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An Optical Technique for Measurement of Ventilation Rates in Models

D. W. ETHERIDGE*
J. A. NOLAN†

An optical technique has been adapted to measure ventilation rates in wind tunnel models. The technique has been compared with the conventional tracer gas technique and good agreement has been found. The optical probe described has considerable potential for measurements in small models where conventional techniques are not feasible.

1. INTRODUCTION

AS FAR as the authors are aware, measurements of ventilation rates in wind tunnel models have been restricted to simple single-cell models. Such models are not representative of most real buildings and the scope of wind tunnel tests would be widened if multi-cell models could be tested. For example, the effects of wind direction on cross-ventilation between rooms in complex structures could be investigated. One problem which would be encountered with such models is that of measuring the ventilation rates in model rooms which would of necessity be very small.

Motyčka and Leutheusser have described [1] a photo-electric technique for the instantaneous determination of tracer concentration in wind tunnel studies of stack gas dispersion. The device which they describe has considerable potential for ventilation measurements in model buildings in wind tunnels. Firstly, because it is not expensive and can be constructed from readily available components. Secondly, because it is small and it could therefore be fitted into the small cells of a multi-cell model. Previous model tests at Watson House have been carried out with a helium katharometer installed inside the model [2, 3] to monitor the decay of the helium and thereby obtain the ventilation rate. Although satisfactory for single-cell models, the katharometer is too large for use in multi-cell models.

In view of this it was decided to investigate the feasibility of the photo-electric technique for ventilation rate measurement.

For the device to be suitable for determining ventilation rates from tracer decay curves it is necessary that the output signal should be linearly related to tracer concentration. Motyčka and Leutheusser verified this indirectly by demonstrating that the output signal decayed exponentially when the device was placed inside a space ventilated at a constant rate. This procedure has been repeated for the modified device and the tracers used in the present tests. However, it was considered desirable to extend this procedure by comparing ventilation rates obtained with the optical technique with those obtained with the katharometer.

2. OPTICAL TECHNIQUE

2.1. *The probe*

The basis of the technique is the probe, which is shown in Figs. 1 and 2. The probe developed for the present work consists of an i.r. light emitting diode and a hybrid photodiode–amplifier detector. Light

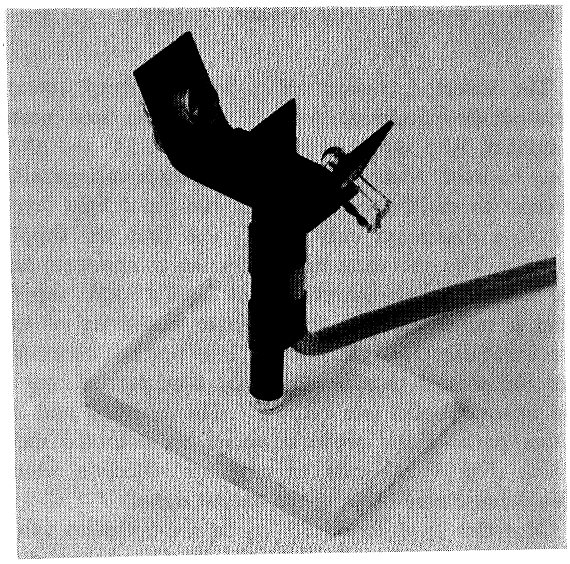

Fig. 1. Optical probe.

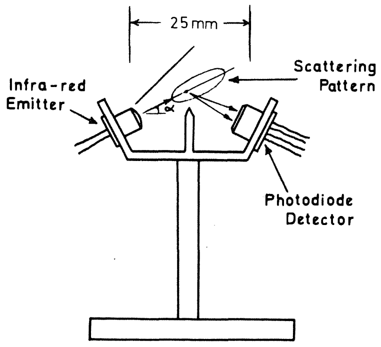

Fig. 2. Geometry of probe.

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scattered by particles in the air is detected by the photodiode which has an output signal related to the particle concentration. The partition between emitter and detector (Fig. 2) prevents direct illumination of the detector. Infra-red light is employed because it gives a wider scattering pattern than visible light and ambient lighting is less of a problem. Also, the output power of i.r. lamps is higher than that of lamps emitting visible light, and their spectral emission matches the spectral sensitivity of the detector, as can be seen in Fig. 3. The mean wavelength of the emitter spectral band is 0.94 μm and hence is of similar dimension to the mean diameter of cigarette smoke particles [4].

