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Air Infiltration Characteristics of Windows

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SUMMARY

This report analyses and correlates the data obtained for air infiltration during performance tests for weathertightness of windows. The correlations are compared with data from existing standards for natural ventilation, the comparison highlighting the considerable variation between weathertightness and natural ventilation performance. Recommendations for resolving the differences in performance are proposed which will assist the designer in achieving a better balance between energy conservation needs and ventilation requirements.

1. INTRODUCTION

Weathertightness of windows has been investigated by the MACDATA unit of Paisley College of Technology for the past 15 years, during which time in excess of 1000 windows have been tested and classified using the appropriate British Standard publications [1 - 4]; the window classifications are based on the overall performance with respect to air infiltration, water penetration and wind resistance. Assessment of the data [5, 6] indicated that windows which did not achieve the required performance classifications for weathertightness failed generally in the watertightness test and rarely in the air infiltration test. This has resulted in windows achieving a higher classification for air infiltration than necessary with a consequent reduction in natural ventilation and a greater risk of condensation and dampness. A consequence of the performance assessment also indicated an incompatibility between the British Standard for weathertightness with respect to air infiltration and the British Standard for natural ventilation [7]. The purpose of this report is to resolve this incompatibility and to propose methods of assessing natural ventilation requirements based on weathertightness performance with respect to air infiltration.

2. WEATHERTIGHTNESS OF WINDOWS

2.1. Background

Weathertightness testing of windows has been carried out in the United Kingdom (U.K.) since 1968. The methods of testing and classifying windows were initially governed by *BS 4315* [2] and *BS DD4*, 1971 [1] and were later superseded by *BS 5368* [4] and *BS 6375* [3]. *BS 5368*, describing the test methods, is also published as a European Standard (EN); *BS 6375*, specifying the relevant classifications, relates only to the U.K. Compliance with *BS 6375* requires a combined satisfactory performance for air infiltration, water penetration and wind resistance as reported elsewhere [5, 6]. This report considers only the air infiltration performance for comparison with natural ventilation criteria outlined in the relevant standards [7 - 9]. The analysis of all data is therefore related to the performance levels for air infiltration given in *BS 6375*, these performance levels being reproduced in Table 1 and shown graphically in Fig. 1; Table 1 incorporates the derived equations for air infiltration for each pressure classification listed in *BS 6375*.

The method of testing for air infiltration is fully defined in *BS 6375*. The window, when mounted in one wall of a test chamber, is subjected to increasing positive pressure up to 600 Pa, the pressure being applied to the outside face of the window in specified stages. The inner face is maintained at atmospheric pressure. At each pressure stage, the air infiltration rate is measured using suitable

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TABLE 1
Air infiltration classifications from *BS 6375*

Pressure classification		Derived correlation	Notes
Ref.	Pressure (Pa)	$\frac{Q}{l} = a(p_o - p_i)^n$	
I	150	$a = 0.5668,\ n = 2/3$	Maximum infiltration of 16 m^3/h per metre length of opening joint at given pressure classification
II	200	$a = 0.4678,\ n = 2/3$	
III	300	$a = 0.3570,\ n = 2/3$	
IV	600	$a = 0.0928,\ n = 2/3$	Applicable only when stringent performance levels required

