AIR INFILTRATION REDUCTION IN EXISTING BUILDINGS

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PAPER 5

VENTILATION MEASUREMENTS IN LARGE BUILDINGS

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1. SYNOPSIS

This paper compares and contrasts different methods of ventilation measurement in large buildings. Conventional methods of using tracer gas to measure ventilation rates in large volumes are cumbersome and expensive. These constant concentration and decay ventilation measurements require substantial artificial mixing, complex monitoring equipment, and large installation costs to produce accurate results.

By using discrete injection and sampling units consisting of sealed sample gas bags and peristaltic pumps, long term samples of tracer gas can be collected with the minimum of capital and installation costs. The samples collected represent the mean local equilibrium tracer gas concentrations providing the flow rates of injection and sample pumps remain constant.

The comparison between conventional ventilation measurements and discrete bag sampling is drawn. Hence an assessment of the accuracy of this is obtained when using a constant emmission source of sulphur hexafluoride.

The method was found to be a useful measure of ventilation rate but increasing problems are found with increase of measured volume requiring greater attention to thorough mixing of the atmosphere and injection sample bag positioning.

2. INTRODUCTION

Considerable effort has been focussed on the problems of measuring ventilation in domestic premises (1) and a large degree of success and understanding has been achieved and used by architects and building services engineers to improve the air quality and comfort within dwellings. Ventilation heat losses become a major part of a house's heating load when insulation standards are raised, so it is desirable to keep them to a minimum. However, care must be taken that adequate ventilation is provided for comfortable and hygienic living conditions, and for any combustion appliances requiring fresh air supplies. The problems of ventilation research in large commercial and industrial premises has received much less attention despite early reviews of the subject (2).

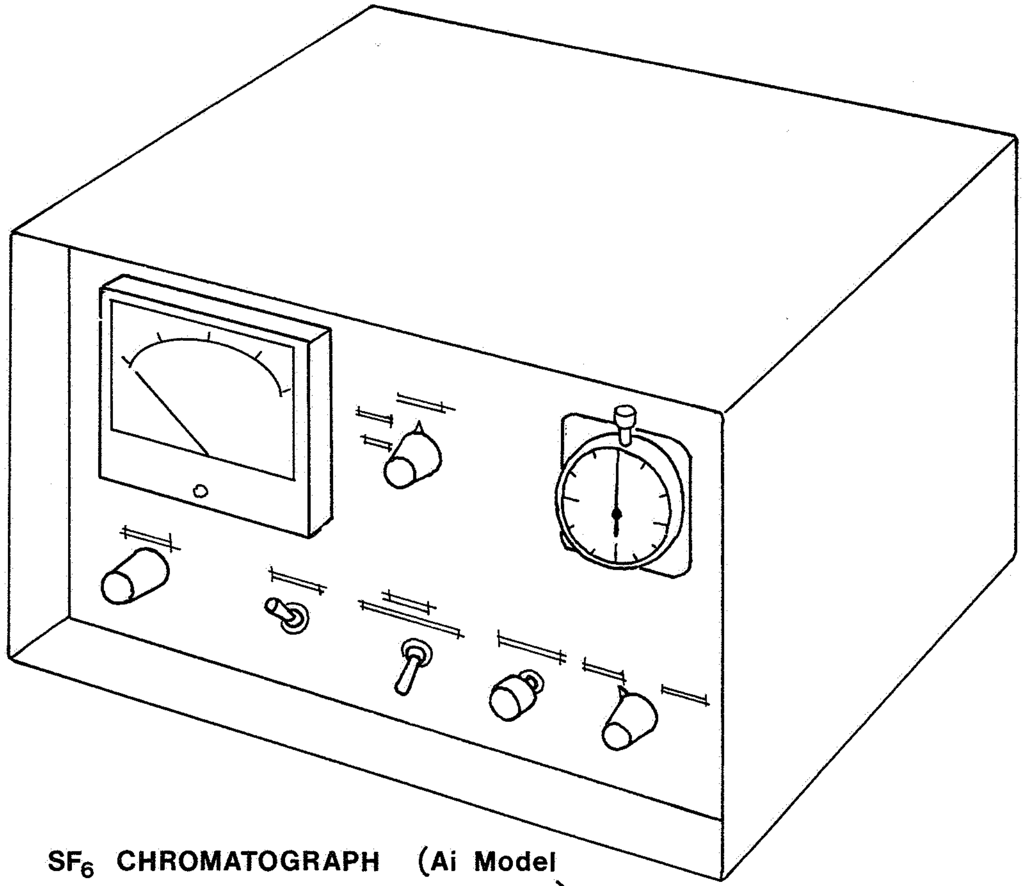
The potential energy savings available from this work are considerable. The large heating bills of factories and commercial complexes may well mean that an individual ventilation survey would be cost effective in terms of subsequent reductions in ventilation heat loss and improvements in air distribution. This is only feasible if simple, inexpensive experimental methods can be devised to provide a suitable level of data capable of indicating where improvements can be made.

