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The Reduction of Air Infiltration in an Industrial Laboratory

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1. Abstract

As part of a programme to develop measurement methods for determining the ventilation rates of large buildings, we performed two series of tests in a single-celled laboratory with a volume of $600m^3$. The first series utilised constant concentration, constant emission and rate of decay tracer gas techniques to determine the characteristics of the infiltration pattern in varying winds and external temperatures. We used both discrete and continuous injection and sampling methods. Pressurisation techniques were employed to determine the overall leakage of the building and the spatial distribution of the leaks with flow visualisation methods. The building was then draught proofed with commonly available materials and techniques before further pressurisation tests and thorough ventilation measurements were undertaken.

The experiment thus provided detailed comparisons of ventilation measurement methods and detailed performance characteristics of the building envelope in two states of leakiness.

The interaction between the changed leakage characteristics and the measurement methods is discussed together with a critical evaluation of the measurement methods themselves.

2. Synopsis

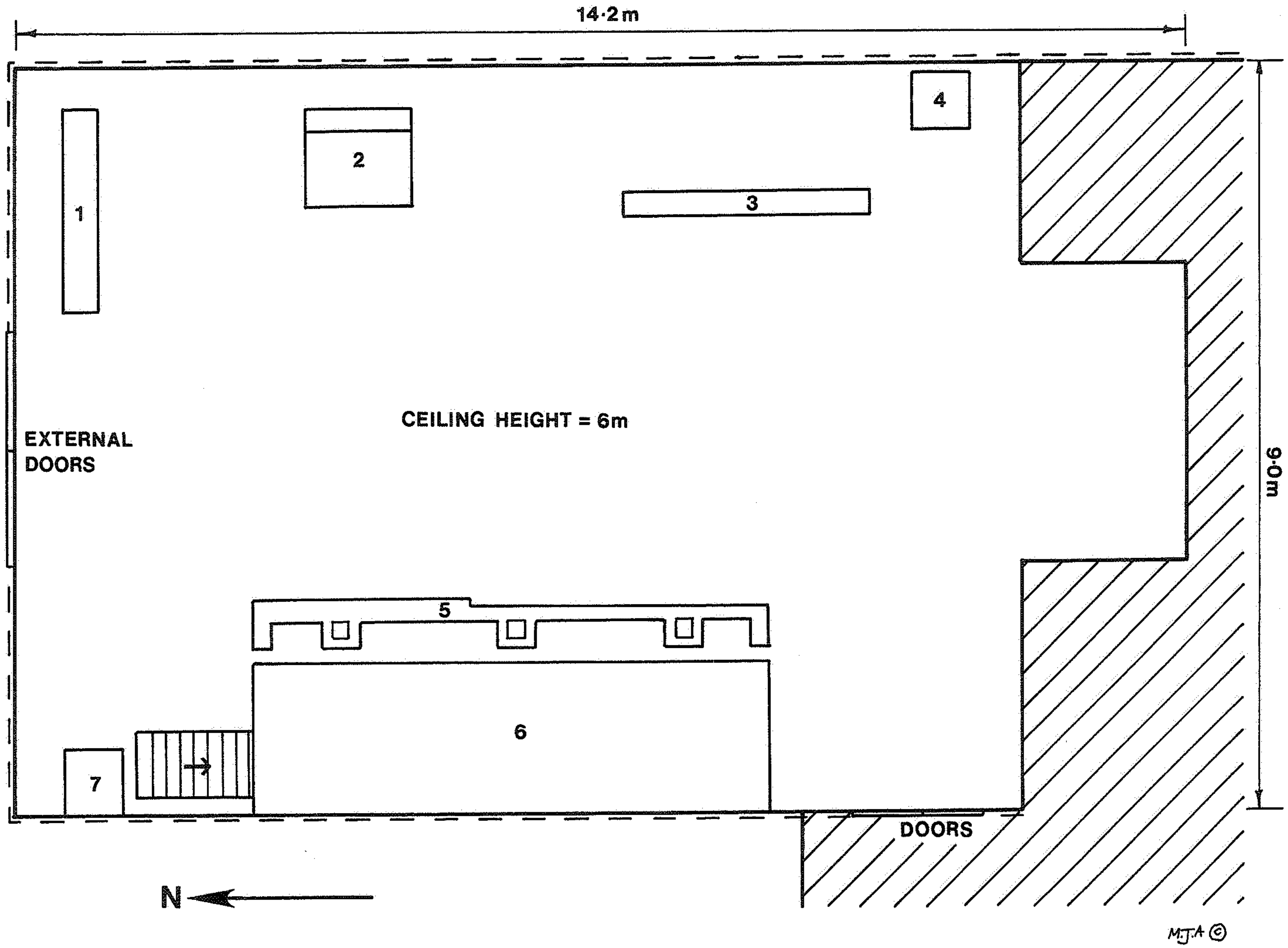
The current trend for the reduction of air infiltration in buildings must necessarily have an impact on the internal environment. If the internal environment is to be controlled to maintain a good standard of air quality, the reduction of air infiltration must also be controlled, particularly if supplementary fanned ventilation systems are not included in changes of design.

