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ENVELOPE LEAKINESS OF LARGE, NATURALLY VENTILATED BUILDINGS

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SYNOPSIS

Whole-building pressurisation tests can quantify the air-leakiness of a building's external envelope. The resulting information can be used in assessing the quality of the building fabric. At present there is little information regarding the leakage characteristics of large, non-domestic UK buldings. As a step towards providing more information, the Building Research Establishment (BRE) has developed and constructed a multifan pressurisation system known as BREFAN to pressurise large buildings like offices and hangars.

This paper presents results from field measurements in five large and naturally ventilated buildings. Using BREFAN, measurements in a medium-sized building specifically designed and constructed as a low-energy office (LEO), showed a reduction of 9% (at a pressure difference of 25 Pa between inside and outside) in its envelope leakiness after new and improved windows were installed as part of a programme of modifications. Using Q_{25}/S (whole building leakage rate at a 25 Pa pressure differential per unit permeable surface area) as an index of the leakiness of the building envelope, these results, when compared with measurements made previously in a conventional UK office, showed that the LEO building was twice as tight as the more conventional building. Comparison with measurements made in North American showed the LEO building was as tight as buildings found there.

BREFAN measurements in a second building, a conventional hangar built in the early 1960's, showed it to be very leaky. At 25 Pa pressure difference, the opening of a roof vent increased the leakiness by 17% and unsealing a large folding door increased it by 8%.

The envelope leakiness of the hangar was compared with measurements in three other large single-cell factory buildings using a different system of fans to pressurise the buildings. One of these, built 35 years ago, was as leaky as the hangar building. The other two buildings, built within the last decade under current UK Building Regulations, were shown to be twice as tight.

KEYWORDS: pressurisation, fan pressurisation, pressurisation testing, air leakage, leakage area, air tightness, large building, nondomestic building, commercial building, office building, multistorey building.

1. INTRODUCTION

Air enters a naturally ventilated building either through purpose-built openings like windows or by uncontrolled leakage (infiltration) through cracks and gaps in the building envelope. In most circumstances, this adventitious leakage through the building fabric is a source of excessive ventilation which can lead to energy waste and, in some cases, to discomfort.

The leakiness of the building envelope can be quantified by measuring the whole-building air leakage rate at an appropriate applied pressure differential between inside and outside. This is done by sealing a portable fan into an outside doorway and measuring the airflow rates required to maintain a set of pressure differences across the building envelope. Although the technique, equipment and protocol to carry this out are well established for dwellings[1], this is not the case for large and complex buildings like offices.

In North America, where most office-type buildings are mechanically ventilated, the ventilation system can be used[2] to pressurise the building. For the UK, this is not a fully viable method since most buildings are naturally ventilated. In Canada, an alternative approach[3] has been to use a large diameter trailer-towed fan with its own power generator.

To avoid using a large, cumbersome fan, the Building Research Establishment (BRE) has developed a multiple-fan pressurisation system[4,5] called BREFAN. Novel features of this system include portability, ability to be powered from conventional 13 amp sockets and stable fan-speed control during multiple-fan operation.

This paper presents results obtained from field measurements in five naturally ventilated non-domestic buildings comprising one office and four single-cell industrial units. Measurements in the medium-sized office building located at BRE are compared with earlier measurements[4] to assess the effect of installing improved windows throughout the building.

Measurements in a hangar, also at BRE and one of the four single-cell buildings tested, show the reduction in the overall envelope leakiness when a folding steel door is sealed or the increase when a roof vent is opened.

Finally, to place the results in some context, a leakage index is used to compare the leakiness of these two buildings at BRE with similar buildings elsewhere. This comparison includes measurements from the other three industrial buildings which were pressurised with a different system of fans.

2. EXPERIMENTAL ARRANGEMENTS

2.1. BREFAN System

The design and construction of the BREFAN pressurisation system is fully described fully in the earlier papers[4,5] but, for completeness, the essential features are as follows. The system consists of three identical fan pressurisation units. Each unit is fully portable, powered from conventional 13 amp sockets and operated using a single- to three-phase speed controller to stabilise its speed during multiple-fan operation.

Airflow through each fan is measured using a conical inlet [6]. Each fan unit is capable of providing a flow rate of 5.5 m^3/s against a building envelope pressure difference of 50 Pa. The number of fans used in any building is set by that required to achieve a target pressure difference. Short lengths of flexible ducting are used to connect the fans to 'false' plywood door panels which are temporarily sealed onto an outside doorway of the test building.

