide, as its density is only slightly different from that of air. Determination of carbon monoxide through absorption of infrared radiation permits the employment of very low concentrations and there is no toxic or explosion risk.

EQUATION FOR DETERMINATION OF RATE OF AIR CHANGE

In the ventilated space we designate the space element (Fig. 1) of volume v , through which passes an amount of air V with an initial concentration of added gas k_1 . The concentration in outgoing air from the element is called k and the change of gas concentration in the element in time dt will be dk , so that

$$V(k - k_1)dt = -v \cdot dk. \quad (2)$$

To this equation we add the rate of air change according to the equation (1) and thus we get

$$\ln(k - k_1) = -It + C. \quad (2a)$$

The integration constant C can be ascertained from the condition that at time $t = 0$ the initial concentration in the element is $k = k_0$. Thus

$$C = \ln(k_0 - k_1),$$

and after adding this to equation (2a) we get the final form of equation for the rate of air change

$$I = \frac{1}{t} \ln \frac{k_0 - k_1}{k - k_1}. \quad (2b)$$

If we operate with an added gas which is not a part of the fresh ventilating air then $k_1 = 0$ and the equation (2b) is simplified as follows

$$I = \frac{1}{t} \ln \frac{k_0}{k} = 2.303 \frac{1}{t} \log \frac{k_0}{k}. \quad (3)$$

The concentration of the added gas in the ventilated space decreases exponentially, and on semi-logarithmic paper will be representing dependent on time, t , as a straight line. We start measuring at the time ($t = 0$) when the added gas must be well mixed in the space and in a uniform concentration.

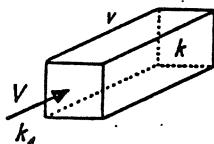


FIG. 1. Derivation of the equation for the rate of air change.

GAS EMISSION AND SAMPLING

Rates of air change were measured in a laboratory the design of which is shown in Fig. 2. The height of the room was 3.74 m. Before the experiment started, carbon monoxide was let in through rubber tubing, 6 mm in diameter, from the adjoining room. During this operation the air and CO were mixed by means of a table fan which was kept working for another 10 min after the emission of CO ceased. Concentrations of CO were measured at different places and heights in the laboratory under different air conditions and with different sizes of ventilation openings, in this case the windows.

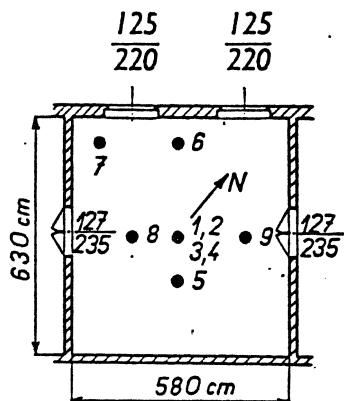


FIG. 2. Design of laboratory. 1-9 show sites of measurement. The dimensions of the windows are given in cm.

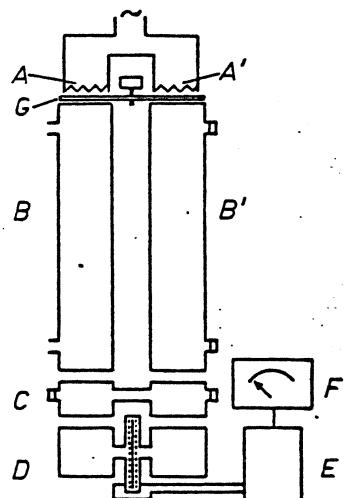


FIG. 3. Schematic diagram of infra-red gas analyser.

- A, A' radiators
- B measuring tube
- B' comparison tube
- C filter tube
- D detector
- E amplifier
- F indicator
- G rotating vane

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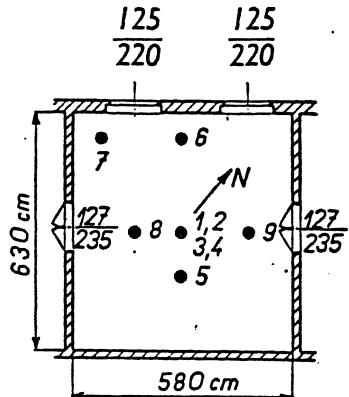


