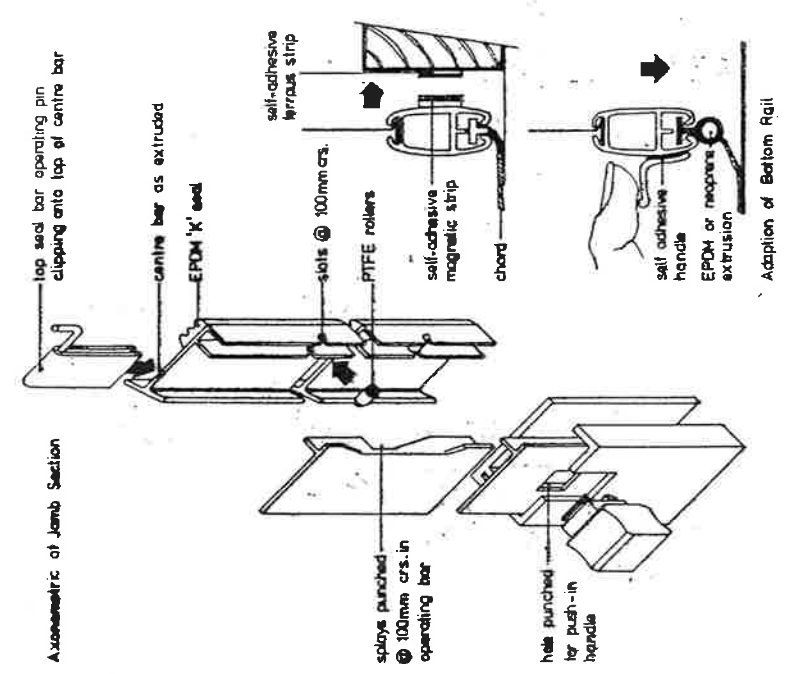

Figure 9. Axonometric of single layer blind

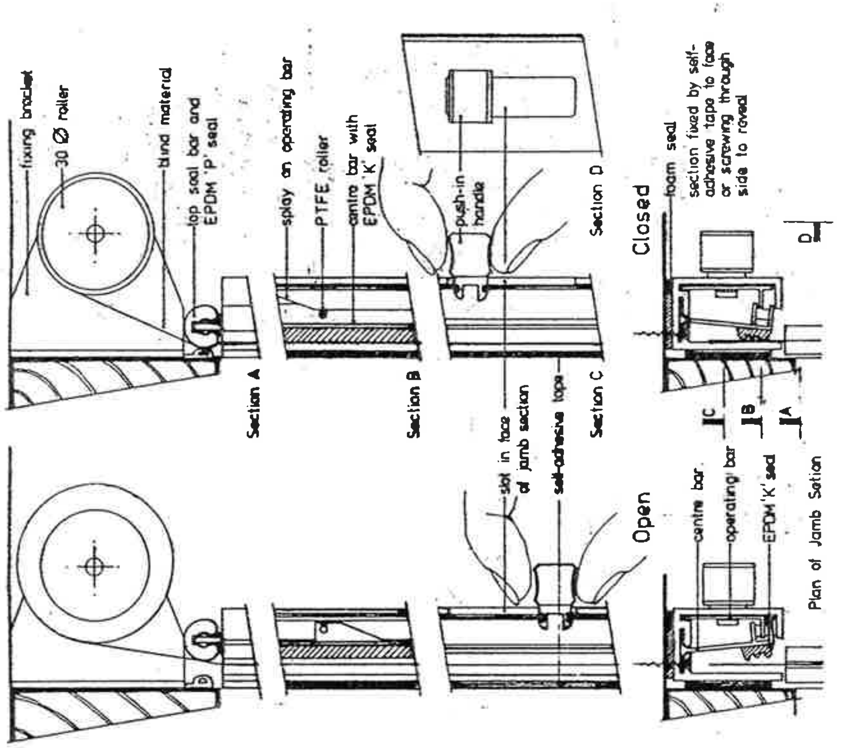

Figure 10. Single layer blind side seals

AIC 1120

THE MEASUREMENT OF AIR INFILTRATION RATES IN LARGE ENCLOSURES AND BUILDINGS

I.N. POTTER, J. DEWSBURY and T.J. JONES

THE BUILDING SERVICES RESEARCH AND INFORMATION ASSOCIATION
BRACKNELL, UK

Summary

The report discusses the need for a proven method of measuring air infiltration rates in large enclosures in order to assess the need for and effectiveness of energy saving measures.
The object of the research is to develop such a proven method. Some possible novel instruments are described, together with theoretical predictions of the implications of poor air mixing in the space for methods of measurement and analysis. The measurement system selected and the results of some preliminary measurements are described. The report concludes with an account of work in progress to validate the measurement and analysis methods.