2.2. Test Buildings at BRE

Two of the naturally-ventilated test buildings are located at the BRE site in Garston. One is a three-storey building built as a 'low-energy' office (LEO)[7] and the other is a conventional single-cell hangar built in the mid-1950s.

The outside walls of the LEO consists of 9 mm thick clay tiles on the outside face followed in succession by 125 mm thick precast concrete panels, a 300 mm void filled with blown polystyrene beads and plasterboard (12.5 mm thick) with an aluminium foil vapour barrier. The building volume is estimated as 5315 m^3 and the external surface area as 1750 m^2.

Although the LEO building was formerly mechanically ventilated, the ventilation system is now disabled and the duct openings of its air handling unit (located on the roof) are blanked off. As part of a program to improve thermal insulation levels, the older double-glazed windows (with 6 mm air gaps) have now been replaced with new tighter units incorporating Argon fill.

The hangar-type building is known in the UK as a 'Marston' shed. Originally a single building, its southern end was extended in the mid 1960's and joined to a similar building. A brick partition separates the two buildings with access between them via a horizontally-sliding folding shutter door. During the field tests, all measurements were carried out in the northern hangar of the combined building.

The walls and roof of the hangar consist of corrugated asbestos cement sheeting fixed to a steel frame with hook bolts and lined internally with plasterboard. The volume and external surface area are estimated as 4690 m^3 and 1400 m^2 respectively.

The other three single-cell factory units tested were all located outside BRE and represented some of the UK stock of industrial buildings. Table 1 gives summary details of these test buildings,

2.3. Test Conditions

After the new windows were installed, a whole-building pressurisation test was carried out in the LEO using two of the fan units (Figure 1). During the test, all outside doors and windows were kept closed while all internal doors were wedged open. Using a nearby meteorological site, wind speed during the test was measured to be about 2 m/s at a height of 10 m. Inside and outside air temperatures were 6 ^{o} and 17 ^{o}C respectively.

Three pressurisation tests (Tests A1, A2 and A3) were made on the hangar. Three fan units were placed (Figure 2) in a gap created by raising the vertical sliding door at the north end. For test A1, the folding shutter door between the test hangar and the adjoining hangar was sealed with polyethylene sheeting. In test A2, a roof vent (measuring 1.5 m by

0.35 m) was opened. In test A3, the roof vent was closed but the polyethylene sheet was removed from the door. Wind speed was about 2 m/s during the test and the inside and outside air temperatures were similar at about 22 °C.

3. RESULTS

Figures 3 and 4 show the airflow rates, Q, plotted against applied pressure differential, ΔP, across the outside wall envelopes of the LEO and the hangar respectively. For comparison, Figure 3 includes a best-fit pressurisation profile obtained previously[4] for the LEO before the new windows were installed.

Best-fit power-law profiles of the form,

$$Q = K \, \Delta P^n$$

where the coefficient K and the exponent n (lying between 0.5 and 1.0) are constants, were fitted to the data. This was done by transforming the above equation to the form,

$$\log_e(Q) = \log_e(K) + n \log_e(\Delta P)$$

and fitting a linear regression line on the transformed variables. The computed coefficients and exponents (with associated 95% confidence intervals), together with the correlation (r^2) for the goodness-of-fit, were evaluated and are as follows:

Building	*Test*	*Ln(K)*	*Coeff. K* $(m^3/s)/Pa^n$	*Exponent, n*	*Corr. r^2*
LEO		-0.888 ± 0.026	0.412	0.58 ± 0.01	0.999
HANGAR	A1	0.713 ± 0.143	2.041	0.64 ± 0.06	0.976
HANGAR	A2	1.125 ± 0.098	3.081	0.56 ± 0.04	0.986
HANGAR	A3	0.913 ± 0.088	2.492	0.61 ± 0.03	0.992

Note that no confidence interval has been ascribed to the coefficient K since the regression analysis was carried out on the log transform of this coefficient.

4. DISCUSSION

4.1. Leakiness of the LEO Office Building

Using the coefficient and exponent given above, the whole building air leakage rate can be calculated for any applied pressure differential over the measured pressure range. For dwellings, it is usual[8] to quote the leakage rate, Q_{50}, at an applied pressure difference of 50 Pa.

