THE VARIABILITY OF TEST RESULTS WHEN ASSESSING THE RESISTANCE OF WINDOWS TO WATER AND AIR PENETRATION USING BS4315

by J F S Carruthers and C J Newman
Princes Risborough Laboratory of the
Building Research Establishment, UK

INTRODUCTION

The investigation was undertaken to assess the variability of windows tested to British Standard 4315:Part 1:1968, Methods of test for resistance to air and water penetration: windows and gasket glazing systems. Since the issue of this Standard, it has been widely used as a means of specifying the performance of windows for use in the UK. However, the variability of this test method had not been examined systematically.

The programme was intended to assess variability in both water and air tests from five causes:

Different designs of window
Differences between individual windows of the same type
Different pressure test boxes
Different test operators
The residual variability inherent in the test after excluding all other factors

THE WINDOWS TESTED

One hundred and thirty windows, approximately 1.2 m square and of the five types described in Table 1, were tested.

THE PRESSURE TEST BOXES

Three different pressure boxes were used, though the majority of the tests were carried out on two. Two skilled operators were involved.

RESULTS

The main results for air penetration are shown in Tables 2 and 3 and for water penetration in Tables 4 and 5.

CONCLUSIONS

The test programme has shown that considerable variation occurs in the testing of the air and water penetration attributes of windows to BS 4315:Part 1.

With both water and air penetration there was no single source of the wide variation found in the test results. Indeed, the differences between individual windows of a type, between boxes, between operators and associated with the test procedure as such appeared to contribute to a similar extent to the total variation experienced.

THE IMPLICATIONS OF THE TEST PROGRAMME FOR THE SPECIFICATION OF AIR AND WATER PENETRATION

With the range in variation found in the test programme, it is not possible to predetermine without an extensive background of test results the variation that could occur with a particular design and type of window. As a result, it becomes difficult to set realistic performance levels for specification and procurement purposes. One approach is simply to assume a maximum variation and apply it to all windows in setting performance levels. This approach, however, could penalise windows giving a consistent performance, especially in the case of water penetration. A second alternative is to adopt a two-stage statistical procedure that can accommodate the variation associated with the actual group of windows tested.

Table 1 Details of windows examined

Type				
Designation	Description	Material and finish	Draught stripping	Number obtained for testing
IA	Horizontal slider in timber sub-frame One opening light one fixed light	Aluminium mill finish	Brush and neo- prene seals	30
IB	Horizontal slider in timber sub-frame One opening light one fixed light	Aluminium mill finish	Brush seal	5
II	Side-hung casement in timber sub-frame One opening light one fixed light Weather bar at head	Aluminium mill finish	Neoprene seal	40
III	Vertical slider in timber sub-frame Two sliding lights	Aluminium mill finish	Brush and neo- prene foam seal	20
IV	Side-hung casement and vent light Two opening lights one fixed light Weather bar at head	Timber Gloss paint finish	None	30
V	Side-hung casement and vent light in timber sub-frame Two opening lights one fixed light Weather bar at head	Steel Gloss paint	None	6

Table 2 Air penetration at 100 Pa of windows tested using two boxes and two operators

Type designation	Number of windows tested	Mean air penetration (m^3/h m)*	Standard deviation (m^3/h m)*	Range within which 95% of window tests occur (m^3/h m)*
IA	30	3.6	1.6	0.4 – 6.8
IB	5	13.8	1.8	10.2 – 17.4
II	40	2.2	1.3	0 – 4.8
III	20	11.1	1.6	7.9 – 14.3
IV (a) whole window	30	7.9	3.2	1.5 – 14.3
(b) side-hung casement only	30	8.7	4.2	0.3 – 17.1
(c) vent light only	30	6.4	3.1	0.2 – 12.6
V (a) whole window	6	23.8	3.8	16.2 – 31.4
(b) side-hung casement only	6	25.0	4.5	16.0 – 34.0
(c) vent light only	6	21.8	4.1	13.6 – 30.0

