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AIR LEAKAGE PERFORMANCE OF VERTICAL SLIDING, DOUBLE-HUNG AND HINGED WINDOWS FOR RESIDENTIAL USE

by

J.R. Sasaki

Internal Report No. 315

of the

Division of Building Research

Ottawa

September 1965

PREFACE

Information on the air leakage performance of windows continues to be of some importance, for use in the assessment of window performance and in the estimation of heating and cooling loads. Results obtained on the air leakage performance of residential horizontal sliding windows carried out as part of a program of window studies were previously reported. The studies have now been extended to include a number of other types, the results for which are now reported.

The main conclusions from both of these studies have already been published in a paper entitled "Air Leakage Values for Residential Windows" by J.R. Sasaki and A.G. Wilson. This was presented at the 72nd Annual Meeting of ASHRAE at Portland, July 1965 and will appear in ASHRAE Transactions Part II 1965. The present report, as does DBR Report No. 251, provides further details of the window constructions and of the results than was possible in the paper.

The author, a mechanical engineer and a research officer with the Building Services Section of the Division, is in charge of the window leakage studies.

Ottawa, Ont.,
September 1965

N.B. Hutcheon,
Assistant Director.

AIR LEAKAGE PERFORMANCE OF VERTICAL SLIDING, DOUBLE-HUNG AND HINGED WINDOWS FOR RESIDENTIAL USE

by

J. R. Sasaki

Air leakage measurements of twenty-one hinged, vertical sliding, and double-hung factory-built windows for residential use are reported. This series of tests is the second part of a program undertaken by the Division of Building Research to investigate the air leakage performance of some typical Canadian residential windows purchased in the period, 1960-61. The first series of tests, on horizontal sliding windows, was reported in DBR Internal Report No. 251. The present report compares the leakage characteristics of the test windows with (1) air leakage criteria for residential windows established by the Canadian Government Specifications Board and (2) design values for residential windows suggested by the Guide of the American Society of Heating, Refrigerating and Air Conditioning Engineeers. The sources of leakage are also described.

DESCRIPTION OF TEST WINDOWS

The twenty-one windows tested can be divided into nine groups according to the material of the sash and frame:

(1) E1 to E3 - vertical sliding and double-hung windows with wood sash and frame;

(2) F1 and F2 - vertical sliding and double-hung windows, wood frame, aluminum sash and tracks;

(3) G1 and G2 - double-hung windows, aluminum frame, sash and tracks;

(4) H1 - vertical sliding windows, steel frame, sash and tracks;

(5) K1 to K4 - projected windows, wood frame and sash;

(6) L1 - projected windows, aluminum frame and sash;

(7) M1 to M4 - casement windows, wood frame and sash;

(8) N1 and N2 - casement windows, aluminum frame and sash;

(9) P1 and P2 - casement windows, steel frame and sash.

The vertical sliding and double-hung windows of groups (1) to (4) are described in Table I. The sash of the double-hung window is attached to the frame by some form of balance device such as a counterweight, a spiral-spring or a spring-wound tape; the sash in a sliding window is held open either by friction of the sash in the tracks or by sash-mounted lock pins that engage holes along the jamb tracks. Windows F1, F2, G1 and G2 are double windows with nearly identical inner and outer operating units; window H1 is a single window; and windows E1 and E2 are basically single windows equipped with storm units. The details of the vertical sliding and double-hung window types are shown in Figures 1 to 7.

The projected and casement windows are described in Table II. All the windows of groups (5) to (9) are single windows, but the wood projected and casement windows are provided with removable glazing units, with light aluminum surrounds, attached to the operating sash. The light aluminum sash or glazing unit does not have the strength required of a full-weight aluminum residential window sash in CGSB Specification 63-GP-3. Its primary function is to protect the glass edge from chipping and to carry the hardware and weatherstripping; it adds little rigidity or strength to the glass. The four wood projected windows are bottom-outswinging awning types; the aluminum projected window is a side-outswinging unit. All the casement windows are side-hinged outswinging units. The details of typical wood projected and casement windows are shown in Figures 8 and 9. Details of the aluminum and steel casement windows are shown in Figures 10 to 12.

APPARATUS AND TEST PROCEDURE

The tests were performed in the DBR window air leakage apparatus (Figure 13). It consists of two air-tight boxes with provision for mounting the window between them in an air-tight panel. Air is supplied to the high pressure chamber from a d-c motor-driven blower. Calibrated orifice meters are mounted on the rear wall of the metering chamber. As the chambers are sealed to the mounting panel, the air supplied to the pressure chamber flows through the window into the metering chamber, then through the flowmeter to the room. The flow of air measured at the orifice meter is nominally equal to the flow of air that passes through the window. Perfect sealing is never achieved, however, and the extraneous leakage from the metering box must be determined before the test and accounted for in the calculation of the window air leakage.

The window under test was mounted in the panel, with sealing between the panel and moulding along the exterior face of the window frame only. The sash and lock adjustments as well as any other alternations to the window configuration were made and the air supply to the high pressure chamber varied to give the required pressure difference across the window. The resulting pressure difference across the orifice meter was then measured. This procedure was repeated in each test for approximately eight values of air pressure difference ranging from 0.10 to 0.79 in. water gauge (wg) corresponding to the stagnation pressure for wind speeds of 15 to 40 mph.

The method used to calculate the window air leakage value is shown in Appendix A, which also includes a table of stagnation pressures for various wind speeds.

TEST CONDITIONS AND RESULTS

The results of the air leakage tests are shown in Figures 14 to 17, and are summarized in Tables III and IV. The air leakage values listed in the tables and quoted elsewhere in the report correspond to a window pressure difference of 0.30 in. wg (1.56 lb/sq ft), the total stagnation pressure equivalent of a 25 mph wind. This value of pressure difference is commonly used in Canada and the U.S.A. for the comparison and specification of window air tightness.

Prime Unit Air Leakage

The prime unit air leakage values were obtained with the prime or inner operating unit of the window locked and the storm or outer operating unit, if any, open. This is the window test configuration required for double windows by the CGSB specifications. The prime unit leakage is the most convenient value to use when comparing the performance of different window units.

The prime unit leakage characteristics of the double-hung and vertical sliding windows are shown in Figure 14 and the characteristics of the projected and casement windows in Figure 15. The CGSB air leakage criterion for residential windows, 3/4 cu ft/(min)(ft of sash crack) at a window pressure difference of 0.30 in. wg, is shown in both figures for comparison.

Windows F2, G1, G2, H1 and K1, K2, K3, L1, M1, M2, N2 met the CGSB air leakage limit without modifications.

ASHRAE Configuration

The Guide of the American Society of Heating, Refrigerating and Air Conditioning Engineers gives air leakage values for various window types for use in calculating building heating and air conditioning loads. Values for double-hung, single wood windows and for steel casement windows are given. The Guide also suggests that the design values for average-fit double-hung windows are appropriate for wood casement windows.

Guide design values were obtained in tests in which the double-hung windows were closed but unlocked and the hinged windows were locked. These configurations were assumed to be those normally found on a building. The comparable sash configuration for normal operation of double windows was assumed to be with both the outer (storm) unit and inner (prime) unit closed but unlocked, except when locking occurred automatically.

All the double-hung and vertical sliding windows, with the exception of G2, were tested with the ASHRAE configuration. The results are compared with the ASHRAE design values for wood double-hung windows (Figure 16). The ASHRAE values shown in Figure 16 have been modified from the Guide table values by excluding the adjustments for leakage between window frame and wall and for pressure build-up in the building.

The ASHRAE configuration for hinged windows is the same as that used to determine the prime unit air leakage. Leakage values for wood casement and projected windows are also shown in Figure 16. The values for the metal casement and projected windows are compared with the ASHRAE design values for residential steel casement windows in Figure 17.

With the exception of window E3, all the sliding windows and wooden hinged windows were at least partially weatherstripped. Leakage values ranged from just above the ASHRAE values for poor-fit weatherstripped, double-hung windows down to values well below those for average-fit weatherstripped windows. The leakage characteristic for the non-weatherstripped double-hung window, E3, coincided well with the ASHRAE value for the poor-fit, non-weatherstripped, double-hung window. These results indicate that the Guide design values can be applied to sliding and wooden hinged windows in current use.

The test results for metal hinged windows were not consistent with the values given in the Guide. The three weatherstripped windows leaked more than the two non-weatherstripped windows; leakage values for the latter were much lower than the ASHRAE value for average-fit, non-weatherstripped, steel casement windows. The results demonstrate the effect on air tightness of a good sash-to-frame fit and good locking hardware. The air leakage results obtained for the three weatherstripped metal windows cannot be considered representative because they were from a single manufacturer. The value of weatherstripping on metal projected and casement windows and the applicability of Guide data to current metal hinged windows cannot be determined on the basis of the limited experimental evidence obtained on this type of window.

Leakage Sources

Infiltration tests were performed on all the windows with some of the following test configurations in order to determine the amount of leakage occurring at the various leakage sources.

(i) inner unit locked - storm or outer unit, if any, open;

(ii) configuration (i) with head track sealed;

(iii) configuration (ii) with sill track sealed;

(iv) configuration (iii) with jamb tracks sealed;

(v) configuration (iv) with meeting rail sealed (sliders),

or configuration (iv) with hinges sealed;

(vi) configuration (v) with frame face moulding (if any) sealed.

Vertical Sliding and Double-Hung Windows - Wood

The prime unit air leakage rate of all three wood sliders exceeded the CGSB limit. The major source of leakage for window E1 was the frame moulding. Leakage around the sash proper was relatively small and evenly distributed. The face moulding of E2 was also a large leakage source, but a larger one was around the jamb tracks. This window had spring-tensioned light aluminum tracks set in the wood frame; the tracks were not weatherstripped. Leakage occurred through the cracks between sash and tracks as well as through cracks between tracks and frame. Window E3, which had a leakage rate exceeding four times the maximum permissible rate, was badly constructed for air tightness. The fit of the sash in the tracks and frame was poor, the meeting rail lock was ineffective, and weatherstripping was not provided.

Vertical Sliding and Double-Hung Windows - Metal

All the metal sliding windows except F1 met the CGSB criteria for air tightness. Metal sliding sashes must be made to fit loosely in the tracks in order to permit ease of operation; weatherstripping is therefore necessary to ensure air tightness. Without exception, all the windows in the group were weatherstripped. The jamb tracks and meeting rails were normally the worst leakage sources, but where they intersected weatherstripping was also difficult. Insufficient closing pressure at the meeting rails was the main cause of air leakage at this point. Another source was the frame which, being fabricated from many separate metal sections, presented sealing difficulties. Window F1, which had a large frame leakage had a wood frame with an exterior cladding of aluminum. Air was able to pass through the cracks in the metal cladding, around the wood frame and leak to the inside.