In many industrial buildings, undesirable airborne pollutants are released in isolated areas. Knowledge about local ventilation rates and air distribution within the building can help to contain these contaminants and provide for their local extraction, while being able to reduce the overall ventilation rate and still maintain a healthy working environment. This is not unlike the question of air distribution within a dwelling where higher local ventilation rates in kitchens, toilets and bathrooms can lead to both a more healthy environment, and result in energy savings by reducing the necessary ventilation in other parts of the house.

There are two fundamental approaches that can be made to developing ventilation measurements in large buildings. Firstly, the existing experimental equipment developed for domestic ventilation measurements, can be increased in size. It can be adapted to deal with large single cell buildings instead of small, multi-cell buildings. When automated constant concentration techniques are employed, this entails many controlled injection and sample channels, automatically controlled by computer. Mixing must be very carefully performed so that local ventilation rates are measurable without radically altering the airflows in the building. These devices are very expensive to manufacture. Also when a building is measured, many sample and injection lines must be laid requiring much time and labour.

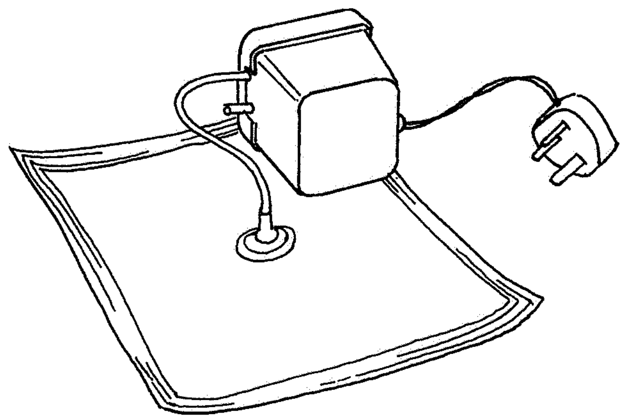
Alternatively, simplified methods of measuring ventilation can be developed which require less capital outlay, and are easy to transport and install. The disadvantages of simplified methods such as taking tracer gas samples in bags are in the limited amount of information obtained and the fact that analysis and data collection cannot easily be automated. These limitations may not be important as analysis is easy and rapid. The information gathered may well also be comparable with automated constant concentration techniques if a few instantaneous samples can be taken to investigate how the ventilation rate in a specific area varies from the mean, under differing weather conditions and ventilation opening configurations.

Figure 1 EQUIPMENT USED: SF_6 CHROMATOGRAPH AND INJECTION/SAMPLE PUMP & GAS BAG



SF_6 CHROMATOGRAPH (Ai Model 505)

PERISTALTIC PUMP



GAS BAG

3. EXPERIMENTAL PRINCIPLES

The experimental method investigated involves injecting a continuous flow of sulphur hexafluoride into the room being measured. The gas is metered by a peristaltic pump and is supplied from a gas bag (FIG. 1, PAGE 4). The speed of the pump can be altered, as can the diameter of the peristaltic tubing. This results in a large variety of flow rates being available, typically from 6cc/hr to 1 l/hr. A small fan is used to provide initial mixing, thus ensuring no layering of the tracer gas due to density differences. Gas samples are taken from the atmosphere with similar peristaltic pumps, collecting a sample in the attached gas bags.

