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AIR LEAKAGE VALUES FOR RESIDENTIAL WINDOWS

BY

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SOMMAIRE

Au moment de la rédaction du présent exposé, les seules données contenues dans le manuel de l'ASHRAE et concernent les fuites d'air avaient été tirées d'essais menés à bien 35 années auparavant sur divers types de fenêtres, bien qu'un certain nombre de nouveaux types de fenêtres soient actuellement utilisés. Nien peu de données ont été publiées au sujet des caractéristiques de non-herméticité de ces dernières. Les auteurs donnent les résultats de recherches sur les fuites affectant 39 types de fenêtres domiciliaires, représentatives du matériel utilisé actuellement au Canada et dans le nord des E.-U., et les comparent avec les chiffres ayant servi à dresser les tableaux du manuel de l'ASHRAE. Ils ont découvert que les caractéristiques de non-herméticité des nouveaux types de fenêtres différaient peu de celles des anciens types. Les auteurs proposent que les tableaux du manuel soient complétés pour représenter les caractéristiques des nouveaux types, et que quelques modifications soient apportées au format des tableaux. Depuis la rédaction du présent exposé le manuel de l'ASHRAE a été révisé en tenant compte de quelques propositions avancées ici au sujet des données de non-herméticité et du format des tableaux.

No. 1950

ANALYZED

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Air Leakage Values for Residential Windows

Air leakage through windows constitutes a major component of the heating load in residences and other buildings, and can also be a significant part of the cooling load. The increased emphasis on heat insulation in recent years, especially with electric heating, has reduced the proportion of heat loss due to wall and roof transmission and has focused attention on windows. The window air infiltration information in the current ASHRAE Guide And Data Book is based on tests conducted on windows in use during the period 1924 to 1931. Since that time, many new designs have been developed and there have been modifications to some of the older types. It is natural, therefore, that the applicability of the Guide And Data Book data to current windows is sometimes questioned.

SUMMARY OF EARLIER STUDIES

The Guide And Data Book data for wooden double-hung windows are based on values obtained at the University of Wisconsin in 1930.[1] The range of leakage values obtained at Wisconsin for loose and average fits of the sash in the frame, with and without weatherstripping, is shown in Figs. 1 and 2. The values shown in the figures are for locked windows; the data for double-hung windows presented in the Guide And Data Book are the Wisconsin values for unlocked windows. Air leakage test data for double-hung windows were also obtained at the ASHVE Laboratory in 1924,[2,3] the National Bureau of Standards in 1940,[4] and at the University of Minnesota in 1952.[5]

The current Guide And Data Book does not include air leakage design data for wood casement windows, and suggests for these that the values for the average-fit double-hung windows be used. Some air leakage data for wood casement windows have been published; the ASHVE Laboratory tested one in 1924,[6] and in Europe, especially Norway, they have been investigated extensively.[7] These studies

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Table I Recommended Industry Standards

(Maximum permissible air leakage values, cu ft per hr per lineal ft of sash crack, with an air pressure difference of 1.56 lb per sq ft (= 0.30 in. of water column, the stagnation pressure equivalent to a 25-mph wind) exerted across the locked window.)

Window Type	Air Leakage Rate cfh/ft
STEEL[12]	
Light and heavy duty double-hung; residential casement; intermediate, heavy intermediate and heavy custom casement and projected; architectural projected; industrial commercial projected and horizontal pivoted.	60
ALUMINUM[13]	
(a) Residential double-hung; residential vertical slider; residential and commercial horizontal sliders.	45
(b) Commercial and monumental double-hung.	30
(c) Residential, commercial and monumental casement; residential and commercial projected.	
Non-weatherstripped	60
Weatherstripped	30
(d) Monumental projected.	30*
(e) Residential and commercial awning.	60**
(f) Residential jalousie	90**
(g) Commercial top-hinged inswinging cleaning sash	22½
(h) Monumental, top-hinged inswinging cleaning sash	30*
WOOD[14]	
Double-hung—weatherstripped	45
Casement and projected—weatherstripped	30
ARCHITECTURAL CUSTOM BUILT[15]	
All types and materials	15

* Leakage at an air pressure difference of 6.24 lb per sq ft (= 1.2 in. of water column).