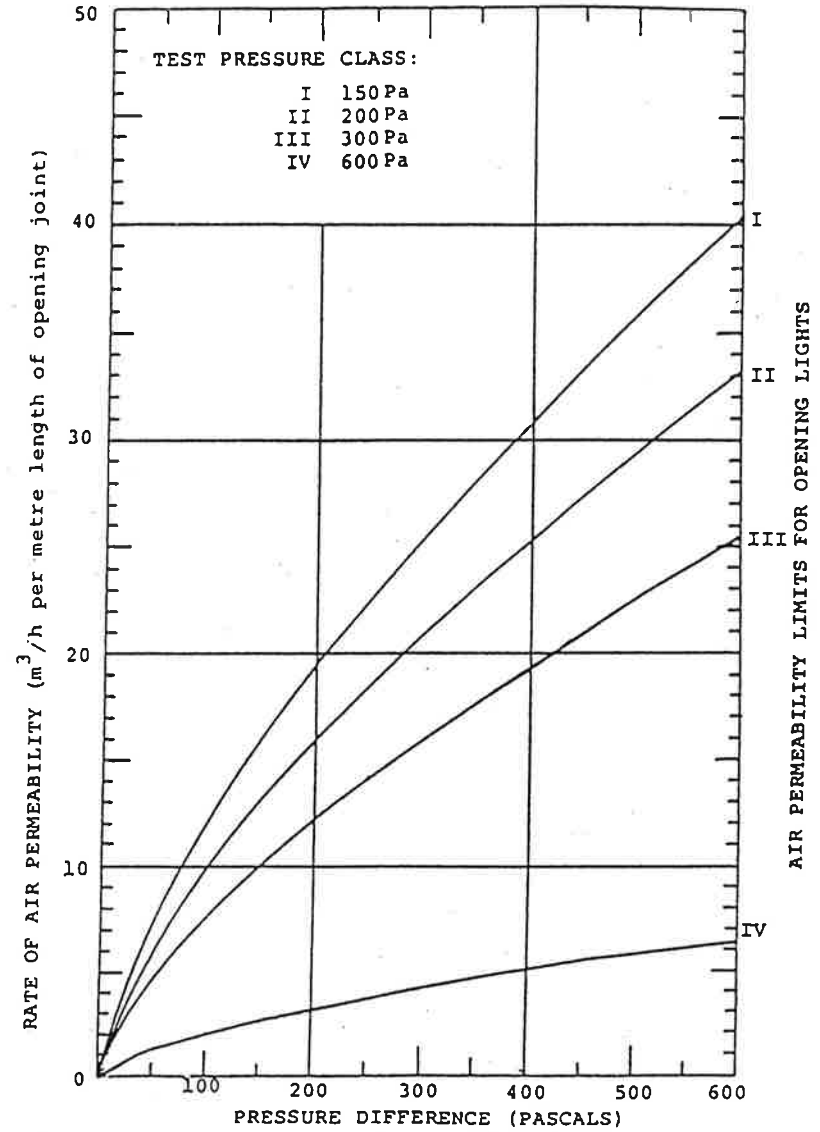


Fig. 1. Air infiltration classifications from *BS 6375*.

instrumentation. The test pressure is then applied in the reverse order and the air infiltration rate again measured. The higher of the two values of air infiltration rate at each pressure difference is recorded.

2.2. Description of windows

A total of 1004 windows have undergone testing since 1968 of which 209 have been excluded from the present analysis; those excluded from the analysis comprised 182 composite windows, which could not be categorized due to the multiplicity of opening lights, and 27 which were not included for various technical reasons. The distribution of the remaining 795 single-opening lights is given in Table 2. These comprised 675 with weatherseals and 120 with no weatherseals; weatherseals have normally been incorporated in all windows since approximately 1975. The material of the window frames comprised 75% timber, 10% aluminium, 4% steel, 11% PVC. PVC-framed windows were uncommon

TABLE 2
Distribution of tests

Type	No. of tests	Material	No. of tests
Horizontal pivot	411 (51.7%)	Timber	373 (90.8%)
		Aluminium	19 (4.6%)
		Steel	11 (2.7%)
		PVC	8 (1.9%)
		Total	411 (100%)
Vertical pivot	40 (5.0%)	Timber	30 (75.3%)
		Aluminium	1 (2.5%)
		Steel	8 (20.0%)
		PVC	1 (2.5%)
		Total	40 (100%)
Side hung	81 (10.2%)	Timber	61 (75.3%)
		Aluminium	3 (3.7%)
		Steel	6 (7.4%)
		PVC	11 (13.6%)
		Total	81 (100%)
Top hung	108 (13.6%)	Timber	84 (77.8%)
		Aluminium	6 (5.5%)
		Steel	4 (3.7%)
		PVC	14 (13.0%)
		Total	108 (100%)
Bottom hung	16 (2.0%)	Timber	15 (93.8%)
		PVC	1 (6.2%)
		Total	16 (100%)
Tilt-and-turn	74 (9.3%)	Timber	24 (32.4%)
		PVC	50 (67.6%)
		Total	74 (100%)
Horizontal slider	29 (3.7%)	Aluminium	28 (96.6%)
		Steel	1 (3.4%)
		Total	29 (100%)
Vertical slider	36 (4.5%)	Timber	15 (41.7%)
		Aluminium	19 (52.8%)
		PVC	2 (5.5%)
		Total	36 (100%)
Total analysed	795 (100%)		
Composite and others (excluded from analysis)	209		
Total tested	1004		

prior to about 1980 but have become increasingly popular in recent years. No distinction is made between single- and double-glazed windows as this has no bearing on the air infiltration through opening joints.

The windows are generally supplied for test in the "as new" condition and the test results applied to the actual installation and operating conditions which exist in a finished building. Although the method of testing takes some account of the quality control in the manufacturing process, it takes no account of random factors such as bad handling and poor installation on site. Nevertheless, providing that reasonable supervision is exercised in the factory and on site, the test results give an excellent indication of the performance to be expected in practice.

2.3. Classification for air infiltration

It is important to appreciate that the classification of windows is based on an individual assessment of the particular window under test. Repeatability of results for similar windows depends to a great extent on quality control in the manufacturing process, site-handling and installation techniques. This effect is clearly demonstrated in Fig. 2 which illustrates that, for three similar windows selected at random from a batch for a particular site, different pressure classifications were obtained.

The results for the 795 windows considered in the analysis are given in Table 3 and Table 4 which illustrate clearly the improved performance when weatherseals are incorporated; 94% of those tested with weatherseals achieved at least the 300 Pa classification compared with 69% of those without weatherseals. No distinction is made between materials of similar windows or types of weatherseal.

