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VENTILATION RATES AND INTERCELL AIRFLOW RATES IN A NATURALLY VENTILATED OFFICE BUILDING

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by M D A E S Perera, R R Walker and O D Oglesby

SUMMARY

Ventilation rates and intercell airflow rates in a naturally ventilated office building have been determined using multiple tracer gases. To do this, the building was subdivided into three zones and each zone was then seeded individually with a different tracer gas. The time histories of the concentrations of all gases in each zone were then monitored using non-dispersive infrared gas analysers. The airflow rates were then calculated from the experimental data. A computer programme written in-house to predict the dispersion of a tracer gas in a multi-zoned environment was used to compare the predicted time histories of concentrations with those obtained from experiment.

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1. INTRODUCTION

In a programme of retrofit measures carried-out by the Property Services Agency to reduce fuel consumption in Government office buildings, it was found[1] that although significant savings were achieved over the programme as a whole, particular difficulty was found in reducing consumption in a number of high energy using buildings. A common feature of these was that occupants judged them to be generally cold and draughty, suggesting excessive ventilation and infiltration.

The following research programme was designed to explore this problem; in particular to,

(a) develop techniques to enable a better understanding of the ventilation of large complex buildings,

(b) identify the movement of air, and hence contaminants or heat, from one zone to another and,

(c) determine the effectiveness of remedial measures or to indicate zones where selected remedial measures will be cost-effective.

The main object of this paper is to give details of a multiple tracer technique which could be used to determine interzone airflows and infiltration rates in complex, multicelled buildings. To illustrate this, results are presented here from one set of measurements carried-out in a naturally ventilated office building.

2. EXPERIMENTAL DETAILS

A conventional two-storey office building (with a volume of 2153 m^3) at the Building Research Station, Garston was used. The building (Fig 1) is rectangular in plan (40 m x 11 m) and each storey is 2.44 m high. A stairwell region located near one end of the building allows access between each storey. For this experiment, the building was nominally divided into three zones; Zones G and F (each with 783 m^3 volume) incorporating the major portion of the ground floor and first floor respectively, and Zone S (587 m^3) encompassing the stairwell and the offices in the southern end of each of these two floors. During the experiment, the building was unoccupied but had its heating turned on to give an internal temperature of about 16°C.

During this particular experiment, the wind was blowing at a mean speed of 2 m/s from the SW. This wind speed at a height of 10 m was monitored at a nearby open site. The outside air temperature at this time was -1°C.

Three existing Leybold-Heraeus analysers, dedicated to measuring either one of SF_6, N_2O or CO_2, were used. For the future, a multicomponent infrared analyser will be used to determine concentration levels of the tracer gases. The tracer gases used in this experiment were determined by these analysers, but in future other gases such as Freons will be used.

The tracer gases were injected manually into each zone until a target concentration was reached. Zone G was seeded with N_2O to a concentration of approximately 200 ppm, Zone F with SF_6 to about 200 ppm and Zone S to 2000 ppm with CO_2. During injection, small desk-top fans were used to provide mixing within each zone. The doors to each office space were kept open throughout the experiment.

Single-point or blended multi-point samples were takes from each zone using equal-length 6 mm diameter polyethylene tubes. A sample line was also placed outside the test building in order to provide reference ambient concentrations of the test gases. All tubes were then brought back to individual solenoid valves which were under the control of an ITT Director microprocessor unit. Using this unit, each sample line was connected in turn to the three analysers and the concentrations of tracers present in each sample were recorded on cassettes. Figure 2 gives a schematic drawing of this system. The data recorded on these cassettes were later transcribed using an off-line computer.

3. THEORY

The theoretical basis for deriving ventilation rates and interzone airflow rates from concentration measurements of multiple tracer gases is given in detail in Reference 2. It is shown that in the 'decay' method, the conservation of tracer gas and of air can be written in the form

$$^{(l)}\{Y\} = [A].^{(l)}\{X\}$$

for any zone l where l=1,2,....,N and N is the number of zones.

