VENTILATION TECHNOLOGY - RESEARCH AND APPLICATION

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VENTILATION AND LEAKAGE MEASUREMENTS IN INDUSTRIAL BUILDINGS

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SYNOPSIS

It has been estimated that 15% of the energy used for building services in the United Kingdom is consumed in industrial buildings. A large proportion of this is thought to relate to infiltration and ventilation. There has been very little information produced concerning infiltration rates in industrial buildings because of the difficulty in making accurate measurements.

During the past three years, British Gas has made ventilation and building leakage measurements in a number of industrial and other large buildings in the UK. These include detailed measurements in a school, industrial laboratories, warehouses and industrial production units. These employ a variety of different construction types, heating systems, and provisions for ventilation.

Detailed measurements have been made of ventilation rates and natural air infiltration using the British Gas "Autovent" measuring system and simple tracer gas decay tests. Building leakages were measured using "Watson House Leakage Testers". Some of the buildings were draught-sealed and re-measured to assess the effectiveness of certain retrofit measures.

This paper discusses the results of the measurements made with respect to the building type and construction, the sensitivity of the building to weather driven air infiltration and the effects of heating and ventilation systems on the ventilation heat losses. The effectiveness of some retrofit sealing methods on the modification of building ventilation rates and heat losses is also discussed, along with some examples of the cost effectiveness of these measures.

MEASUREMENT EQUIPMENT

British Gas has developed much equipment for the measurement of building air leakage and ventilation.

The Watson House leakage testers (See Fig.1) were designed for the pressurisation testing of domestic dwellings with maximum flow rates of $1.25m^3s^{-1}$ each at 50Pa. Up to four of these testers were used in parallel in order to obtain leakage data for tests 5,6,7,8 and 9. (See Table 1) A wind generator (12.5HP) was used for the pressure testing of the industrial laboratory (tests 1&2) up to a pressure of 20Pa with flow rates up to $20,000m^3/hr$. A purpose built leakage tester for large buildings is now in operation to generate 50Pa pressure differences at flow rates of up to $150,000m^3/hr$ (Fig.2).

Ventilation measurements were predominantly made with the British Gas Autovent system, (Fig.3) using the constant concentration method. Alternatively decay tests were used (automated decay tests were made possible by using the Watson House mobile ventilation laboratory. (Fig.4)).

RESULTS

Table 1 shows the results of ventilation and pressurisation tests performed on seven large buildings. These comprise two old industrial buildings (a warehouse and laboratory), a school, and four modern factory units. The volume of these buildings vary from 660 to 12,600m^3. The age and construction of each building is briefly described in Table 1 together with the results of building leakage and ventilation tests. The detail of the ventilation measurements in each building varies considerably, so the available data has been reduced to each buildings sensitivity to stack and wind driven infiltration. These are expressed in airchanges per hour per ms^{-1} wind speed and $K^{\frac{1}{2}}$ stack effect. In tests 3,4 and 6 measurements not performed over a wide enough range of temperature difference to enable stack driven infiltration rates to be determined. The infiltration rates in test 7 were not measured directly, but were obtained from a combination of building leakage data and calculations using the British Gas ventilation model"VENT 2."

The building leakage data is presented using a reference pressure difference of 50Pa between the inside and the outside of the building. Not all the results were obtained using equipment capable of producing the required flow rate and pressure difference. In these cases, a quadratic curve fit to the experimental pressurisation curve has been obtained. The quoted figures marked thus (*) are extrapolations based on the quadratic equations fitted to the experimental curves.

Figure 5 shows a graph which compares the measured infiltration sensitivities to wind speed and stack effect and the measured leakage rates obtained from the pressurisation tests.

DISCUSSION (See Table 1)

Building A was an industrial laboratory built in the 1950's with a very leaky construction of breeze block and metal cladding. Most of the leakage in test 1 was therefore due to a large leakage path through the cavity. This was easily sealed with polyurethane foam sealant at a cost of £175. (£35 materials, £140 labour @ £10/hr (includes draught-stripping doors)). The results of test 2 show that after sealinbg the infiltration reduced by a factor of 2.6, and the leakage reduced by a factor of 3.0. These measures would reduce the typical heating season infiltration rate from 2.6 ac/hr to 1.0 ac/hr[5]. The high level of ventilation in this laboratory was not necessary and no problems with air quality resulted from these sealing measures. This direct reduction in ventilation represented an annual saving of £163 in gas heating costs (for an average 210 day 7°C heating season). The draught sealing measures therefore had an approximate simple payback period of 1.1 years. (The efficiency of the gas heating plant is taken as 70%).