*The rate of air penetration is expressed at m^3/h per metre length of opening light

Table 3 Source and extent of variation in the air penetration of windows

Type designation	Source and extent of variation					
	Between windows		Between two box/ operator combinations		Associated with test procedure	
	Number of windows examined	Standard deviation ($m^3/h\ m$)	Number of windows examined	Difference in mean value ($m^3/h\ m$)	Number of windows examined	Standard deviation ($m^3/h\ m$)
IA	20	0.9	10	1.3	20	1.3
IB	5	1.3	–	–	5	0.8
II	20	1.3	10	1.3	20	0.8
III	20	0.9	10	1.4	20	1.1
IV (a) whole window	20	2.1	10	1.3	20	1.3
(b) side-hung casement only	10	3.5	10	3.3	10	0.8
(c) vent light only	10	2.7	10	2.0	10	0.9
V (a) whole window	6	*	–	–	6	2.5
(b) side-hung casement only	6	} *	–	–	6	3.7
(c) vent light only	6					

*No statistically significant difference at the 5% level
–No test carried out

Table 4 Water penetration (pressure at which 'gross' leakage occurred) tests on windows using two boxes and two operators

Type designation	Number of windows tested	Mean pressure for 'gross' leakage (Pa)	Standard deviation (Pa)	Range within which 95% of window tests occur (Pa)
IA	30	160	55	50 – 270
IB	5	190	22	146 – 234
II	40	360	241	0 – 842
III	20	630	184	262 – 998
IV (a) whole window	30	200	102	0 – 404
(b) side-hung casement only	30	230	101	28 – 432
(c) vent light only	30	310	259	0 – 828
V (a) whole window	5	260	22	216 – 304
(b) side-hung casement only	5	280	27	246 – 314
(c) vent light only	5	260	22	216 – 304

Table 5 Source and extent of variation in water penetration of windows

	Source and extent of variation							
	Between windows		Between two operators		Between two boxes		Associated with test procedure	
Type designation	Number of windows	Standard deviation (Pa)	Number of windows	Difference in mean value (Pa)	Number of windows	Difference in mean value (Pa)	Number of windows	Standard deviation (Pa)
IA	6	10	10	*(1)	10	*(1)	6	29
IB	5	19	–	–	–	–	5	25
II	5	253	10	*(1)	10	*(1)	5	209
III	5	70	8	63	8	144	5	125
IV (a) whole window	5	*	5	80	5	*	5	97
(b) side-hung casement only	5	*	5	130	5	40	5	50
(c) vent light only	5	89	5	*	5	95	5	114
V (a) whole window	5	23	–		–		5	24
(b) side-hung casement only	5	22					5	20
(c) vent light only	5	23					5	24

*No statistically significant difference at the 5% level
–No test carried out

(1) For window types IA and II differences between operators and between boxes were not isolated. The result given for the window types refers to the difference between two box/operator combinations.

SUGGESTED TEST PROCEDURES

It is suggested that the criteria for acceptance should be such that there is a 75 per cent chance that the group of windows tested is drawn from a population of which 95 per cent of the windows have a higher test result than the specified level. It can be shown[2] that this criterion is met when the mean of five results is more than 2.46 times the standard deviation of those 5 results above the specified level. With fewer test samples the multiplying factor is increased, for example for four windows it is 2.68, and for more test samples the multiplying factor is decreased, for example for 6 windows it is 2.33. The use of five samples is suggested in this paper as being appropriate taking into account, on the one hand, the need to minimise the cost incurred by testing and on the other, the benefits obtained from testing a larger number of windows.

If the five windows tested fail this initial coarse assessment, it is permissible to examine another five windows. The tests on these ten windows are then repeated to remove the effect of the variability of the test procedure and the mean result when reduced by 2.1 standard deviations should then be above the specified level for a 'pass' to be accepted.

The proposed method is detailed and an example of the calculation for the water penetration attribute is given in the Appendix to this paper.