These must be positioned so that the samples are collected only when the tracer gas is well mixed with the air. No representative samples can therefore be taken from the immediate vicinity of the injection point. The variation in flow rate available with the pumps enables collection of adequate samples over time intervals of 1/2 hr to 14 days. Instantaneous samples are easily obtainable by manually pumping air into a collection bag. Many samples are taken at different heights and positions in the room being measured. Typically, 12 samples points are used simultaneously.

Analysis is performed with an Analytical Instruments SF_6 detector/chromatograph. Typical equilibrium concentrations used in sampling are 10^{-2}ppm. The chromatograph has a useful measuring range of 10^{-4} to $5x10^{-2}$ppm.

By the use of gas bags to contain injection tracer gas, long term tests can be performed without the need to use large, hard to transport, gas cylinders and the risk of high pressure leaks.

4. EXPERIMENTAL DEVELOPMENT

Our aim in developing this method was to test it in increasingly difficult circumstances, gradually increasing the volumes of the test rooms. At each stage we compared the bag sampling method with constant concentration and decay measurements.

Initial tests were performed in a domestic dwelling, using a naturally ventilated room of $33m^3$ volume. A single injection point of 6.3cc/hr 10% sulphur hexafluoride was used in conjunction with three sampling positions, as shown in figure 2, page 7. Some variation in concentrations was noted in different parts of the room, depending on the amount of ventilation and mixing used. Simultaneous measurements of nitrous oxide and tracer gas decay rates were performed once equilibrium sulphur hexafluoride concentrations had been reached.

An increase in volume to a $100m^3$ room with a 2.5m ceiling height produced repeatable results of good correlation between equilibrium bag sample (with 31cc/hr pure SF_6 injection) and nitrous oxide decay measurements. The room was ventilated mechanically with six ceiling mounted supply terminals, and two ceiling mounted extract terminals (Fig. 3, page 7). Consistently low equilibrium concentrations at ceiling level demonstrated a considerable amount of short-circuiting between intake and exhaust terminals.

A laboratory of $650m^3$ with a ceiling height of 6m was the subject to much experimentation with injection and sampling configurations. New bag sampling experiments were continuously compared with conventional decay and constant concentration methods. For these experiments, an autovent apparatus was used. It has 12 computer controlled injection and sample ports, each pair of which was associated with a volume of approximately $50m^3$ within the laboratory (Fig. 4, page 8). The injection rate of sulphur hexafluoride for equilibrium experiments was 73cc/hr pure sulphur hexafluoride.