For some buildings, which are either large or excessively leaky or a combination of both, it is not always possible to achieve this target pressure. In such an instance, extrapolation to 50 Pa is considered acceptable[9] if the maximum achieved pressure is greater than 35 Pa and the correlation, r^2, of the best-fit line is better than 0.990. In large building pressurisation testing, it is not always possible to fulfill these conditions and a leakage rate of Q_{25} at a lower target pressure of 25 Pa can be used[4].

At 25 Pa, the leakage rate of the LEO with new windows is 2.67 m^3/s. This is a 9% reduction from the 2.93 m^3/s obtained a year before the modification programme. Because of this time gap between the two tests, it is difficult to state categorically that this small reduction is due to the new windows since it is known that, for dwellings, seasonal variations do occur[8] in their leakage rates. Measurements will therefore be repeated during the coming heating season to clarify this aspect.

4.2. Leakiness of the Hangar Building

The Q_{25} leakage rate for Test A1 with the partition door sealed was calculated as 16.0 m^3/s. Opening a roof vent (Test A2) or unsealing the partition door (Test A3) increased this to 18.7 and 17.2 m^3/s respectively representing increases of 17% and 8%.

Using the roof-vent open area of 0.53 m^2 and a measured partition door periphery length of 18.8 m, a first-order approximation indicates a nominal door crack width of 1.3 cm for this type of horizontally-sliding folding steel door. It should, however, be noted that in reality the cracks are not only distributed around the perimeter of the door but also between each leaf of the door.

4.3. Comparison with Buildings Elsewhere

It has been shown previously[4] that the index Q_{25}/S (where S is the total permeable external surface area) is a suitable measure of a building's constructional quality with regard to the leakiness of its envelope. In Figure 5, the envelope leakiness of the LEO and hangar buildings are compared with other office and single-celled buildings found elsewhere. Relevant leakage and physical characteristics of these buildings are tabulated in Table 1.

Office buildings

As mentioned earlier, data on office leakage is scarce. Apart from the LEO, only one other UK building (a conventional office built in 1963) has been tested[4]. Other available data is limited to the USA (6 offices) and Canada (12 offices). The leakage for each of these two North American data sets have been aggregated[4] and are given in Table 1.

Figure 5 shows that whereas the LEO is as tight as the North American buildings, the conventional UK office is twice as leaky. Although it is not possible to generalise these findings to the majority of conventional UK office buildings, this comparison shows the tightness of a building designed to be relatively tight by current UK standards.

Single-celled buildings

It is useful to compare the leakiness of the hangar building with the following single-cell buildings elsewhere:

(a) A 35-year old conventional masonry building in the UK.

(b) Two factories built within the last decade to contemporary *UK Building Regulations* standards. (It should be noted that the Regulations do not give guidance on air leakage but on thermal performance).

(c) Three large buildings in Sweden.

The measured air leakage characteristics [Jones and Powell, personal communication] of these three Uk buildings are tabulated in Table 1 together with similar details[10] for the Swedish buildings. Using the tabulated values, the leakage index Q_{25}/S for each of the buildings have been calculated and shown graphically in Figure 5.

It can be seen that the two older UK buildings, the asbestos-walled hangar and the masonry building, have similar high leakage indices of 41 and 45 m^3/hr per m^2 respectively. A leakage of about 20 m^3/hr per m^2 for the other two UK buildings built to current *Building Regulations Standards* show a halving of the leakage rates. However, the three Swedish buildings with leakage indices between 2 and 5 m^3/hr per m^2 show that it is possible to reduce the envelope leakage of UK buildings much more with suitable construction techniques.

5. CONCLUSIONS

Whole-building pressurisation tests can quantify the air-leakiness of a building's external envelope. The resulting information can be used in assessing the quality of the building fabric. At present, there is only limited information regarding the airtightness of large, naturally ventilated non-domestic buildings in the UK. As a step towards obtaining this information, this paper presents results from measurements made in a small sample of office and single-cell industrial buildings in the UK.

Measurements in a building, built specifically as a low-energy office, shows this building to be as tight as those found in North America whereas a more conventional UK office building was twice as leaky. Installing improved windows appears to have increased the tightness of the low-energy building by about 9% but further tests will be made to ensure that this increase is not caused by a seasonal variation.

Measurements made in older conventional hangars show these to be twice as leaky as those built according to current UK *Building Regulations Standards*. There is, however, interest currently in the UK to improve the design of 'new-builds' and build tighter, low-energy factory units[11]. Published measurements in large Swedish single-celled buildings show that a further 10-fold increase in tightness is possible with known construction techniques.