** Air leakage rate expressed as cu ft per hr per sq ft of ventilated area.

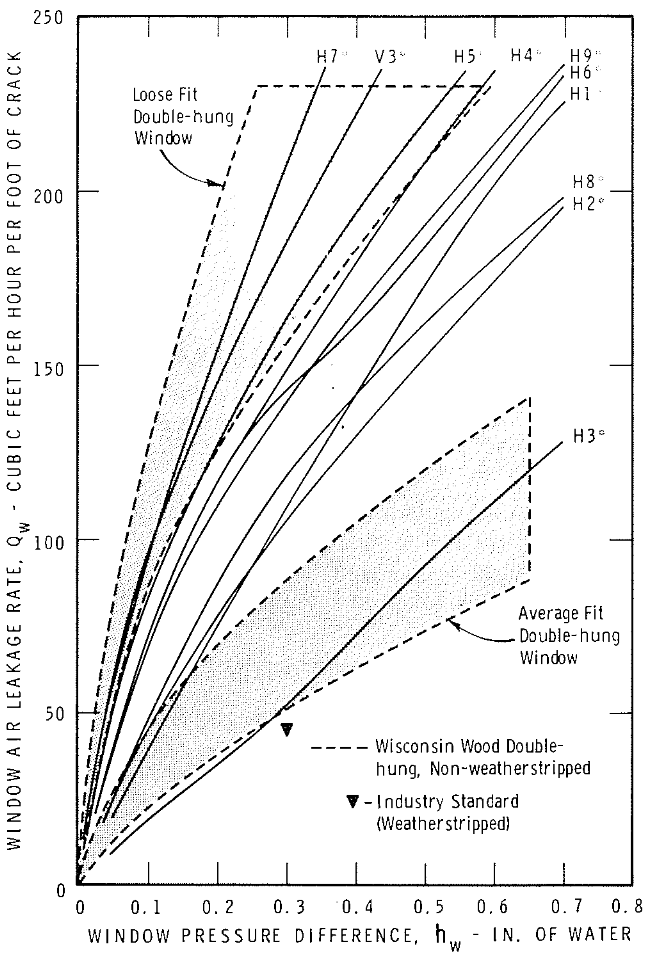

Fig. 1 Prime unit infiltration characteristics (non-weatherstripped horizontal sliding and double-hung windows; windows locked)

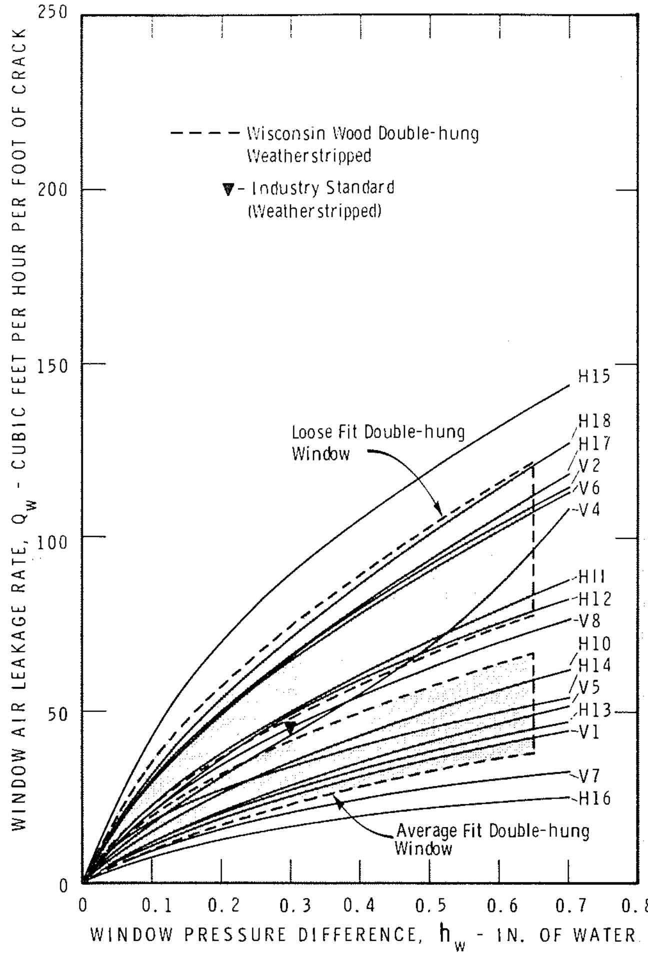

Fig. 2 Prime unit infiltration characteristics (weatherstripped vertical and horizontal sliding windows; windows locked)

demonstrate the high degree of tightness obtainable with casement windows, when weatherstripped, well fitted, and equipped with good hardware.