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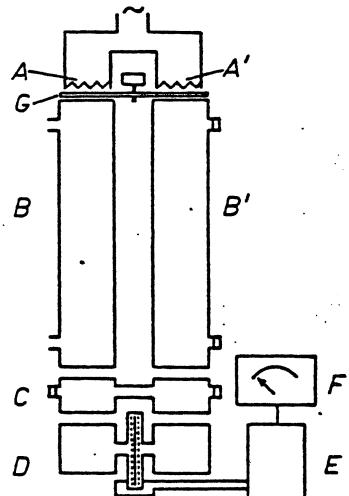


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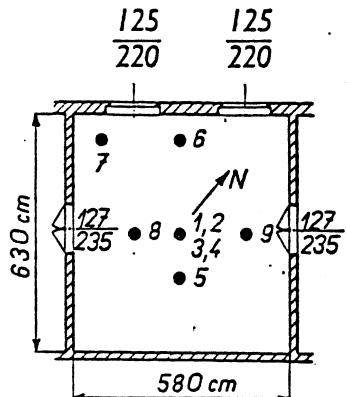


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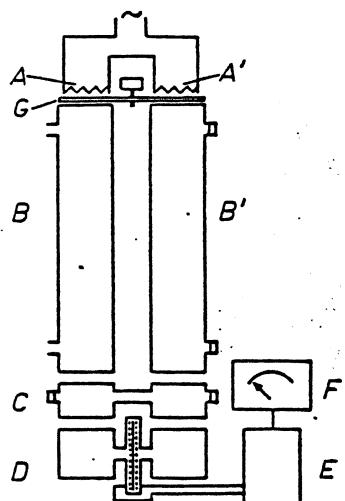


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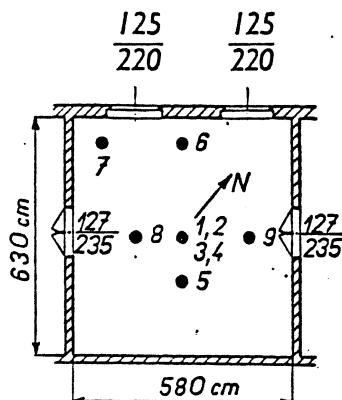


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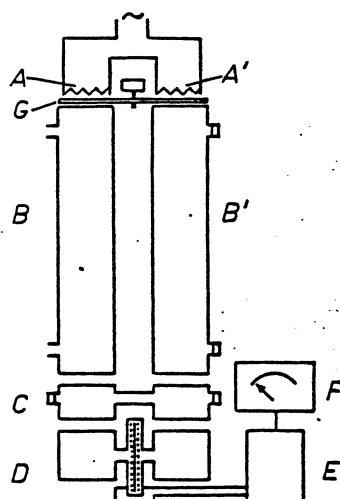


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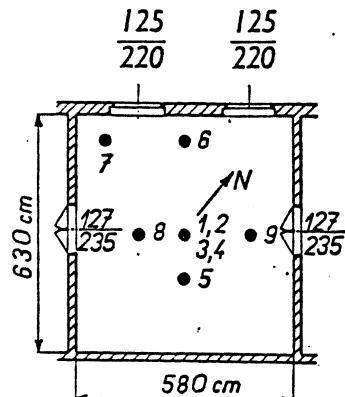


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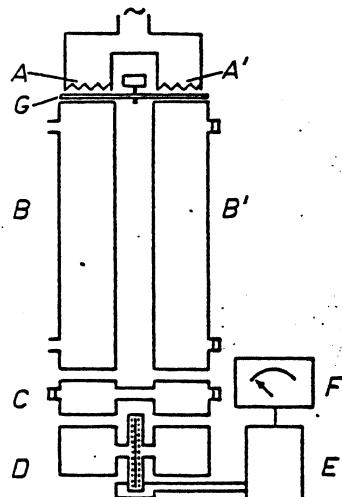


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Air samples from the test chamber were taken by rubber tubing (inside diameter about 6 mm, 4 m long) to a gas burette filled with mercury, and thereafter the air was blown into rubber balloons, the volume taken being 0.5 to 1 l. of air. Before taking individual samples the rubber tubing, as well as the burette, was rinsed through with sample air. In cases where the decrease of concentration in the room was followed continually, the air was sucked directly into the analyser through a diaphragm pump: the flow of gas through the analyser was about 0.5 l/min.

All analyses were carried out with an improved analyser, type SCL, made by the Infra-red Development Co., Ltd., of Great Britain (Fig. 3).

