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WEATHERTIGHTNESS AND NATURAL VENTILATION CHARACTERISTICS OF WINDOWS

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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 (1,2,3,4); 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.

The results of the weathertightness investigations have recently been analysed (7) with reference to existing standards for natural ventilation (8,9,10) and the balance between energy conservation needs and ventilation requirements discussed.

The purpose of this paper is to present the results obtained from the weathertightness investigations and from the natural ventilation analysis in a form suitable for use by designers in predicting the interrelated objectives of energy conservation and ventilation requirements.

BACKGROUND

Weathertightness testing of windows has been carried out in the United Kingdom 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methods of testing and classifying windows were initially governed by BS 4315 (2) and BS DD4,1971 (1) and were later superseded by BS 5368 (4) and BS6375 (3).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 United Kingdom. Compliance with BS 6375 requires a combined satisfactory performance for air infiltration, water penetration and wind resistance (5,6).

The air infiltration performance of the window is an important consideration in determining natural ventilation requirements for a building. Published standards (8,9,10) for determining natural ventilation performance have shown considerable variations; a recent analysis (7) has been published which provides up-to-date criteria for determining natural ventilation based on weathertightness testing for air infiltration. The analysis is related to the performance levels for air infiltration given in BS 6375, these performance levels being reproduced in Table 1 and shown graphically in Figure 1; Table 1 incorporates derived equations for air infiltration at the limit of each pressure classification listed in BS 6375.

The method of testing for air infiltration is fully defined in BS 6375 in conjunction with BS 5368. 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 instrumentation. The test pressures are 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 adopted.

The windows are generally supplied for test in the 'as new' condition. 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.

RECOMMENDATIONS FOR DESIGN

The recent analysis (7) comparing weathertightness and natural ventilation performance highlighted 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 a balance 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 and on other factors such as stack effect, orientation, shape and internal layout of the building. Nevertheless it is important to establish compatibility between performance standards for weathertightness and natural ventilation.

The proposed method of design is simple to apply. BS 6375 relates design criteria to the 'exposure' of the window, the exposure being expressed as a design wind pressure. This pressure, which is the wind pressure for structural design purposes, 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 3-second period on a once in 50 year probability and adjusted to give a value corresponding to 10m above ground in an open situation. Values of basic wind speeds and correction factors for topography, ground roughness and building shape are given in BS 6375 in conjunction with BS CP3 (11) , the appropriate data being included as an Appendix to this report. The relationships between design wind pressure and pressure classification for air infiltration are reproduced from BS 6375 as Table 2. Having obtained the appropriate weathertightness classification for air infiltration, the corresponding correlation for natural ventilation by air infiltration can be obtained from the general equation for air infiltration through the opening joint of a window expressed in the form

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

where

a = crack coefficient [$m^3/h\ m\ Pa^n$]
l = length of crack [m]
n = exponent of pressure difference [-]
p_i = inside pressure [Pa]
p_o = outside pressure [Pa]
q = air flow through building component [m^3/h]

The values of a, n given in Table 3 were obtained by correlating the experimental data (7) pertaining to each pressure classification, the upper and lower limits of the correlated data in each classification being represented by the derived correlations given in Table 1. 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 (9,10) on air infiltration.

The correlations are derived on the basis of wind pressure difference only and exclude such variable parameters as stack effect, orientation, shape and internal construction of the building which will have an effect on the infiltration rate. The values obtained from the correlations are therefore conservative but give a satisfactory indication of the natural ventilation infiltration rate to be expected for a given pressure difference and weathertightness classification.

In practice, the actual infiltration rates measured during the weathertightness tests may indicate air infiltration rates which are less than the required design values. In these circumstances, additional means of achieving the designed infiltration rate will need to be provided, for example, by the incorporation of controlled ventilators in the window design.