When considering the varying need for ventilation within a building, a minimum uniform ventilation rate may not be the most efficient alternative, especially if there are small areas which require high localised ventilation. When seeking to determine infiltration rates throughout a building, the interaction between the ventilation measurement techniques used and the ventilation characteristics must not be ignored. The errors in different infiltration measurement techniques (SANDBERG[1]) vary depending on the type of building considered. This is largely dependent on the individual nature of infiltration and mixing, which will change with building type, experimental technique, weather conditions, and that most fickle of variables, human behaviour.

In the practical application of the measurement of infiltration there are two important links which need to be rationalised:

a) The relationship between complex research techniques (which have by no means mastered the art of accurate infiltration measurement) and easily executed practical measurements. This link can be typified by the desire to obtain adequate information from building envelope pressurisation tests regarding infiltration characteristics which cannot yet be easily measured by direct infiltration measurement,

Figure 1 INDUSTRIAL LABORATORY-SEGAS CENTRAL LABORATORIES



1 SE-DUCT TEST RIG
2 BLOCK FLUE TEST RIG
3 TIMBER FRAME TEST WALL
4 HEATER FAN
5 TEST CHIMNEYS
6 GANTRY
7 SEALED HEATER

— — — WINDOWS (Forming Upper Half of Walls) and b) the relationship between the real infiltration and airflow patterns within a building, and the disturbing influence of techniques used to measure these characteristics.

The experiments described attempt to try and link some of these factors, and starts to look at the influence that they have on one another. In particular the limits of application of existing decay measurements are considered, by comparing the nature of concentration decay results in different building constructions.

3. Methodology

An industrial laboratory at Segas Central Laboratories has been used frequently to test and develop ventilation measurement techiques (see Figure 1). Consequently, a great deal of information has been collected about the ventilation characteristics of the building, including the distribution of "leaky" and "tight" areas around the perimeter of its $600m^3$ volume. The main methods used have been 12 channel constant concentration, 12 channel decay, and various multichannel constant emission techniques including continuous instantaneous and discrete bag sampling methods (FREEMAN et al[2]) detailed analysis of the building's response to wind speed, direction, and stack was collected, along with many indications of primary infiltration sites and flow paths within the building. The variation in concentration of tracer gas in decay tests confirmed bulk air movement trends, and the finer constant emission methods identified specific areas of high infiltration (FREEMAN et al[3]).