Hinged Windows - Wood

The four wood projected windows and casement windows M1 and M2 met the CGSB criterion for air tightness. Except for K2 and M2, all the wood windows had very large frame moulding leakage, but when this was eliminated, all the wood hinged windows met the air tightness requirement. Casement windows, M2 and M4, with close hinges had relatively larger leakages than had M1 and M3, which had extended hinges; weatherstripping around the sash is probably simplified with extended hinges.

Hinged Windows - Metal

Of the five metal hinged windows tested, only L1 and N2 met the air tightness requirement. Both windows were non-weatherstripped, but the fit of the sash in the frame was good and the locks were very effective. The maximum measured clearance between sash and frame was 0.015 in. and was measured on window N2 along the hinge jamb. Windows N1, P1 and P2 were weatherstripped, but failed to meet the air tightness requirement. The weatherstripping provided was either too small or poorly positioned to compensate for the large clearance between sash and frame. The hinge-jamb clearance of window P2 was as large as 0.085 in.

Exfiltration

Exfiltration values (for air flow from inside to outside) are given in Tables III and IV as a percentage of prime unit infiltration values and were determined with the same sash configurations. The exfiltration values for the weatherstripped windows, with the exception of K2, differed from the infiltration values by no more than 30 per cent. This indicates that locking limited the sash movement, or that the effect of sash movement was compensated for by weatherstripping. The ratio of exfiltration to infiltration for K2 is apparently large because of the exceptionally low infiltration. The relatively large exfiltration through N2 would be expected of a non-weatherstripped, outswinging, hinged window because of the tendency of the pressure to push the sash away from the frame. Window L1, which was similar in design, showed an exfiltration rate only slightly greater than the infiltration rate, probably indicating very effective locking.

Lock and Sash Configuration

The two single sliding windows with storm units, E1 and E2, and the four double windows, F1, F2, G1 and G2, were tested with some or all of the following configurations:

(i) inner unit closed and unlocked - outer unit open;

(ii) inner unit locked - outer unit open;

(iii) inner unit locked - outer unit locked;

(iv) inner unit open - outer unit locked.

Configurations (i) and (ii) indicate the effectiveness of the lock on the inner or prime unit. Vertical sliding windows, E1 and F2, could not be tested in the unlocked configuration since the locks engaged upon closing. The locks on windows E2 and G1, both cam-type locks mounted on the meeting rail, did not increase window tightness. The locks on windows F1 and G2, however, reduced leakage by as much as 70 per cent.

Configurations (ii) and (iii) indicate the reduction in overall window leakage effected by closing and locking the outer or storm unit. The leakage through windows E2, F1 and F2 was noticeably decreased by the storm unit, whereas the leakage through E1 and G1 was only slightly reduced. Resistance to condensation between panes and to rain penetration requires an inner or prime unit many times tighter than the outer or storm unit. To ensure this degree of inner sash tightness the CGSB window specifications state that the air tightness requirement must be met by the prime unit alone.

COMMENTS AND CONCLUSIONS

The following factors determine the initial air tightness of windows:

(1) design and workmanship in fabrication;

(2) fit of the sash in the track or frame;

(3) design, position and installation of weatherstripping;

(4) design and adjustment of the lock.

The present series of tests demonstrates how window air tightness suffers when these factors are not given adequate consideration.

Following are some comments on the air tightness of the hinged, vertical sliding, and double-hung windows that were tested:

(1) Factory-built, non-weatherstripped, wood double-hung windows, such as E3, will probably not meet the specification air tightness requirement unless the design and workmanship in fabrication are exceptionally good.

(2) Spring-tensioned aluminum jamb tracks used in double-hung wood windows (such as E2 and E3) introduce additional leakage sources in providing ease of sash removal, and are not a satisfactory substitute for weatherstripping.

(3) Aluminum cladding applied to the exterior face of the wood window frame, as in window F1, must be carefully sealed to avoid excessive frame leakage.

(4) Effectiveness of the sash lock becomes increasingly important as the quantity of applied weatherstripping decreases.

(5) Weatherstripping for vertical sliding and double-hung windows should be located along the innermost sealing surface on the upper sash and along the outermost sealing surface on the lower sash to prevent air penetration up along the jamb tracks.

(6) When the vertical sash edges of double-hung windows, such as F1 and G2, are bare glass, they should sit well inside the jamb tracks; otherwise the edges will jump out of the tracks onto the weatherstripping and damage the weatherstripping, making sash operation difficult and possibly chipping glass.

(7) Wood projected and casement windows are satisfactorily air tight provided that care is taken to ensure a tight frame construction.

(8) The primary aim in the design of hinged metal windows should be to obtain a good fit of the sash in the frame and to provide a lock capable of exerting a positive closing pressure. Only when the fit and locking of the sash are not satisfactory does weatherstripping become absolutely necessary. This is demonstrated by the tightness exhibited by windows L1 and N2, both non-weatherstripped.

(9) In general, the air leakage characteristics of hinged windows were more affected by the direction of air flow than were sliding windows.

(10) Air leakage tests using test configurations comparable to those used to obtain the ASHRAE Guide values would indicate that the ASHRAE window design air leakage rates for wood double-hung windows can be used for residential double-hung, vertical sliding, and wooden hinged windows. Because of insufficient data, a similar statement cannot be made concerning metal hinged windows.

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TABLE I VERTICAL SLIDING AND DOUBLE-HUNG WINDOWS

Identification	Prime Unit Opening (Width x Height)	Description
E1	39 x 49 in. L_c^* = 17.9 ft	Single Vertical Sliding window with attached wood storm unit; two sliding wood prime sashes, two light aluminum panels sliding in storm unit; wood main frame with face moulding and blind stops; spring-type aluminum w/s attached to upper prime sash meeting rail and to lower prime sash sill rail; no w/s around storm unit; jamb rail pressure-strip prime sash positioners; cam-type lock on prime sash.
E2	40 x 55 in. L_c = 19.2 ft	Single Double-Hung window with attached wood storm unit; two sliding wood prime sashes hung on spiral-spring balances, two non-sliding removable wood storm sashes hung on main frame; wood frame with light aluminum spring jamb tracks and face moulding along the head, sill and jamb frame members; spring-type bronze w/s attached along prime head frame member, upper prime sash meeting rail and lower prime sash sill rail; can-type lock on prime sash.
E3	39 x $53\frac{1}{4}$ in. L_c = 18.8 ft	Single Double-Hung window; two wood sliding sashes hung on spiral spring balances; wood frame with light aluminum spring jamb tracks and face moulding along head and jamb members; no w/s; cam-type lock on sash.
F1	$37\frac{1}{2}$ x $53\frac{1}{4}$ in. L_c = 18.3 ft	Double Double-Hung window; two prime and two storm sliding sashes hung on spiral spring balances, each sash having only light aluminum horizontal rails; wood frame with aluminum capping on exterior and aluminum prime and storm tracks; foam plastic w/s along head track and spring-type stainless steel along jamb tracks of both storm and prime units; cam-type locks on both inner and outer unit.
F2	36 x 50 3/4 in. L_c = 17.5 ft	Double Vertical Sliding window; two prime and two storm light aluminum sliding sashes, maintained in open or closed position by the engagement of sash lock pins into holes in the jamb tracks; wood main-frame with aluminum sill, head and jamb tracks attached to inner and outer frame face; wool pile w/s along jamb and head sash rails, and vinyl plastic w/s along meeting rails of both inner and outer units.
G1	$39\frac{1}{2}$ x 54 in. L_c = 18.9 ft	Double Double-Hung window; two prime and two storm sliding aluminum sashes, hung on spring-loaded tape balances; aluminum storm and prime frames separated by a rigid vinyl thermal break; one jamb track of each sash has a foam rubber cushion permitting the removal of the sashes for cleaning, wool pile w/s attached to all jamb tracks and to the upper prime sash meeting rail; and vinyl plastic w/s attached to the prime head and sill tracks, and to the prime and storm sill rails; cam-type lock on prime unit only.
G2	$39\frac{1}{2}$ x $54\frac{1}{2}$ in. L_c = 18.9 ft	Double Double-Hung window; two prime and two storm sliding sashes hung on spiral-spring balances, each sash having only aluminum horizontal rails; aluminum storm and prime frames separated by a rigid vinyl thermal break; felt w/s along head and sill tracks and along upper sash meeting rails of both storm and prime units; spring-type stainless steel w/s along all jamb tracks; sliding wedge-type lock on both units.
H1	$36\frac{1}{2}$ x $50\frac{1}{2}$ in. L_c = 17.5 ft	Single Vertical Sliding window; sliding lower and stationary upper tubular sheet steel sashes; lower sash positioned by sash lock pin engaging holes in jambs and upper sash held stationary by screen; tubular sheet steel frame and tracks; wool pile w/s attached to head and jamb rails of both sashes and to the jamb tracks of lower sash; vinyl w/s attached to meeting rail.

* L_c = total prime unit crack perimeter.

TABLE II PROJECTED AND CASEMENT WINDOWS

Identification	Prime Unit Opening (Width x Height)	Description
K1	$47\frac{1}{2}$ x 32 3/4 in. L_c = 13.6 ft	Single Projected window; one wood sash, bottom outswinging, with light aluminum removable glazing unit attached to outer face; wood frame with blind stop and face moulding along jamb and head members; friction sash adjuster tracks attached to jamb members; spring-type aluminum w/s applied to head and jamb frame members and to sash sill rails; bar-type underscreen operator/lock.
K2	$46\frac{1}{4}$ x 29 3/4 in. L_c = 12.7 ft	Single Projected window; one wood sash, bottom outswinging, with light aluminum removable glazing unit attached to inside face and with $2\frac{1}{4}$-in. holes in sill rail venting to outside; wood frame with friction sash adjuster tracks attached to jamb members; spring-type stainless steel w/s along jamb frame members and sash sill and head rails; vinyl w/s around removable glazing unit; bar-type underscreen operator/lock.
K3	$40\frac{1}{4}$ x 24 in. L_c = 10.7 ft	Single Projected window: one wood sash, bottom outswinging, with light aluminum removable glazing unit attached to outer face: wood frame with face moulding along head and jamb members and with a wood sub-sill; friction sash adjuster tracks attached to jamb members; spring-type aluminum applied to head, sill and jamb sash rails; underscreen roto-operator/lock.
K4	48 x 25 in. L_c = 12.2 ft	Single Projected window; sash arrangement similar to K2 and frame assembly similar to K3; spring-type aluminum w/s applied to head, sill and jamb frame members; vinyl w/s around removable glazing unit; two cam-type locks mounted on operating sash.
L1	$50\frac{1}{2}$ x $26\frac{1}{2}$ in. L_c = 12.8 ft	Single Projected window; one aluminum sash, bottom outswinging; aluminum frame with $1\frac{1}{4}$-in. hole draining frame sill; no w/s; two cam-type locks mounted on operating sash.
M1	21 x 49 in. L_c = 11.7 ft	Single Casement window; one wood sash, side-hung on extended hinges, with a light aluminum removable glazing unit attached to inner face and with $1\frac{1}{4}$-in. hole at top of one jamb rail and $1\frac{1}{4}$-in. hole at bottom of other jamb rail venting to outside; wood frame with blind stop and face moulding along head and jamb members, and blind stop along sill member; spring-type aluminum w/s applied to head and jamb frame members, and to sash sill rail; aluminum w/s around removable unit; underscreen roto-operator and two positive pressure locks.
M2	23 x 52 in. L_c = 12.5 ft	Single Casement window; one wood sash, side-hung on close hinges, with a light aluminum removable glazing unit attached to inner face; steel frame with wood inner lining; spring-type stainless steel w/s attached to head, sill and jamb frame members; vinyl w/s around removable unit; same sash operator and lock as M1.

