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MEASUREMENTS OF INTERCELL AIRFLOWS IN LARGE BUILDINGS USING MULTIPLE TRACER GASES

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Summary

This paper presents the results to date of the use of the multiple tracer gas technique to determine interzonal airflow and ventilation rates in large, multicelled buildings like offices. This work is part of a wider project designed to extend knowledge of natural ventilation in all types of buildings other than dwellings.

The work presented here includes, (a) an experiment in a naturally ventilated office building using an automated system connected to infrared analysers dedicated to each of three gases, and (b) results from a similar experiment on a mechanically ventilated office building using a more sophisticated version of the system interfaced to a single multicomponent infrared analyser.

1. INTRODUCTION

A previous report (1) has given indications of energy savings that could result from a detailed knowledge of interzone air movements within large multicelled buildings. Such detailed information would also lead to,

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

(b) determining the effectiveness of remedial measures or indicating zones where selected remedial measures will be cost-effective.

The same report proposed various techniques, ranging from simple 'grab' sampling to complex multiple tracer gas analysis, to determine such airflows. Extensive details about the tracer gases that could be used in such measurements and the underlying theoretical basis for measuring interzone airflows were also given.

This present paper gives details of two field experiments on office buildings using the multiple tracer technique. The first test was carried out in a naturally ventilated two-storey building and the other in a mechanically ventilated three-storey building. This report describes the automated systems used in these measurements, the method of analysis and the results obtained.

2. TESTS IN A NATURALLY VENTILATED OFFICE BUILDING

The experiment was carried out in a conventional, naturally ventilated two-storey office building at the Building Research Station, Garston. The building is rectangular in plan (40 m x 11 m) and each storey is 2.44 m high.

2.1. Experimental details

For the purposes of the experiment, the building was nominally divided into three zones; two of these zones (each with 783 m^3 volume) incorporated the major portions of the ground floor and of the first floor whilst the third zone encompassed a common stairwell region together with the adjacent offices at one end of the building.

Tracer gases were injected manually to reach target concentration in each zone. The ground floor zone was seeded with nitrous oxide and the first floor zone with sulphur hexafluoride to concentrations of about 200 ppm, and the stairwell zone with carbon dioxide to about 2000 ppm. During injection, small desk-top fans were used to mix the tracer gases within the zones.

Air samples were taken from each zone through equal length 6 mm diameter polyethylene tubes. A sample tube was also placed outside the building in order to provide reference ambient concentrations of the test gases. All tubes were then brought together to a central unit where each sampling line was terminated by a three-way solenoid valve. These valves were controlled by an ITT Director microprocessor. This allowed an air sample from each zone to be analysed by all three infrared Leybold-Heraeus gas analysers where each analyser was dedicated to one of the three tracer gases. The concentrations of the gases in each zone were then recorded on cassettes for off-line analysis. Reference 2 gives fuller details of this automated system.

2.2. Results and discussion

Using the mathematical procedure detailed in Reference 1, the interzone airflows were calculated. It was found that some of the airflows were negative. However, the definitions for these preclude any physical meaning for such values. This is a consequence of experimental error which possibly arises from imperfect mixing of the tracer gases in each zone. Solutions can be constrained in the least-squares sense to have positive values only.

The results (2) show that it is possible to determine interzone airflows as well as the fresh air infiltration to each zone. It also shows that the infiltration rates in each zone are not similar to one another. This kind of information could be obtained from single tracer measurements only with great difficulty.

. TESTS IN A MECHANICALLY VENTILATED OFFICE BUILDING

A more powerful and sophisticated automated system was built to replace the prototype system. The new system incorporates a multicomponent infrared gas analyser to replace the individual analysers. The new system also includes a microcomputer to control the sampling sequences as well as in abstracting and archiving the data given out by the analyser. A description of tests carried out in a mechanically ventilated office building using this equipment is given below.