ILLUSTRATIONS OF DESIGN METHOD

The following examples illustrate the proposed method of determining natural ventilation infiltration rates from weathertightness classifications. It must however be emphasised that, in order to achieve a realistic design value for infiltration rate, the normal or average pressure difference for a given location has to be determined.

Example 1. Building location - City Centre, Oxford
Building dimensions - Height 10m, Length 10m, Width 3m

As building height is not greater than 10m refer to BS 6375 abstracts in appendix:

From Fig 2, basic wind speed = 40m/s
From Table 4, ground roughness category = 4
From Table 5, $\frac{h}{w} = \frac{10}{3}$, $\frac{l}{w} = \frac{10}{10}$ Cp = 1.4
From Table 6, design wind pressure = 650 Pa

From Table 2, assume weathertightness classification = 200 Pa
From Table 3, a = 0.0853, n = 0.910
From natural ventilation correlation, maximum air infiltration rate = 10.59 m^3/h/m

ie, the maximum allowance for natural ventilation at a weathertightness classification of 200 Pa is 10.59 m^3/h per metre length of window opening joint.

It is necessary to emphasise the effect on the natural ventilation rate of installing a window which has achieved a higher weathertightness classification for air infiltration than is required for the above location. Assume that the window has achieved a 300 Pa pressure classification.

From Table 3, 300 Pa classification: a = 0.0657, n = 0.786
From natural ventilation correlation at 200 Pa, maximum air infiltration rate = 4.23 m^3/h/m

ie, the maximum allowance for natural ventilation at a weathertightness classification of 200 Pa has been reduced by (10.59 - 4.23) = 6.36 m^3/h per metre length of opening joint. To maintain the correct relationship between weathertightness classification and natural ventilation requirements would require this shortfall in ventilation rate to be made available by other means eg, a controlled ventilator incorporated in the window design.

If the building is to be constructed in a location where the average pressure difference is 50 Pa, the allowance for natural ventilation at a weathertightness classification of 200 Pa will be 3.0 m^3/h per metre length of opening joint.

Example 2. Building location - City Centre, Oxford
Building dimensions - Height 50m, Length 30m, Width 10m

As building height is greater than 10m refer to BS CP3 abstracts in appendix:

From Fig 2, basic wind speed = 40m/s
From Table 7, factor S_1 = 1.0
From Table 8, factor S_2 = 1.02
From Table 5, $\frac{h}{w} = \frac{50}{10}$, $\frac{l}{w} = \frac{30}{10}$, Cp = 1.4

Design wind speed = 40 x 1.0 x 1.02 = 40.8 m/s
Design wind pressure = 1.4 x 0.613 $(40.8)^2$ = 1428Pa

From Table 2, assume weathertightness classification = 200 Pa
Hence, natural ventilation requirement similar to Example 1

ie, the maximum allowance for natural ventilation at a weathertigheness classification of 200Pa is 10.59 m^3/h per metre length of window opening joint.

Example 3. Building location - Open Country, near Glasgow
Building dimensions - Height 10m, Length 10m, Width 3m

As building height not greater than 10m refer to BS 6375 abstracts in appendix:

From Fig 2, basic wind speed = 51 m/s
From Table 4, ground roughness category = 1

From Table 5, $\frac{h}{w} = \frac{10}{3}$, $\frac{l}{w} = \frac{10}{10}$ Cp = 1.4
From Table 6, design wind pressure = 2250 Pa + 20% = 2700Pa

From Table 2, weathertightness classification = 300 Pa
From Table 3, a = 0.0657, n = 0.786
From natural ventilation correlation, maximum air infiltration rate = 5.82 $m^3/h/m$

ie, the maximum allowance for natural ventilation at a weathertightness classification of 300 Pa is 5.82 m^3/h per metre length of opening joint.