A comparison of the performance of the different types of window depends on the size of the sample taken and on the design pressure requirement. In Scotland, all windows are normally required to achieve a 300 Pa classification and the results indicate that

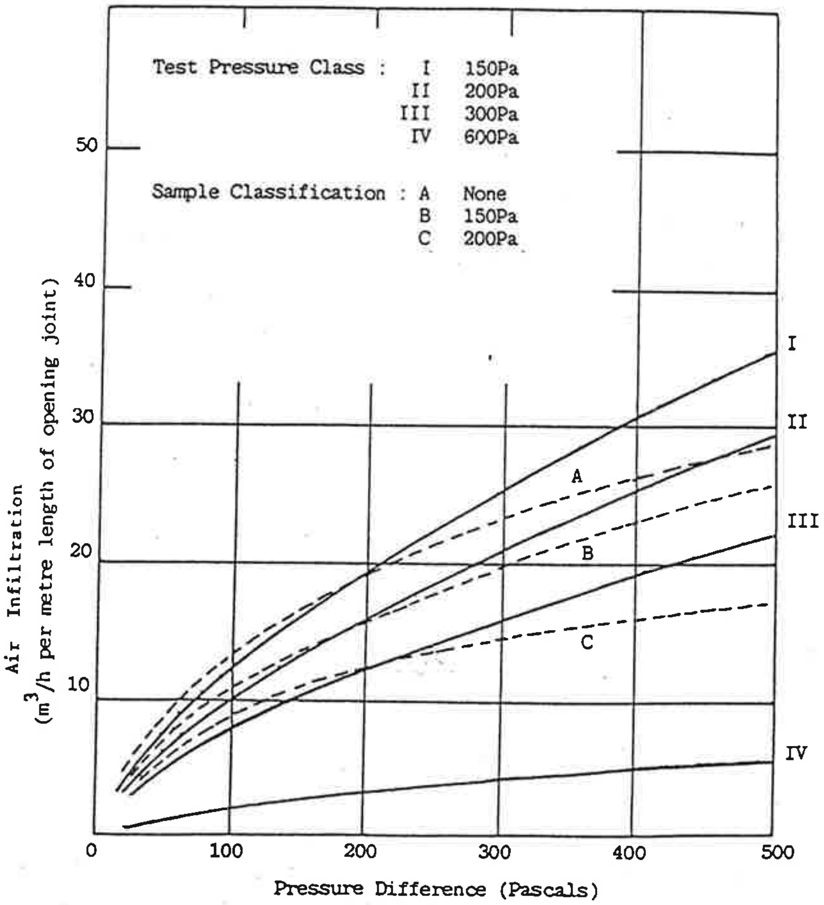


Fig. 2. Air infiltration rates for similar windows.

TABLE 3

Air infiltration classification — with weatherseals

Type	Number of each type	Numbers achieving the following pressure classifications				
		600 (Pa)	300 (Pa)	200 (Pa)	150 (Pa)	0 (Pa)
Horizontal pivot	353 (100%)	257 (72.8%)	72 (20.4%)	11 (3.1%)	4 (1.1%)	9 (2.6%)
Vertical pivot	36 (100%)	23 (63.9%)	10 (27.8%)	2 (5.5%)	—	1 (2.8%)
Side hung	65 (100%)	54 (83.1%)	8 (12.3%)	—	3 (4.6%)	—
Top hung	100 (100%)	86 (86.0%)	14 (14.0%)	—	—	—
Bottom hung	4 (100%)	4 (100%)	—	—	—	—
Tilt-and-turn	74 (100%)	63 (85.1%)	11 (14.9%)	—	—	—
Horizontal slider	16 (100%)	—	14 (87.5%)	2 (12.5%)	—	—
Vertical slider	27 (100%)	7 (25.9%)	13 (48.2%)	4 (14.8%)	1 (3.7%)	2 (7.4%)
Total no.	675 (100%)	494 (73.2%)	142 (21.0%)	19 (2.8%)	8 (1.2%)	12 (1.8%)

TABLE 4

Air infiltration classification — no weatherseals

Type	Number of each type	Numbers achieving the following pressure classifications				
		600 (Pa)	300 (Pa)	200 (Pa)	150 (Pa)	0 (Pa)
Horizontal pivot	58 (100%)	25 (43.1%)	16 (27.6%)	1 (1.7%)	4 (6.9%)	12 (20.7%)
Vertical pivot	4 (100%)	3 (75.0%)	1 (25.0%)	—	—	—
Side hung	16 (100%)	6 (37.5%)	6 (37.5%)	—	—	4 (25.5%)
Top hung	8 (100%)	3 (37.5%)	2 (25.0%)	—	3 (37.5%)	—
Bottom hung	12 (100%)	3 (25.0%)	2 (16.7%)	1 (8.3%)	1 (8.3%)	5 (41.7%)
Tilt-and-turn	—	—	—	—	—	—
Horizontal slider	13 (100%)	—	10 (76.9%)	1 (7.7%)	—	2 (15.4%)
Vertical slider	9 (100%)	—	6 (66.7%)	—	1 (11.1%)	2 (22.2%)
Total no.	120 (100%)	40 (33.3%)	43 (35.8%)	3 (2.5%)	9 (7.5%)	25 (20.8%)

more than 90% of all window types, with the exception of the horizontal and vertical slider types, achieved this classification when weatherseals were incorporated. A lower percentage of the windows without weatherseals achieved the required classification.