TABLE II (Cont'd)

Identification	Prime Unit Opening (Width x Height)	Description
M3	$21 \times 48\frac{1}{2}$ in. $L_c = 11.6$ ft	Similar to M1, except for absence of blind stops around frame and replacement of w/s around removable glazing unit with vinyl w/s.
M4	23×43 in. $L_c = 11.0$ ft	Single Casement window; one wood sash, side-hung on close hinges, with a light aluminum removable glazing unit attached to inner face; and with $2\frac{1}{4}$-in. holes in sill rail venting to outside; wood frame with face moulding along head and jamb members and with a wood sub-sill; spring-type bronze w/s along entire frame opening perimeter; vinyl w/s around removable unit; cam-type hook jamb lock.
N1	21×44 in. $L_c = 10.9$ ft	Single Casement window; one aluminum sash, side-hung on close hinges; aluminum frame; full-perimeter vinyl w/s attached to frame opening; roto-operator and cam-type lock.
N2	$20\frac{1}{2} \times 50\frac{1}{2}$ in. $L_c = 11.9$ ft	Single Casement window; one aluminum sash, side-hung on extended hinges; aluminum frame with 3 3/16-in. holes along inner sill, draining to outside; no w/s; same operator and lock as N1.
P1	$21\frac{1}{2} \times 46$ in. $L_c = 11.1$ ft	Single Casement window; one steel sash, side-hung on extended hinges; steel frame; spring-type aluminum w/s attached to all frame members along inner sealing lip; underscreen roto-operator and hook-type lock.
P2	$21\frac{1}{2} \times 46$ in. $L_c = 11.1$ ft	Identical to P1, except frame w/s replaced by vinyl w/s attached to inside screen which is pressed against both sash and frame.

TABLE III AIR LEAKAGE TEST RESULTS - VERTICAL SLIDING AND DOUBLE-HUNG WINDOWS

(CFM/FT AND PER CENT AT $h_w = 0.30$ INCH WATER)

		WOOD WINDOWS			METAL AND METAL-WOOD WINDOWS				
		E1	E2	E3	F1	F2	G1	G2	H1
I	Prime Unit Leakage - As received	0.80	1.61	3.40	1.07	0.47	0.35	0.75	0.72
	- Frame face moulding sealed	0.43	1.11	3.11	-	-	-	-	-
II	ASHRAE Configuration Leakage	0.76	1.19	3.40	1.18	0.30	0.32	-	0.72
III	Distribution Of Leakage (% of prime leakage - as received)								
	Frame - Total	64%	37%	12%	50%	40%	20%	31%	47%
	- Moulding	46	31	9	-	-	-	-	-
	Head track	14	9	7	4	11	1	5	1
	Sill track	7	15	31	16	8	1	9	1
	Jamb tracks	6	37	23	5	30	33	7	29
	Meeting rail	9	2	27	25	11	45	48	22
IV	Exfiltration (% of prime leakage - as received)	107%	102%	-	100%	108%	106%	93%	74%
V	Lock and Sash Configuration (% of prime leakage - as received)								
	Prime unlocked - Storm open	-	100%	-	175%	-	100%	165%	-
	Prime locked - Storm open	100%	100	-	100	100%	100	100	-
	Prime locked - Storm locked	96	75	-	60	64	94	-	-
	Prime open - Storm locked	-	-	-	66	119	-	-	-

TABLE IV AIR LEAKAGE TEST RESULTS - PROJECTED AND CASEMENT WINDOWS

(CFM/FT AND PER CENT AT $h_w = 0.30$ INCH WATER)

	PROJECTED (SLIDING HINGE)					CASEMENT (FIXED HINGE)							
	WOOD				ALUMINUM	WOOD				ALUMINUM		STEEL	
	K1	K2	K3	K4	L1	M1	M2	M3	M4	N1	N2	P1	P2
I Prime Unit Leakage (Also ASHRAE config. leakage)													
- As received	0.52	0.08	0.68	0.77	0.61	0.66	0.40	1.28	1.07	1.38	0.44	1.28	2.03
- Frame face moulding sealed	0.12	-	0.24	0.62	-	0.21	-	0.17	0.43	-	-	-	-
II Distribution Of Leakage (% of prime leakage - as received)													
Frame - Total	85%	0	69%	21%	10%	86%	-	95%	67%	0%	28%	13%	4%
- Moulding	75	-	65	19	-	68	-	87	60	-	-	-	-
Head	6	75	14	20	10	3	6%	2	5	21	14	24	11
Sill	7	13	7	16	22	2	12	2	4	17	2	35	12
Jamb	2	12	10	43	58	3	27	1	8	62	56	28	73
Hinges	-	-	-	-	-	6	55	-	16	-	-	-	-
III Exfiltration (% of prime leakage - as received)	100%	180%	104%	100%	107%	81%	95%	100%	106%	104%	405%	110%	116%