Figure 2 SEGAS TEST HOUSE—BEDROOM 3

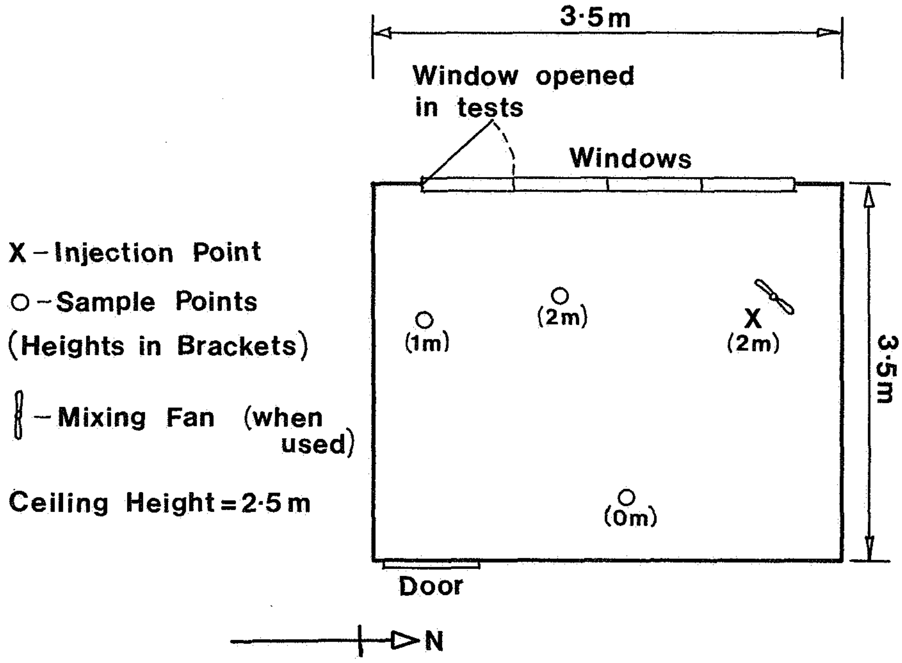


Figure 3 GUILDFORD UNIVERSITY METALLOGRAPHY LABORATORY