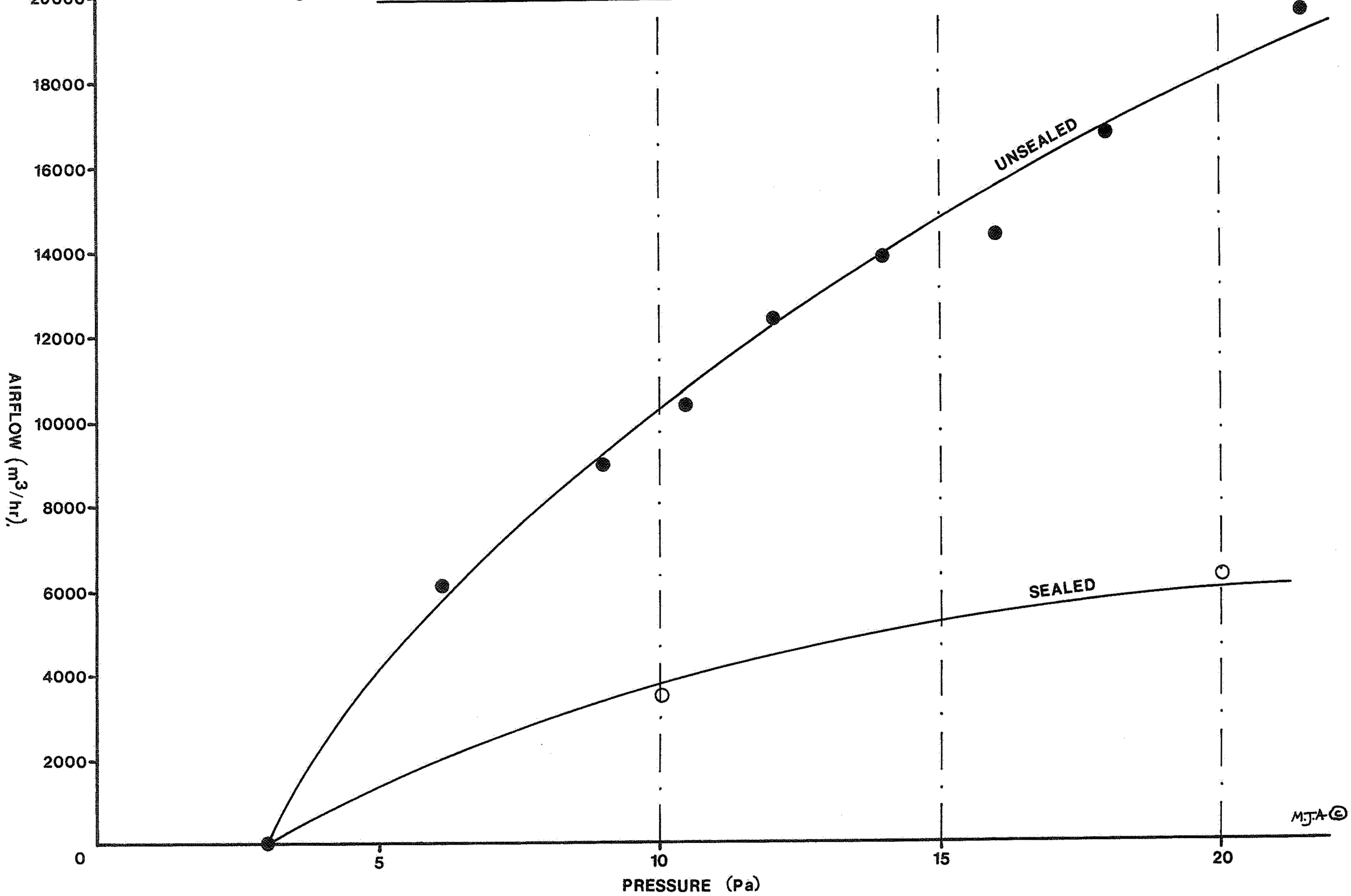
A depressurisation test of this relatively leaky building was then performed by connecting the outlet of a wind tunnel to the outside of the building, using a fabricated nylon tube connected to a false door. All the conventional leakage points were sealed including leakage through a partition wall and electrical ducting to an adjoining laboratory, doors and many disused flue vents in the roof. The largest single contribution to the leakage was through the cavity between the breeze block and metal clad wall, which had a loose fitting metal cover on. No draught proofing of the windows was performed as they were of a well-fitting metal construction. The depressurisation of the building (AL-NASSER[4]) could then be taken to -30Pa with respect to ambient, at a much reduced flow rate. (The extent of depressurisation was limited by the equipment used).