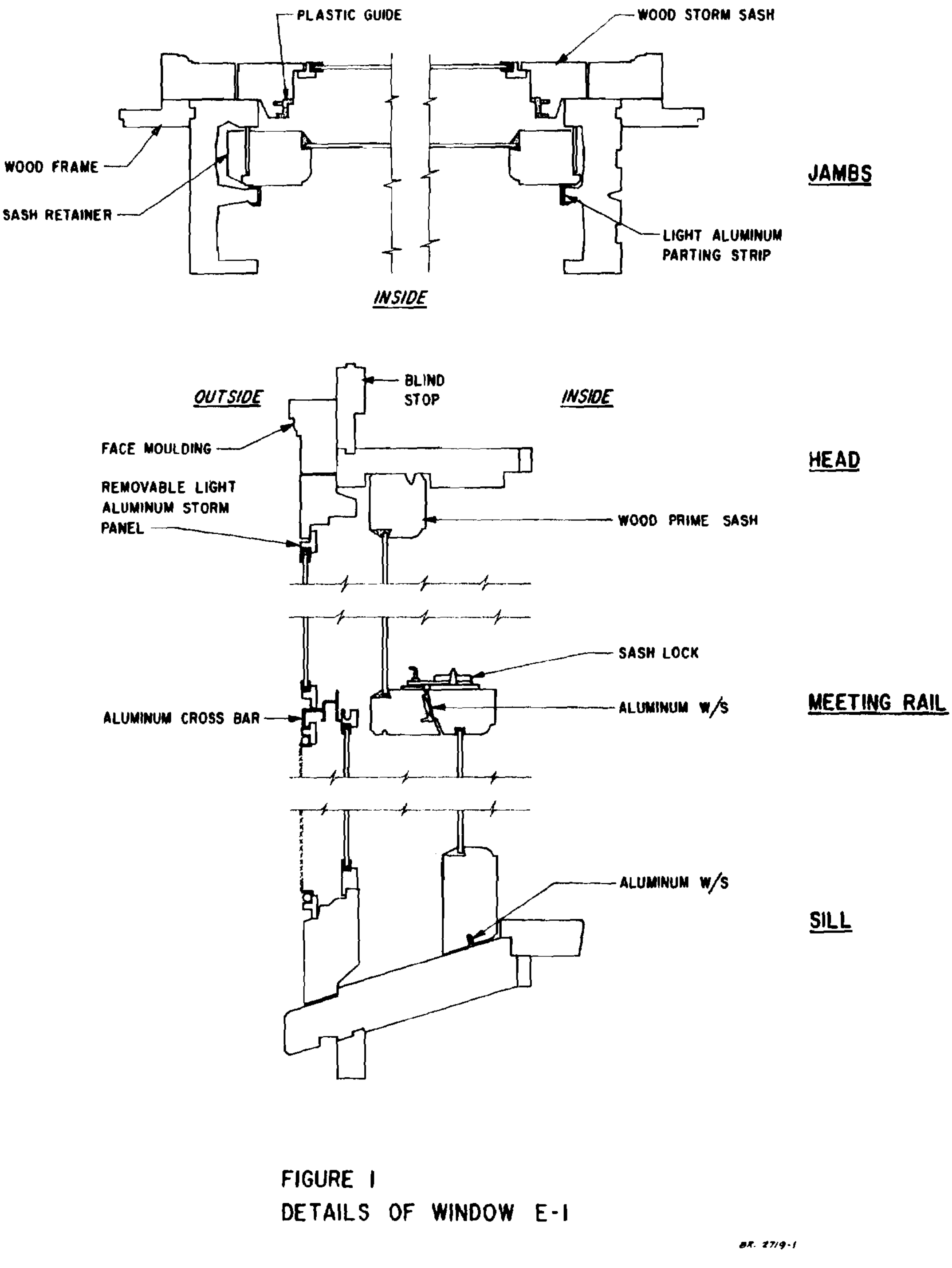


FIGURE I
DETAILS OF WINDOW E-I

BR. 2719-1

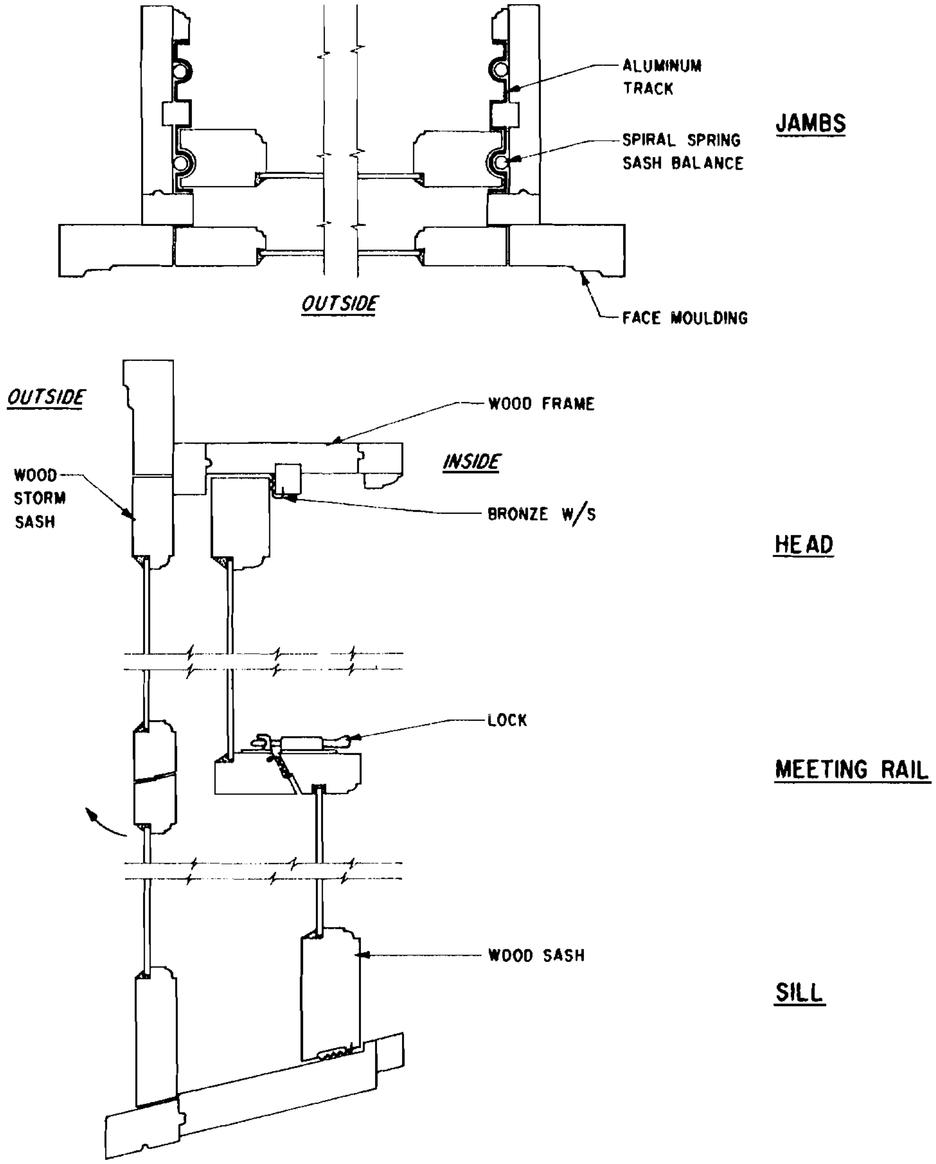


FIGURE 2
DETAILS OF WINDOW E-2

BR 2719-2

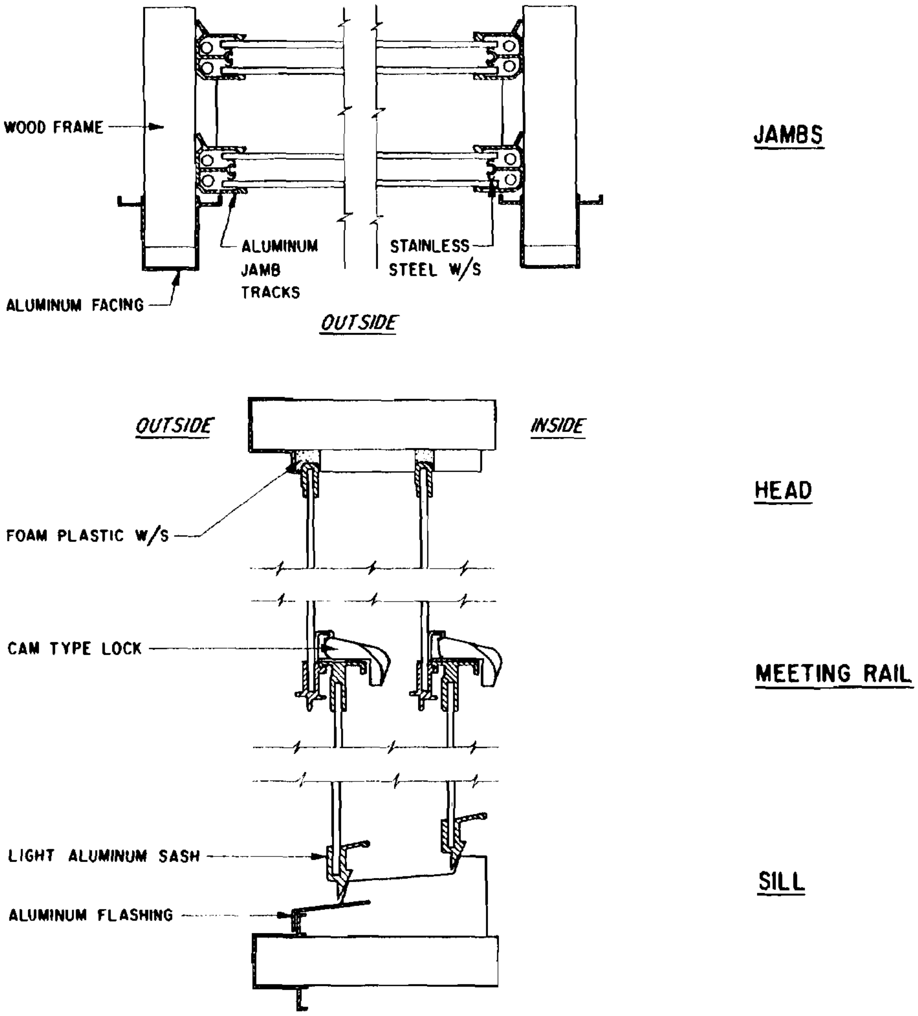


FIGURE 3
DETAILS OF WINDOW F-1

BR 2719-3

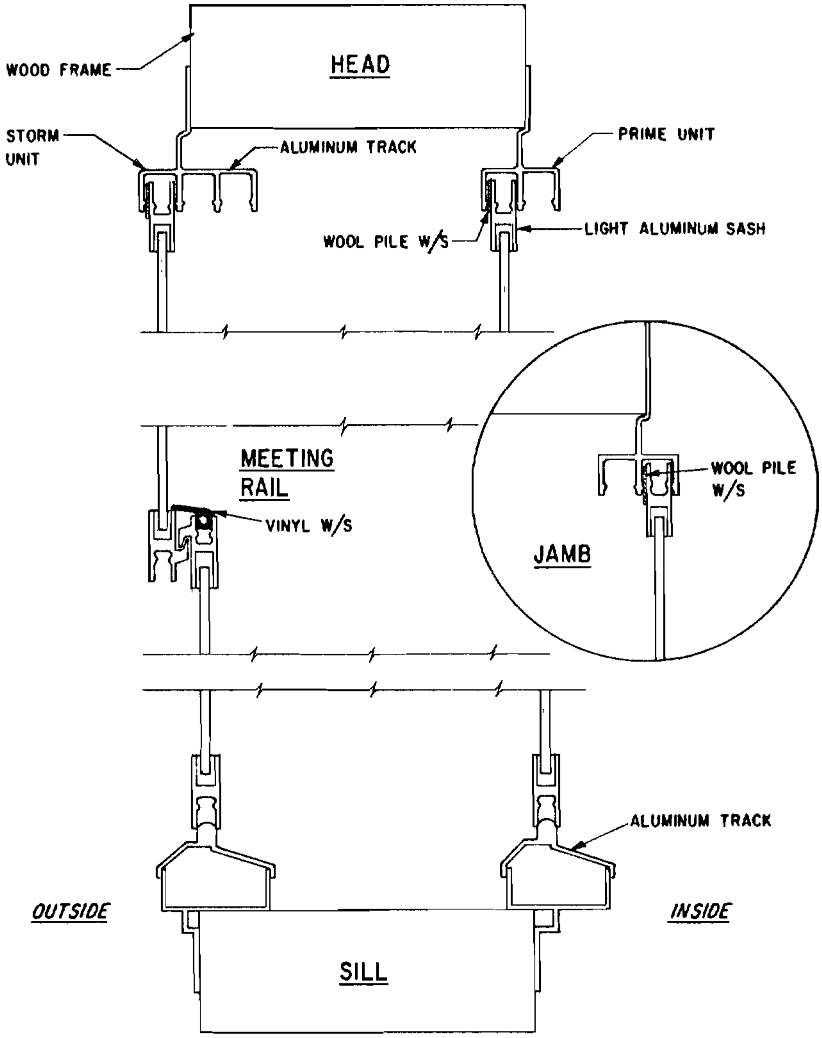


FIGURE 4
DETAILS OF WINDOW F-2

BR. 2719-4

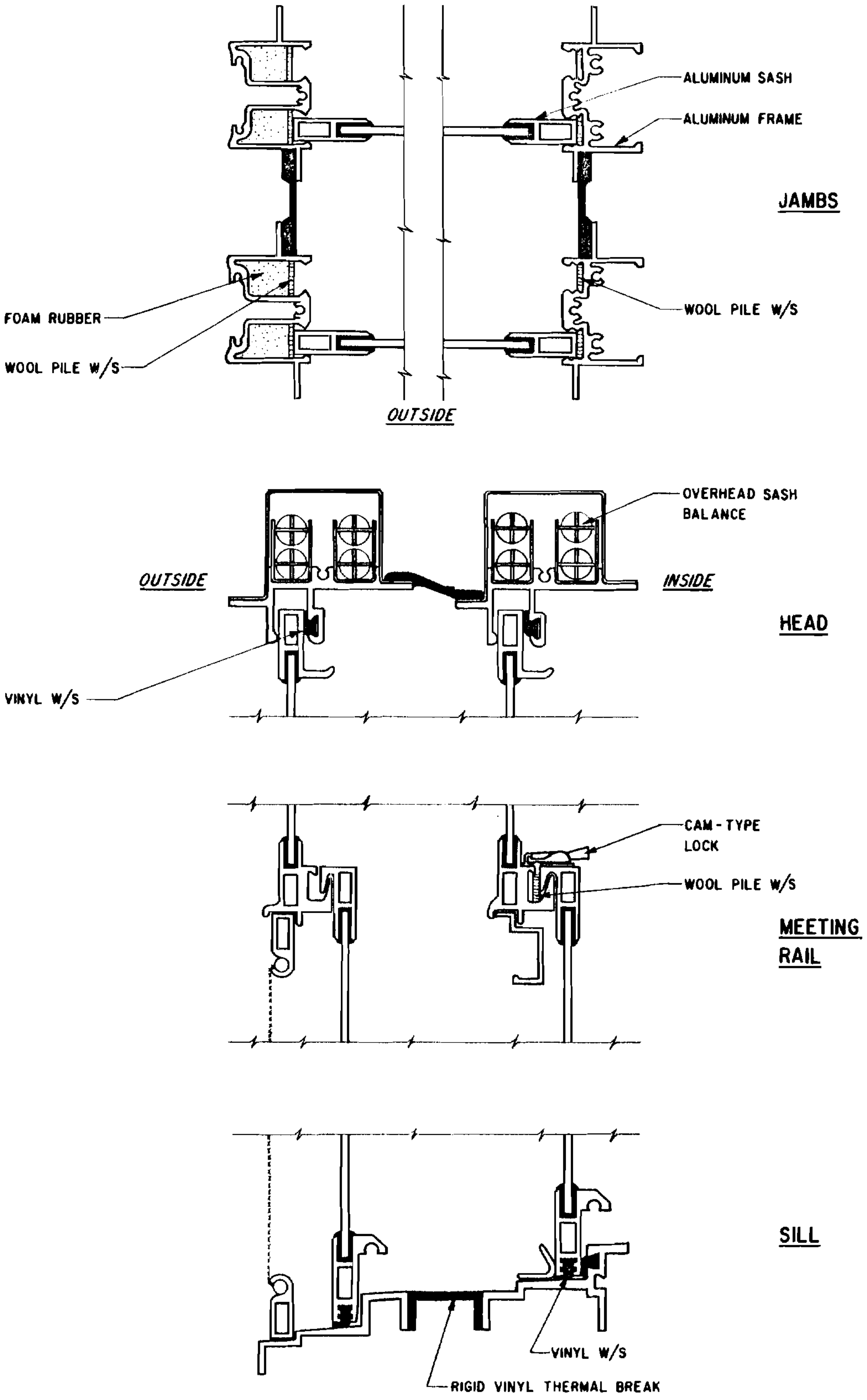