(NO EXTERNAL WALLS)

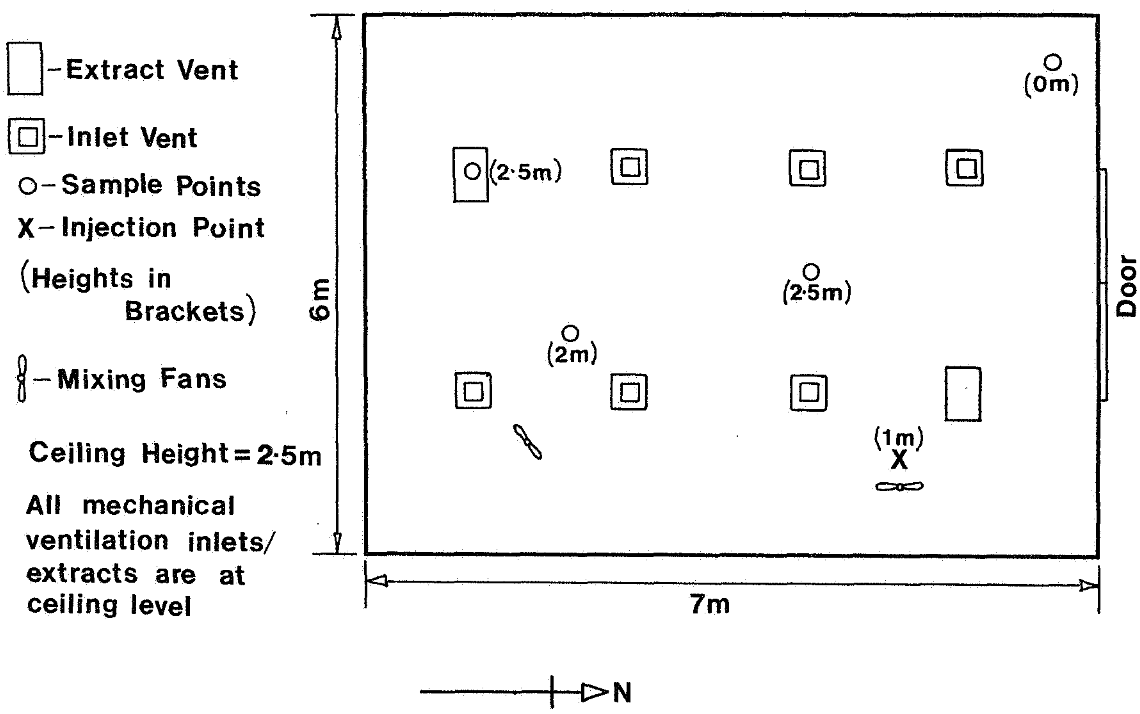
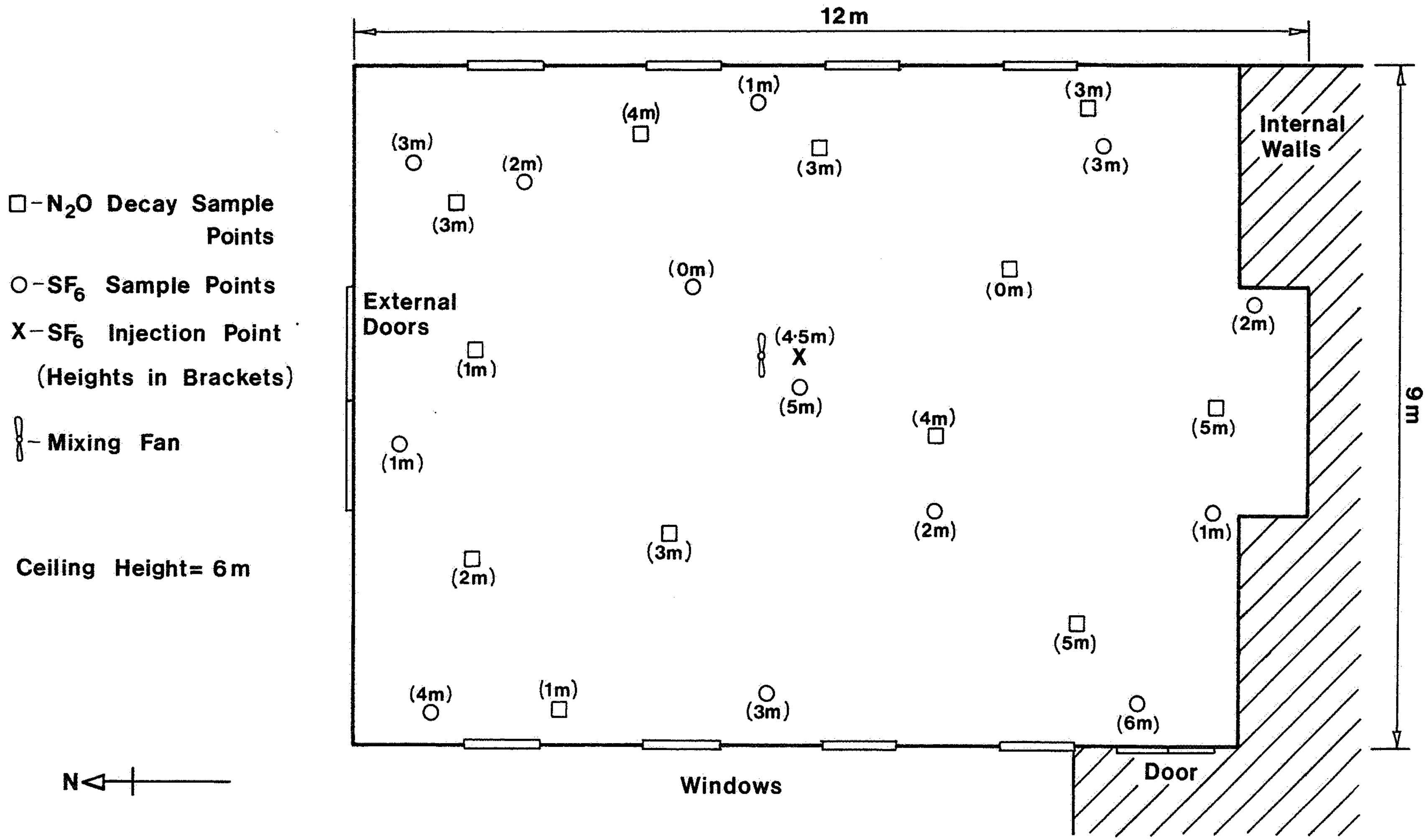