3.1. Office building

The three storey building used in these tests was built as a 'low energy' office and is sited at the Building Research Station. The low energy office building is rectangular in plan (60 m x 12 m) and has its major axis aligned east-west. The floor to ceiling height of each floor is 2.6 m. Offices are located on each floor along either side of a central corridor. The construction of the building and the layout of the mechanical ventilation system allows the building to be 'zoned' in many ways. For the experiment reported here, however, each floor was considered as a separate zone with a volume of 1762 m^3 each.

This low energy office incorporates a number of energy saving features. Among these is a mechanical ventilation system which allows a variable amount of fresh air to be taken into the building. This value can be varied from nominally zero (full recirculation) to full (no recirculation) fresh air intake depending upon the setting of mechanical dampers at its air handling unit. It is set to 30% fresh air (about 1.5 ach) during the heating season. Full details of this building and its energy saving features are given in Reference 3.

3.2. Injection and sampling points

The design of the ventilation system enabled each floor to be individually seeded with a tracer gas. These were injected at various strategic points into the supply side of the mechanical ventilation system through 6 mm diameter polyethylene tubing laid out from a central 'control' room.

Using 10 mm inner diameter polyethylene tubes, air samples were taken from various points along the extract side of the ventilation system. These larger tubes were necessary so as to ensure an adequate volume flow rate to the cell of the infrared analyser. In each zone, all sampling tubes from that zone were brought together to a common junction and manifolded together. A single tube from each junction then carried the blended samples into the automated system for analysis.

3.3. Automated system

The automated system (Figure 1) contains three principal components of which the CBM 4032 microcomputer has overall command of (a) the gas line sampler and, (b) the Miran 980 multicomponent infrared gas analyser.

Of these, the gas line sampler consists of two trays of instrumentation. One tray contains sixteen three-way solenoid valves. Figure 2 is a schematic drawing of the pneumatic connections between these valves. The other tray contains the relay control units required to operate them. The relays are in turn controlled by commands from the microcomputer.

Once the operator has fed in the initial operating conditions, the operating sequence is then entirely under the control of the microcomputer. In any one cycle of operation, this involves the microcomputer in (a) selecting the required zone, (b) directing a fresh sample through into the cell of the Miran analyser, (c) initiating an 'analyse' command to the Miran, (d) storing the data relating to the concentrations of the constituent gases put out by the Miran, and (e) repeating this sequence for other zones and other cycles.

3.4. Experimental details

Tests 13, 14 and 15 presented here were designed, amongst other things, to give an initial appreciation of the performance of the mechanical ventilation system. Of these, Test 13 was carried out with the ventilation system on full recirculation, i.e. nominally zero fresh air intake. Test 14 was then made with no recirculation, i.e. full fresh air intake whilst Test 15 used the 30% fresh air intake usually set for the building during the heating season.

These tests were made with all windows and doors, both internal and external, closed. The building was unoccupied during the tests and the heating was off. The internal temperature during the tests was approximately 23°C. All tests were carried out within a space of few hours thereby excluding to a large degree any effects caused by changes in the weather. Table 1 gives the weather data relating to these tests.

Sulphur hexafluoride (SF6), Freon 114 and Freon 13B1 were used as the tracers and were injected into the ground (G), first (F) and second (S) floor zones respectively to reach target concentrations of about 17, 124 and 53 ppm in each corresponding zone. This combination of gases were choosen because of their small values of cross absorption during infrared analysis. The target concentrations were set by the linearity and the strengths of the signals from the Miran analyser for those concentration ranges. The accuracy of the concentration measurement of any one gas in a mixture was better than 1% of the upper value of its linearised range.

3.5. Results

Figure 3 shows the SF6 tracer gas concentration as a function of time in the three zones for the experiment carried out with full recirculation (Test 13). Similar curves were derived for the remaining tracers and tests.

The interzone airflows and fresh air infiltration rates were derived from these graphs using the mathematical procedure given in Reference 1. Figure 4 is a schematic drawing of the results from Test 13. Unlike the results obtained for the naturally ventilated building (Section 2.2), the calculated zonal airflows were always positive. This is believed to be the result of better mixing of the tracer gases which can be expected with mechanical ventilation.