FIGURE 5
DETAILS OF WINDOW G-1

BR. 8718-5

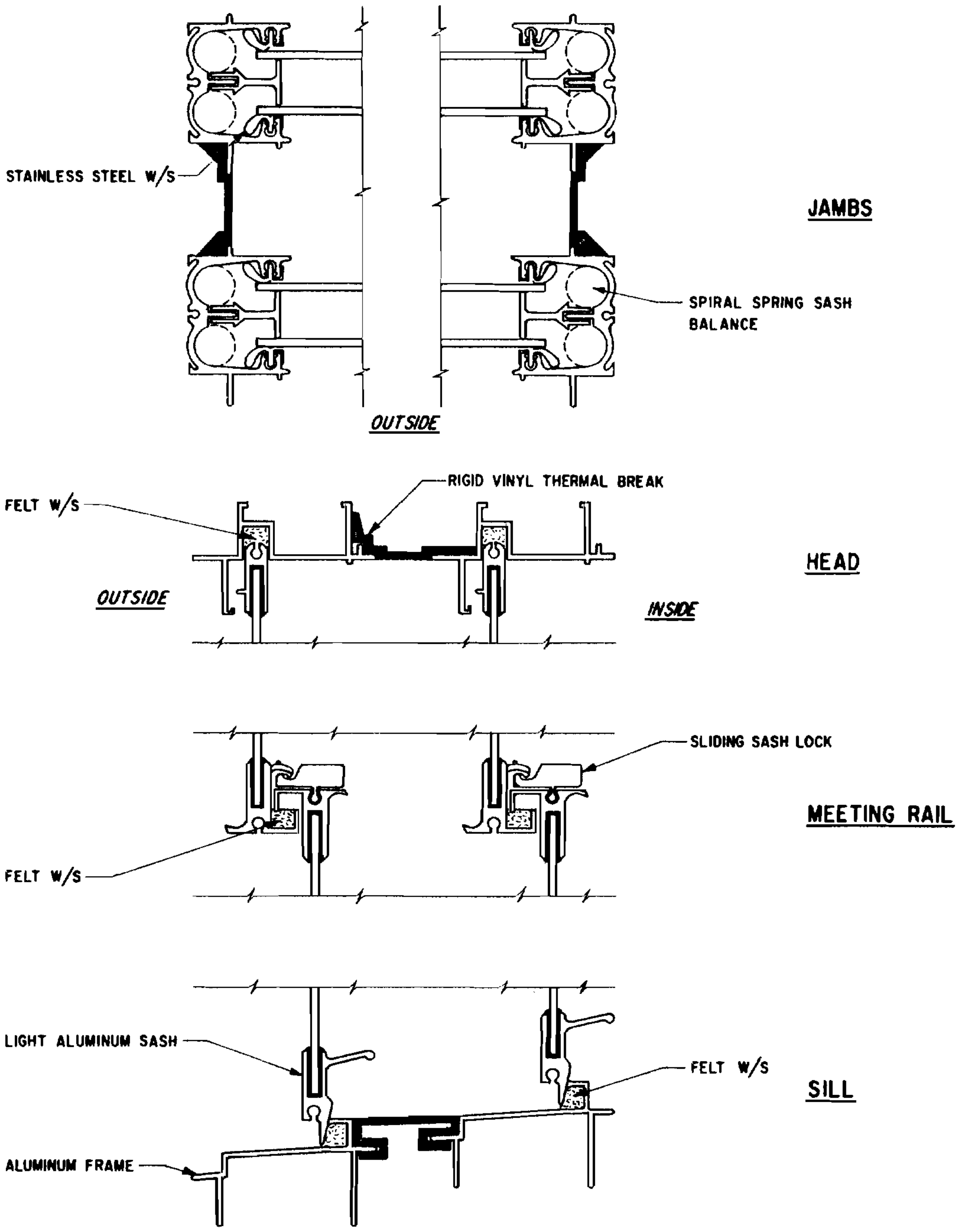


FIGURE 6
DETAILS OF WINDOW G-2

BR 2719-6

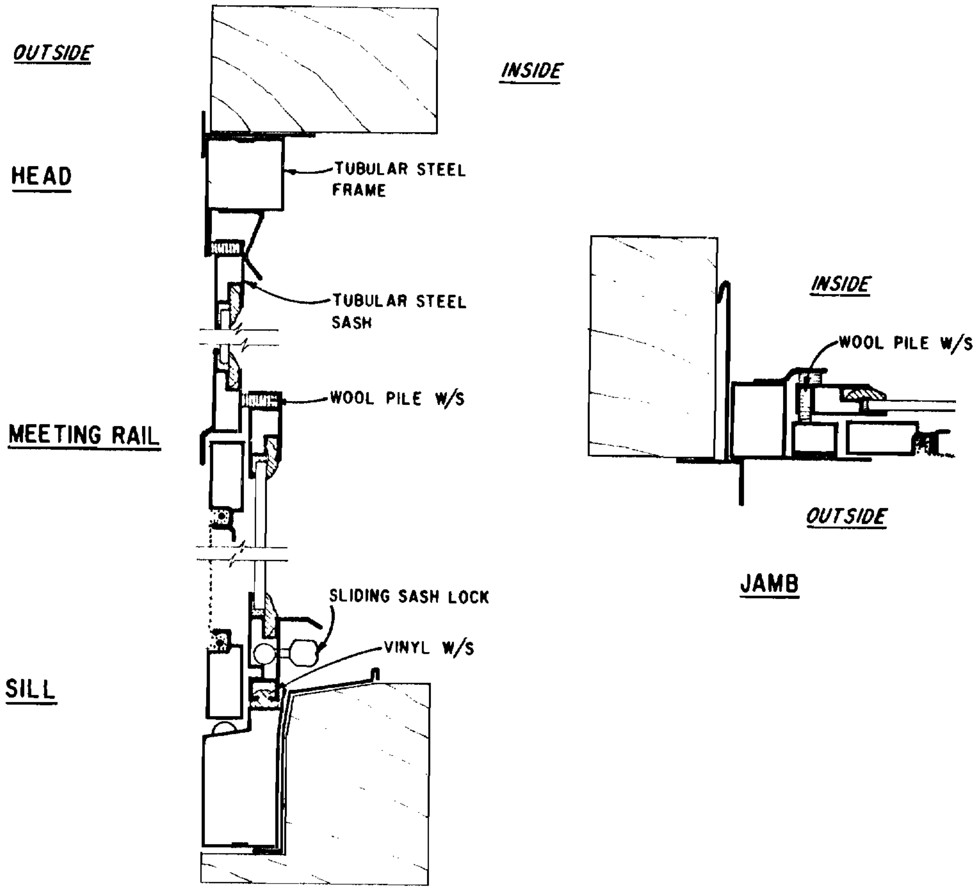


FIGURE 7
DETAILS OF WINDOW H-1

BR. 2719-7

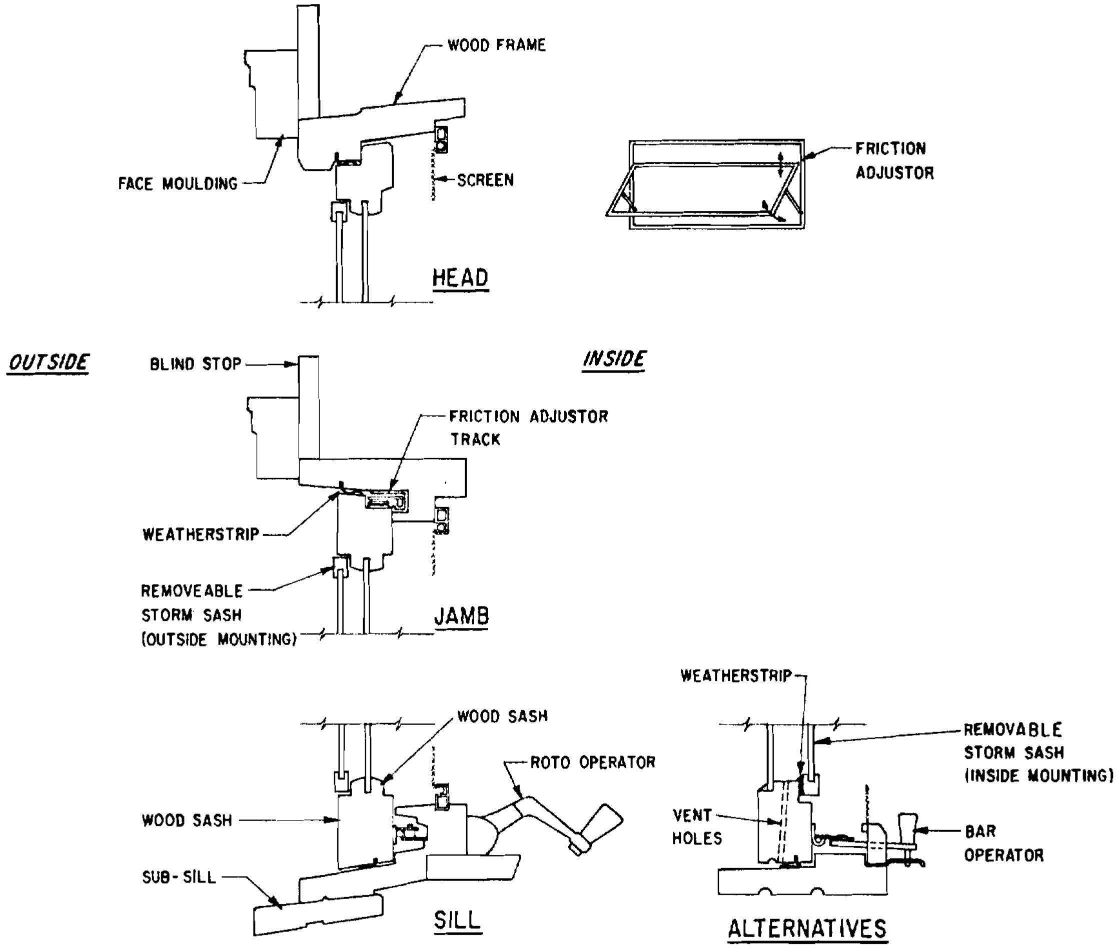
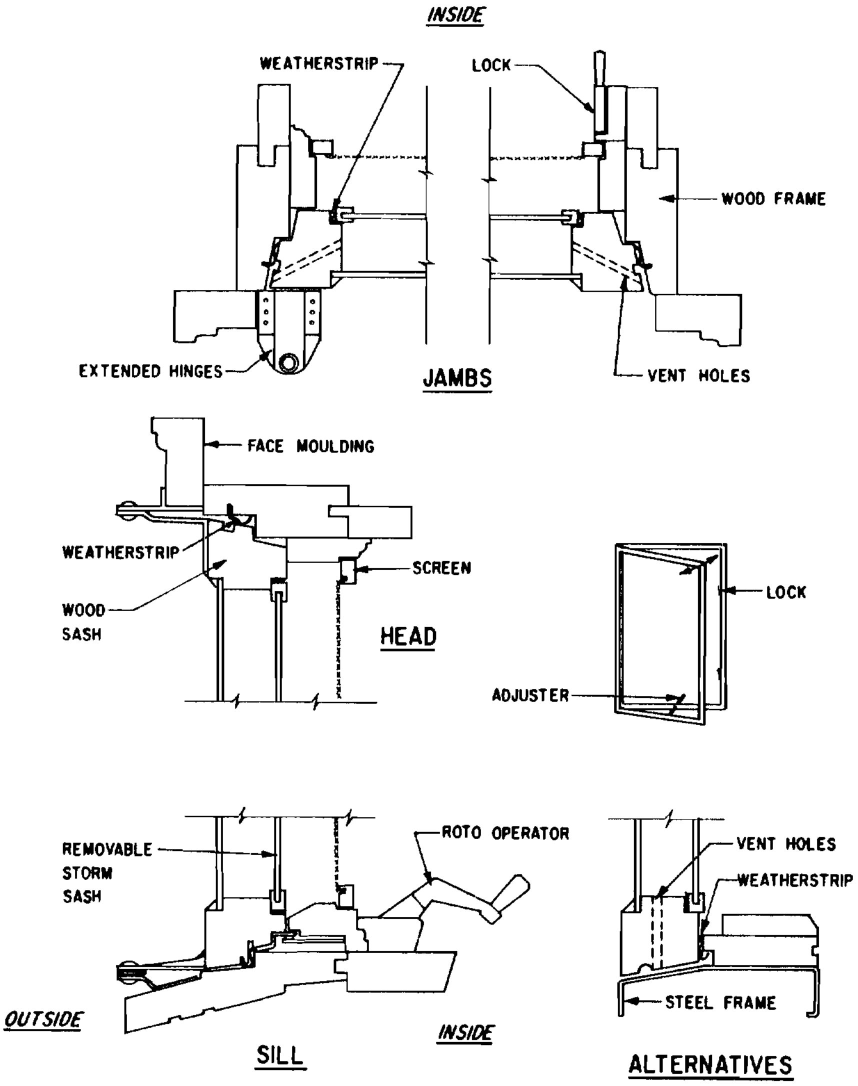


FIGURE 8
DETAILS OF TYPICAL PROJECTED WOOD AWNING TYPE WINDOW

BR 2719-8