The reduction of building air leakage was slightly larger than the reduction in infiltration. This is probably due to the changes in leakage distribution of the building before and after sealing. A large proportion of the building's leakage was concentrated at a height of 3m (at the junction between the cavity wall and the upper glazed area). The sealing of this major leakage source was likely to significantly change the infiltration characteristics of the laboratory.

Building B was an industrial warehouse, built before 1900. It is a very leaky building with badly fitting loading bay doors, and considerable gaps at the eaves. The multiple pitch roof was also in bad repair and of leaky construction. The specific ventilation rate was the highest of any of the buildings tested[7]. As this was also the largest building tested, it represents an exceptionally high level of air leakage and infiltration. Pressurisation fans of sufficient capacity were not available to perform leakage tests at the time of ventilation measurements.

Building C was a small, open plan school built in 1974, with a mechanical ventilation system providing 3 airchanges per hour[2]. It had an infiltration rate of 0.22 airchanges per ms^{-1} wind speed. A pressurisation test was not performed.

Building D was a modern factory unit built in 1981 with insulation in the walls and roof. Building E was built at the same time, but to a modern low energy specification. Building D had a roof vent which increased the ventilation rate by 20% with a temperature difference of 10.5°C, although only a 5% increase in leakage was observed with the vent open[6]. A large proportion of the total leakage was due to a badly fitting loading door. Sealing the loading door resulted in a 45% reduction in infiltration and air leakage. In practice, a good quality loading door would cost £280 more than the door fitted. The resultant reduction in seasonal infiltration from 1.4 to 0.8 ac/hr would save £127 per annum in gas used for heating the building over a typical heating season. This single measure would therefore have a simple payback period of 2¼ years.

Building E only had its air leakage measured on site. The ventilation rates have been calculated by the British Gas ventilation computer model VENT 2. The values marked on Table 1 are derived from these calculations. Particular attention had been paid to the air tightness of this factory unit during construction, including the use of a well-fitting loading bay door. The calculated specific ventilation rates are approximately 20% lower than building D when the loading door was sealed. The air leakage was 11.6 airchanges at 50Pa, which is similar to the air leakage of an average UK house[9]. It is therefore probable that the air leakage of factory units like building E could be further reduced with relative ease.

Buildings F and G were modern low energy factory units of $6000m^3$ volume with attention paid to the air tightness during construction which included the installation of well fitting roller loading bay doors. The specific ventilation rates are quite low, as would be expected in buildings of this size and construction. Although the measured infiltration rates were identical for both units, their leakage varied by 5000 m^3/hr at 50Pa. This occurred because the more leaky of the two adjacent factory units was in the lee of the tighter factory unit when the wind was in the prevailing SW direction (as was the case during the bulk of the measurement period). Additional air was drawn into the factory unit by the radiant tube heating system which would increase the ventilation rate during the heating season by up to 0.2 airchanges per hour. A roof vent and extract fan could increase ventilation to 1.2 airchanges per hour if necessary.

The graph in figure 5 shows the relationship between the air leakage at 50Pa and the specific ventilation rate due to wind speed and stack effect for the buildings measured.

It is interesting to note that buildings that were draught sealed (A&D) reduced their infiltration rates in approximate proportion with their air leakage at 50Pa. The greater deviation of building A from the proportional reduction in infiltration with leakage is probably due to the significant changes in vertical leakage distribution caused by the draught-sealing measures used.

As a result of the experience gained in gathering the data, there is strong evidence that the British Gas Autovent system can accurately measure infiltration rates in large open plan buildings 3,4,5,6,8. Larger industrial buildings will require care to ensure uniform mixing of tracer gas for constant concentration measurements. Good agreement between constant concentration tests and concentration decay tests have also been observed[8].