During the next heating season, further extensive ventilation measurements were performed, mainly using simple decay techniques, with a variety of injection and mixing methods.

By using this series of tests the relevance of different measurement techniques capturing different types of ventilation data could be determined, along with an understanding of the interaction of different techniques with the building's ventilation characteristics.

All the data, apart from the manually analysed constant emission bag samples, were collected and summarised by the 12 channel sampling Segas Autovent (a computer controlled integrated data logger and control system).

Figure 2 BUILDING DEPRESSURISATION CURVES BEFORE & AFTER SEALING



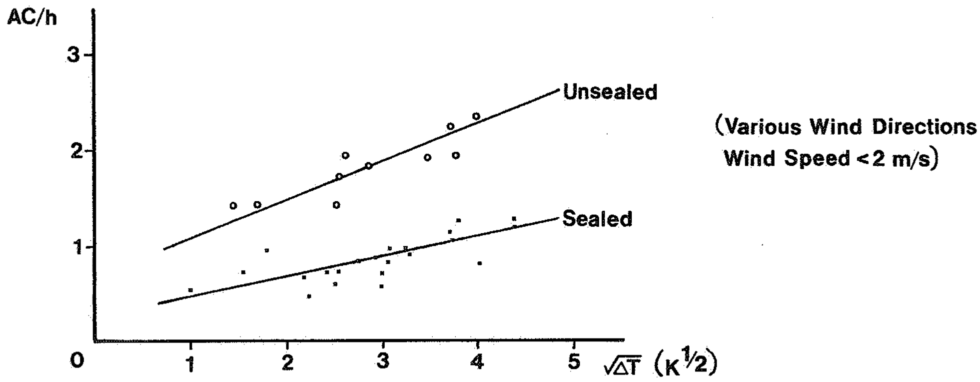
4. Results

4.1 Airchange Rates

The change in leakage flow/pressure charactertistics are shown in Figure 2. The flow rate reduction after sealing the building was consistent at 2.8 (± 0.08):1 at -10, -15 and -20Pa pressure differential.

Figure 3, below, shows the reduction in sensitivity of the building to temperature differential induced ventilation. This shows an approximate 2:1 reduction in ventilation rate after sealing.