The values in the Guide And Data Book for hinged and horizontally pivoting steel windows are based on tests conducted at the University of Michigan in 1928.[8] The range of leakage values obtained at Michigan for various fits of the sash is shown in Fig. 3. The Guide And Data Book values for a hollow steel vertically-pivoting window, obtained at the ASHVE Laboratory,[9] are also shown in Fig. 3.

The Guide And Data Book values for sheet-steel double-hung windows were obtained at the ASHVE Laboratory in 1927;[10] the average values of the test results are shown in Fig. 4. Additional test data on steel double-hung windows are reported in Ref. 11, including tests performed at the University of Wisconsin.

Various window manufacturers associations in the United States have developed recommended standards, including air leakage requirements for steel, aluminum, and wood windows.[12, 13, 14, 15] These standards indicate the air tightness expected of contemporary windows under laboratory conditions. Values in the standards are summarized in Table I; appropriate values are also shown in Figs. 1 to 6.

AIR LEAKAGE TEST RESULTS

Thirty-nine residential windows were chosen for test. The units were all factory prebuilt, since the majority of windows used in residential construction are of this type, and were typical of those used in Canada and the colder regions of the U.S. Most were, therefore, either double windows, double-glazed windows, or single windows with attached storm units. (Double windows have nearly identical inner and outer units that operate independently but are mounted in a common frame; double-glazed windows are basically single windows, with a removable glazing unit placed over a single sheet of glass fixed in the operating sash. In the subsequent discussion, double window will be used to denote both double windows as described above and single windows with attached storm units.)

The test windows can be broadly grouped as either sliding windows or hinged windows. The sliding windows include horizontal sliding single and double windows, vertical sliding single windows, and both double and single double-hung windows. The hinged windows include both projected awning and side-hinged casement single windows. A description of the windows tested is given in Table II.

Each window specimen was sealed into an airtight mounting panel which was sealed between two