Figure 4 SEGAS CENTRAL LABORATORIES; AERODYNAMICS LABORATORY



5. PRELIMINARY RESULTS

5.1 Segas Test House, Central laboratories, Bedroom 3,33m^3 (Fig.2, page 7)

(Fig.2, page 7)

(Natural Ventilation; windspeed, ms^{-1}, wind direction)

SAMPLE POSITION	SF_6 EQUILIBRIUM CONCENTRATION (PPM)	EQUILIBRIUM VENTILATION RATE (ac/hr)	N_2O DECAY VENTILATION RATE (ac/hr)
a) FAN MIXING			
1)	4.5×10^{-2}	0.42	0.35
2)	4.5×10^{-2}	0.42	0.42
3)	4.8×10^{-2}	0.40	-
b) NO MIXING			
1) (WINDOW "A" OPEN)	9.2×10^{3}	2.1	4.6
2) (WINDOW "A" OPEN)	6.0×10^{-3}	3.2	4.8
3) (WINDOW "A" OPEN)	6.5×10^{-3}	2.9	-

Injection Flow Rate 6.3cc/hr 10% SF_6.

5.2 Guildford University Laboratory, $100m^3$ (Fig.3, page 7)

(Mechanical Ventilation System + 2 mixing fans)

SAMPLE POSITION	SF_6 EQUILIBRIUM CONCENTRATION (ppm)	EQUILIBRIUM VENTILATION RATE (ac/hr)	N_2O DECAY VENTILATION RATE (ac/hr)
1) UNDER SINK	$4.8x10^{-2}$	6.5	6
2) AT CEILING	$2.9x10^{-2}$	11	7
3) HEAD HEIGHT, MID ROOM	$4.1x10^{-2}$	7.5	7.5
4) AT EXTRACT TERMINAL	$4.2x10^{-2}$	7.5	8

Injection Flow Rate 31cc/hr SF_6

5.3 Segas Central Laboratories: Aerodynamics Laboratory, $650m^3$,(Fig.4, page 8)

(Natural ventilation; windows open; wind speed, ms^{-1}, wind direction; single for mixing).

SAMPLE POSITION	SF_6 EQUILIBRIUM CONCENTRATION (ppm)	EQUILIBRIUM VENTILATION RATE (ac/hr)	N_2O DECAY VENTILATION RATE (ac/hr)
9) (MINIMUM N_2O DECAY)	$1x10^{-2}$	11.2	11.6
4) (MINIMUM SF_6 CONCENTRATION)	$0.85x10^{-2}$	13.2	12.2
12) (MAXIMUM N^2O DECAY)	$1x10^{-2}$	11.2	14.2
1) (MAXIMUM SF^6 CONCENTRATION	$1.55x10^{-2}$	7.2	13.2
MEAN		10.1 (13 SAMPLES)	12.8 (12 SAMPLES)

Injection Flow Rate 73cc/hr

6. DISCUSSION

The bag sampling equilibrium method seems to work fairly well when compared to standard methods. Agreement between equilibrium and decay results is good under conditions of thorough mixing.

In both experiments A) and C), equilibrium ventilation results are less in agreement with decay results than in experiment B), in which there is a high degree of mixing. The only result in experiment B) which does not closely agree is position 2), at the ceiling. This is because of ventilation short-circuiting between inlet and exhaust mechanical ventilation terminals situated on the ceiling. This implies that the equilibrium method used is more sensitive to local high ventilation rates than standard decay methods.

Many practical problems have been encountered in attempts to increase the accuracy of the bag sampling method in the $650m^2$ building. Problems have also been encountered in measuring local ventilation rates with "autovent" apparatus in order to verify the bag sampling experiments.

By providing good initial mixing for tracer gas decay experiments and allowing induced air movement to subside before sampling the tracer gas at many points simultaneously (see Fig. 4), a useful representation of local ventilation rates can be obtained. Figure 5, page 12, shows such local ventilation measurements in the Segas Aerodynamics Laboratory in an easterly wind of $4ms^{-1}$. Figure 6, page 12, shows the influence of an operational conventional flue in the laboratory in a $2ms^{-1}$, westerly wind. The highest ventilation rate measurement in the vicinity of the flue indicates that inadequate mixing is occurring, as there is no source of fresh air by the flue entrance at ground level. Both these results show that the NE corner of the laboratory is not well sealed. In figure 5, the higher ventilation rate in an easterly wind indicates more air is entering there. In figure 6, the lower ventilation rate in a westerly wind indicates more air is leaving the laboratory by that corner.

Constant concentration experiments using various mixing methods produced overall ventilation results which agreed closely with the overall decay results, but local ventilation results were affected seriously by "pockets" of high concentration of inadequately mixed tracer gas drifting around the building. This made the computer control of the concentration locally unreliable, and no satisfactory method of overcoming this problem has been found.

Figure 5 SEGAS CENTRAL LABORATORIES; AERODYNAMICS LABORATORY
N_2O DECAY DISTRIBUTION RESULTS; EAST WIND, $4 ms^{-1}$.