Figure 3 REDUCTION IN BUILDING SENSITIVITY TO TEMPERATURE DIFFERENCE INDUCED VENTILATION RATE

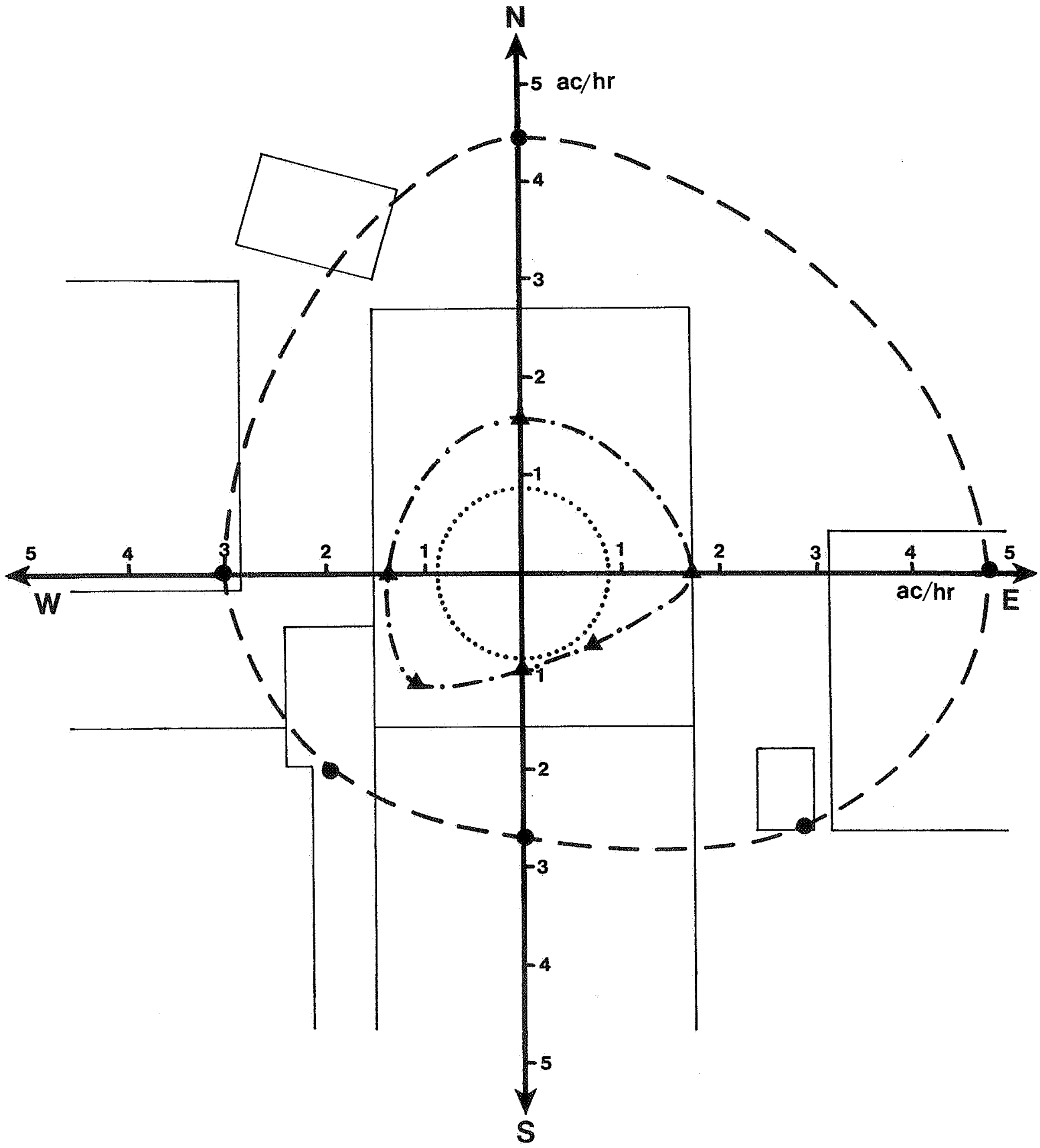


The sensitivity of the building to wind speed was also very much reduced, as was the sensitivity to wind speed on exposed or particularly leaky faces of the building. The polar diagram in Figure 4 shows the reduction in air infiltration at a wind speed of $3.5 ms^{-1}$ with respect to wind direction. The ratios expressed in the figure show the reduction in infiltration that sealing effected for that particular wind direction. This ranges from 3.8:1 for south easterly winds' glancing impingement on the eastern face of the building (the southerly face being sheltered by an adjoining laboratory) to 1.8:1 south westerly winds, which are likely to be very turbulent as a result of the complex array of buildings to the windward of the laboratory.

4.2 Leakage Distribution

In the first set of ventilation measurements, concentration decay tests showed a distinct gradient across the laboratory with easterly and westerly wind directions. Areas of high infiltration could be determined by observing the sample points of lower concentration. These tests showed particularly high localised infiltration from the doors in the north wall, and the north-eastern corner of the laboratory in easterly and northerly winds. These results were endorsed by bag sample constant emission tests (FREEMAN et al[3]) and 12 point injection constant emission tests (FREEMAN et al[2]) which could identify these sites as points of predominant

Figure 4 POLAR DIAGRAM DEPICTING BUILDING SENSITIVITY TO WIND DIRECTION BEFORE & AFTER SEALING



— — — Before Sealing, 3·5 m/s, $\sqrt{\Delta T} = 3K^{1/2}$

— · — · — After Sealing, 3·5 m/s, $\sqrt{\Delta T} = 3K^{1/2}$

·············· Stack Effect, $\sqrt{\Delta T} = 3K^{1/2}$

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exfiltration, (along with the roof) in westerly winds. When performing these tests, no mixing was employed apart from a small central fan in the constant emission The most effective method of injecting tracer gas into this intermediate sized volume without affecting the natural air flow paths was by bursting balloons full of the appropriate tracer gas (SANDBERG[7]).