JAMBS

HEAD

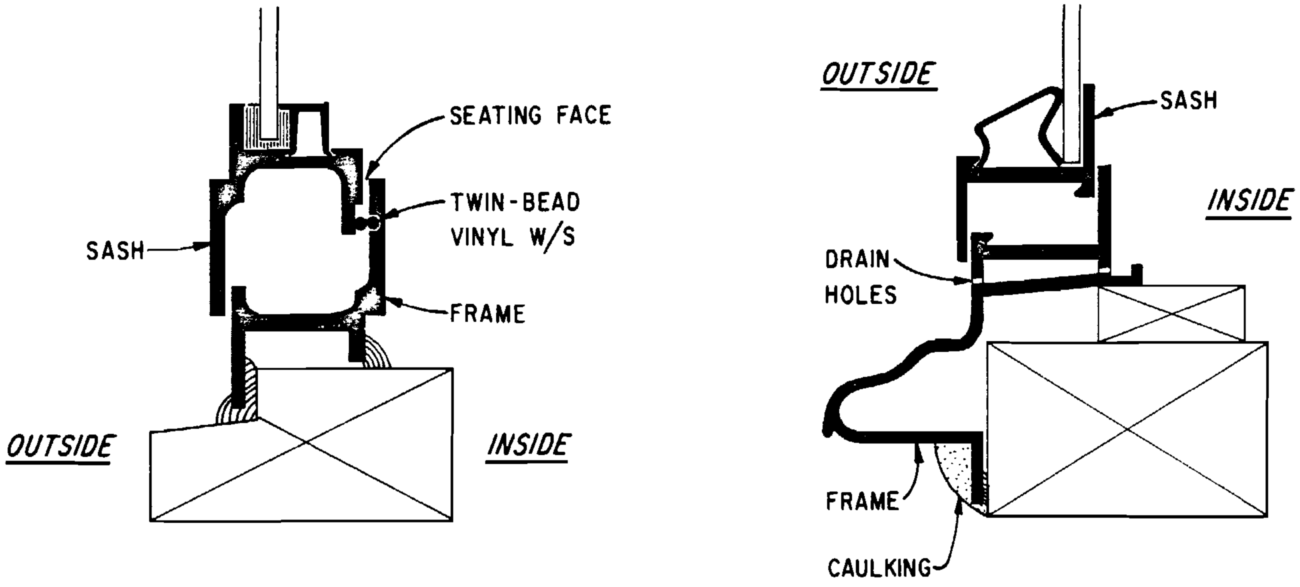
SILL

ALTERNATIVES

FIGURE 9

DETAILS OF TYPICAL WOOD CASEMENT WINDOW

BR 2719-9



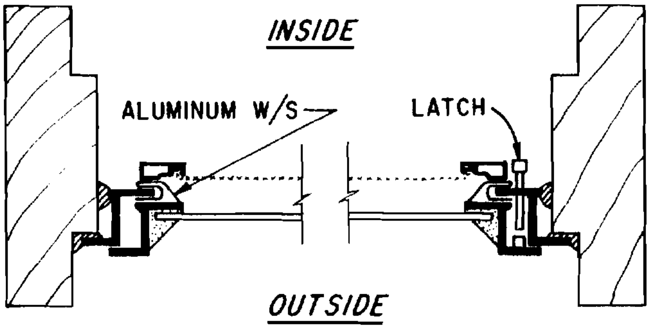
(a) WINDOW N-1

(b) WINDOW N-2

FIGURE 10

TYPICAL CROSS-SECTIONS OF ALUMINUM CASEMENT WINDOWS

BR. 2719-10



JAMB SECTION

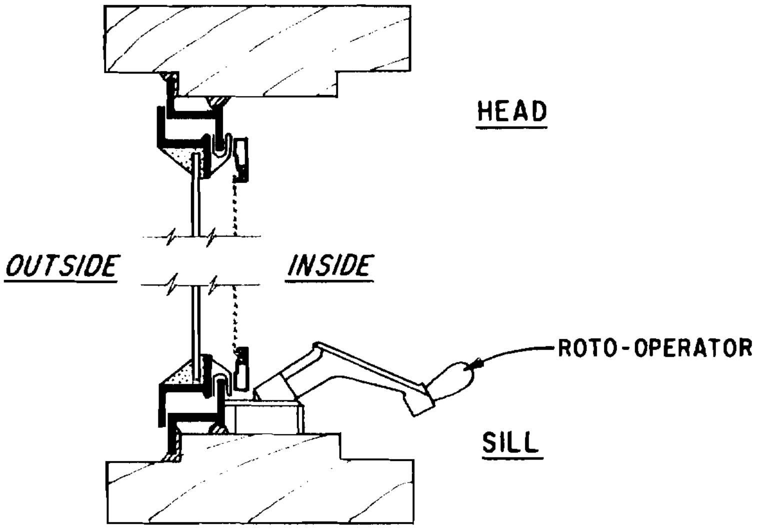
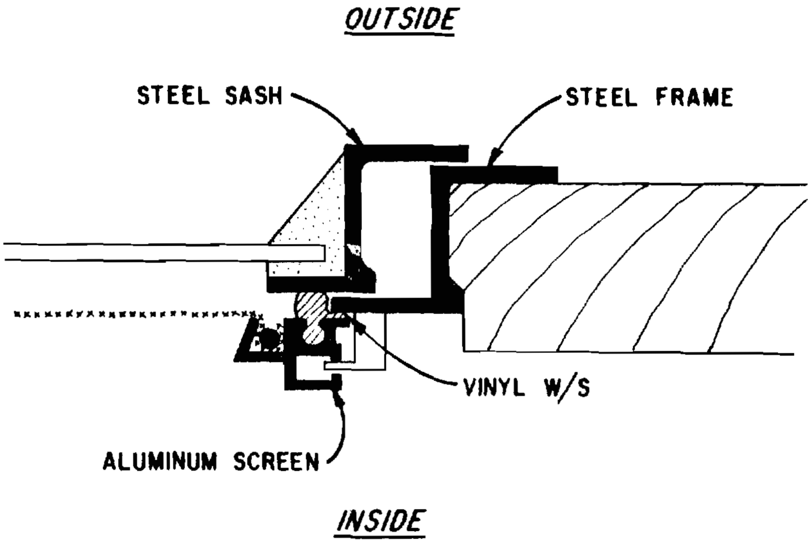