The i^{th} and j^{th} elements of the column vectors $\{Y\}$ and $\{X\}$ are given respectively by

$$^{(l)}y_i = V_l \dot{C}_l^{(i)}$$

$$^{(l)}x_j = -S_l \delta_{lj} + Q_{jl}(1-\delta_{lj})$$

where δ_{ij} is the Kronecker delta and the a_{ij} element of the square matrix [A] is given by

$$a_{lj} = C_j^{(i)}$$

Thus, knowing

V_l	volume of zone l
$\dot{C}_l^{(i)}$	time derivative of the concentration of the i tracer in zone l
$C_j^{(i)}$	concentration of tracer i in zone j

the unknown flow quantities,

S_l	total outflow/inflow into zone l
Q_{jl}	flow from zone j to zone l

can be determined for any cell l.

4. RESULTS

Figure 3 shows the N_2O concentration as a function of time in the three zones. Similar results were derived for the other two gases giving in all a total of nine curves. Where appropriate, the outside background concentration levels have been subtracted from the raw data in plotting these results.

In order to determine the values for the interzone airflows, the mathematical procedure described above was used. For each of the nine data plots, a smoothed curve was drawn over a small portion of the experimental points. These smoothed curves were centred at time t=7.5 minutes and were drawn to cover a time range of about 5 minutes. Tangents were drawn at t=7.5 minutes and the gradients determined. Using the values of the gradients and the concentrations at these points, the interzone airflow values were determined. These are shown in Figure 4.a.

It will be noticed that some of the airflows are negative. Since the original definitions of these airflows as derived in Reference 2 preclude any physical meaning for negative interzone airflows, these results indicate that experimental errors, possibly arising from imperfect initial mixing have contributed to these negative values.

To avoid these negative airflow quantities, a method of analysis advocated by Penman and Rashid[3] has been used. Since the airflows are calculated from a set of simultaneous linear equations, the solutions can be constrained in the least-squares sense to have positive values. Using a computer programme given by Lawson and Hanson[4] the constrained solutions have been found and are shown in Figure 4.b.

5. DISCUSSION

To test the validity of these results, a computer programme, utilising the Runge-Kutta-Merson routine from the NAG library[5] was written. Here, knowing the interzone airflow quantities and the initial concentrations, the time histories of tracer concentrations in a multi-zone environment can be predicted.

The positive constrained values for the airflows calculated over the 5 minute period centred at time t=7.5 minutes of the experimental values were used as input to the computer programme. These, together with values of intitial tracer gas concentrations were then used to predict the dispersion of all the tracers in each zone during the 30 minutes period of measurement.

As an example, Figure 3 shows the predicted curves superimposed over the experimental data points obtained for the N_2O tracer. The matching between the experimental values and the predicted curves is seen to be good.

To ensure that no drastic change has occured in constraining the airflows to be positive, predicted curves using the initial solution which included negative values were plotted. These are shown as the full lines in Figure 5. For comparison, the predicted values of Figure 3 (i.e. solutions containing only positive constrained airflows) are drawn as broken lines in Figure 5. The comparison shows that there is only a marginal difference between the two solutions.

With regard to the performance of the building during this present experiment, the following results were obtained.

(a) The total fresh air infiltration rate for the whole building was 0.76 ach.

(b) The fresh air infiltration rate to the first floor zone was only 0.46 ach compared to values of 0.99 and 0.84 ach for the ground floor and stairwell zones respectively.

(c) The dominant route for the zonal interchange of air was from the stairwell to the first floor.

(d) There was negligible direct interchange of air between the ground and first floor zones.

(e) Only 15% of the fresh air entering the ground floor zone took part in any interzone mixing. The remaining 85% of fresh air is dispersed directly back to the outside.