The 300 Pa pressure classification is the highest classification normally required in the United Kingdom. The 600 Pa pressure classification is applicable only when stringent levels of performance are required eg, when there is a special need to limit heat loss, when an abnormal interior environment is intended or when air conditioning is to be employed. For any of these conditions:

From Table 3, a = 0.017, n = 0.524
From natural ventilation correlation, maximum air infiltration rate = 0.51 $m^3/h/m$

ie, the maximum allowance for natural ventilation at a weathertightness classification of 600 Pa is 0.51 m^3/h per metre length of window opening joint.

The effect of installing a window which has achieved a 600 Pa classification in a location which only requires a 300 Pa classification is to reduce the maximum allowance for natural ventilation by (5.82-0.35) = 5.47 m^3/h per metre length of opening joint and this reduction may have serious consequences in relation to energy conservation needs and ventilation requirements.

If the building is to be constructed in a location where the average pressure difference is 50Pa, the allowance for natural ventilation at a weathertightness classification of

(i) 300Pa will be 1.42 m^3/h per metre length of opening joint
(ii) 600Pa will be 0.13 m^3/h per metre length of opening joint

Example 4. Building location - Open Country, near Glasgow
Building dimensions - Height 50m, Length 30m, Width 10m

As building height is greater than 10m refer to BS CP3 abstracts in appendix.

From Fig 2, basic wind speed = 51 m/s
From Table 7, factor S_1 = 1.1
From Table 8, factor S_2 = 1.14
From Table 5, $\frac{h}{w} = \frac{50}{10}$, $\frac{l}{w} = \frac{30}{10}$, Cp = 1.4

Design wind speed = 51 x1.1 x1.14 = 63.95 m/s
Design wind pressure = 1.4 x 0.613 $(63.95)^2$ = 3510 Pa

From Table 2, weathertightness classification = 300Pa
Hence, natural ventilation requirement similar to Example 3

ie, the maximum allowance for natural ventilation at a weathertightness classification of 300 Pa is 5.82 m^3/h per metre length of opening joint.

CONCLUSIONS

A method of resolving the different objectives of weathertightness and natural ventilation requirements of windows 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.

The method forms a useful guideline for regions where natural ventilation is preferred to mechanical ventilation. Also, the 600Pa pressure classification for weathertightness performance is applicable to mechanically ventilated buildings and an indication of the air infiltration rate can therefore be obtained from the appropriate correlation.

The design recommendations, although related to British Standards, can readily be adapted to conform to the appropriate structural design, weathertightness and airtightness codes and standards used in other countries.