The larger buildings described in this paper were pressurised to less than 50Pa due to limitations in the capacity of the leakage testing equipment used. From the extrapolated air leakage flow rates given in Table 1 and the range of infiltration/air leakage ratios shown in figure 5, it is unlikely that it will be practical to maintain 50Pa as a standard pressure difference for estimating the air leakage of buildings larger than 5000 to 10,000m^3 in volume. For example, building D was a modern factory unit of 1300m^3 volume with an estimated leakage flow rate of 65,000 m^3/hr at 50Pa. The larger factory units F and G were built with particular care to reduce air leakage and yet would still require 40,000m^3/hr flow rate at 50Pa. The warehouse (Building B) was not pressure tested, but is likely to require at least 900,000 m^3/hr flow rate to generate 50Pa across the building envelope. A practical limit of flow rate for pressurisation testing buildings is considered to be 150,000m^3/hr. If a standard for pressure testing larger buildings is to be adopted, it will be necessary to reduce the 50Pa pressure difference currently adopted for the measurement of domestic buildings or develop alternative methods of leakage measurement (eg acoustic methods).

CONCLUSIONS

1. The equipment and techniques developed by British Gas can satisfactorily measure ventilation and air leakage rates in large buildings.

2. Measurements of building leakage for the small industrial buildings described in this paper requires pressurisation equipment sufficient to generate flow rates in excess of 65,000m^3/hr at 50Pa.

3. It will be impractical to pressurise most industrial buildings larger than 5000 to 10,000m^3 in volume to a pressure of 50Pa.

4. If a standard for the air leakage measurement of large industrial buildings is required, a lower standard pressure difference across the building envelope will be necessary to avoid the inaccuracies involved with the extrapolation of building leakage/flow rate/pressure curves.

5. Alternative methods of building leakage measurement (eg acoustic) may be necessary for the measurement of particularly large or leaky buildings such as the industrial warehouse referred to in this report (Building B). In this type of building infiltration measurements have proved more practical than leakage measurements which use the techniques available at present.

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TABLE 1

TEST	BUILDING	VINTAGE	CONSTRUCTION (S.A.)	INSULATION	GLAZING
1	A: INDUSTRIAL LAB - SEGAS REF 1,3,5	1950	660m³ 5m HIGH WALLS x 9m x 14m. 3m BLOCK-LEAKY CAVITY-METAL. 1 PAIR LEADING DOORS CLADDING 1 SHELTERED WALL.	INSULATED ROOF (GENTLY ARCHED) SOLID FLOOR	2m GLAZING ON 3 OF 4 WALLS ABOVE BLOCK & CLAD WALLS.
2	A: AS ABOVE	1950	a) INTERNAL CAVITY LEAKAGE SEALED WITH POLYURETHANE FOAM. b) DISUSED FLUES IN ROOF SEALED. c) DOORS DRAUGHT-SEALED d) DISUSED FRESH AIR FAN SEALED.	AS ABOVE	AS ABOVE
3	B: INDUSTRIAL WAREHOUSE - SEGAS. REF 3,7	C1900	12600m³ 5.5m VERY LEAKY ASBESTOS SHEET MULTIPLE PITCHED ROOF. 18m LOADING BAY COVERING N WALL. 3 x 3 LOADING BAYS AT N END OF W WALL. 1 x 3m LOADING BAYS ON S WALL.	NONE SOLID FLOOR	HALF GLAZED PITCHED ROOF
4	C: SCHOOL REF 2,4,6,	1974	800m³ BRICK WALLS FLAT ROOF OPEN PLAN	CAVITY & ROOF	EXTENSIVE
5	D: FACTORY UNIT 1 GWENT. REF 4,6	1981	1300m³ 5m HIGH WALLS x 12.5m x 21.5m. 21.5m WALLS SHELTERED BRICK-INSULATION - METAL CLAD GENTLY PITCHED ROOF, SINGLE LOADING DOOR.	WALLS + ROOF SOLID FLOOR	ROOF GLAZING LIMITED
6	D: FACTORY UNIT 1 GWENT. AS ABOVE.	1981	AS ABOVE. + LOADING DOOR DRAUGHT SEALED	AS ABOVE	AS ABOVE
7	E: FACTORY UNIT 2 GWENT REF 6	1981	810m³ 5.5m HIGH WALLS x 10m x 14m. 14m WALLS SHELTERED. BRICK, INSULATION, METAL CLADDING. ATTENTION PAID TO AIR TIGHTNESS.	WALLS + ROOF SOLID FLOOR	ROOF GLAZING LIMITED
8	F: LLANELLI FACTORY UNIT 8 REF.8	1985	6000m³ 8m HIGH x 30m x 28m. ONE 30m SHELTERED WALL BRICK/INSULATION/ METAL CLAD.	WALLS + ROOF SOLID FLOOR	LIMITED ROOF GLAZING
9	G: LLANELLI FACTORY UNIT 7 REF.9	1985	AS ABOVE	AS ABOVE	AS ABOVE