Table II Test Windows

Identification	Description	Q_w** (cfh/ft)	L_c*** (ft)
H1*	Double Horizontal Sliding—Sashless—Wood frame with cut tracks; no weatherstripping; pressure type locks on both inner and outer units.	109	10.3
H2*	Similar to above	104	15.3
H3*	Similar to above	50	16.2
H4*	Similar to above	150	18.3
H5*	Similar to above	163	18.3
H6*	Similar to above	142	23.8
H7*	Similar to above; additional vinyl sill track	209	16.2
H8*	Similar to H7	118	17.1
H9*	Similar to H7	140	18.3
H10	Double Horizontal Sliding—Wood sash and frame; plastics tracks; fully weatherstripped; cam-type lock on inner unit only.	34	18.8
H11	Double Horizontal Sliding—plastics sash, wood frame, plastics tracks; partial weatherstripping; no lock on inner unit.	50	17.7
H12	Double Horizontal Sliding—light aluminum sash, wood frame, plastics tracks, partial weatherstripping; wedge-type lock on inner unit.	48	19.1
H13	Similar to above, except non-pressure lock on inner unit.	28	19.6
H14	Double Horizontal Sliding—light aluminum sash with plastics sliders, wood frame, aluminum tracks; full weatherstripping; non-pressure locks on both units.	34	18.9
H15	Similar to above except for partial weatherstripping.	89	16.1
H16	Double Horizontal Sliding—light aluminum sash, aluminum frame, stainless steel inner sill track; full weatherstripping; non-pressure lock on inner unit; one-half of inner unit fixed-glazed.	17	10.6
H17	Single Horizontal Sliding—wood sash with light aluminum removable double glazing unit, wood frame, aluminum sill and spring-mounted head tracks; partial weatherstripping; cam-type lock.	66	18.6
H18	Similar to above, except for additional weatherstripping	71	17.4
V1	Single Vertical Sliding—with attached wood storm unit; wood sash and frame; pressure-strip sash retainer; partial weatherstripping; cam-type lock.	26	17.9
V2	Single Double-Hung—with attached wood storm unit; wood sash and frame with aluminum jamb tracks; spiral-spring sash balance; partial weatherstripping; cam-type lock.	67	19.2
V3*	Single Double-Hung—wood sash and frame, with aluminum jamb tracks; spiral-spring sash balance; no weatherstripping; cam-type lock.	187	18.8
V4	Single Vertical Sliding—sheet steel sash and frame; sash retainer and lock consists of pins engaging jamb tracks; partial weatherstripping.	43	17.5
V5	Double Vertical Sliding—light aluminum sash, wood frame and aluminum tracks; sash retainer and lock consists of pins engaging jamb tracks; partial weatherstripping.	28	17.5
V6	Double Double-Hung—light aluminum head, sill and meeting sash rails, sashless jambs, wood frame with aluminum tracks; spiral-spring sash balance; partial weatherstripping; cam-type locks.	64	18.3
V7	Double Double-Hung — aluminum sash, frame and tracks; spring-loaded tape sash balance; full weatherstripping; cam-type lock on inner unit.	21	18.9
V8	Double Double-Hung — aluminum partial-sash, sashless jamb, aluminum frame and tracks; spiral-spring sash balance; full weatherstripping; wedge type pressure locks.	45	18.9
P1	Single Projected Awning—wood sash with light aluminum removable glazing unit, wood frame; full weatherstripping; bar-type operator/lock.	7	13.6
P2	Similar to above	5	12.7
P3	Similar to above, except for roto-gear operator/lock.	14	10.7
P4	Similar to P1, except for absence of operator and addition of two cam-type locks.	37	12.2
P5*	Single Projected Awning—aluminum sash and frame; no weatherstripping; two cam-type locks.	37	12.8
C1	Single Side-hinged Casement—wood sash with light aluminum removable glazing unit, wood frame; full weatherstripping; roto-type sash operator; two hook-type jamb pressure locks.	13	11.7
C2	Similar to above, except for addition of steel outer-lining around wood frame.	24	12.5
C3	Similar to C1.	10	11.6
C4	Similar to C1, except for absence of sash operator, and replacement of lock with cam-type lock.	26	11.0
C5	Single Side-hinged Casement—aluminum sash and frame; full weatherstripping; cam-type lock.	83	10.9
C6*	Similar to above, except no weatherstripping.	26	11.9
C7	Single Side-hinged Casement—rolled steel sash and frame; full weatherstripping attached to frame; hook-type pressure lock.	77	11.1
C8	Identical to above, except weatherstripping attached along perimeter of screen.	122	11.1

* Non-weatherstripped.

** Air leakage rate of window, in cu ft of air per hr per ft of sash crack, determined for a window pressure difference of 0.30 in. of water or 1.56 lb. per sq ft. Windows are tested with the sash locked; the storm unit or the outer unit of double windows is left open.

*** Total sash crack length of the window, including the sash-to-sash crack along the meeting rails of sliding windows but excluding the crack around the storm unit or outer unit of double windows.