ACKNOWLEDGEMENTS

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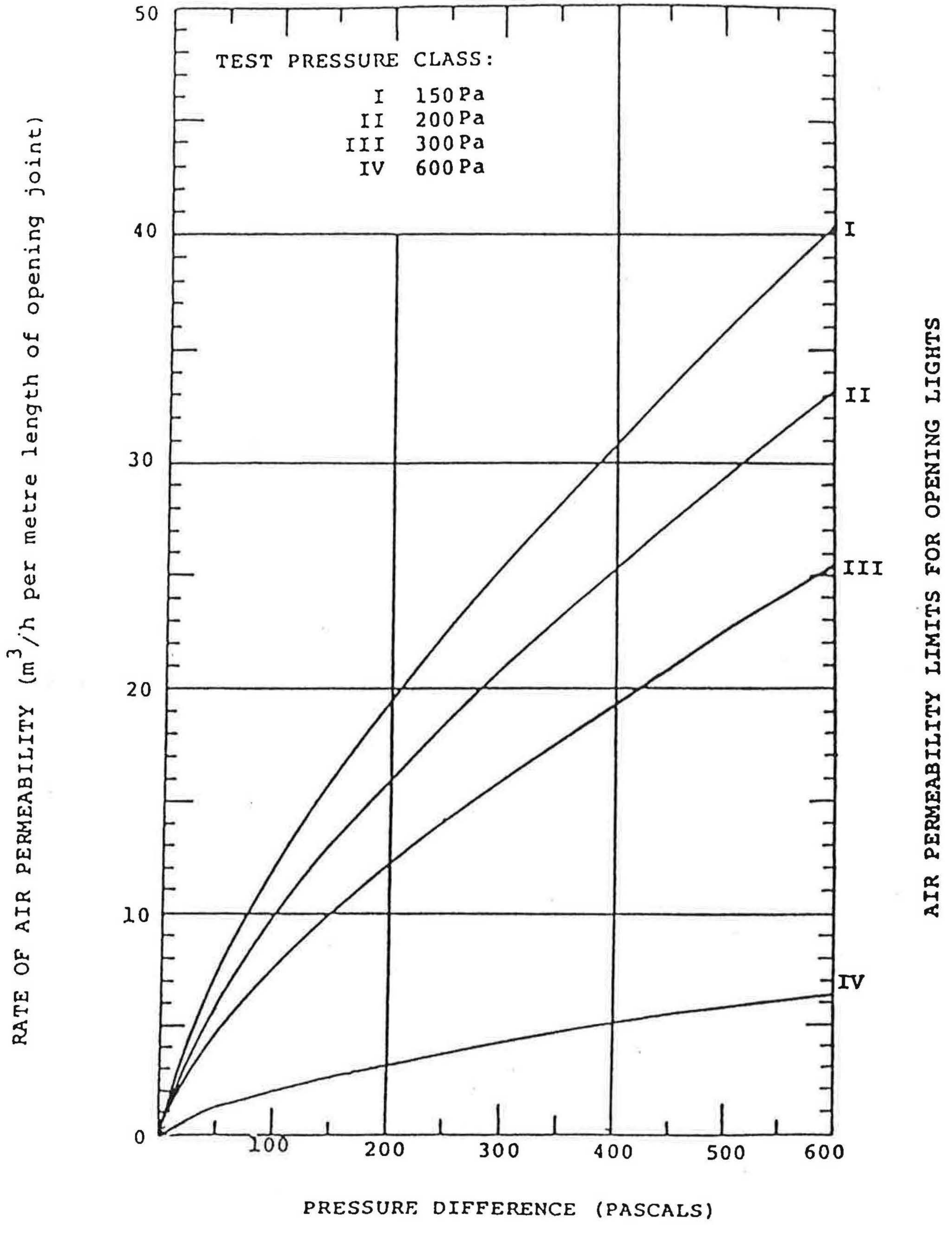

FIG. 1 : BS 6375 AIR INFILTRATION CLASSIFICATIONS.

DESIGN WIND PRESSURE (Pa)	BS6375[3] PRESSURE CLASSIFICATION FOR AIR INFILTRATION
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
	IV: 600 Pa : Applicable for any design wind pressure when stringent performance levels are required.

TABLE 2 : GRADE OF EXPOSURE CLASSIFICATION[3]

BS 6375[3] 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 & 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 & 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 3 : RECOMMENDED DESIGN CORRELATIONS[7]

APPENDIX

This appendix contains abstracts from BS 6375[3] and BS CP3[11] which are used to determine weathertightness classification for air infiltration.

Location	Category
Open country with no obstructions, and all coastal situations	1
Open country with scattered windbreaks	2
Country with many windbreaks; small towns; outskirts of large cities	3
Surface with large and frequent obstructions, e.g. city centres	4

NOTE: The locations are taken from Table 3 of CP 3: Chapter V: Part 2: 1972 for S_2 factors.

TABLE 4: GROUND ROUGHNESS CATEGORIES[3]

Building height (h/w) ratio	Building plan (l/w) ratio	Combined pressure coefficients (C_p)
Less than 1/2	From 1 to 3/2 From 3/2 to 4	1.0 1.2
From 1/2 to 3/2	From 1 to 4	1.3
From 3/2 to 6	From 1 to 4	1.4

NOTE 1. h is the height to eaves, l is the greater horizontal dimension of a building and w is the lesser horizontal dimension of a building.

NOTE 2. These combined internal and external pressure coefficients take into account the wind from any direction.