REFERENCES

1 The repeatability and reproduceability of test results on windows and wall span elements and the expected results. By J F S Carruthers and C J Newman. BRE Current Paper CP 49/77.

2 A note on performance testing and use of statistics. By G Christensen, Danish Building Research Institute. Paper 10/10, CIB W60, Oslo, March 1977.

APPENDIX

SUGGESTED ASSESSMENT PROCEDURE FOR AIR AND WATER PENETRATION TESTS

Stage 1 Calculation of characteristic test performance from results of testing five windows once each.

Let $x_1\ x_2\ \ldots\ldots\ x_5$ be individual results

$$\text{the mean } \bar{x} = \frac{\Sigma x}{5}$$

$$\text{and standard deviation } s = \sqrt{\frac{\sum(x^2) - \frac{(\Sigma x)^2}{5}}{4}}$$

With a 75 per cent chance that this group of windows is drawn from a population of which 95 per cent of the windows have a higher or lower test result than the specified level then:

the characteristic test performance = $\bar{x} \pm 2.46s$

For example if five windows gave the following results for the water penetration test:

150 200 150 200 250 Pa

$\Sigma x = 950, \bar{x} = 190$ and $\Sigma(x^2) = 187500$

$$s = \sqrt{\frac{187500 - \frac{950^2}{5}}{4}} = 41.8$$

Therefore characteristic water test performance = 190 – (2.46 x 41.8) Pa
= 87 Pa

If the specification pass level is 50 Pa the windows would pass. However if it was 100 Pa they would just fail and stage 2 of the assessment procedure could be invoked especially as the characteristic water test performance approaches the pass level required.

Stage 2 Calculation of characteristic test performance from results of testing ten windows twice each:

Let $x_{1.1}\ x_{1.2}\ \ldots\ldots\ldots\ x_{1.10}$ be first test results

and let $x_{2.1}\ x_{2.2}\ \ldots\ldots\ldots\ x_{2.10}$ be second test results

Then to use the analysis of variance techniques to identify the window variance:

(a) square each test result and sum, ie $\Sigma(x^2)$

(b) add together two test results for each window, square these totals, sum the squares and divide by 2, ie

$$\frac{(x_{1.1} + x_{2.1})^2 + (x_{1.2} + x_{2.2})^2 + \cdots (x_{1.10} + x_{2.10})^2}{2}$$

(c) add together all twenty test results, square this total and divide by 20 ie

$$\frac{(\Sigma x)^2}{20}$$

Then test variance $s_t^2 = \frac{(a) - (b)}{10}$

As the variance between results for different windows

$$2s_w^2 + s_t^2 = \frac{(b) - (c)}{9} \text{ where } s_w \text{ is the window variance}$$

$$\text{then window variance alone } s_w^2 = \frac{\frac{(b) - (c)}{9} - \frac{(a) - (b)}{10}}{2}$$

$$\text{and characteristic performance now } = \bar{x} \pm 2.1\, s_w$$

For example if two water penetration tests on each of ten windows give the following results

1st test	150	200	150	200	250	150	150	200	150	200 Pa
2nd test	150	150	200	200	200	200	100	150	150	100 Pa
then $(x_1 + x_2)$	300	350	350	400	450	350	250	350	300	300 and $\bar{x}$ = 170 Pa

(a) $\Sigma(x^2) = 605\,000$

(b) $\frac{\Sigma(x_1 + x_2)^2}{2} = 592\,500$

(c) $\frac{(\Sigma x)^2}{20} = 578\,000$

$$\text{Therefore test variance } s_t^2 = \frac{605\,000 - 592\,500}{10} = 1250$$

As variance between results for different windows

$$2s_w^2 + s_t^2 = \frac{592\,500 - 57\,800}{9} = 1611.1$$

$$\text{Then window variance alone } s_w^2 = \frac{1611.1 - 1250}{2} = 180$$

and $s_w = 13.4$

Therefore characteristic performance = 170 – (2.1 x 13.4)
= 142 Pa

The windows now pass the 100 Pa specified level.