2.4. Correlation of results

Inspection of the results indicated that similar opening windows exhibited common characteristics. In view of this fact and the small sample of certain types, the windows have been grouped into four categories, namely,

(a) centre-pivot type, i.e., horizontal/vertical pivot;

(b) edge-hung type, i.e., side/top/bottom hung;

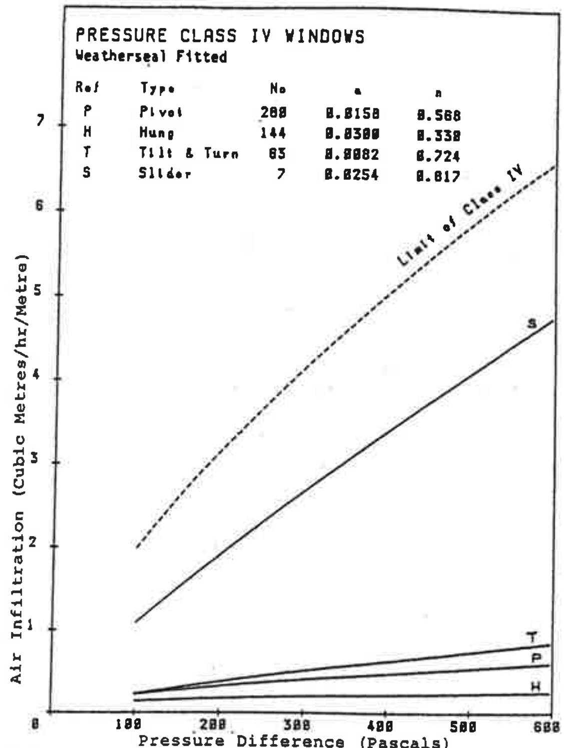
(c) tilt-and-turn type;

(d) side-slider type, i.e., horizontal/vertical slider.

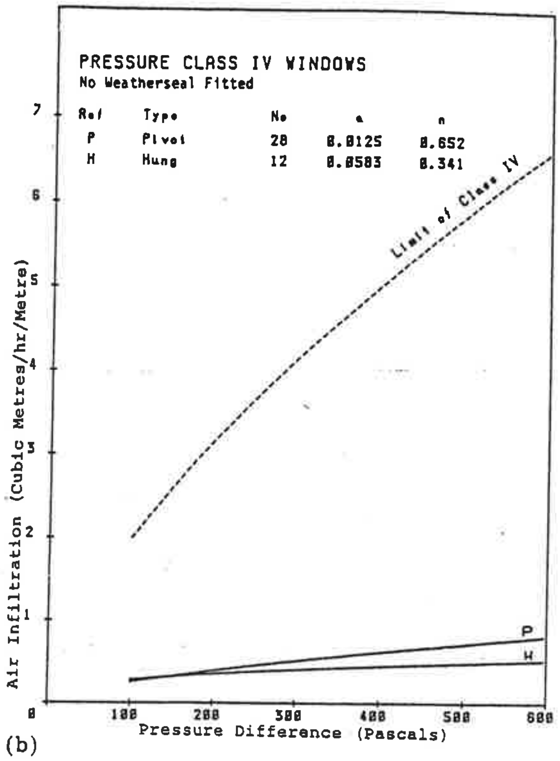
The non-repeatability characteristics of similar windows indicated that the analysis of the performance data be carried out within each range of performance classifications given in *BS 6375*, i.e., in the ranges

(i) 0 to 150 Pa: no classification
(ii) 150 to 200 Pa: classification I
(iii) 200 to 300 Pa: classification II
(iv) 300 to 600 Pa: classification III
(v) over 600 Pa: classification IV

The experimental data was subjected to a statistical analysis and, by using a power-curve fit equation, correlations were obtained for each category of window with and without weatherseals; in addition, correlations were obtained for all windows with weatherseals, without weatherseals and irrespective of



(a)



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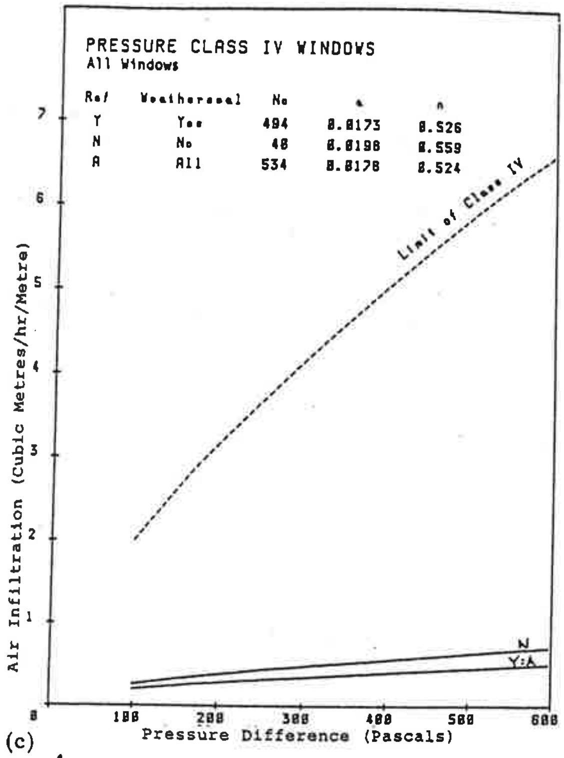