TABLE 5: COMBINED INTERNAL AND EXTERNAL PRESSURE COEFFICIENTS[3]

Basic wind speed (see figure 2)	Height to eaves	Design wind pressures (Pa)															
		Categories from table 4:															
		1				2				3				4			
		Coefficients from table 5:															
		1.0	1.2	1.3	1.4	1.0	1.2	1.3	1.4	1.0	1.2	1.3	1.4	1.0	1.2	1.3	1.4
m/s	m																
	3	1350	1600	1750	1850	1000	1200	1300	1400	800	950	1050	1100	600	750	800	850
56	5	1500	1800	1950	2100	1200	1450	1600	1700	950	1150	1250	1350	700	850	900	1000
	10	1950	2350	2500	2700	1700	2000	2200	2350	1200	1400	1550	1650	900	1050	1150	1250
	3	1250	1500	1600	1750	950	1150	1200	1300	750	900	950	1050	600	700	750	800
54	5	1400	1700	1800	1950	1150	1350	1450	1600	900	1050	1150	1250	650	800	850	900
	10	1800	2150	2350	2500	1650	1900	2050	2200	1100	1350	1450	1550	800	1000	1050	1150
	3	1150	1400	1500	1600	900	1050	1150	1200	700	850	900	950	550	650	700	750
52	5	1300	1550	1700	1800	1050	1250	1350	1450	850	1000	1050	1150	600	750	800	850
	10	1700	2000	2150	2350	1450	1750	1900	2000	1050	1250	1350	1450	750	900	1000	1050
	3	1100	1300	1400	1500	800	950	1050	1150	650	750	850	900	500	600	650	700
50	5	1200	1450	1550	1700	950	1150	1250	1350	750	900	1000	1050	550	700	750	800
	10	1550	1850	2000	2150	1350	1600	1750	1850	950	1150	1200	1300	700	850	900	1000
	3	1000	1200	1300	1400	750	900	950	1050	600	700	750	550	450	550	600	650
48	5	1100	1350	1450	1650	900	1100	1150	1250	700	850	900	1000	500	650	650	750
	10	1450	1700	1850	2000	1250	1500	1600	1750	900	1050	1150	1200	650	800	850	900
	3	900	1100	1200	1250	700	800	900	950	550	650	700	750	450	500	550	600
46	5	1000	1250	1300	1400	850	1000	1050	1150	650	800	850	900	500	600	600	650
	10	1300	1600	1700	1850	1150	1350	1450	1600	800	950	1050	1100	600	700	750	850
	3	850	1000	1100	1150	650	750	800	900	500	600	650	700	400	450	500	550
44	5	950	1150	1200	1300	750	900	1000	1050	600	700	750	850	450	550	550	600
	10	1200	1450	1650	1200	1050	1250	1350	1450	750	900	950	1050	550	650	700	750
	3	750	900	1000	1050	600	700	750	800	450	550	600	650	350	400	450	500
42	5	850	1050	1100	1200	700	850	900	950	550	650	700	750	400	500	500	550
	10	1100	1300	1400	1650	950	1150	1250	1350	650	800	850	950	500	600	650	700
40	3	700	850	900	950	550	650	700	750	400	500	550	600	350	400	400	450
	5	750	950	1000	1100	650	750	800	850	500	600	650	700	350	450	450	500
	10	1000	1200	1300	1400	850	1050	1100	1200	600	750	800	850	450	550	600	650
	3	650	750	800	850	500	550	600	650	400	450	500	550	300	350	400	400
38	5	700	950	900	1000	550	700	750	800	450	550	600	600	350	400	450	450
	10	900	1100	1150	1250	800	950	1000	1100	550	650	700	750	400	500	550	650

NOTE 1. The figures have been rounded.

NOTE 2. The building life factor S_3 used in the table is 1.0 (i.e. 50 year period).