6. CONCLUSIONS

A description has been given here of a multiple tracer gas technique which could be used to determine ventilation rates and air movement in complex, multicelled buildings. As an example of the use of this technique, results have been presented from one set of measurements made in a naturally ventilated office building. Further measurements in a controlled multi cellular test chamber operating under known and set conditions will enable this technique to be fully validated.

ACKNOWLEDGEMENTS

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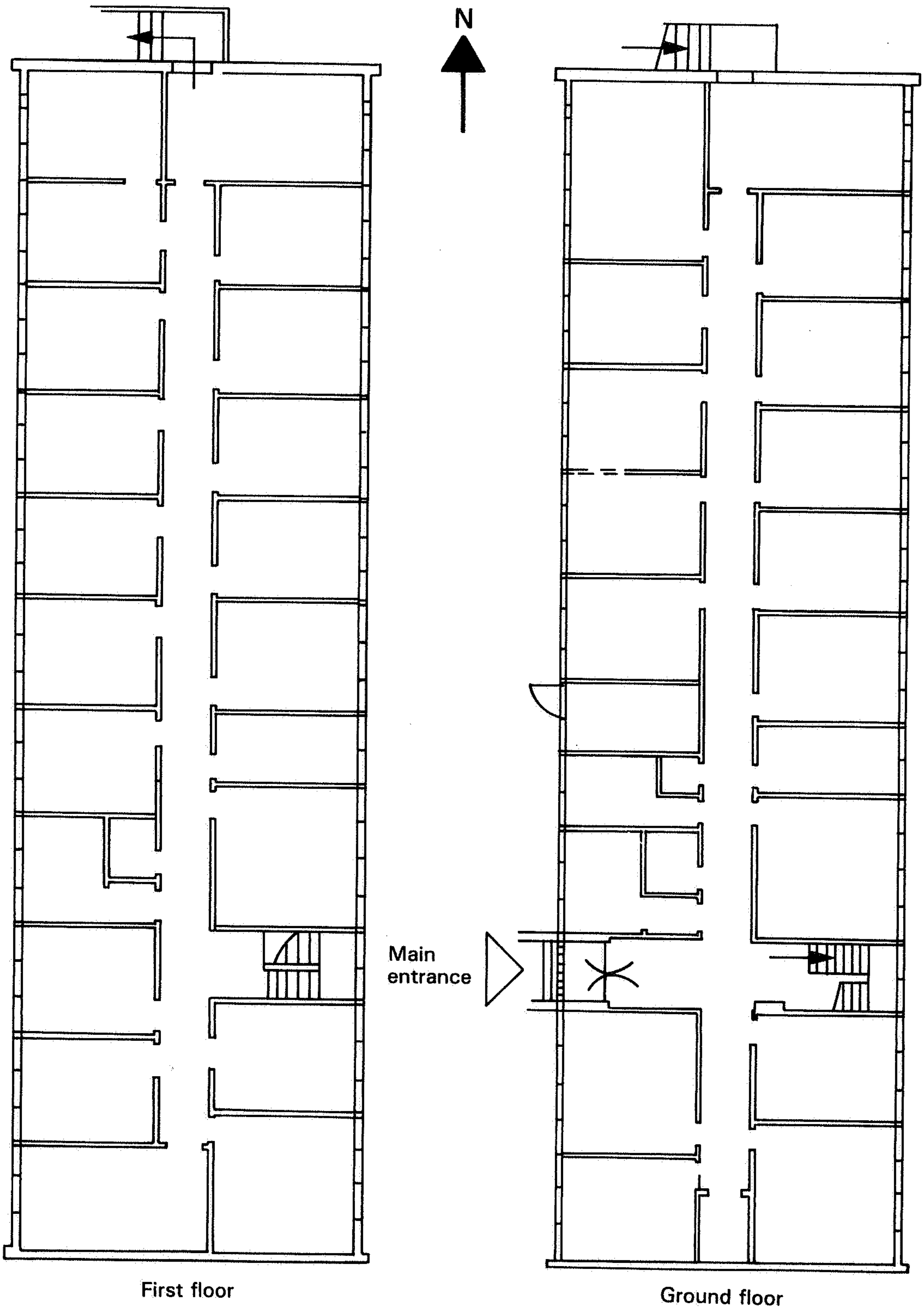