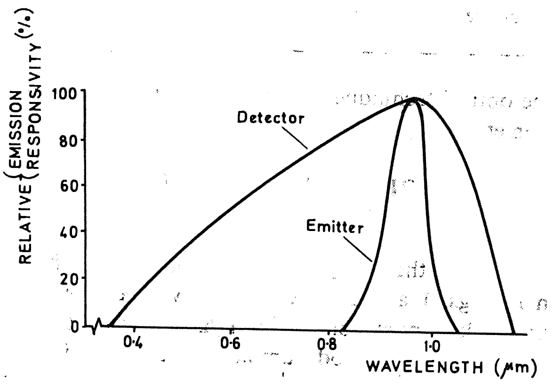

Fig. 3. Spectral emission and responsivity of the emitter and the detector.

The detector consists of a high efficiency silicon photodiode combined with a high gain low noise amplifier. Any supply voltage between 2.5 V and 18 V may be used. A single output line gives a voltage with respect to earth proportional to the input light level, up to a maximum only slightly less than the supply voltage. The operating circuits for the components can be seen in Fig. 4. Motyčka *et al.* used a 3 kHz supply and a tuned detector to eliminate sensitivity of the device to external light sources. This was not necessary for the present tests because they were carried out in an opaque model (see below). The partition and all other parts of the probe structure are coloured matt black (Fig. 1) in order to minimise reflection which could cause zero-offset of the output signal.

Motyčka *et al.* found 25° to be the optimum value for the detection angle, α, (see Fig. 2). This was used in the present device, but the separation between the emitter and detector was increased to 30 mm due to the slightly larger components.

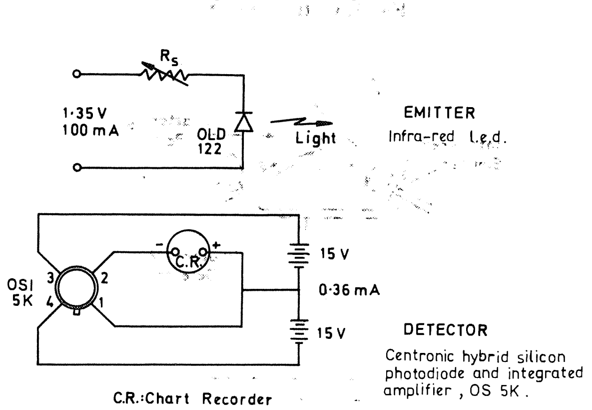

Fig. 4. Operating circuits of emitter and detector.

2.2. *Choice of tracer*

Several different tracers were investigated: Cigarette smoke and smoke produced by MSA Ventilation Smoke Tubes were found to be suitable. Both of these smokes have disadvantages. The former has the unpleasant odour of the tar condensate. The latter has a slight corrosive action. However both gave large output signals from the detector and neither was found to be significantly prone to condensation. Condensation of some part of the tobacco smoke did occur, as evidenced by the gradual appearance of tar on the surfaces of the model. But over the time periods of interest (about 10 min) tests showed that the effect on the output signal was small in relation to the effect of ventilation.

Condensation occurred very rapidly with 'smoke' produced by an oil vapour generator and for this reason it was unsuitable. Smoke pellets were considered but not used, because none could be found which did not emit toxic fumes.

Lycopodium powder was also tried, but the detector showed very little response, presumably because of the size of the particles.

3. VENTILATION RATE MEASUREMENTS

Ventilation rates have been measured with the photo-electric probe and with the helium katharometer in a simple single-cell model equipped with a circular opening in two opposing faces. The model had been built for ventilation tests and has dimensions 0.4 × 0.2 × 0.2 m [3]. For the present measurements the wind incidence angle was chosen for maximum ventilation, such that the openings lay on the windward and leeward faces.

To prevent interference from the surrounding illumination the exterior of the model was covered with opaque adhesive tape. A simple shield over the probe was also found to be satisfactory, provided that the ambient light level was reduced.

The emitter was fed with 1.35 V, 100 mA, and the detector with ±15 V, 0.36 mA, from laboratory power supply units (see Fig. 4). The detector output was connected to a chart recorder and, after zeroing the signal, the model was filled with smoke. This was done by simply allowing a cigarette to burn inside the model until a suitable output signal was obtained, and then the cigarette was removed. The required tunnel speed was obtained and the output recorded for subsequent analysis. A small fan inside the model was used to promote a uniform distribution of smoke. For the helium decay tests the rotating arms of the katharometer had been found to be adequate.