NOTE 3. The topography factor S_1 used is 1.0. For an S_1 factor of 1.1, add 20 % to the above wind pressures and for S_1 = 0.9 deduct 20 %. (See CP 3 : Chapter V : Part 2 for a further explanation.)

NOTE 4. For a description of categories 1, 2, 3 and 4, see table 4.

NOTE 5. For height of buildings not covered by this table, determine the design wind pressure in accordance with CP 3 : Chapter V : Part 2 .

TABLE 6: DESIGN WIND PRESSURES [3]

Topography	Value of S_1
a. All cases except those in *b.* and *c.* below	1.0
b. Very exposed hill slopes and crests where acceleration of the wind is known to occur. Valleys shaped to produce a funnelling of the wind	1.1
c. Steep sided, enclosed valleys sheltered from all winds	0.9

TABLE 7: TOPOGRAPHY FACTOR S_1 (11)

	(1) Open country with no obstructions			(2) Open country with scattered windbreaks			(3) Country with many windbreaks; small towns; outskirts of large cities			(4) Surface with large and frequent obstructions, e.g. city centres		
H	Class A	B	C	Class A	B	C	Class A	B	C	Class A	B	C
m												
3 or less	0.83	0.78	0.73	0.72	0.67	0.63	0.64	0.60	0.55	0.56	0.52	0.47
5	0.88	0.83	0.78	0.79	0.74	0.70	0.70	0.65	0.60	0.60	0.55	0.50
10	1.00	0.95	0.90	0.93	0.88	0.83	0.78	0.74	0.69	0.67	0.62	0.58
15	1.03	0.99	0.94	1.00	0.95	0.91	0.88	0.83	0.78	0.74	0.69	0.64
20	1.06	1.01	0.96	1.03	0.98	0.94	0.95	0.90	0.85	0.79	0.75	0.70
30	1.09	1.05	1.00	1.07	1.03	0.98	1.01	0.97	0.92	0.90	0.85	0.79
40	1.12	1.08	1.03	1.10	1.06	1.01	1.05	1.01	0.96	0.97	0.93	0.89
50	1.14	1.10	1.06	1.12	1.08	1.04	1.08	1.04	1.00	1.02	0.98	0.94
60	1.15	1.12	1.08	1.14	1.10	1.06	1.10	1.06	1.02	1.05	1.02	0.98
80	1.18	1.15	1.11	1.17	1.13	1.09	1.13	1.10	1.06	1.10	1.07	1.03
100	1.20	1.17	1.13	1.19	1.16	1.12	1.16	1.12	1.09	1.13	1.10	1.07
120	1.22	1.19	1.15	1.21	1.18	1.14	1.18	1.15	1.11	1.15	1.13	1.10
140	1.24	1.20	1.17	1.22	1.19	1.16	1.20	1.17	1.13	1.17	1.15	1.12
160	1.25	1.22	1.19	1.24	1.21	1.18	1.21	1.18	1.15	1.19	1.17	1.14
180	1.26	1.23	1.20	1.25	1.22	1.19	1.23	1.20	1.17	1.20	1.19	1.16
200	1.27	1.24	1.21	1.26	1.24	1.21	1.24	1.21	1.18	1.22	1.21	1.18

Class A. All units of cladding, glazing and roofing and their immediate fixings and individual members of unclad structures (see 7.2, Note).

Class B. All buildings and structures where neither the greatest horizontal dimension nor the greatest vertical dimension exceeds 50 m (165 ft).

Class C. All buildings and structures whose greatest horizontal dimension or greatest vertical dimension exceeds 50 m (165 ft).

TABLE 8: GROUND ROUGHNESS, BUILDING SIZE AND HEIGHT ABOVE GROUND, FACTOR S_2 (11)

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 $m^3/h/m$ 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.