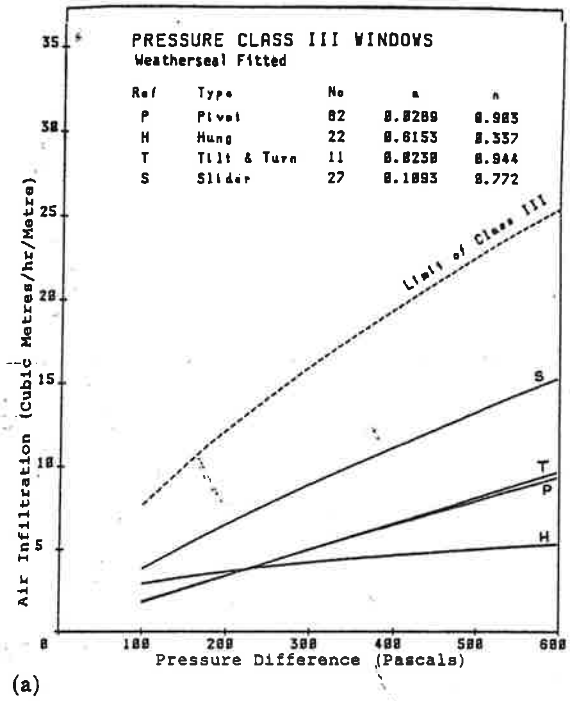
(c)

Fig. 3. (a) Class IV weathertightness correlations with weatherseal; (b) class IV weathertightness correlations with no weatherseal; (c) class IV overall weathertightness correlations.

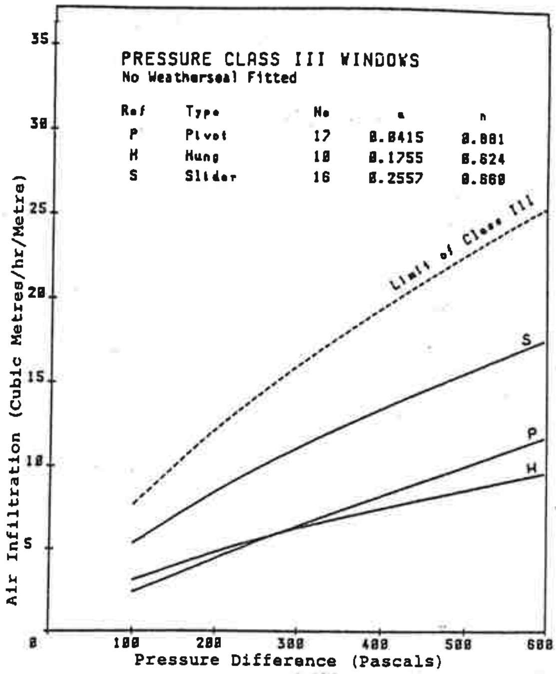
weatherseals. The correlations are shown graphically in Fig. 3 through to Fig. 6 and tabulated in Table 5, the correlations being expressed in the form

$$\frac{Q}{l} = a(p_o - p_i)^n$$

Data failing to achieve classification I and data from sets where the sample size was



(a)



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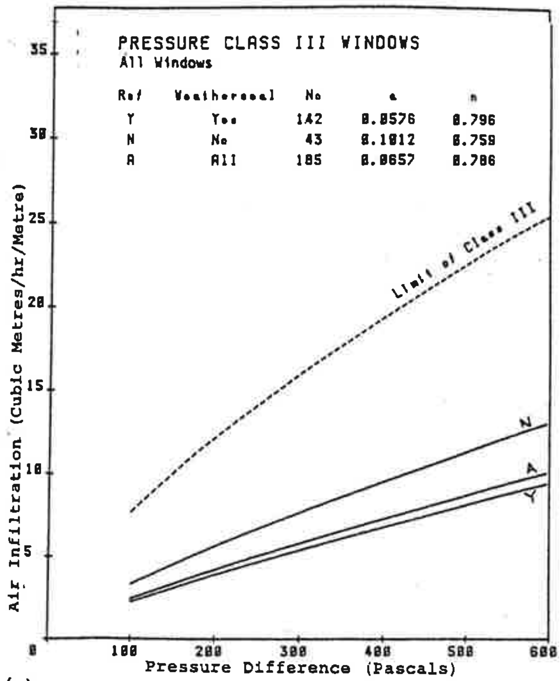


(c)

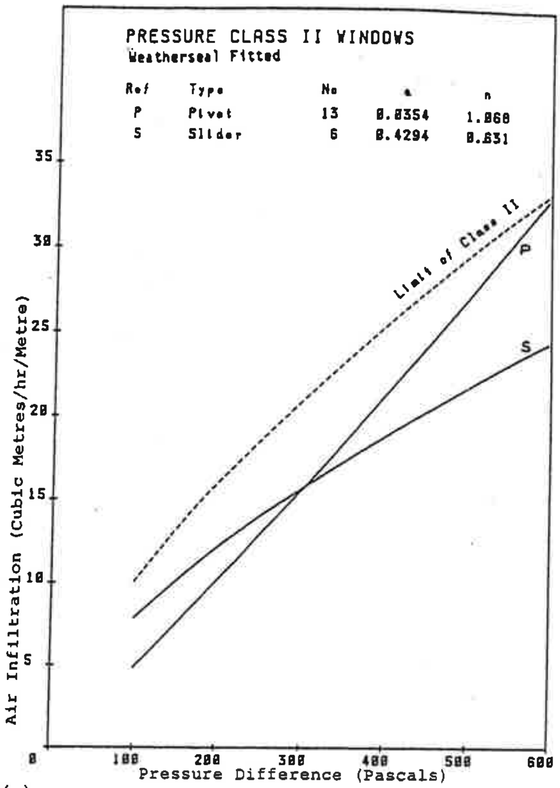
Fig. 4. (a) Class III weathertightness correlations with weatherseal; (b) class III weathertightness correlations with no weatherseal; (c) class III overall weathertightness correlations.

less than six have been excluded from the analysis.