Figure 5 shows a typical output decay curve recorded during the tests using cigarette smoke. A curve for smoke produced by the MSA smoke tube is shown for comparison. The decay times for the curves are about three and five minutes respectively and the output signals at the start of the decay are usefully

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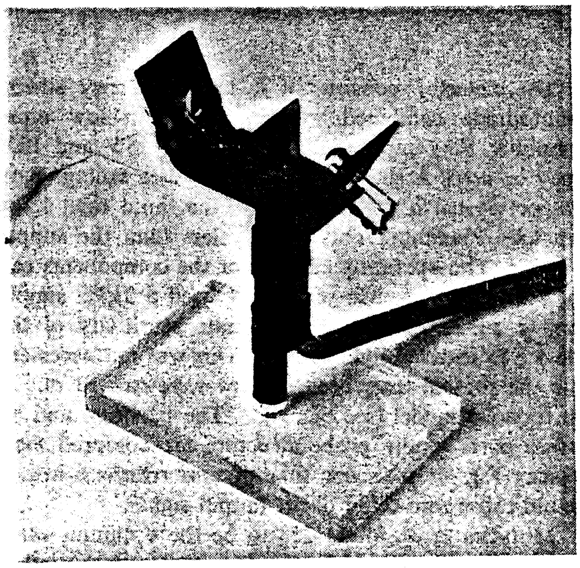

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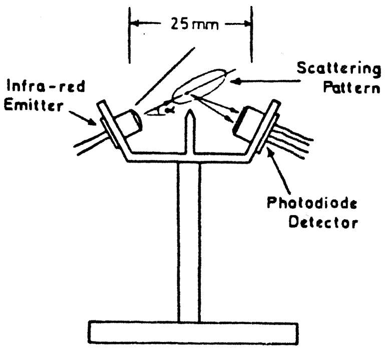

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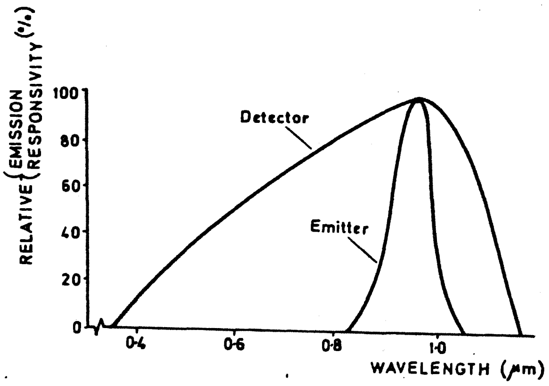

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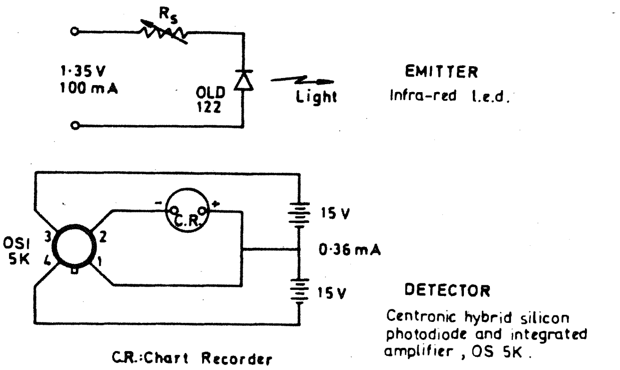

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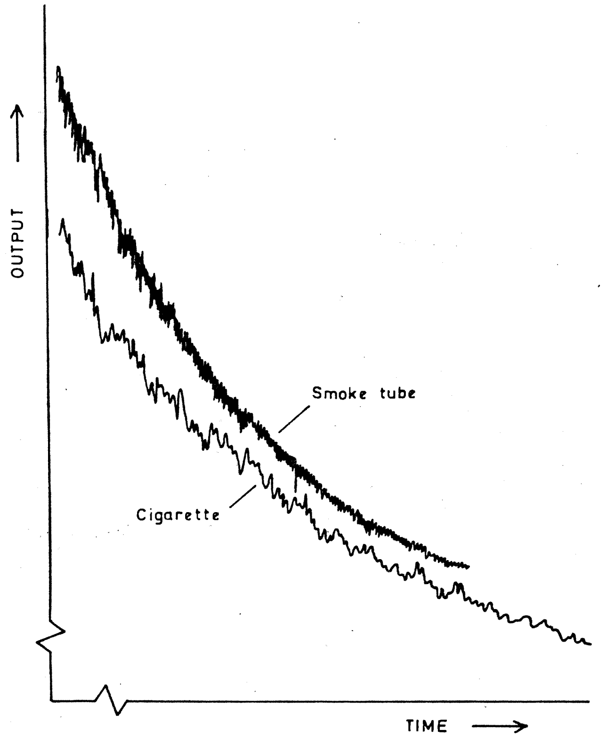