ACKNOWLEDGEMENTS

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CODE	BUILDING DESCRIPTION	PERMEABLE AREA (m^2)	VOLUME (m^3)	TEST CONDITION	LEAKAGE COEFFICIENT, K $(m^3/s)/Pa^n$	EXPONENT n
<u>Offices</u>						
LEO	Low energy office at BRE	1,750	5,315	Before new window	0.424	0.60
				After new windows	0.412	0.58
UK	Conventional UK office	2,195	6,254	as-built	1.388	0.51
USA	Six USA office buildings	Ref 4	Ref 4	as-built	0.72 (*)	0.60
CANADA	Twelve Canadian office buildings	Ref 4	Ref 4	as-built	0.64 (*)	0.65
<u>Single-cell buildings</u>						
UK #1	25-year old hangar at BRE	1,400	4,690	door sealed (A1)	2.041	0.64
				roof-vent open (A2)	3.080	0.56
				door unsealed (A3)	2.492	0.60
UK #2	10-year od factory unit (current UK standard)	3,459	15,000	as-built	4.162	0.50
UK #3	5-year old factory unit (current UK standard)	1,100	3,050	as-built	1.052	0.54
UK #4	35-year old UK unit	1,694	4,955	as-built	3.936	0.52
SW #1	Swedish industrial building (Code A in Ref 10)	6,796	36,373	as-built	Ref 10	Ref 10
SW #2	Swedish store (Code B in Ref 10)	9,876	61,127	as-built	Ref 10	Ref 10
SW #3	Swedish sports hall	5,809	31,622	as-built	Ref 10	Ref 10

(* USA/Canadian office leakage coefficients in units of $(m^3/hr)/Pa^n$ pr unit permeable area)