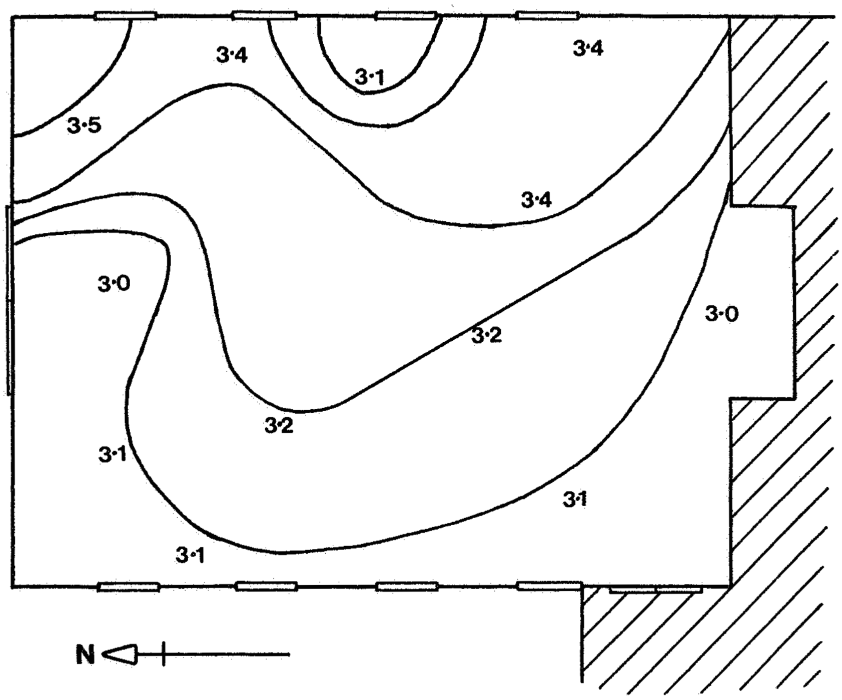
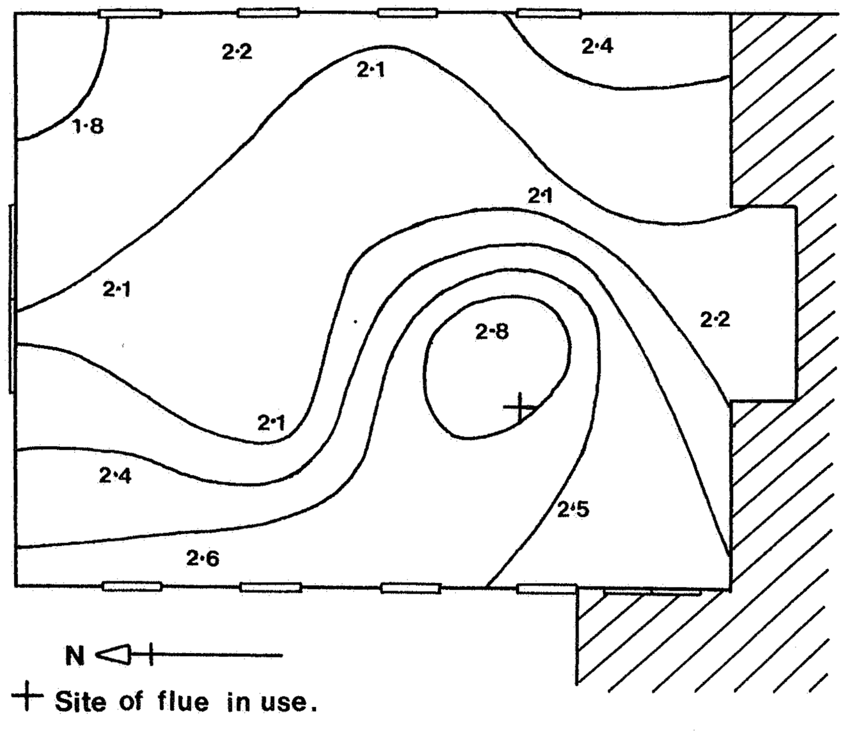


Figure 6 SEGAS CENTRAL LABORATORIES; AERODYNAMICS LABORATORY
N_2O DECAY DISTRIBUTION RESULTS; WEST WIND, $2 ms^{-1}$.