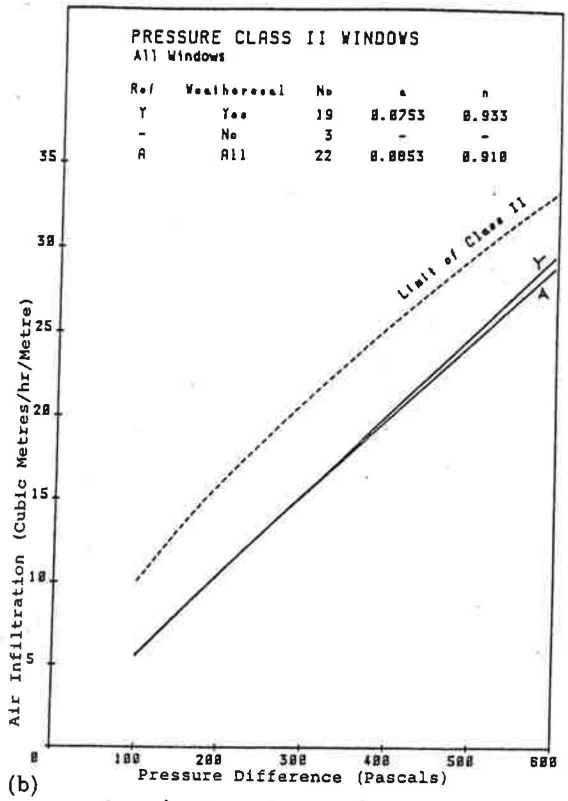
2.5. Conclusions

The weathertightness tests for air infiltration indicate that the performance is improved by the fitting of weatherseals; weatherseals are now regarded as an integral part of the window.

Results of classifications III and IV indicate that the windows may be ranked in order of increasing air infiltration as follows:



(a)



(b)

Fig. 5. (a) Class II weathertightness correlations with weatherseal; (b) class II overall weathertightness correlations.

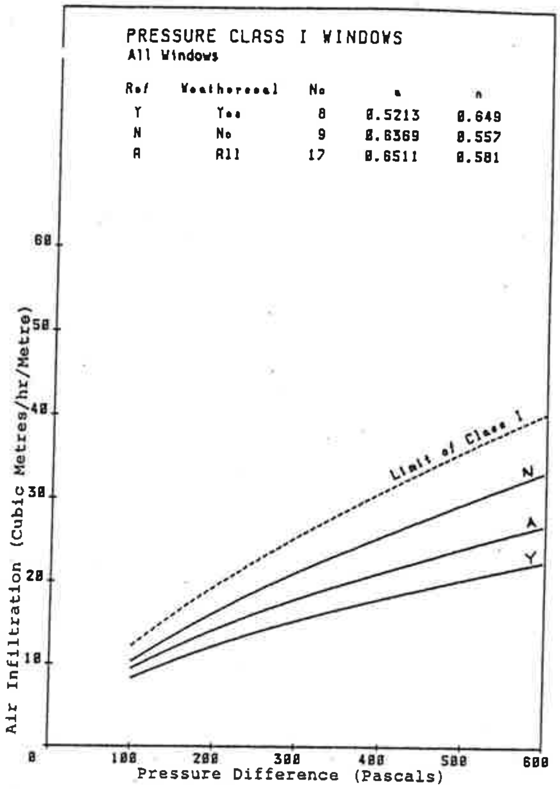


Fig. 6. Class I overall weathertightness correlations.

(a) side/top/bottom hung types;
(b) horizontal/vertical pivot types;
(c) tilt-and-turn type;
(d) horizontal/vertical slider types.

Insufficient data were available to confirm a similar ranking for classifications I and II.

The results also indicated that a very high proportion of the windows achieved classification IV which is only required for stringent performance levels. However, many windows incorporate a controllable ventilator which may be used to increase air infiltration. These ventilators, where fitted, are set in the closed position when air infiltration rates are being measured.

Correlations have been obtained for each type of window for a given pressure classification. Although individual correlations may be useful in particular cases, it is recommended that, for normal purposes, it is sufficient to use the overall correlation for each classification irrespective of window type. The exponent n in the overall correlations varies between 0.5 and 1.0 which is in agreement with current literature [8, 9] on air infiltration.

TABLE 5

Weathertightness correlations

Pressure classification	Window Type	No.	Weather-seals	Derived correlation a	n
IV (600 Pa)	Pivot	280	Yes	0.0158	0.568
	Hung	144	Yes	0.0300	0.330
	Tilt and turn	63	Yes	0.0082	0.724
	Slider	7	Yes	0.0254	0.817
	All	494	Yes	0.0173	0.526
	Pivot	28	No	0.0125	0.652
	Hung	12	No	0.0583	0.341
	All	40	No	0.0198	0.559
	All	534	All	0.0178	0.524
III (300 Pa)	Pivot	82	Yes	0.0289	0.903
	Hung	22	Yes	0.6153	0.337
	Tilt and turn	11	Yes	0.0230	0.944
	Slider	27	Yes	0.1093	0.772
	All	142	Yes	0.0576	0.796
	Pivot	17	No	0.0415	0.881
	Hung	10	No	0.1755	0.624
	Slider	16	No	0.2557	0.660
	All	43	No	0.1012	0.759
	All	185	All	0.0657	0.786
II (200 Pa)	Pivot	13	Yes	0.0354	1.068
	Slider	6	Yes	0.4294	0.631
	All	19	Yes	0.0753	0.933
	All	22	All	0.0853	0.910
I (150 Pa)	All	8	Yes	0.5213	0.649
	All	9	No	0.6369	0.557
	All	17	All	0.6511	0.581

3. NATURAL VENTILATION THROUGH WINDOWS

3.1. Background

Natural ventilation is the air flow resulting from the designed provision of specified apertures in a building. Air infiltration is the fortuitous leakage of air into the building due to the imperfections. In the case of window opening joints, it is assumed that natural ventilation and air infiltration are one and the same, i.e., the opening joint is considered to be a designed provision.