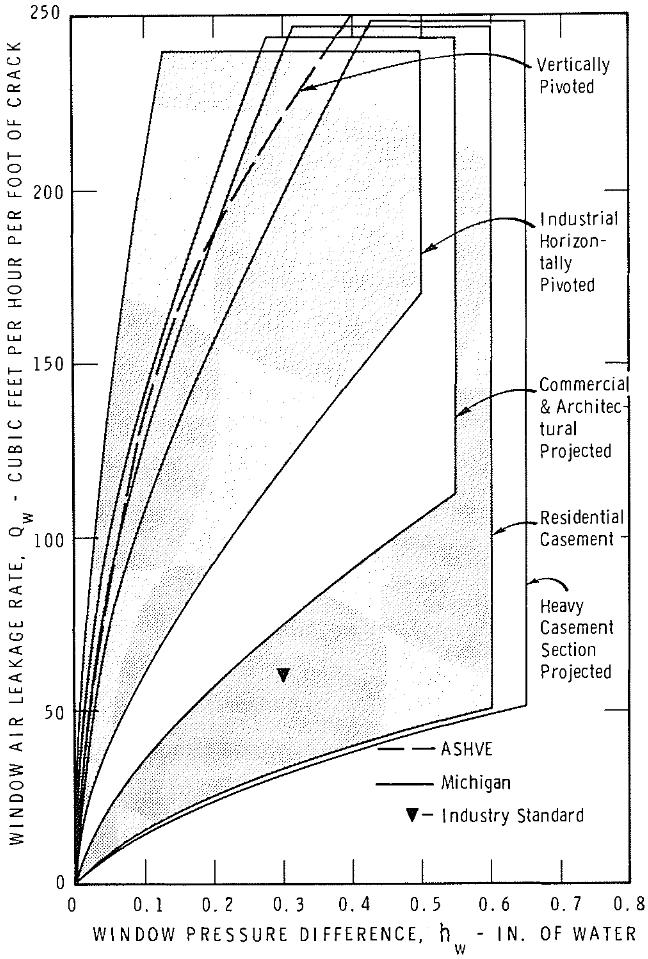

Fig. 3 Air leakage characteristics of non-weatherstripped steel hinged windows (ASHRAE Guide And Data Book table data)

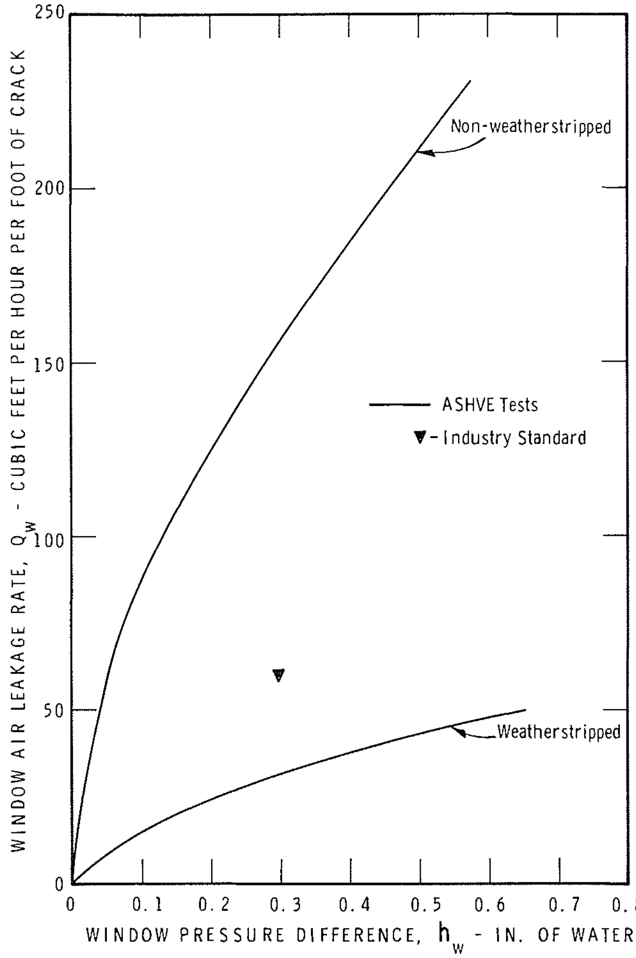

Fig. 4 Air leakage characteristics of steel double-hung windows; windows locked (ASHRAE Guide And Data Book table data)

airtight chambers. Air from a blower was introduced to one chamber, from which it leaked through the window into the second chamber and then discharged to the room through a calibrated orifice flow meter. The window was sealed into the mounting panel in such a way that no leakage occurred around the window frame. The small, extraneous leakage from the orifice chamber to the room was determined separately. Pressure measurements were made with a sensitive micromanometer. The total error in the window leakage determinations did not exceed ± 5%.

The prime unit leakage characteristics of the single windows were obtained with the sash closed and locked. The prime unit characteristics of the double windows were obtained with the outer or storm unit left open while the inner or prime unit was locked shut. The window specifications of the Canadian Government Specifications Board[16] require that double windows be tested in this manner. This requirement ensures a tight inner sash and permits a relatively loose outer or storm unit, which is consistent with principles to be followed in providing resistance to rain penetration and to condensation between the inner and outer panes.[17] The infiltration characteristics were obtained with air flowing through the window from outside to inside; exfiltration characteristics with the air flow from inside to outside.