1. INTRODUCTION

The floor area of industrial and warehouse buildings in the UK is about 410,000,000 m^2. The authors have estimated that the heat loss from these buildings due to air infiltration is of the order of 1.6×10^{17} J/year. This represents about 3% of the total UK energy consumption by final users (5.8×10^{18} J/year). Therefore, if the air infiltration rate were to be halved, a saving of 1.5% of the national energy consumption might be made.

However, industrial and warehouse buildings usually consist of a single large space or a small number of large spaces. There is at present no proven method of measuring ventilation rates in these spaces. Therefore, there is no way of knowing whether the energy loss and possible savings estimated above are over or under estimated and no certain way of determining the cost effectiveness of any measures taken to reduce unwanted air infiltration.

2. OBJECTIVES

The objectives of the research are to develop and validate a method of measuring ventilation rates in large enclosures, to use the method to measure ventilation rates in selected buildings and to assemble the results of the measurements into the foundations of a data base.

As well as the ventilation rate, other significant variables will be recorded. These will include temperatures at selected points, wind velocity, factors affecting building air-tightness, etc.

These and future measurements using the validated ventilation rate measurement method will enable the effectiveness of measures for reducing unwanted air infiltration to be assessed, and thus enable energy conservation measures to be directed to where they will have most effect.

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3. PROGRAMME OF WORK

The first part of the research consisted of a survey of existing and possible novel techniques for measuring ventilation rates, and laboratory trials of an unconventional gas analyser.

The second part commenced with the selection of suitable instrumentation, and included the construction and commissioning of the measurement system and trials in a medium-sized enclosure in the laboratory.

The third part consists of full scale trials of the measurement system in a large enclosure having a controlled ventilation rate. The measured ventilation rate will thus be able to be compared to the known controlled ventilation rate, and an investigation of factors affecting the accuracy of the method will be made.

The fourth part will consist of using the validated measurement method to measure ventilation rates in selected buildings. The results of the measurements will be used to form the foundations of a data base.

4. INVESTIGATION OF POSSIBLE MEASUREMENT TECHNIQUES

The normal method of measuring an enclosure's ventilation rate is to inject a tracer gas into the air in the enclosure according to some defined strategy, and to measure the concentration of tracer gas in the enclosure over a period of time. Provided the air in the enclosure is well mixed the ventilation rate can easily be calculated from a knowledge of the tracer gas injection strategy and the history of its concentration. This method has been used successfully in many countries, but has been mainly confined to small enclosures. This is partly because of practical difficulties concerning the amount of equipment and labour involved for large scale work, partly because of theoretical difficulties connected with the interpretation of results and control of test equipment when good mixing is difficult or impossible to obtain.

The search for possible novel measurement methods was directed to finding either a low cost substitute for conventional tracer gas concentration measurement instruments, or an instrument with significant technical advantages over conventional equipment.

A method based on analysis of air samples on site by individual low cost fuel cell gas analysers at each sampling point was selected for initial trials. A laser method was also of interest as it would have been able to cover a large volume from a single point, but it was not selected for trials due to the high capital cost of the equipment.

Two fuel cell gas analysers were obtained and tested in the laboratory. The calibration of the analyers were initially subject to significant variation. This variation was reduced when the analyser was maintained at 60°C instead of at room temeprature, with the added benefit of much faster response. Ventilation rates were measured using the fuel cell and a conventional analyser simultaneously, and similar results were obtained.

5. SIMULATION OF IMPERFECT MIXING

Little work on air movement in large buildings has been published, but what there is indicates that poor mixing is likely.

A simple numerical model was developed which simulates a ventilation rate measurement by the concentration decay method in a poorly mixed space. Figure 1 shows the results of a simulation, and Figure 2 shows the air flow pattern assumed in calculating the results shown in Figure 1. The perfect mixing line in Figure 1 is that which would be obtained if the air in the enclosure had been fully mixed. If perfect or near perfect mixing is obtained in an experiment then the ventilation rate can be obtained directly from the slope of the concentration decay line.

It can be seen from Figure 1 that the concentration lines for the individual zones can fall either above or below the perfect mixing line, and that their slopes can be either greater or less than that of the perfect mixing line. The line for the mean concentration has a slope which is different from that of the perfect mixing line.

The results of this and other simulations showed that in a poorly mixed enclosure it would be necessary to know the details of the variation of the concentration of tracer gas through the space in order to estimate the ventilation rate.