Infiltration or natural ventilation depends on natural phenomena and cannot be relied upon to provide a guaranteed rate of air interchange. Nevertheless the designer must be able to assess the extent of infiltration with respect to ventilation on the one hand and energy conservation on the other. The purpose of this section of the report is therefore to compare the recent data obtained from the weathertightness tests with existing correlations for natural ventilation.

3.2. Review of existing correlations

It has previously been stated that the classification of windows is highly susceptible to design criteria, quality control, site-handling and installation and that variations in performance of similar windows are to be expected. Nevertheless published data [7 - 9] are available which indicate methods of assessing air infiltration characteristics of different types of window either by means of appropriate correlations or by indicating infiltration data at specific pressure differences. For the purposes of comparison all data, including the single point data, have been expressed in the general equation for air infiltration through the opening joint, i.e., in the form

$$\frac{Q}{l} = a(p_o - p_i)^n$$

BS 5925 [7] gives correlations for particular types of window with and without weatherseals and irrespective of material. The data indicates the range and average value of the crack coefficient and suggests an exponent of 0.67.

The CIBS Guide on air infiltration [8] gives a graphical method of obtaining a basic air infiltration rate for a given building height, location and window type, again irrespective of material; correction factors are given to allow for the effect of internal room resistance. The basic method has been converted in this report to conform to the general equation and appropriate crack coefficients determined using an exponent of 0.67.

ASHRAE [9] gives individual values of permissible air infiltration which were determined at specific pressure differences. Although subject to deviation, the data has again been converted to conform to the general equation and the appropriate crack coeffi-

TABLE 6

Existing correlated data for air infiltration

Source	Type	Weatherseals	Material	Derived correlation		Weathertight-ness class (Pa)
				a	*n*	
BS 5925 [7]	Pivot	Yes	All	0.288	0.67	300
	Pivot	No	All	0.756	0.67	0
	Slider	No	All	0.288	0.67	300
CIBS [8]	Pivot	Yes	All	0.0954	0.67	300
	Pivot	No	All	0.4770	0.67	150
	Slider	Yes	All	0.2385	0.67	300
	Slider	No	All	0.4770	0.67	150
ASHRAE [9]	Pivot	*	Aluminium	0.1321	0.65	300
	Slider	*	Aluminium	0.2094	0.65	300
	Slider	*	Timber	0.2328	0.65	300
	Hung (loose fit)	No	Timber	0.8715	0.65	0
	Hung (loose fit)	Yes	Timber	0.8715	0.65	0
	Hung (av. fit)	No	Timber	0.3162	0.65	300
	Hung (av. fit)	Yes	Timber	0.1648	0.65	300
	Hung	*	Timber	0.2589	0.65	300
	Hung	*	Aluminium	0.1621	0.65	300
	All types	*	Timber	0.1675	0.65	300
	All types	*	All	0.5525	0.65	150

*Crack coefficient depends on design specification which will include weatherseal information.

cient determined by averaging common data and using the exponent of 0.65 suggested in the text.

The correlations obtained from the published data are tabulated in Table 6 which also indicates the appropriate weathertightness classification.

3.3 *Comparison of correlations*

The existing correlations tabulated in Table 5 indicate that although the correlations show marked variations, two-thirds of them satisfy the 300 Pa classification III for weathertightness. Comparison of the weathertightness correlation with the existing correlations for pivot-type windows with weatherseals is illustrated in Fig. 7. Similar comparisons can be made for other window types with and without weatherseals.

It must be emphasised that the ASHRAE correlations were based mainly on single point data using an exponent of 0.65. Alternative correlations can of course be obtained using different exponents.

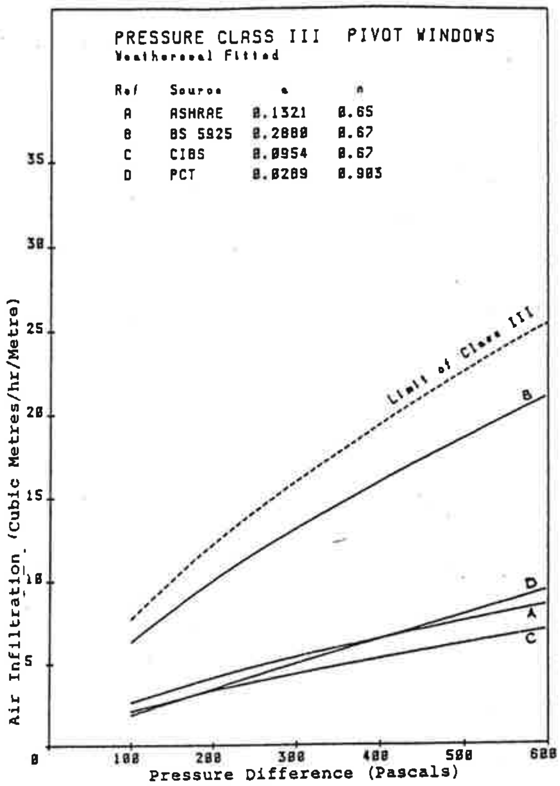


Fig. 7. Comparison of correlations.