Table 1 summarises the results obtained. In each zone, the fresh air infiltration rate as well as its total ventilation rate is given. The total ventilation rates are calculated by summing either the inflows or outflows into those zones. The whole building infiltration rate is also given. All values are in airchanges per hour (ach).

3.6. Discussion of results

Interzonal airflow information, as supplied by Figure 4, allows the fresh air contibution to any zone to be separated from the total ventilation rate into that zone or to the building as a whole. The differences between these rates can be seen in Table 1.

For this series of measurements, the results tabulated in Table 1 can be compared with 'design' values (given in the same table). It is seen that there are marked discrepancies between them. One striking feature is the amount of fresh air entering the building when the mechanical ventilation system is on full recirculation (Test 13) when there should nominally be no such inflow. It is believed that this inflow of fresh air is partly due to infiltration through the external fabric of the building and partly through leaks in the mechanical dampers and the ductwork housing the mechanical ventilation plant.

Since the tests reported here are of a preliminary nature, it is too early to comment on these differences or in the way they reflect on the energy performance of the building. Further tests, using information as derived from flow rates such as those in Figure 4, would however enable these differences to be clarified.

4. CONCLUSIONS

Details are presented here of the prototype and 'final' automated sytems designed and built to carry out multiple tracer measurements. Results presented from two field experiments, one in a naturally ventilated and the other in a mechanically ventilated office building, have shown that such systems allow interzonal airflows and ventilation rates in complex, multicelled buildings to be determined.

The complexity of these multiple tracer gas systems precludes them from being used widely. Future field work will therefore be confined to in-depth monitoring of a few selected office buildings. Work will however continue on other techniques (1), such as grab and spot sampling as well as the continuous injection of a tracer gas. This will show how the different techniques interrelate and will enable the most appropriate technique to be choosen for any specific

circumstance.

AKNOWLEDGEMENTS

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TEST CONDITIONS

TEST	MECH. VENT. SETTING	TEMPERATURES deg C Int.	Ext.	WIND SPEED m/s	WIND DIRECTION deg N
13	Full recirculation	23.	19.	0.82	47
14	No recirculation	23.	18.	1.12	85
15	30% 'fresh' air	23.	17.	0.31	43

VENTILATION RATES (ACH)

TEST	GROUND FLOOR		FIRST FLOOR		SECOND FLOOR		WHOLE BUILDING	
	Fresh	Total	Fresh	Total	Fresh	Total	Measured	Design
13	1.05	3.10	1.02	3.38	0.55	3.70	0.87	0.0
14	2.33	3.22	2.00	3.22	1.95	2.64	2.09	4.0
15	1.81	4.57	1.35	3.00	1.15	3.19	1.44	1.5

Table 1. Test conditions and results from the mechanically ventilated office building experiment.