The proposed laser method of measuring tracer gas concentrations was essentially an averaging method and was therefore rejected.

6. ANALYSIS METHOD FOR IMPERFECT MIXING

It is assumed that the space can be divided into a number of well defined zones of known shape and size.

The general equation governing the tracer gas concentrations within the space is:

Rate of supply of gas - Rate of removal of gas
= Rate of change of quantity of gas in space

The easiest ventilation rate measurement method to use is the concentration decay method, in which:

Rate of supply of gas = 0

The removal of gas from the space is simply the sum of the air flow rates from each zone to the outside, each multiplied by its appropriate tracer gas concentration:

$$= \sum_{z=1}^{Z} Q_{zo} C_z$$

where Q_{zo} is the air flow rate from zone z to the outside and C_z is the tracer gas concentration in zone z. Z is the number of zones.

The rate of change of the quantity of tracer gas in the space is the sum of the volumes of the zones each multiplied by the appropriate rate of change of tracer gas concentration:

$$= \sum_{z=1}^{Z} V_z \frac{dC_z}{dt}$$

where V_z is the volume of zone z.

Thus $$0 - \sum_{z=1}^{Z} Q_{zo} C_z = \sum_{z=1}^{Z} V_z \frac{dC_z}{dt}$$

During a concentration decay measurement the values of C_z and $\frac{dC_z}{dt}$ will vary with time, so by integrating over T time intervals and inserting estimated value of Q_{zo} the following set of equations can be obtained:

$$\sum_{z=1}^{Z} V_z(C_{z,t1} - C_{z,to}) + Q_{zo} \int_{to}^{t1} C_z dt) = E_1$$

$$\sum_{z=1}^{Z} V_z(C_{z,t2} - C_{z,t1}) + Q_{zo} \int_{t1}^{t2} C_z dt) = E_2$$

etc.

$$\sum_{z=1}^{Z} V_z(C_{z,t1} - C_{z,t(-1)} + Q_{zo} \int_{t(T-1)}^{tT} C_z \, dt) = E_T$$

Where the magnitude of each E represents the magnitude of the discrepancy between the observed values of C_z and the assumed value of Q_{zo}.

Provided that T > Z and that the equations are sufficiently independent, it should be possible to find the values of the Q_{zo} terms which minimise an error function:

$$f(E_1, E_2, \ldots\ldots E_T)$$

subject to the constraint that $Q_{zo} > = 0$ for all z.

The assumption that the space can be divided into a number of well mixed zones of known shape and size is a very great simplification of the true situation. Section 8 outlines the programme of work intended to provide data on the accuracy of the method.

SELECTION AND DESCRIPTION OF MEASUREMENT SYSTEM

Of conventional gas analysers, the research team has found infra-red gas analysers to offer the most suitable combination of cost, accuracy and reliability for this application. Preliminary designs and cost estimates were therefore produced for computer controlled multi-point tracer gas concentration measurement systems using infra-red and fuel cell gas analysers.

The capital costs of the two systems were expected to be similar, but number of significant technical problems were expected with the fuel cell analyser system, mainly concerned with the speed of response of the fuel cell analysers and the extent of the modifications required to them in order to incorporate them into a working system. The infra-red gas analyser system was therefore selected.

The measurement system comprises three infra-red gas analysers with associated sampling valve assemblies, thermocouples for measurement of temperatures and other instruments as required. The sampling valve assemblies permit each gas analyser to be connected to one of a number of sampling points. The instruments are controlled and data recorded by a microcomputer with associated interface equipment. A schematic of the system is shown in Figure 3.

VALIDATION OF MEASUREMENT METHOD

Work is in progress aimed at providing data on the accuracy of the multi-point tracer gas method for measuring ventilation rates in large enclosures.

A fan extracts air from or supplies air to the enclosure so as to create a pressure difference between inside and outside. If the pressure difference created by the fan is larger than those caused by wind and

temperature differences, when all the air ventilating the through the fan. The ventilation rate measured using tracer gas can then be compared with the air flow rate through the fan.

Figure 4 shows the results of a test in which good internal mixing was obtained. Measured concentrations from every third zone of thirty are plotted, together with the theoretical line corresponding to perfect mixing and no ventilation except through the fan. Good agreement is obtained between the measured and theoretical concentration decay rates.

Figure 5 shows the results of a test in which poor internal mixing was obtained. Measured concentrations from selected zones of thirty are plotted, together with the theoretical line corresponding to perfect mixing and no ventilation except through the fan. This Figure should be compared with Figure 1. In Figure 5 the concentration decay lines for the various zones have different slopes, generally steeper than the slope of the theoretical line.