When the pressurisation tests were performed, smoke tests showed that most the leakage was at a relatively high level. The only low level leakage was observed from the doors and a water drain in the laboratory floor. Leakage was concentrated high in the building around the top of the cavity between the metal cladding and breeze block wall, and from many cracks and holes in the roof around flue terminations and the loft hatch. The windows were well fitting metal windows which did not notably contribute to the leakage under depressurisation.

After sealing, the leakage distribution over the building envelope was very much more even, with no particularly dominant leakage sites.

4.3 Ventilation Measurements

Before the sealing of the laboratory was performed, decay, constant concentration and constant emission tests all indicated the spatial distribution of predominant leakage sites and as such the individual sample points had a wide range of standard deviation of the location ventilation rate from the mean. Using concentration decay tests from a constant concentration throughout the laboratory results similar, though less marked, were obtained to such tests performed previously in multi-roomed domestic dwellings (ETHERIDGE et al[5]). There, the localised ventilation rate is described in terms of the area underneath the decay curve. When larger, single-celled buildings are considered, there is a smaller variation in these areas, as would be expected, but the variations in wind speed and direction have a greater influence on different air paths within the volume, much increasing the errors involved in measuring the local infiltration rate. (A comparison of areas under decay curves for different building types is shown in Table 1). These errors reduce with the size of the building, and recent tests in a very leaky 10,000m^3 warehouse (ATKINSON[6]) clearly show the leakiest parts of the building dominating its ventilation charateristics. The most difficult task in doing measurements in this type of building is obtaining adequate mixing of the tracer gas on injection. Even the rapid evacuation of cylinders of tracer gas (DEWSBURY[8]) does not always produce a good initial distribution of tracer gas in these circumstances.

When the laboratory was sealed, the areas of predominant infiltration/exfiltration were removed, and the non wind induced mixing eddies within the building became much more dominant. The effect of this was to produce much more even and

TABLE 1

COMPARISON OF VARIATION OF AREAS UNDER DECAY CURVES FROM CONSTANT CONCENTRATION FOR FOUR BUILDINGS

2 STOREY TERRACED HOUSE (REFERENCE 5)(DOORS CLOSED)			UNSEALED SEGAS LABORATORY ($600m^3$)			SEALED SEGAS LABORATORY ($600m^3$)			LEAKY WAREHOUSE($10,000m^3$) (REFERENCE 6)		
ROOM	LOCAL DECAY RATE (ac/hr)	RELATIVE AREA UNDER DECAY CURVE (LOUNGE=1)	SAMPLE POINT	LOCAL DECAY RATE (ac/hr)	RELATIVE AREA UNDER DECAY CURVE (SAMPLE 10=1)	SAMPLE POINT	LOCAL DECAY RATE (ac/hr)	RELATIVE AREA UNDER DECAY CURVE (SAMPLE 1=1)	SAMPLE POINT	LOCAL DECAY RATE	RELATIVE AREA UNDER DECAY CURVE (SAMPLE 5=1)
LOUNGE	0.13	1	1	0.92	0.86	1	0.81	1	1	1.15	0.56
HALL	0.52	0.23	2	0.98	0.85	2	0.81	0.99	2	1.06	0.65
KITCHEN	0.31	0.43	4	0.91	0.92	3	0.87	0.99	4	0.92	0.91
BED 1	0.33	0.41	5	0.89	0.92	4	0.80	0.99	5	1.01	1
									6	1.44	0.96
BED 2	0.22	0.62	6	0.91	0.98	5	0.83	0.98			
BED 3	0.18	0.74	7	0.90	0.93	6	0.84	0.98			
LANDING	0.34	0.39	8	0.99	0.88	7	0.84	0.97			
TOILET	0.26	0.52	9	1.05	0.90	8	0.77	0.98			
BATH	0.27	0.52	10	0.89	1	9	0.97	0.98			
			11	0.96	0.93	10	0.80	0.97			
						11	0.82	0.97			
						12	0.83	0.97			
MEAN	0.28	0.54	MEAN	0.95	0.92	MEAN	0.83	0.98	MEAN	1.12	0.81
S.D.		0.225	S.D.		0.05	S.D.		0.01	S.D.		0.20