Fig. 5. Output records for two different tracers.

large at about 250 mV. Both curves are subject to noise and it is necessary to draw mean lines through the curves for the estimation of ventilation rates. The curve corresponding to the cigarette smoke in Fig. 5 has a larger noise content, but it was decided to use cigarette smoke for the tests because of the slight corrosive action of the other smoke.

Decay curves were recorded for a range of tunnel speeds (1.5–6.5 ms^{-1}) using the optical probe and the conventional helium decay technique.

4. RESULTS AND DISCUSSION

In order that the probe can be used for determining ventilation rates from tracer decay curves it is necessary that the output from the probe should be linearly related to tracer concentration. With the usual assumption of uniformity the ventilation flow rate, Q, into the model of volume, V, is given by

$$Q = \log(c/c_0)\frac{V}{t}$$

where c_0 and c are the initial and final tracer concentrations and t is the decay time. If the probe output, v, is related to c by $v = k.c$, where k is a constant, the ventilation rate can be determined from the decay curve of v.

It was not possible to measure the tracer concentration by a direct method so the relationship was assessed indirectly, from logarithmic plots of the output decay curve and from a comparison between the ventilation rates estimated from the two techniques.

Figure 6 shows two typical semi-logarithmic plots of points taken from output decay curves. As can be seen the points lie quite closely on straight lines.

Figure 7 compares the ventilation rates estimated from the decay curves obtained with the two techniques. The results are shown as plots of Q/U, where U is the reference wind tunnel speed. There is a tendency for the ventilation rates obtained from the optical technique to be greater than those from the conventional technique. This is particularly evident at low wind speeds where the ventilation rates are also low. It is possible that this is due to condensation of the smoke. At the lowest wind speed the results differ by about 12%, whereas the average of the modulus of the difference between the results from the two techniques is about 8%.

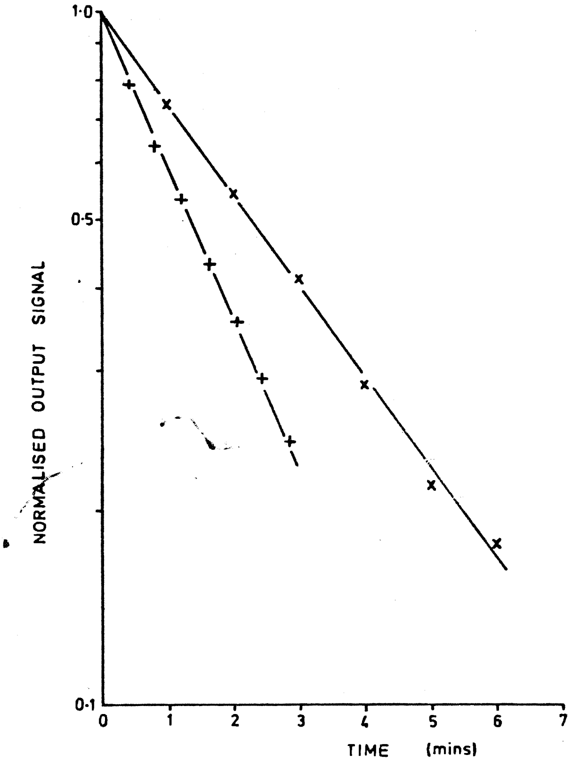

Fig. 6. Typical semi-logarithmic plots of output decay curves with cigarette smoke.

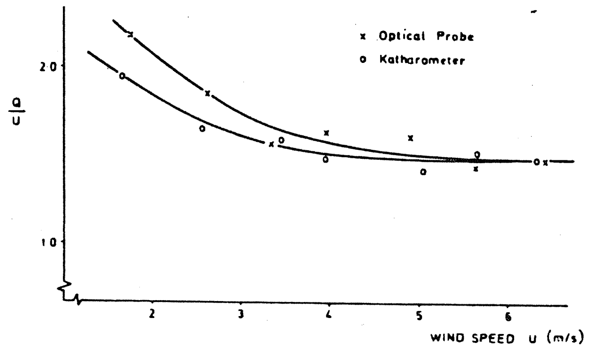

Fig. 7. Comparison between ventilation rates obtained with the optical probe and the katharometer.