Work is proceeding on the calculation of ventilation rates from results such as those shown in Figure 5, by the method outlined in Section 6 of this report.

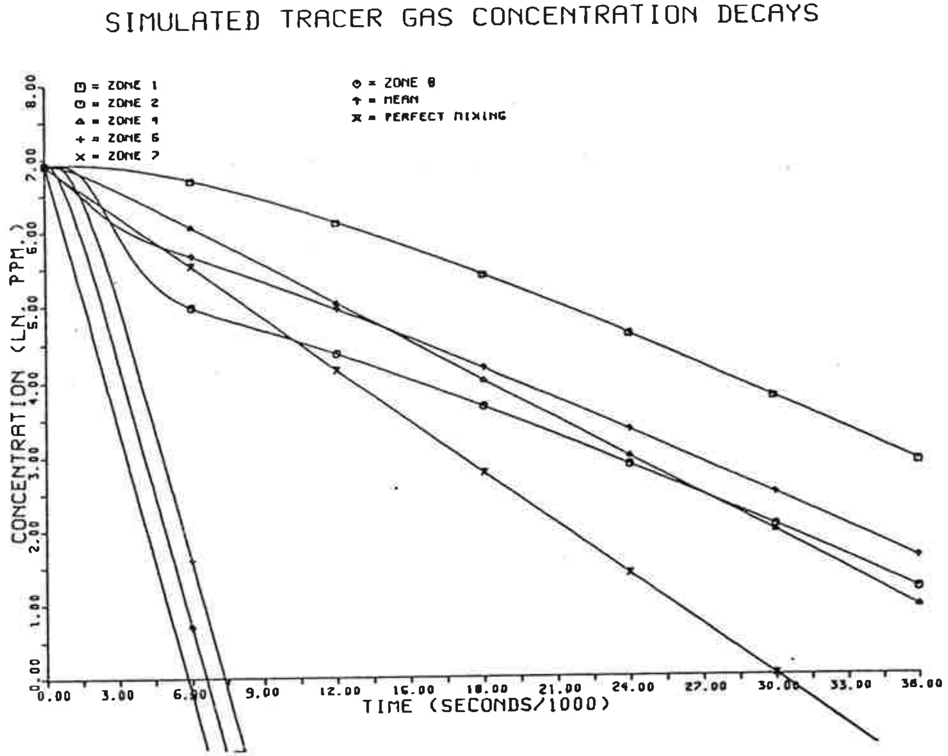
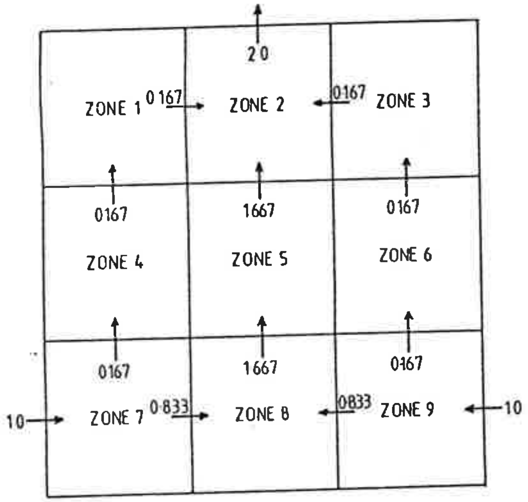