TABLE 1

HEATING SYSTEM	VENTILATION SYSTEM	T SENSITIVITY (h^{-1})	WS SENSITIVITY (h^{-1})	LEAKAGE @50Pa
2 x WATER/AIR HEAT EXCHANGER, 1 RECIRCULATION. 1 FRESH AIR (DISUSED)	1 FRESH AIR HEATING SUPPLY FAN 4 ROOF EXTRACT FANS (+ 1ac/EXTRACT FAN)	0.65ac/K½	1.0ac/ms^{-1}	34,900m^3/hr (52ac/hr)
AS ABOVE	FOUR ROOF EXTRACT FANS	0.25ac/K½	0.4ac/ms^{-1}	11,800m^3/hr (18ac/hr)
LOCAL DIRECT FIRED HEATERS LOCAL WARM AIR HEATERS	NONE	-	1.4ac/ms^{-1}	-
4 ZONE WARM AIR H.W. H.W. COIL H&V SYSTEM	SUPPLY/RECIRCULATION EXHAUST H&V SYSTEM 3ac/hr 4 EXTRACT FANS IN TOILETS (10ac/hr LOCAL)	-	0.22ac/ms^{-1}	-
TEMPORARY ELECTRIC CONVECTION HEATERS	ROOF VENT GIVING VENTILATION INCREASES OF +20%@ T½ = 3.2, WS = 5 +5% @ Q (50)	0.4ac/K½	0.44ac/ms^{-1}	65000m^3/hr* (50ac/hr)
TEMPORARY ELECTRIC CONVECTION HEATERS	ROOF VENT	-	0.24ac/ms^{-1}	35000m^3/hr * (27 ac/hr)
GAS FIRED RADIANT PLAQUE HEATERS	ROOF VENT	INFERRED 0.17ac/K½	INFERRED 0.19ac/ms^{-1}	9360 m^3/hr (11.6 ac/hr)
RADIANT TUBE DRAWING COMBUSTION AIR FROM INSIDE	2 ROOF VENTS WITH EXTRACT FANS.	0.08ac/K½	0.05ac/ms^{-1}	40000m^3/hr* (6.6 ac/hr)
AS ABOVE	AS ABOVE	0.08ac/K½	0.05ac/ms^{-1}	35000 m^3/hr* (5.8 ac/hr)