Bearing in mind that the helium decay technique is not an absolute measure of ventilation rate, Q, the above results are encouraging. It is considered that ventilation rates can be estimated from simple decay curves produced by the optical technique. Where it is possible to make use of a katharometer it is probably advisable to do this, since it is a well tried technique. However, in situations where a katharometer cannot be used, such as in a small multi-cell model, the optical technique offers an acceptable solution to the problem of measuring decay rates. The usefulness of the technique would be much widened if it could be developed to allow measurements of actual tracer concentration to be made. It is possible that the device could be calibrated with sophisticated equipment such as an optical particle counter. This was however outside the scope of the present study.

Acknowledgement—The permission of British Gas Corporation to publish this paper is gratefully acknowledged.

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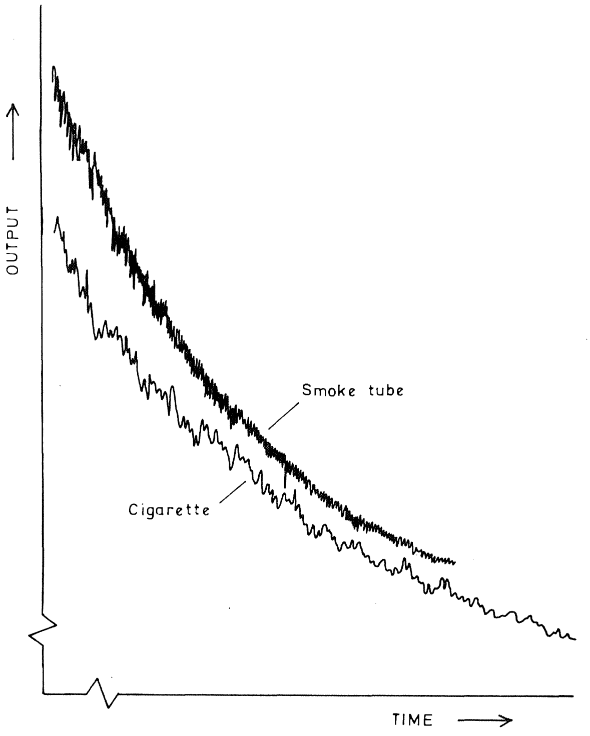

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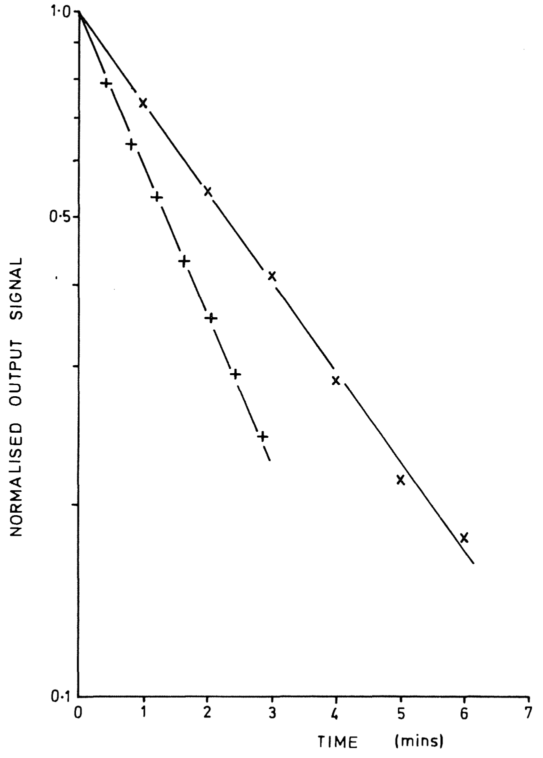

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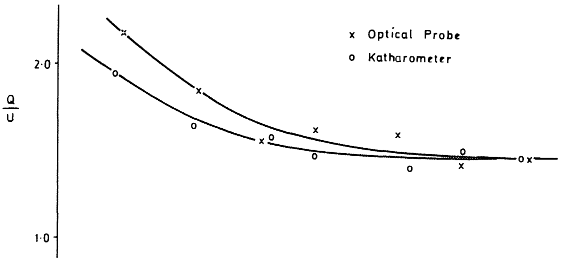

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