consistent local concentration decay curves and constant emission sample concentrations, and should produce better control in unmixed constant concentration experiments. Particular areas of infiltration were not identified, but the roof/window area was still identified as the main exfiltration area, due to the fact that concentration variations in all the tests reduced at high level, showing this area to contain tracer gas with the highest residence time in the building.

When decay tests were carried out after sealing, the length of time required to achieve an even tracer gas distribution for the decay did not appear to alter much. In tests in the leaky 10,000m^3 warehouse, the length of time to reach an even tracer gas distribution was considerably increased from 15-20 minutes for the laboratory to greater than 40 minutes in the warehouse. During this time, a considerable proportion of the tracer gas escaped, and an appreciable over-injection of tracer gas was required to obtain reasonably consistent rates of decay throughout the building.

Table 1 shows the variation in standard deviation of tracer gas decays from constant concentrations in four buildings. The large leaky warehouse and the terraced house, partitioned with walls and closed doors, have similar standard deviations of about 0.2 for the areas under decay curves in different sample positions. This shows that these two buildings have similar proportional variations in local ventilation. The characteristics of the buildings are obviously totally different, and the different mixing mechanisms in each demand due consideration when choosing a method for ventilation measurement.

The standard deviation in the areas under the curves of local sample points for the unsealed and sealed laboratory shows a reduction of 5:1 at similar mean airchange rates. This is due to the reducing importance of wind induced infiltration air streams, and the increasing importance of smaller natural internal eddy air flows in the sealed building, thus maintaining a more evenly distributed tracer gas concentration.

This implies that in practice, extract fans used to exhaust local areas of air pollutant are less likely to have their performance impeded by wind induced air streams. Also non-exhausted pollutants will mix evenly with the air in the building, rather than develop smaller "clouds" of higher concentration which migrate around the building whilst slowly dissipating.

5. CONCLUSIONS

The reduction in leakage under artificial pressurisation of the laboratory measured of 2.8:1 at 10 to 20Pa produced a reduction of ventilation sensitivity to stack induced infiltration of approximately 2:1. It reduced wind dominated ventilation between 1.8:1 to 3.8:1, dependant on wind direction. The measurement of mean ventilation rates by the three major techniques available become easier and more repeatable after sealing as natural internal mixing eddies become dominant under the influence of less predominant ventilation pathways. Decay tests, in particular, developed much more even concentrations throughout the building, and the injection of tracer gas by balloon bursting was very successful in providing quick and reliable mixing with the least influence on the ventilation characteristics being measured.

The sealing of the building and removal of dominant ventilation paths implies that localised fanned extract ventilation would be much more effective for the removal of locally produced pollutants within the volume, without considerable dispersal to adjacent areas, subsequent dilution and high residence time.

The degree of leakiness, as well as the size of single-celled buildings has a great influence on the amount of information that can be derived from different ventilation measurement techniques. It may be useful to express the different information levels, available from different techniques, in terms of the infiltration volume throughout they can successfully measure. The larger and more leaky buildings become, the less useful are constant emission and constant concentration techniques without large increases in the power and capabilities of conventional automatic ventilation measuring instruments. Using any tracer gas technique, the larger and leakier the building, the more information is available about relative local ventilation rates, and the more difficult it is to produce mean ventilation rate measurements. Mixing for constant emission tests becomes excessive, or the need for many injection and sample points increases. This also applies to a lesser extent for constant concentration methods. Decay tests become more difficult or time consuming and wasteful of tracer gas, but for larger buildings, a greater amount of more reliable data can be obtained from simpler experiments. (Further work to investigate the usefulness of analysing concentration gradients in decay tests performed in larger leaky building is underway).

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