THE RESULTS OF MEASUREMENTS AND THEIR ASSESSMENT

The variation with time of measured values of concentrations in a certain place was plotted on semi-logarithmic paper. Fig. 4 shows the k -values obtained by measuring in the centre of the room at 1.5 m above the floor (line 1) and at 2.5 m (line 2). Windows were closed, mean temperature of inside air was 21.5 °C, outside air being 5.5 °C, northwest wind, strength 2-3 (Beaufort Scale). The rate of air change at a height of 1.5 m was 0.64/hr and at a height of 2.5 m it was 0.60/hr. As will be seen from the graph, the measured points in the semi-logarithmic plot really lie on a line.

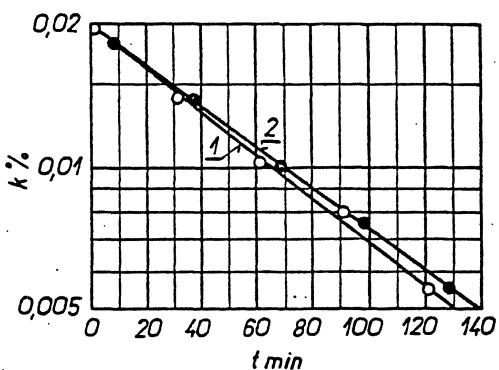


FIG. 4. Dependence of concentration on time at low rate of air change.

The example presented shows that the method described is reliable even for very small air changes occurring in rooms with the windows closed. The method can also be utilized for measuring considerably higher air changes; see Fig. 5. In this case the upper parts of both windows were quite open (area 1.75 m²) so that the rate of air change in the centre of the room, at the height of 1.5 m, increased to 5.55 changes/hr. Temperature in the laboratory was 25 °C, outside temperature 1.8 °C, northwest wind, strength 2-3.

It is evident, from a great number of measurements, that in the case of closed windows (whether double or single) the intensity of air change was low, varying from 0.46 to 0.76/hr, mean value being 0.58/hr. When the lower part of one window was opened a little (area 0.3 m²) the intensities of air change increased to 0.95/hr. When opening the lower part of the window fully (area 0.94 m²) the intensity increased significantly, i.e. it reached the values 2.8-4/hr. On opening one part of both windows (area 1.92 m²) the intensities reached higher values than 5/hr.

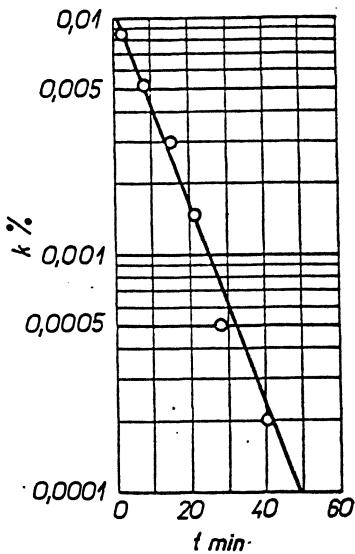


FIG. 5. Dependence of concentration of time at high rate of air change.

These results confirmed the idea (PULKRÁBEK, 1953) that it is more efficient to ventilate living spaces, class-rooms, smaller kitchens and workshops with insignificant occurrence of toxic substances, through windows of large dimensions open for short periods of time than by continual ventilation through small openings; for example, ventilation through leaks which attains only a small rate of air change. The recommended way of ventilating is more convenient with regard to thermal losses caused by ventilation.

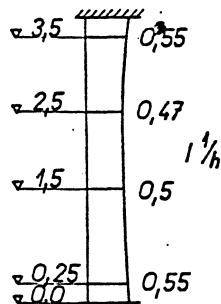


FIG. 6. Rates of air change per hour measured at different levels.

The air change in different parts of the space showed only slight differences both in horizontal and vertical directions. Fig. 6 gives the local rate of air change found when the windows of the laboratory were closed. Slight bending of the curve is caused by air circulation occurring, especially when the heating unit is situated at the inside wall opposite the windows.

CONCLUSION

The indirect determination of the rate of air change by means of carbon monoxide offers the possibility of measuring in detail the different systems of natural

and forced ventilation, and to select, in an objective way, adequate types of equipment and accessories. Thus it is a means for further research work, besides current control measurements, on the subject of the total ventilation of rooms.

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