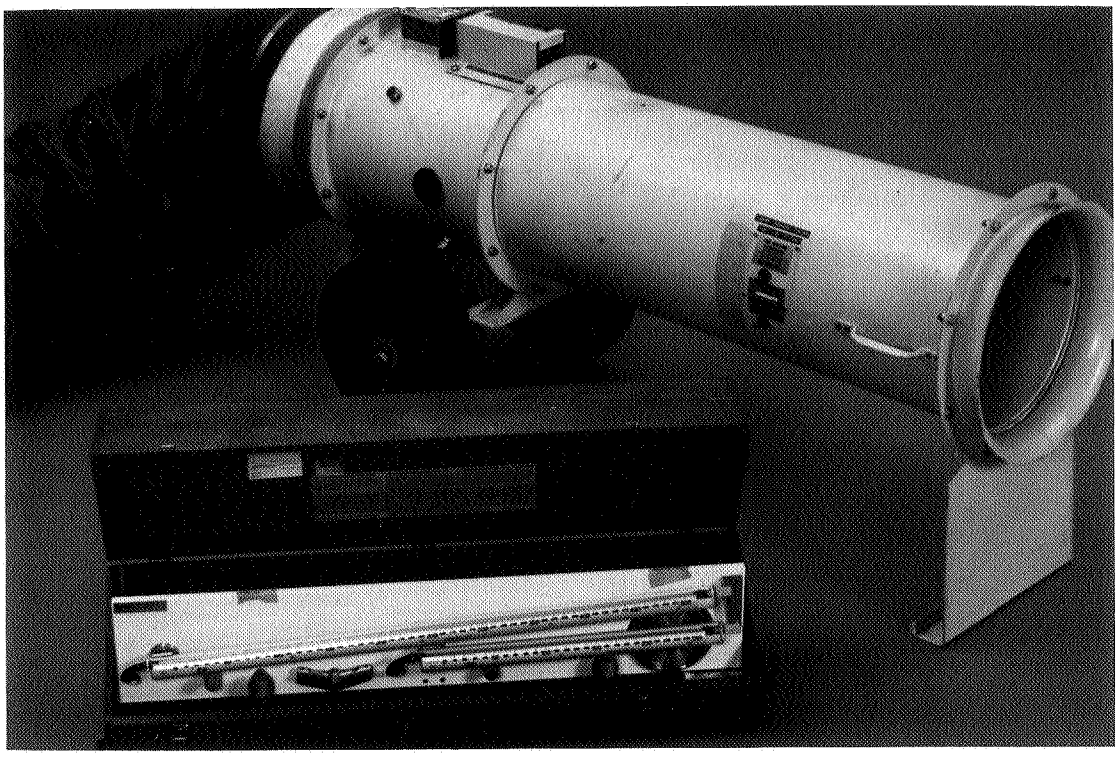

FIGURE 1 : WATSON HOUSE LEAKAGE TESTER

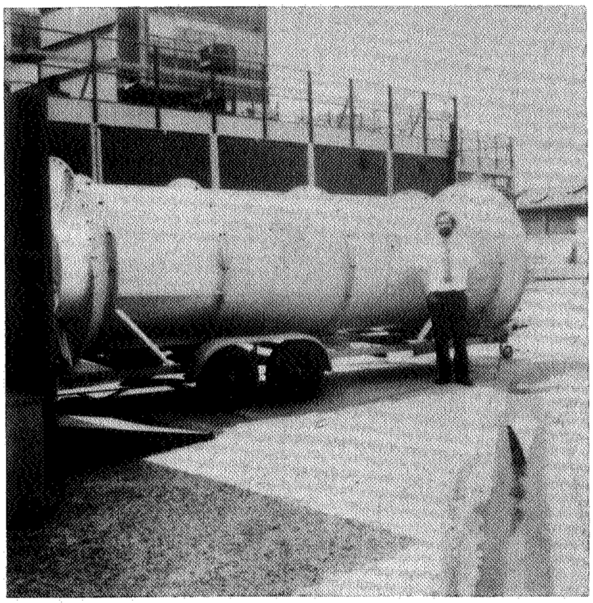

FIGURE 2 : WATSON HOUSE INDUSTRIAL LEAKAGE TESTER