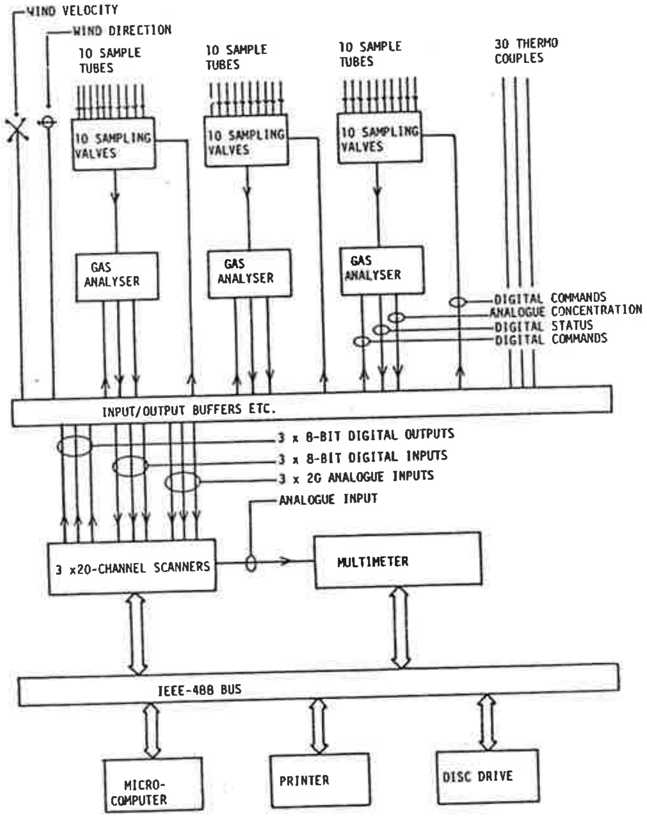
FIGURE 1



All zones 1000m³
Air flows in m³/s

FIGURE 2

Air flows for
figure 1



TRACER GAS CONCENTRATION MEASUREMENT
SYSTEM USING INFRA-RED GAS ANALYSERS

FIGURE 3

GOOD MIXING

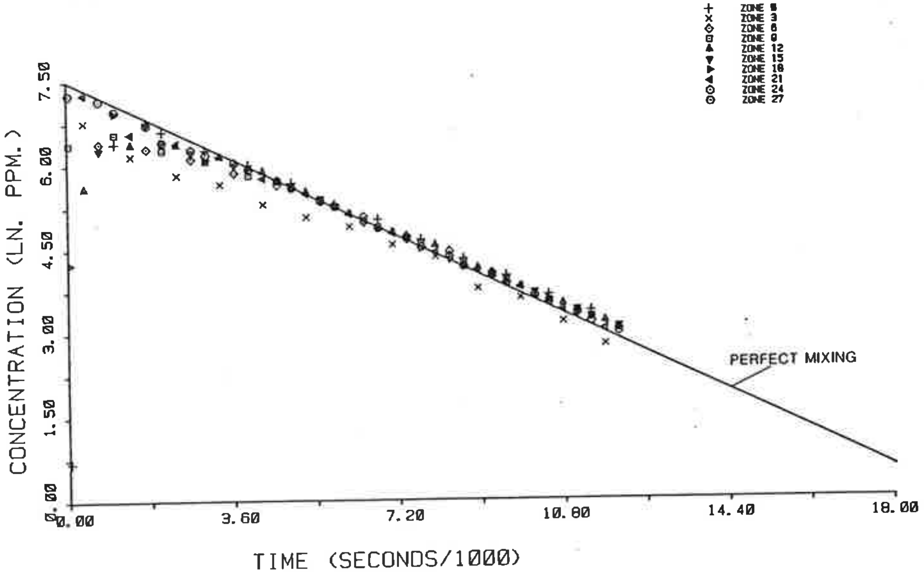


FIGURE 4

POOR MIXING

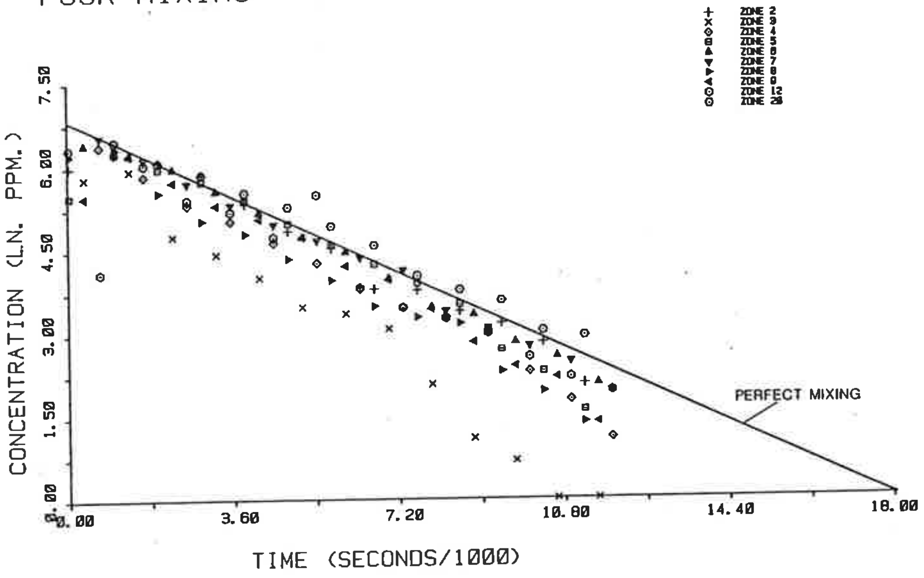


FIGURE 5