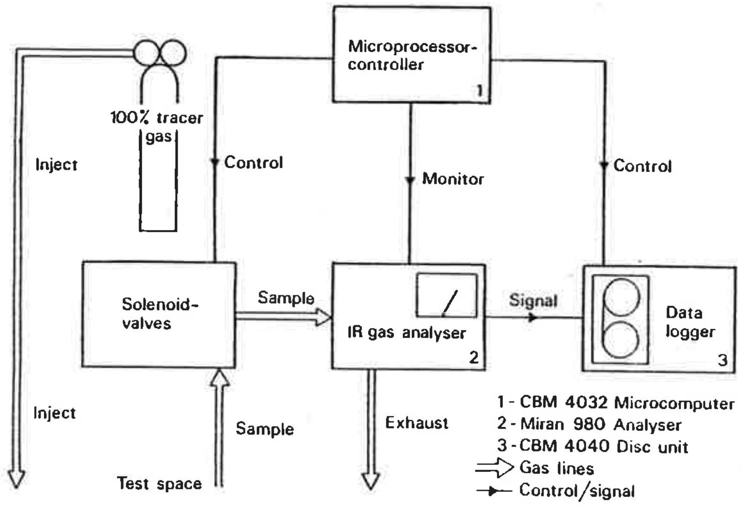

Figure 1 - Schematic of the automated system

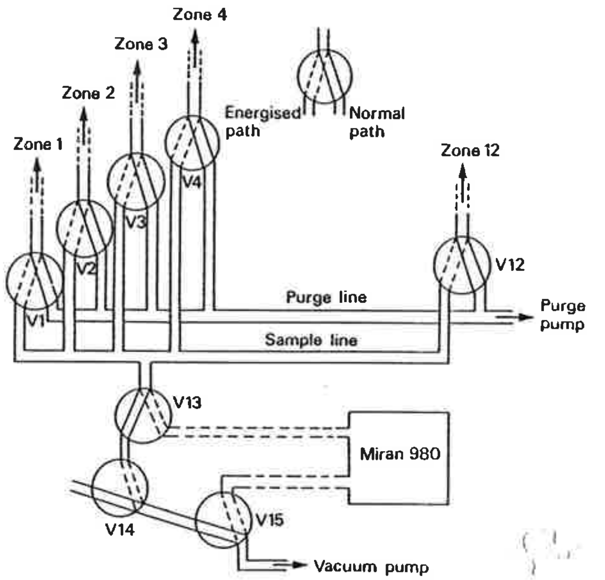

Figure 2 - Pneumatic connections of the solenoid valve unit

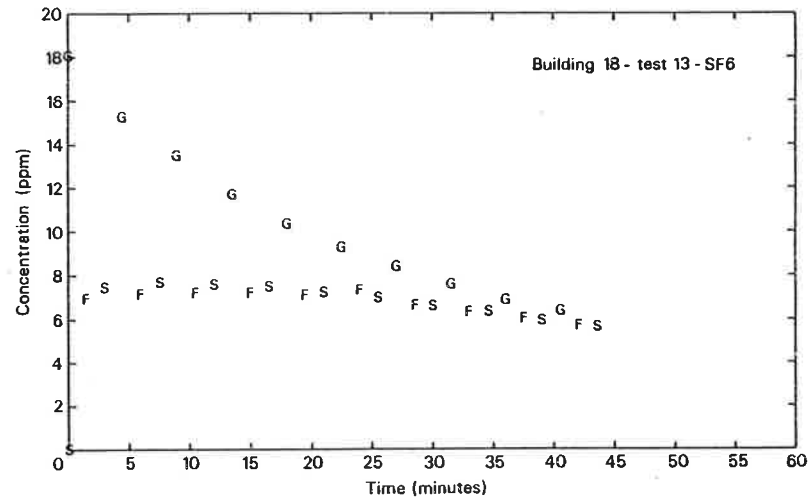

Figure 3 - Sulphur hexafluoride concentrations in all three zones

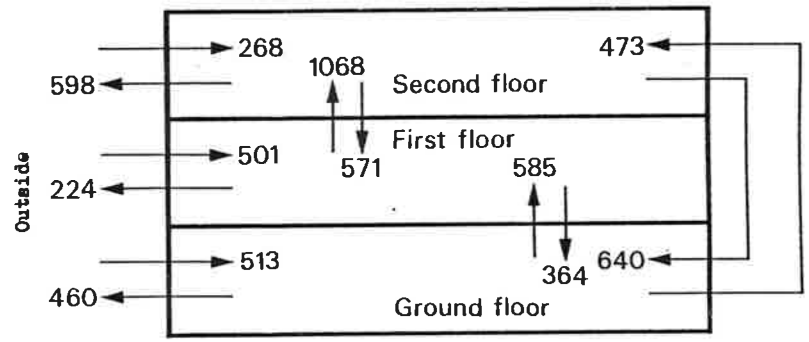

Figure 4 - Interzonal airflows (litres/sec) for Test 13