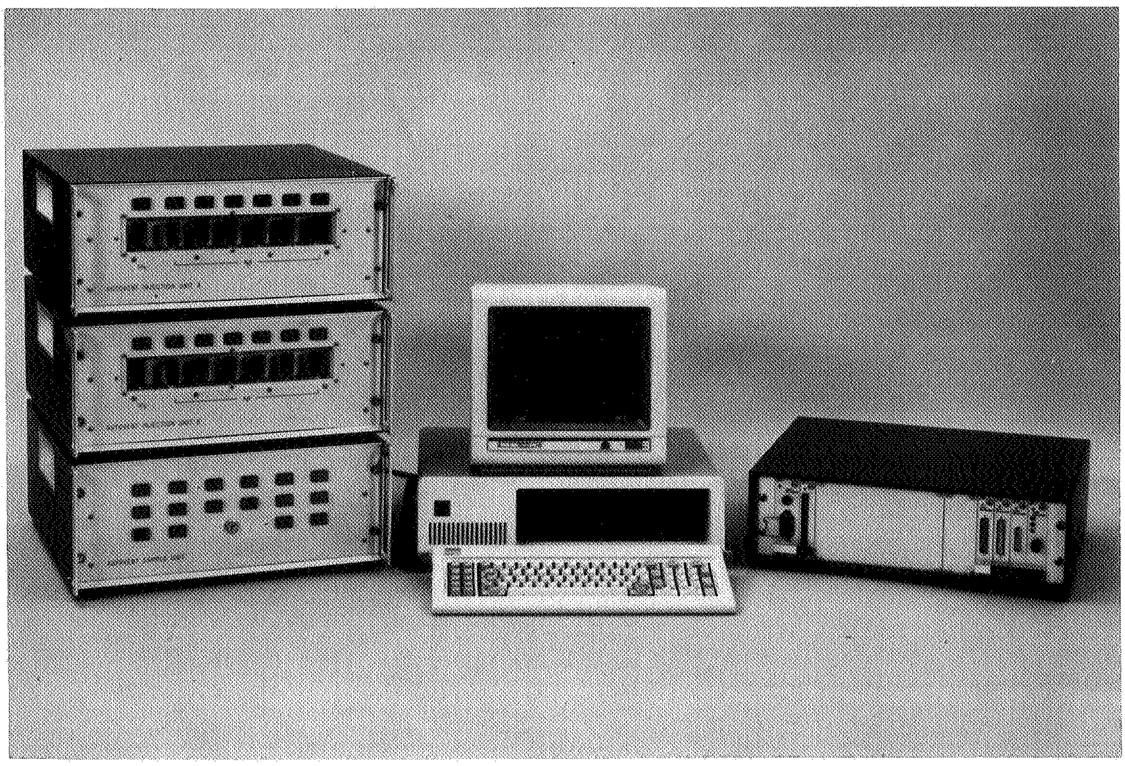

FIGURE 3 : BRITISH GAS AUTOVENT

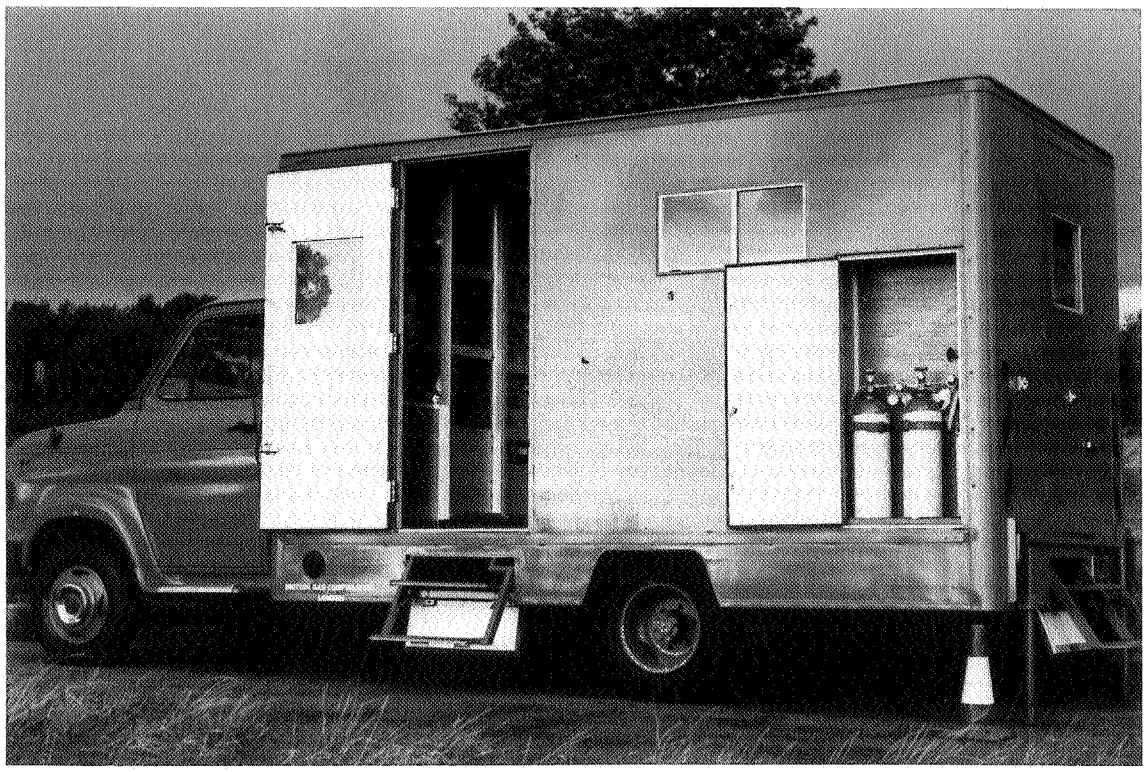

FIGURE 4 : MOBILE VENTILATION LABORATORY

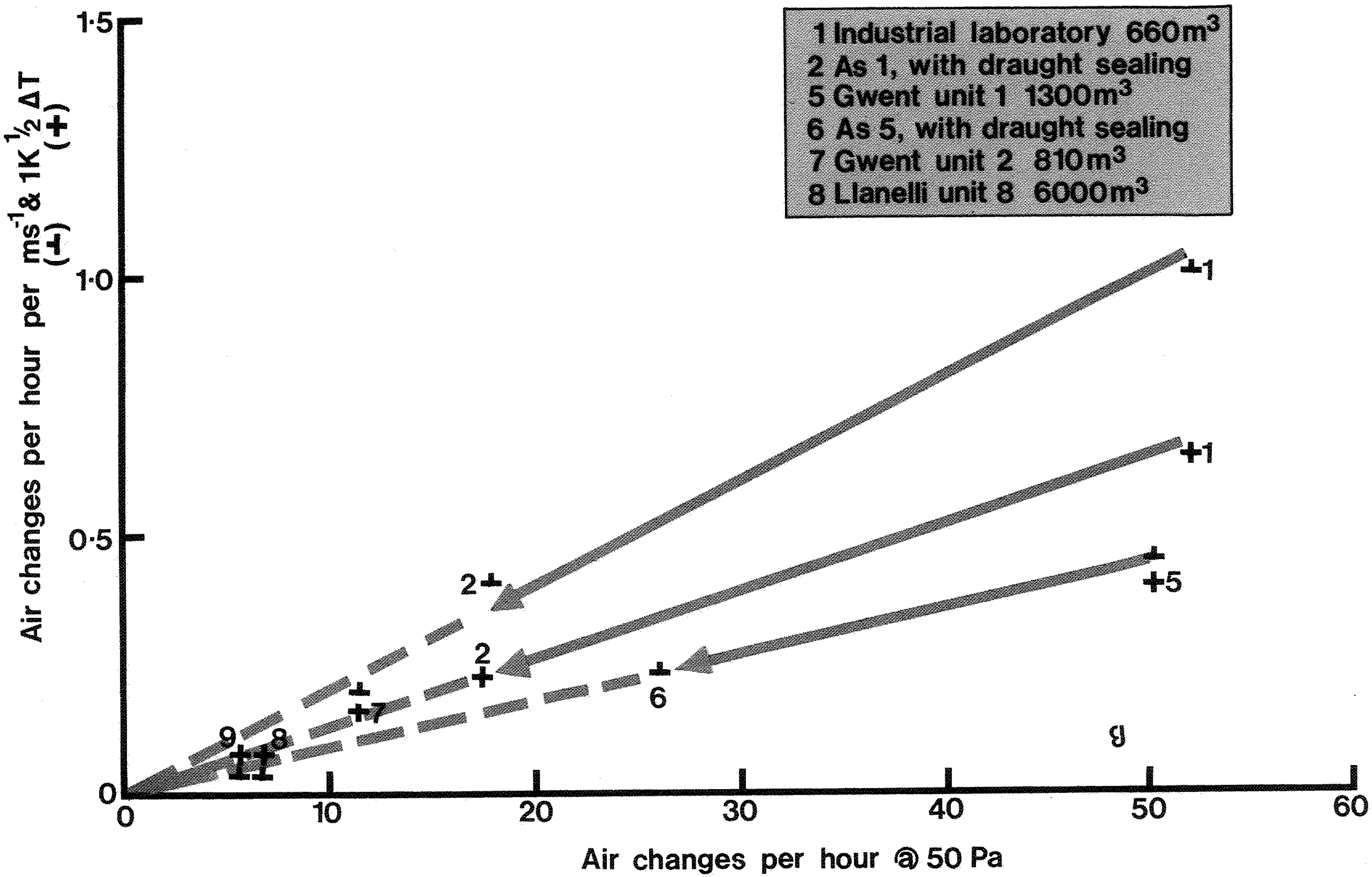

Fig.5 THE COMPARISON OF BUILDING LEAKAGE @ 50Pa ΔP AND SPECIFIC VENTILATION RATE FOR A RANGE OF LARGE BUILDINGS

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