3.4. *Conclusions*

Air infiltration correlations from existing published data and from weathertightness tests have been compared and found to exhibit considerable variation which can be reduced when comparison is carried out within the pressure classification limits for air infiltration given in weathertightness standards. It is therefore recommended that the determination of natural ventilation through windows be determined with reference to weathertightness criteria as discussed in the subsequent section.

4. RECOMMENDATIONS FOR DESIGN

The foregoing analysis has emphasised the different and opposing aims of standards for weathertightness and natural ventilation with respect to air infiltration through the opening joints of windows. Energy conservation may be achieved by restricting the air infiltration but may also lead to condensation and dampness problems; these problems can be avoided by supplying heating and ventilation at the expense of energy conservation. A balance is therefore required between energy conservation needs and ventilation requirements for the complete building but it is also essential for component parts of the building such as windows. The problem of striking the correct balance is of course hampered by the fact that natural ventilation is dependent on atmospheric conditions; nevertheless it is important that standards for weathertightness and natural ventilation performance should be compatible.

The proposed method of design is simple to apply. Both *BS 6375* [3] and *BS 5925* [7] relate design criteria to the "exposure" of the window, the exposure being expressed as a design wind pressure. This design wind pressure is determined from a consideration of meteorological wind speed records, geographical location, ground topography and building dimensions.

A statistical analysis of wind speed records gives a basic wind speed which is defined as the maximum speed averaged over a three-second period on a once-in-50 years probability and adjusted to give a value corresponding to 10 metres above ground in an open situation. Values of basic wind speeds and correction factors for topography, ground roughness and building shape are tabulated in *BS 6375*. The relationships between design wind pressure and pressure classification for air infiltration are reproduced from *BS 6375* as Table 7. Having obtained the appropriate weathertightness classification for air infiltration, the corresponding correlation for natural ventilation by air infiltration can be obtained from Table 8.

TABLE 7

Grade of exposure classification

Design wind pressure (Pa)	*BS 6375* pressure classification for air infiltration [3]	
Up to 1200	I : 150 Pa	Performance expected from opening light that is close fitting and without air seals.
	II: 200 Pa	Suitable for most dwellings and many other buildings.
1200 to 2000	II : 200 Pa or III: 300 Pa	Depends on design of building. Guidance on selection given in *BS 6375*
Over 2000	III: 300 Pa	
All levels	IV: 600 Pa	Applicable for any design wind pressure when stringent performance levels are required.

An illustration of the proposed method of design is given in Table 9. The method is applied to a simple building which is to be constructed in two different locations in the U.K. The Table indicates an appreciable difference between the design wind pressures at the two locations with a consequent requirement of a higher air infiltration classification for weathertightness and a lower air infiltration rate for the Glasgow location.

5. CONCLUSIONS

This report highlights the different objectives of weathertightness and natural ventilation performance and indicates the considerable variations in the existing methods of assessing air infiltration characteristics

TABLE 8

Recommended design correlations

BS 6375 pressure classification for air infiltration	Overall correlation for all window types		Correlation for individual windows (with weatherseal)		
	a	*n*	Type	*a*	*n*
IV: 600 Pa	0.0178	0.524	Pivot	0.0158	0.568
			Hung	0.0300	0.330
			Tilt and turn	0.0082	0.724
			Slider	0.0254	0.817
III: 300 Pa	0.0657	0.786	Pivot	0.0289	0.903
			Hung	0.6153	0.337
			Tilt and turn	0.0230	0.944
			Slider	0.1093	0.772
II: 200 Pa	0.0853	0.910	—	—	—
I: 150 Pa	0.6511	0.581	—	—	—

TABLE 9

Illustration of design method for a building of dimensions 10 m high, 3 m wide and 10 m long

Criteria	Location	
	City centre — Coventry	Open country — Glasgow
Basic wind speed*	44 m/s	51 m/s
Topography factor*	4	1
Shape factor*	1.4	1.4
Design wind pressure*	750 Pa	2350 Pa
Air infiltration pressure classification (Table 7)	I: 150 Pa or II: 200 Pa	III: 300 Pa
Overall correlation (Table 8)	I: $a = 0.6511$ $n = 0.581$ or II: $a = 0.0853$ $n = 0.910$	III: $a = 0.0657$ $n = 0.786$
Natural ventilation air infiltration rate at 150 Pa	I: 11.97 m^3/h per metre length or II: 8.15 m^3/h per metre length	III: 3.37 m^3/h per metre length

*Values obtained from published data — see *BS 6375* [3].

of windows from current standards; the weathertightness investigations confirm this variance. A method of resolving these differences has been outlined which will assist the designer in achieving a better balance between energy conservation needs and ventilation requirements with a consequent improvement in economic strategy. Although the design recommendations are related to British Standards, they can readily be adapted to conform to the appropriate standards used in other countries.

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