TABLE 1 : BS 6375 AIR INFILTRATION CLASSIFICATIONS[3]

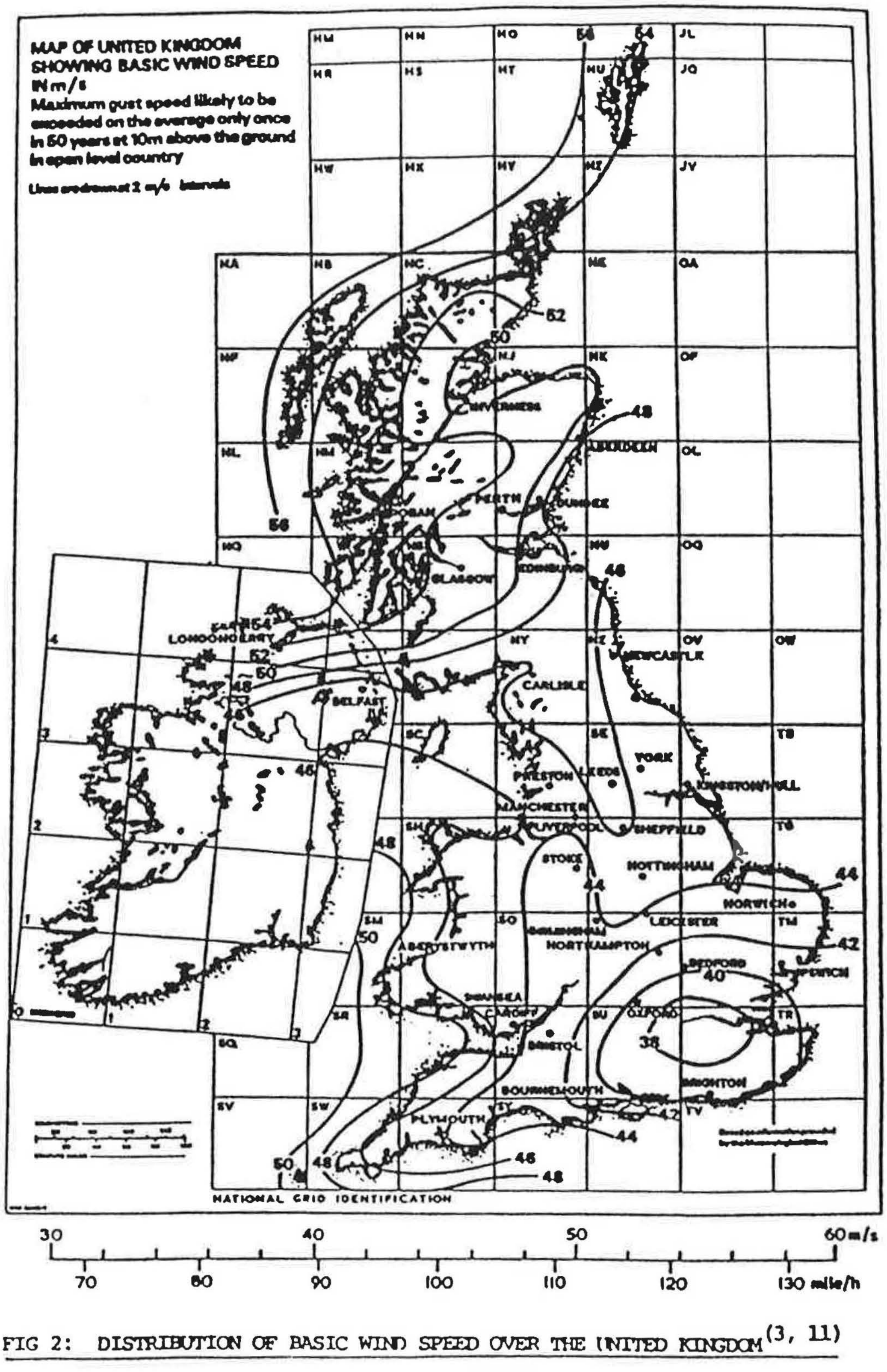

FIG 2: DISTRIBUTION OF BASIC WIND SPEED OVER THE UNITED KINGDOM (3, 11)