TABLE 1 - Building Characteristics

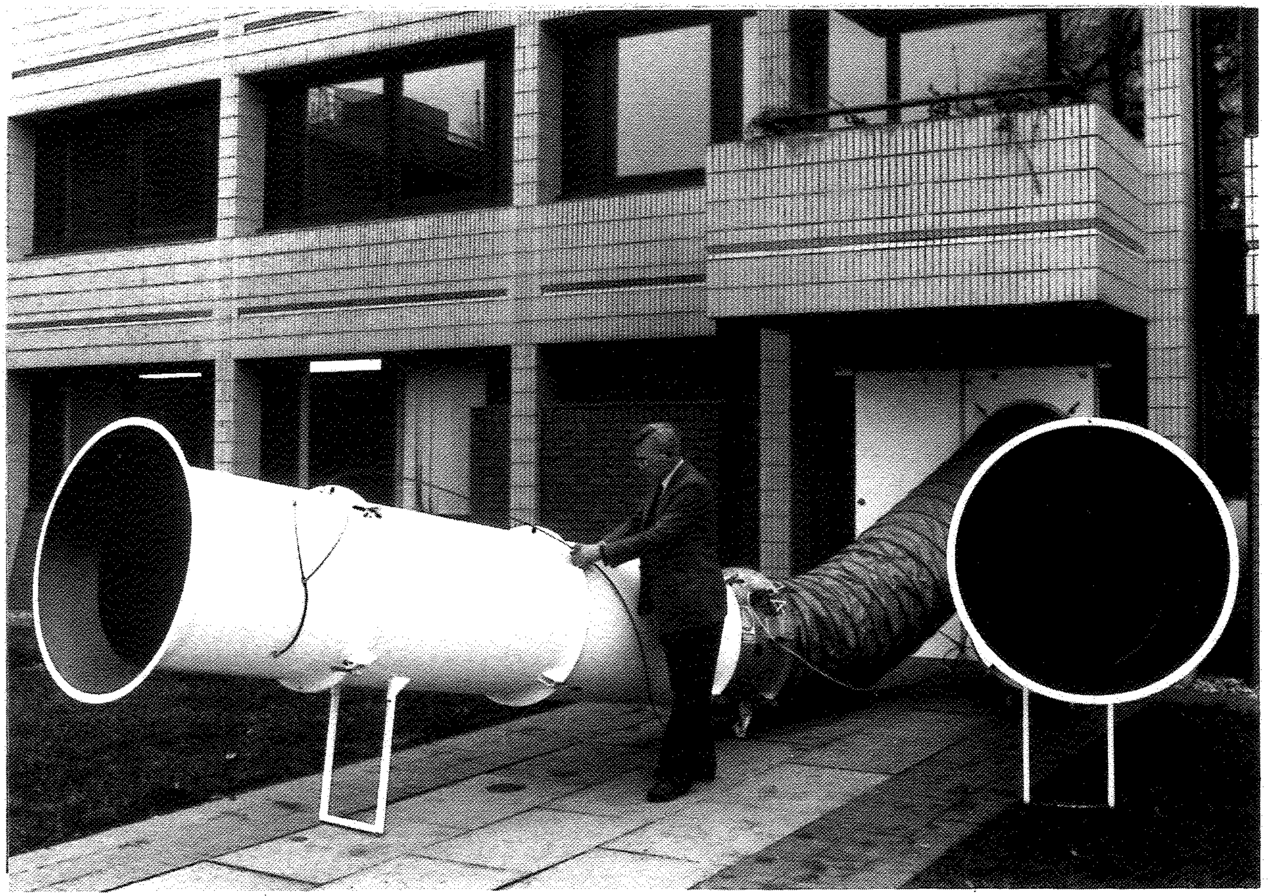

FIGURE 1 - BREFAN installed at the main entrance to the Low Energy Office

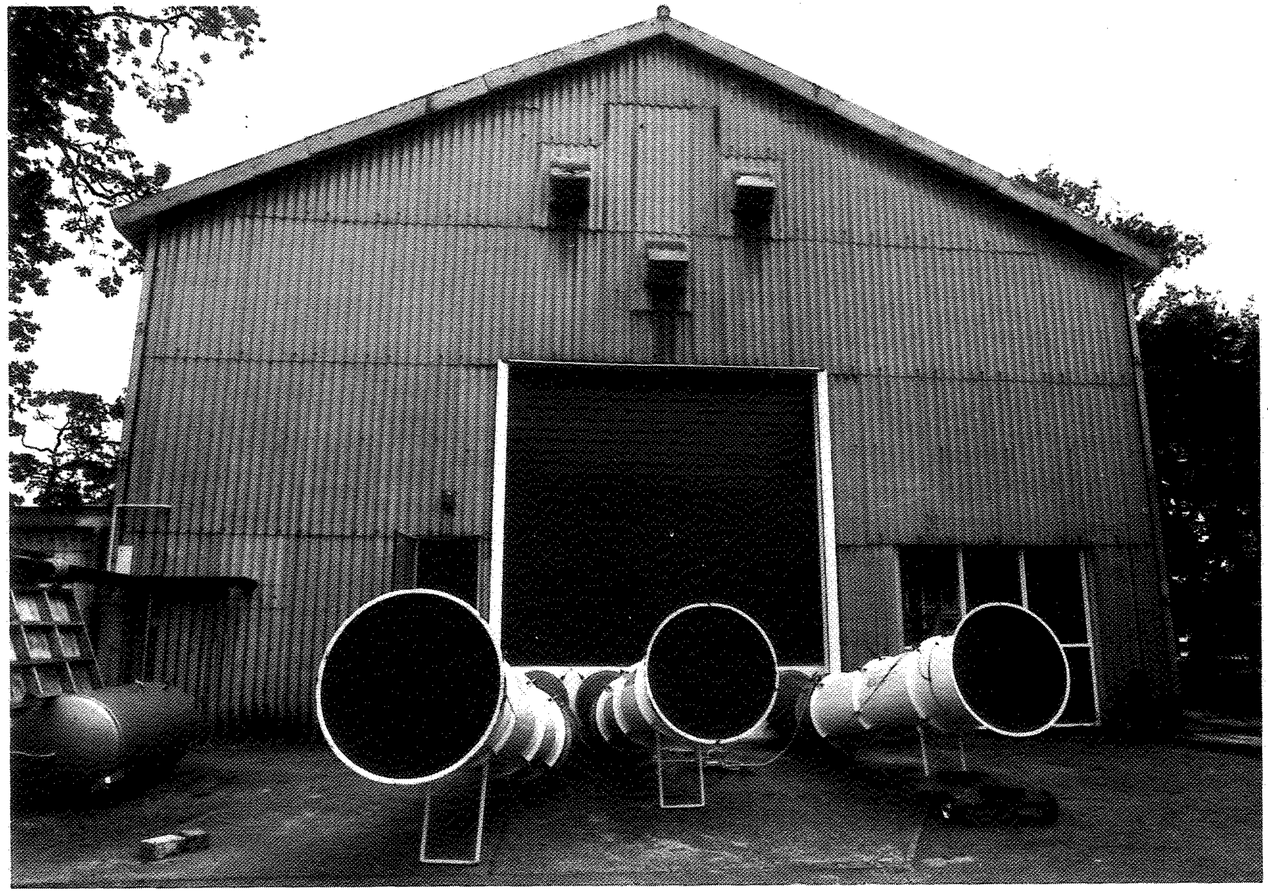

FIGURE 2 – BREFAN installed for testing the hangar building

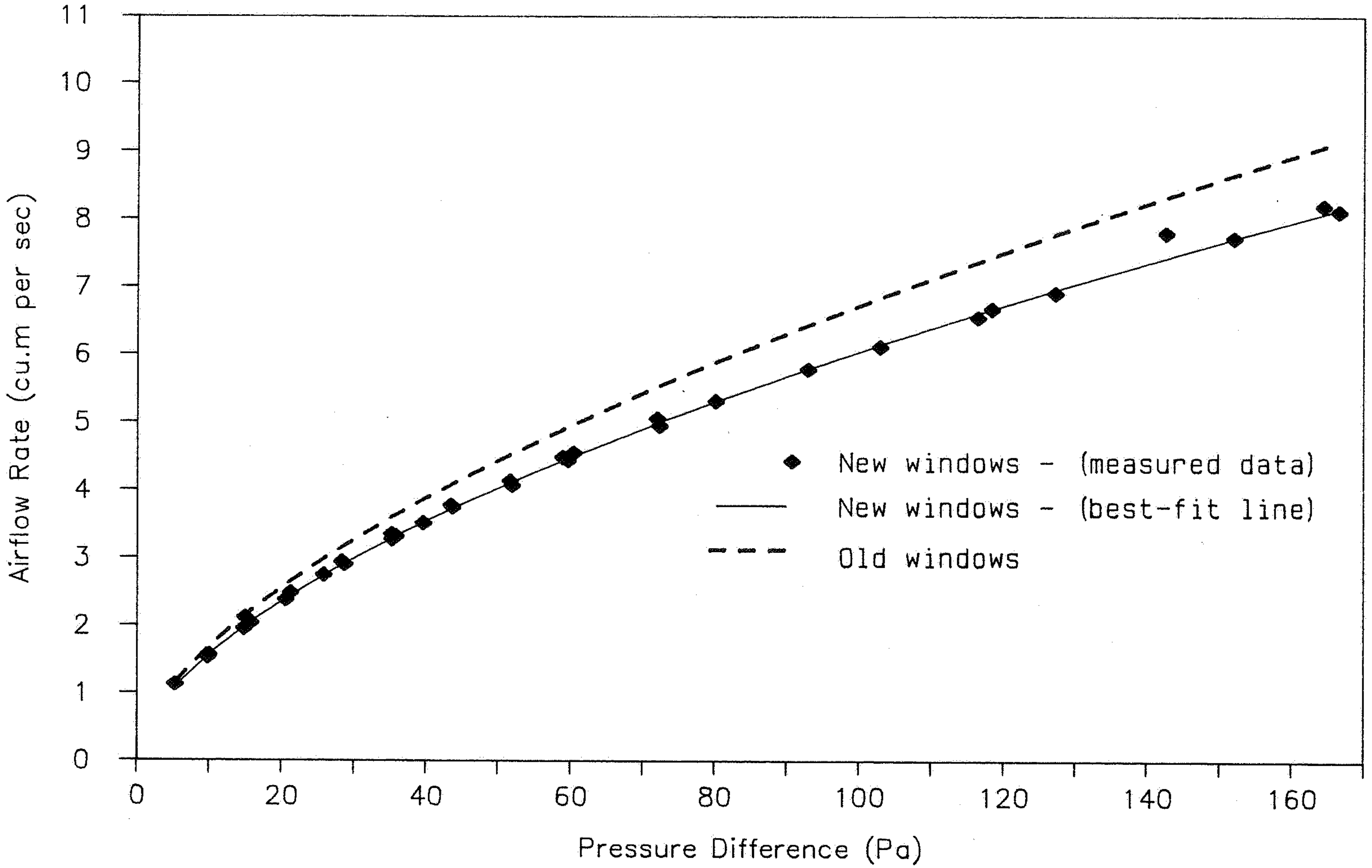

FIGURE 3 – Pressure tests in the low energy office (LEO) building

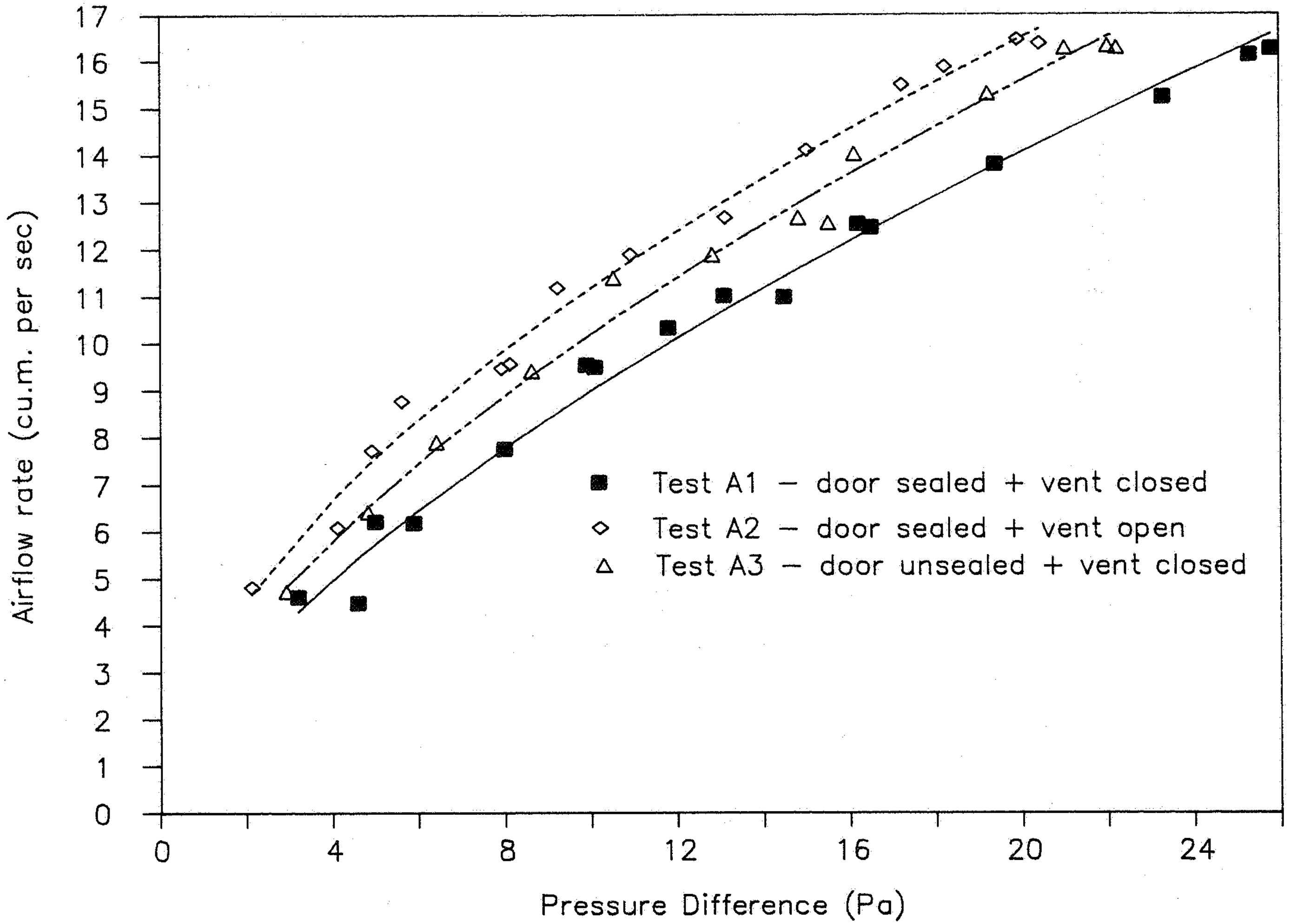

FIGURE 4 – Pressure tests in the hangar building

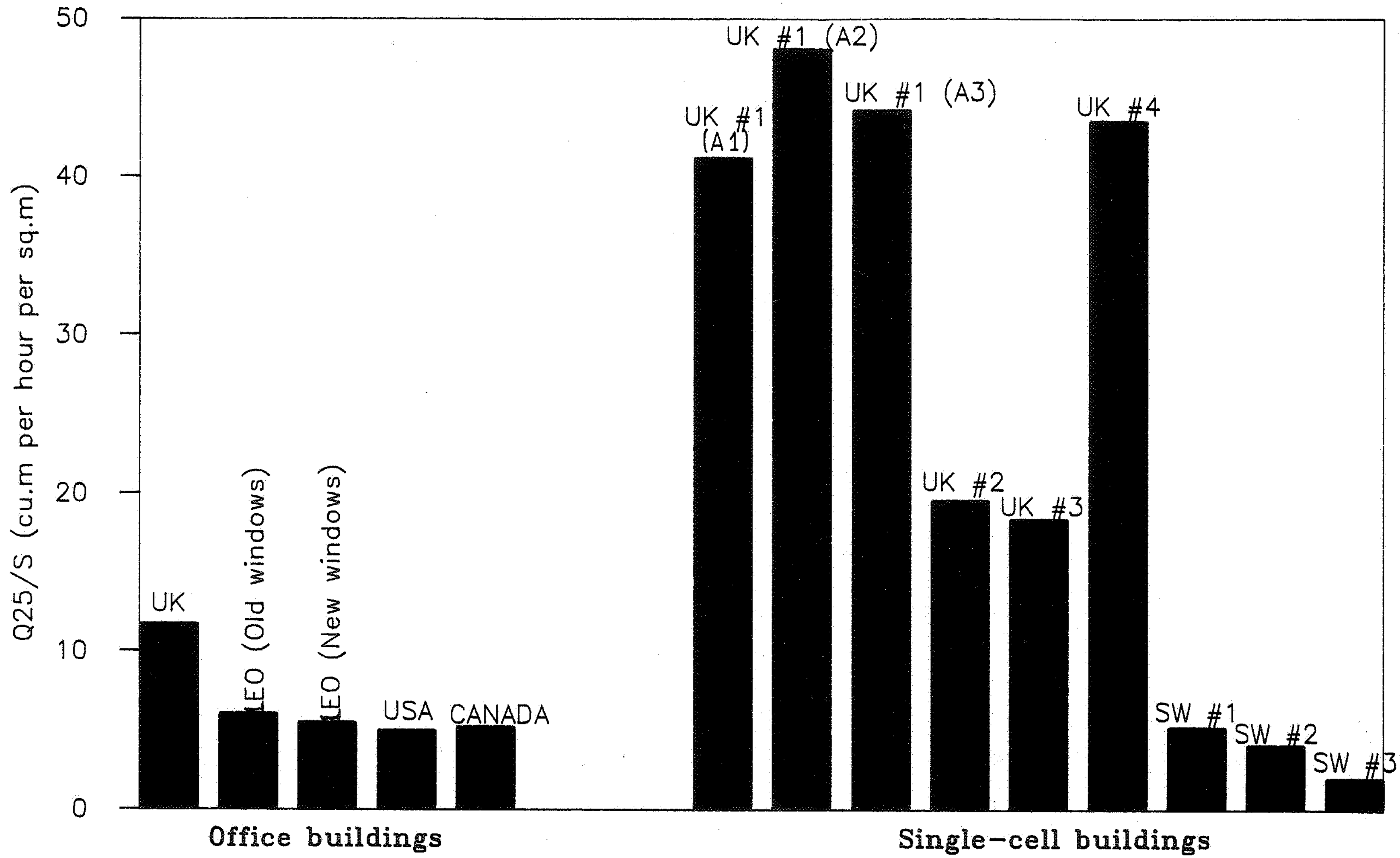