The double windows were also tested with both prime and storm units locked shut, in order to determine the maximum air tightness obtainable.

The prime unit infiltration values, prime unit exfiltration values, overall air infiltration values, and the distribution of leakage in the window are listed in Table III. The leakage values, expressed as cu ft of air per hr per ft of prime sash perimeter, are given for a window pressure difference of 1.56 lb per sq ft (0.30 in. of water column, the stagnation pressure equivalent to a 25 mph wind); this is the reference pressure commonly used in window air leakage specifications.

The prime unit infiltration characteristics for the nine sashless horizontal sliders and the one double-hung window, all non-weatherstripped, are compared with the University of Wisconsin values for non-weatherstripped wood double-hung windows in Fig. 1. Nearly all the windows in this group had leakage values that were greater than the Wisconsin values for average-fit windows. The prime unit infiltration characteristics of the weatherstripped horizontal and vertical sliding single and double windows are compared with the Wisconsin values for weatherstripped double-hung wood windows in Fig. 2. The range of air leakage values for the weatherstripped windows is nearly identical with that obtained in the Wisconsin study.

Air infiltration values obtained for the weatherstripped wood casement and projected windows are shown in Fig. 5. Results are compared with the Wisconsin values for weatherstripped wood double-hung windows; in general, these windows are tighter than the average-fit double-hung windows. Air infiltration characteristics for the metal casement and projected windows are shown in Fig. 6. The samples selected for test in this group are not regarded as fully representative of the windows available; the results demonstrate, however, that a well-fitted sash, even without weatherstripping, can be tighter than a poorly-fitted sash with weatherstripping.

The distribution of prime unit leakage is shown in Table III. Frame leakage implies only the leakage passing through cracks in the frame itself, and does not include the leakage that may normally pass through the space between the window and supporting wall. Many of the wood windows, as received, had exterior frame trims or mouldings through which air leakage occurred. Since this leakage represented workmanship rather than design and because it was easily eliminated, it has not been included in the results given in this paper. In general, the distribution of leakage is peculiar to the individual windows. The sashless horizontal sliding windows, however, were distinct as a group because all had a relatively large head track leakage; the glass lights were held against the head track by retainers or snubbers, which were ineffective as sealers when a pressure drop was exerted across the window from the outside.

The prime unit exfiltration values of the windows, shown in Table III, generally differ from the infiltration values. This difference depended upon the effectiveness and location of the weatherstripping, the locking arrangement, and the fit of the sash in the tracks or frame; windows with nearly identical infiltration and exfiltration values were those having adequate weatherstripping, a good sash fit, or effective locking. The sashless horizontal sliders were the only windows which, as a group, had exfiltration values much less than the infiltration. The outward acting pressure associated with exfiltration held the glass lights tightly against the head-track sealing-face and thereby reduced the large leakage at this point.

The air leakage through all the double windows was reduced when the outer or storm units were closed and locked. The air leakage through a double window with storm unit with the same leakage characteristic as the prime would be approximately 30% less than the leakage through the prime alone. Nearly two-thirds of the windows showed a reduction of 30% or more. A tight storm unit, although reducing air leakage, will increase the possibility of interpane condensation in winter and rain penetration.

In the present study, as in previous ones, the variation in air leakage values obtained for a single-type window is quite large, especially for the non-weatherstripped windows. The range is greatly reduced with weatherstripping, although it may still be significant. In addition to fit, minor differences in construction and condition, such as warpage, cause windows of apparently similar fit to have considerable differences in leakage. The range of values obtained differs very little from that obtained in the earlier studies. This suggests that, even with the great number of new window designs available today, the air leakage performance of residential windows of the types referred to has not changed significantly over the years.