FIGURE 11
DETAILS OF STEEL CASEMENT WINDOW P-1

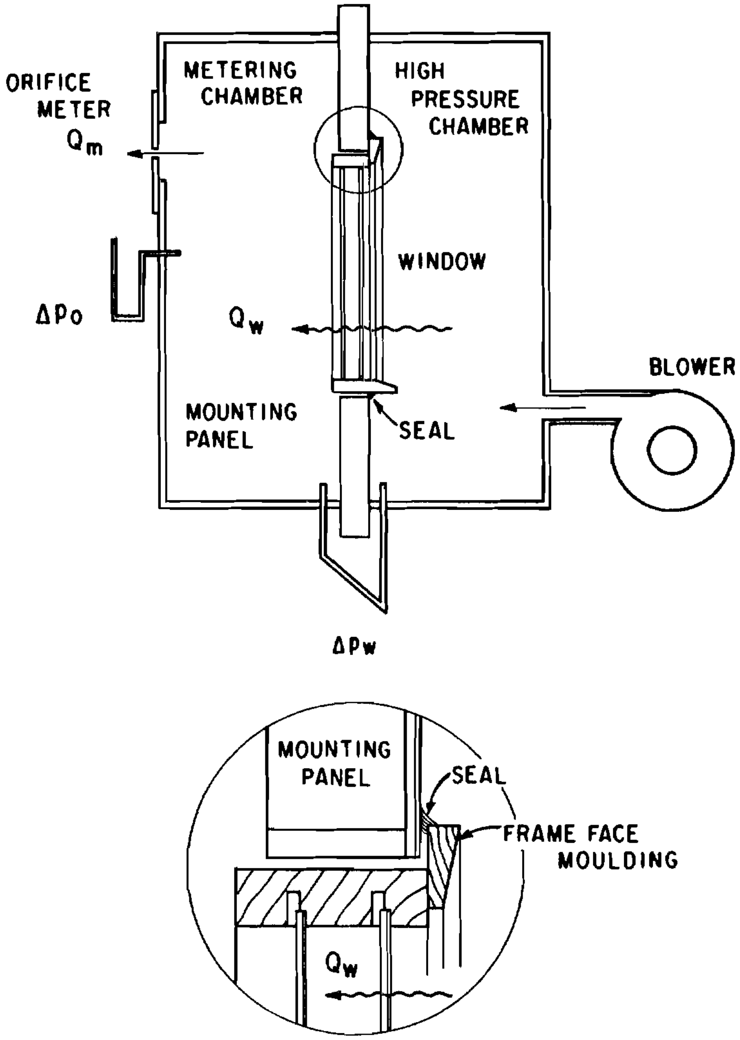
BR. 2719-11



JAMB SECTION

FIGURE 12
DETAIL OF STEEL CASEMENT WINDOW P-2

BR. 2719-12



SEAL BETWEEN WINDOW FRAME AND MOUNTING PANEL

FIGURE 13
TWO-CHAMBER WINDOW AIR LEAKAGE APPARATUS

BR 2638-7

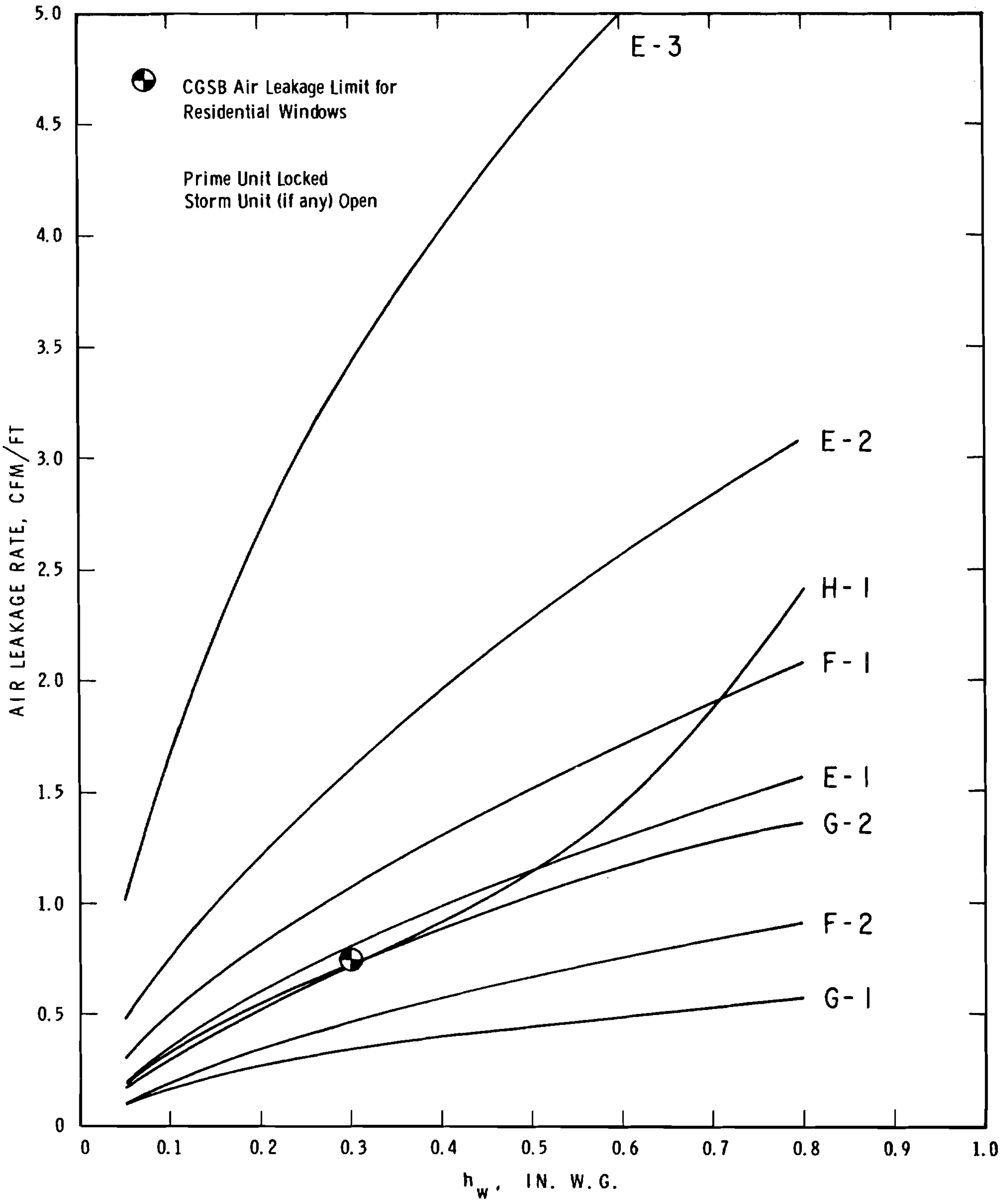


FIGURE 14

DOUBLE-HUNG AND VERTICAL SLIDING WINDOWS PRIME UNIT AIR LEAKAGE CHARACTERISTICS

BR. 2719-14

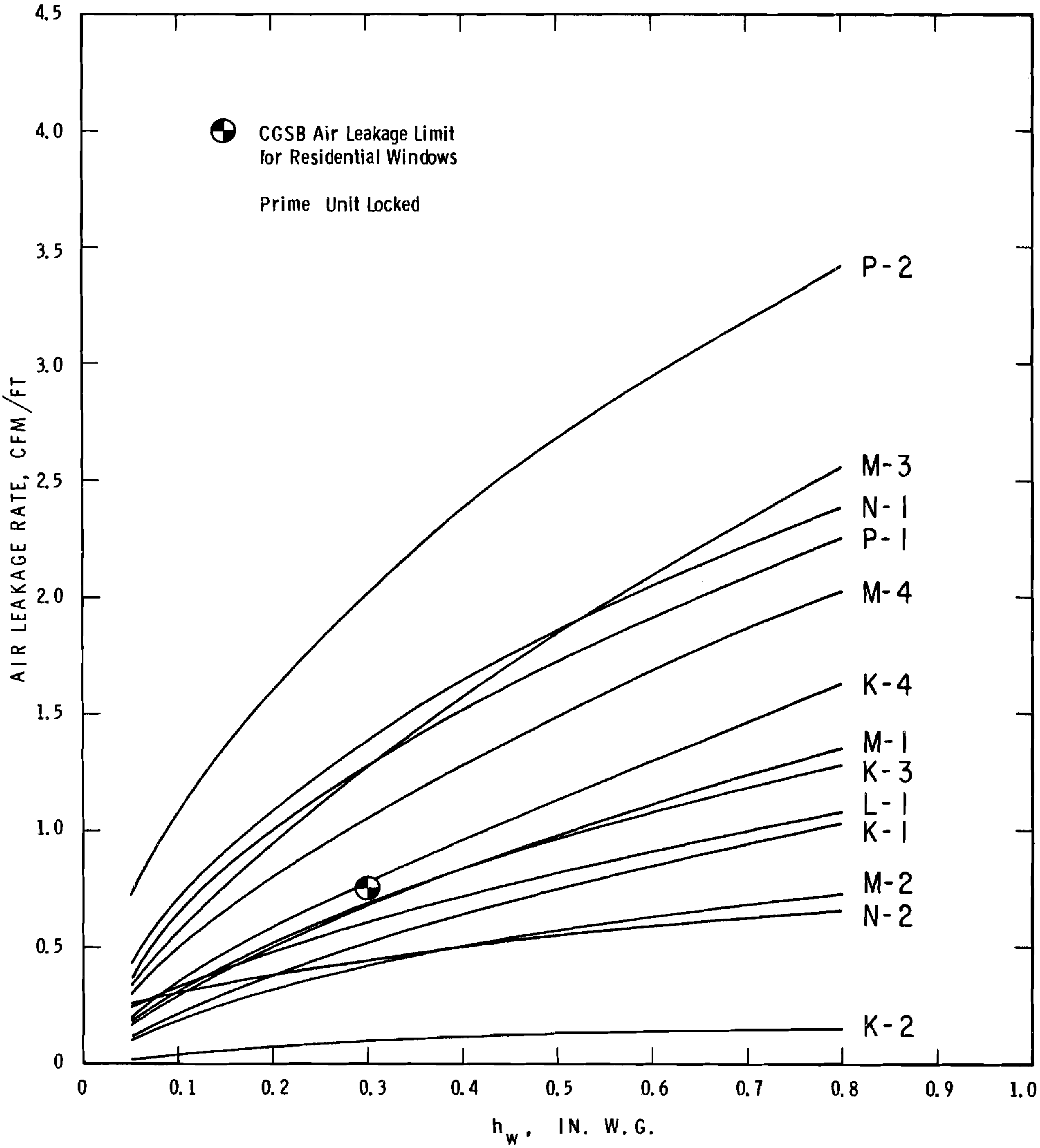


FIGURE 15

PROJECTED AND CASEMENT WINDOW PRIME UNIT AIR LEAKAGE CHARACTERISTICS

BR. 2719-15

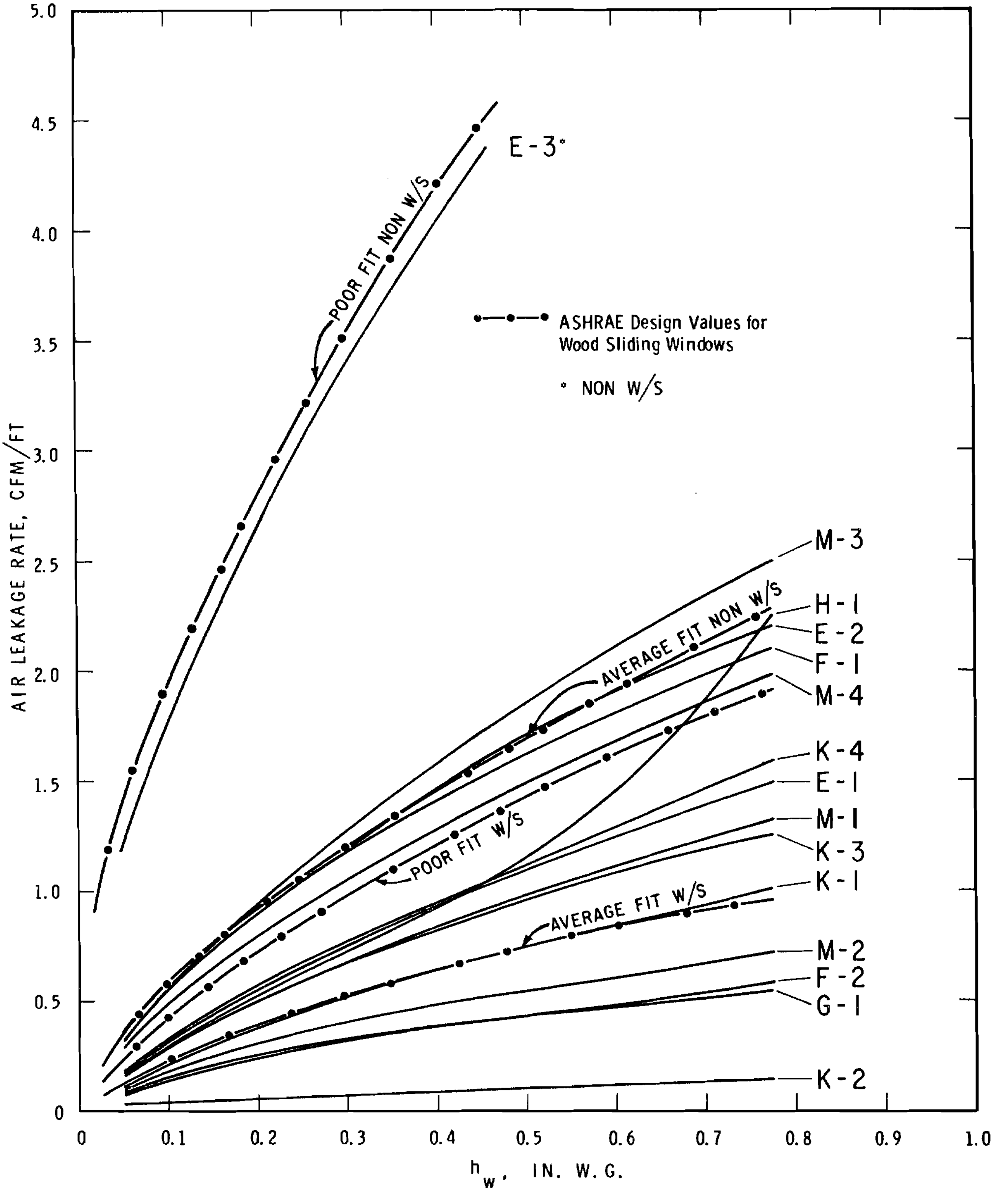


FIGURE 16

DESIGN AIR LEAKAGE CHARACTERISTICS OF DOUBLE-HUNG AND VERTICAL SLIDING WINDOWS AND WOOD CASEMENT & PROJECTED WINDOWS

BR. 2719-16

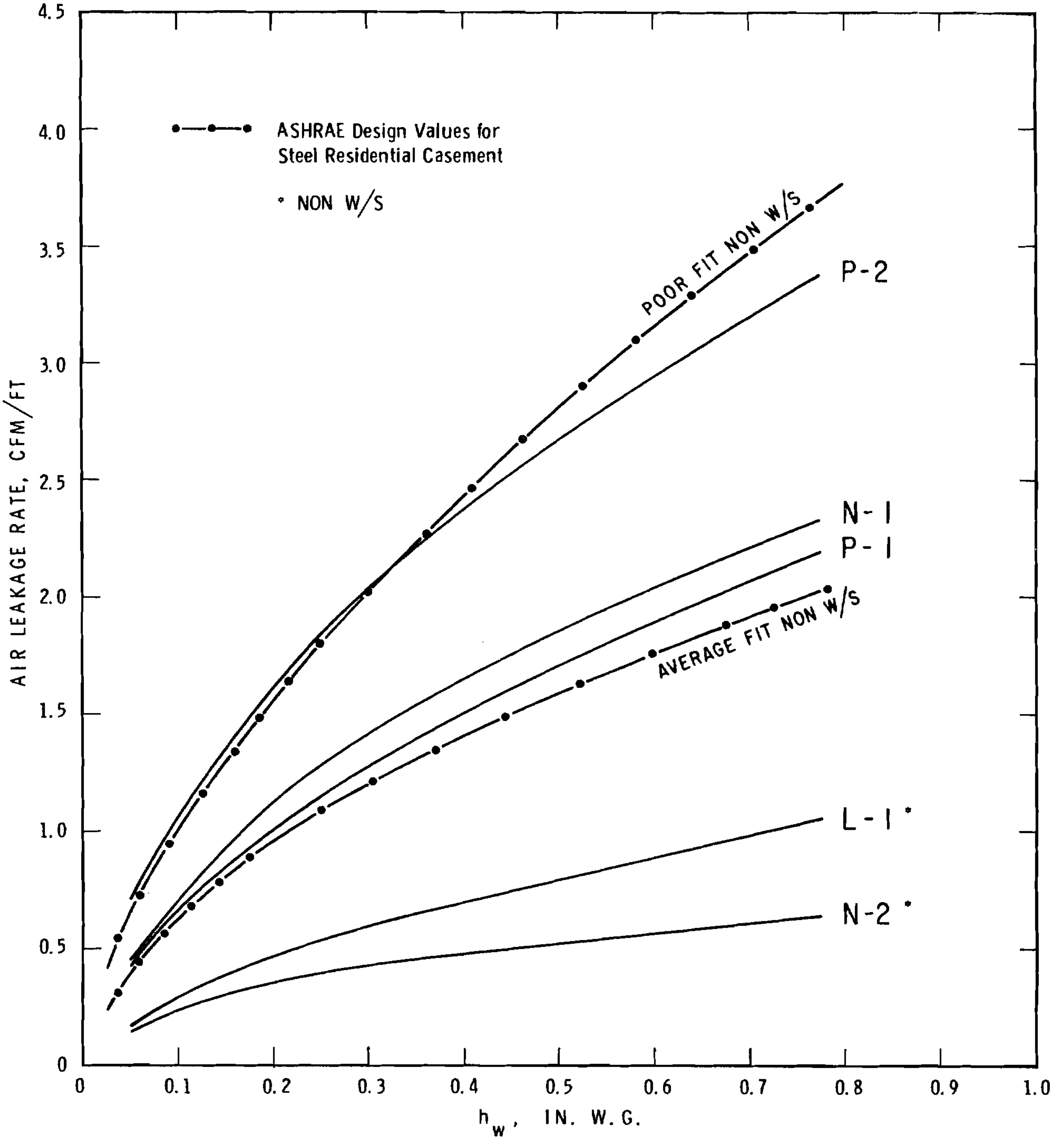


FIGURE 17

DESIGN AIR LEAKAGE CHARACTERISTICS OF METAL PROJECTED & CASEMENT WINDOWS

BR. 2719-17

APPENDIX A

DETERMINATION OF WINDOW AIR LEAKAGE RATE

The following values were obtained during the window air leakage tests:

B_a = barometric pressure at room temperature, in. mercury column

Ω_a = room relative humidity, per cent

t_a = room temperature, °F

t_1 = high pressure box air temperature, °F

t_2 = metering box air temperature, °F

Δp_w = window pressure difference, mm water column

h_o = orifice pressure difference, mm water column.

The specific weights of air flowing through the window and through the orifice are found as follows:

$$w_w = \frac{1.320}{T_w} \left[B_c - 0.378 p_v + 2,9 h_o \times 10^{-3} \right] \text{ lb/cu ft}$$

$$w_o = \frac{1.320}{T_o} \left[B_c - 0.378 p_v \right] \text{ pcf}$$

where,

T_w = absolute temperature, window air °R

$= 459.6 + \frac{(t_1 + t_2)}{2}$