The largest problem encountered with bag sampling methods again was mixing. It is easy to provide a large amount of mixing which destroys the natural air patterns in the building and produces an even concentration of tracer gas throughout all of the sample bags, but this gives no idea of local ventilation rates. When mixing is reduced to a very low level, concentrations vary hugely within the building. The most effective method found so far has been a single small mixing fan at the injection point to ensure sufficient tracer gas mixing such that the sulphur hexafluoride is not subject to settling towards the floor of the building because of its high molecular weight. A high injection point in the centre of the building with the fan pointing down will ensure adequate mixing without the internal stack effect of the building keeping most of the tracer gas at high level. A low injection point with a horizontally orientated mixing fan also produces reasonable mixing, but is more likely to influence local equilibrium tracer gas concentrations at the edges of the building. It may also be susceptible to stack effects resulting in low tracer gas concentrations close to the injection point.

When sampling these low tracer gas concentrations (1×10^{-2}ppm) adsorption of the gas into internal surfaces of the peristaltic pump and gas bag is possible. This was checked by comparing new bags and pumps with sample collectors that had been in use for two months, measuring consistent concentrations of tracer gas. The new sample bags were found to give consistently lower readings of between 1 & 5% at sample sulphur hexafluoride concentration of 0.02ppm. The surfaces in contact with the sample are about 20cm^2 silicone rubber tubing in the peristaltic pump and 600cm^2 of aluminised gas sample bag.

After about two weeks of continuous running, a crystalline deposit forms in the tubing of the peristaltic pump. This deposit restricts the flow rate of the pump, but does not appear to affect the concentration of the sample taken. Initially, it was thought it could be a product of decomposition of the tubing on contact with sulphur hexafluoride. However, these deposits build up to the same extent in bags injecting pure sulphur hexafluoride, and sample bags sampling 0.02ppm sulphur hexafluoride. It would therefore appear that these deposits are a product of mechanical breakdown of the tubing, which would normally be used for pumping liquids, and therefore have a means of internal lubrication.

The manufacturers have been approached to see if alternative tubing can be provided which is not subject to such serious mechanical degradation when used "dry".

Without thorough mixing, ventilation measurements are very susceptible to short circuiting. i.e. Air entering the building and thus contributing to the ventilation rate may have a short residence time, and not reach a doped tracer gas concentration equivalent to the theoretical figure, which should be closely attainable with good mixing.

This results in a higher equilibrium concentration in other areas of the building. It is this short circuiting, or local high ventilation rate which it is desirable to detect. Mixing destroys this effect, but gives a reasonably accurate mean. Detection can only take place with a large number of sample points. This will result in the interception of these high local ventilation airstreams, and give a representation of the airflows involved.

Satisfactory measurements have now been made in a 650m^3 building with a 6m ceiling, and we are confident that this method can usefully be applied to larger buildings.

FUTURE WORK

It would be ideal to rely upon diffusion to carry the tracer gas to different parts of the building, therefore not relying on mixing fans which inherently destroy the characteristics it is desirable to investigate.

In such an ideal situation, air currents would cause deviations from a symmetrical distribution of tracer gas concentrations and this could be used to lend interpretation as to whether a local area was a cource of fresh air, or an extract of used air.

It may be possible to approach this ideal situation with many injection points of lower concentration tracer gas, relying on diffusion only on a small scale, and identifying important air currents individually. For example, injecting tracer gas into identified fresh air streams may prove a useful technique, although susceptible to changing weather conditions.

Here, there is also scope for use of multiple tracer gases to indentify the exchange of air between different part of the building, or for "labelling" of particular fresh air streams and their subsequent distribution.

REFERENCES

1) See for example proceeding of 1st, 2nd and 3rd, AIC Conferences 1980, 81, 82.

2) JACKMAN, P.J. - "Astudy of the natural ventilation of tall office buildings" JIHVE August 1970,38,103-118.