FIGURE 5 - Envelope leakage index of buildings

Discussion

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J-M Fürbringer (EPFL, Lausanne, Switzerland)

a) In the measurements you present (pressurization) where do you measure the pressure difference across the envelope of the building?

b) You present results for 4 Pa pressure difference, but a wind of 3m/s can easily produce a higher pressure difference between leeward and windward side.

Earle Perera (Building Research Establishment, UK)

a) We measure both at ground level and also at an upper location - especially in a multi-storey office building. There is usually a measureable difference between the two (~ 4Pa) but results presented in the paper relate to difference measured at ground level.

b) Agreed, however measurements at the lower levels are carried out during calm periods - otherwise they are not used.

W. Raatschen (Dornier GmbH, Germany)

How did you get to the total permeability of the building or hangar?

Earle Perera (Building Research Establishment, UK)

A power law of the form $Q=k(P)n$ is fitted by the least squares method to the measured values of $Q(m^3/hr)$ and pressure difference $P(Pa)$. From this best fit law we compute the leakage rate at 25 Pa pressure difference as $Q25=k(25)n$.

By studying dimensional drawings of the building we calculate the total external surface area $S(m^2)$ of the building envelope which was subjected to pressure differences and permeable to air flow. The permeability index of the building is then quoted as $Q25/S$ $m^3/hr/m^2$.