T_o = absolute temperature, orifice meter air °R

$= 459.6 + \frac{(t_a + t_2)}{2}$

p_v = air water vapour pressure, in. mercury column

B_c = temperature corrected barometric pressure, in. mercury column

$$0.378 = 1 - \frac{R\ (\text{air})}{R\ (\text{water vapour})}$$

R = gas constant .

The metered flow is,

$$Q_m = 1.188\ C_d \cdot d_o^2 \sqrt{\frac{h_o}{w_o}}\ , \text{ cu ft/min}$$

where,

C_d = orifice flow coefficient,

d_o = orifice diameter, in.

The metering box extraneous leakage, Q_L, which had been obtained by calibration, is added to the metered flow; the actual flow through the window is

$$Q_w = (Q_m + Q_L) \times \frac{w_o}{w_w}\ , \text{ cu ft/min.}$$

The window flow is converted to flow at standard conditions at 70°F, 14.70 psia and 0 per cent R H as follows:

$$Q_{ws} = Q_w \cdot \left\{ \frac{w_w}{w_s} \right\}^{1/2}$$

where,

w_s = specific weight of air, standard conditions,

= 0.075 lb/cu ft .

The above conversion is correct only when fully turbulent flow through the window is assumed. Because all but extremely tight windows will probably experience nearly fully turbulent flows at the conditions of test (i.e., at a window pressure difference greater than 0.2 in. water column), the coversion is a good approximation.

The window air leakage rate $= \frac{Q_{ws}}{L_c}$, cfm/ft

where,

L_c = length of prime unit crack, ft.

The stagnation pressure equivalent of a wind of V miles per hour for standard condition air is given by

$$h_w = 4.82 \times 10^{-4}\ V^2, \text{ in. water column.}$$

The stagnation pressures equivalent to various wind speeds are given below.

h_w, in. wg	V, mph
0.012	5
0.048	10
0.108	15
0.193	20
0.301	25
0.434	30
0.770	40