Figure 1 1:200 Plan view of building 10

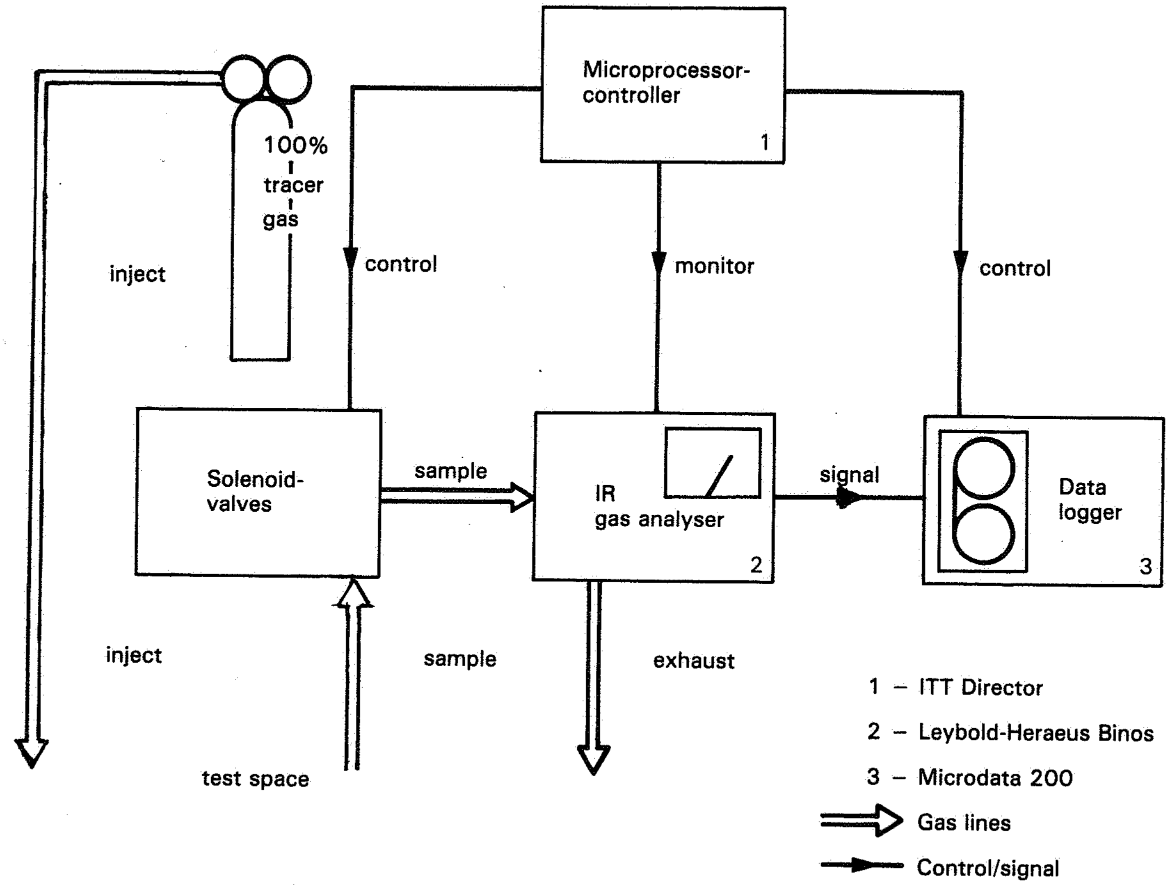

Figure 2 Microprocessor-controlled ventilation rate measuring system (Tracer gas decay)