REVISION OF AIR LEAKAGE DATA

The present investigation indicates that the test results forming the basis of the present Guide And Data Book table are still valid for modern windows of the types covered. There are, however, a number of new

Table III Test Air Leakage Results

(Determined at a Window Pressure Difference of 0.30 in. of water or 1.56 psf)

Window	Prime Unit Infiltration** cfh/ft	Prime Unit Exfiltration, Per Cent of Infiltration	Infiltration of Locked Storm and Prime Units, Per Cent of Prime Infiltration	Distribution of Prime Unit Infiltration, Per Cent of Prime Infiltration				
				Frame	Head	Sill	Jambs	Meeting Rails or Hinges
H1*	109	—	60	11	49	—	40	—
H2*	104	—	51	14	86	—	—	—
H3*	50	—	—	23	77	—	—	—
H4*	150	—	63	3	97	—	—	—
H5*	163	—	63	4	96	—	—	—
H6*	142	—	70	6	89	2	1	2
H7*	209	—	46	9	84	2	5	0
H8*	118	—	48	24	76	—	—	—
H9*	140	35	53	10	78	0	10	2
H10	34	100	74	31	19	11	11	28
H11	50	96	50	5	33	16	12	34
H12	48	—	85	33	31	—	10	26
H13	28	100	70	26	35	5	12	22
H14	34	—	93	28	52	—	10	10
H15	89	45	70	17	44	3	6	30
H16	17	100	84	48	52	—	—	—
H17	66	117	—	26	18	26	28	2
H18	71	89	—	31	26	5	35	3
V1	26	116	93	33	26	13	11	17
V2	67	100	63	9	13	21	54	3
V3*	187	—	—	3	8	34	25	30
V4	43	74	—	47	1	1	29	22
V5	28	108	64	40	11	8	30	11
V6	64	100	60	50	4	16	5	25
V7	21	106	94	20	1	1	33	45
V8	45	93	—	31	5	9	7	48
P1	7	100	—	40	24	28	8	—
P2	5	180	—	0	75	13	12	—
P3	14	112	—	11	40	20	29	—
P4	37	100	—	2	25	20	53	—
P5*	37	107	—	10	10	22	58	—
C1	13	38	—	56	9	6	9	20
C2	24	95	—	—	6	12	27	55
C3	10	100	—	62	15	15	8	—
C4	26	118	—	18	12	10	20	40
C5	83	104	—	0	21	17	62	—
C6*	26	400	—	28	14	2	56	—
C7	77	110	—	13	24	35	28	—
C8	122	116	—	4	11	12	73	—

* Non-weatherstripped.
** Prime unit only, locked; storm or outer unit, open.

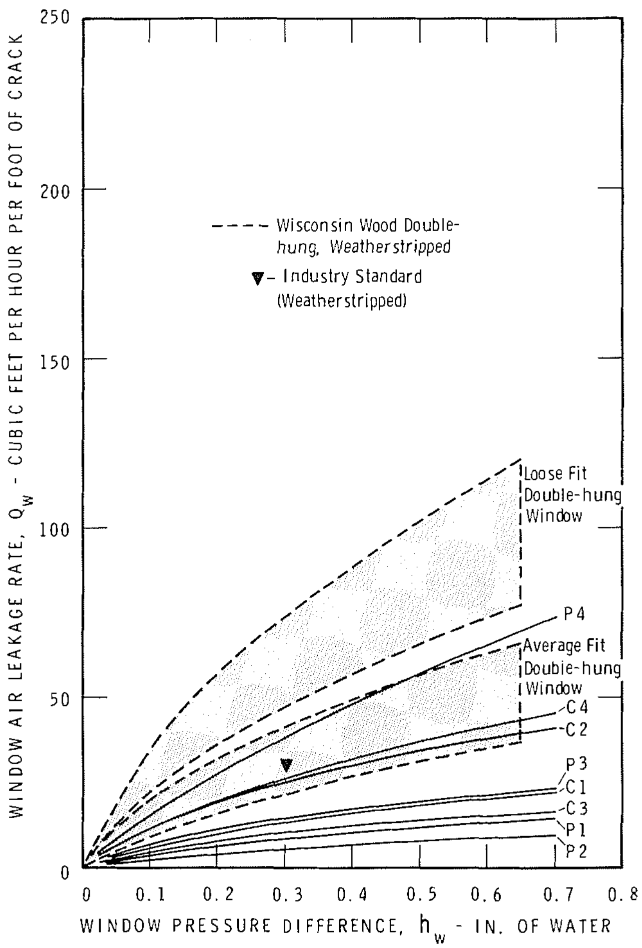

Fig. 5 Air infiltration characteristics of weatherstripped wood casement and projected (awning) windows

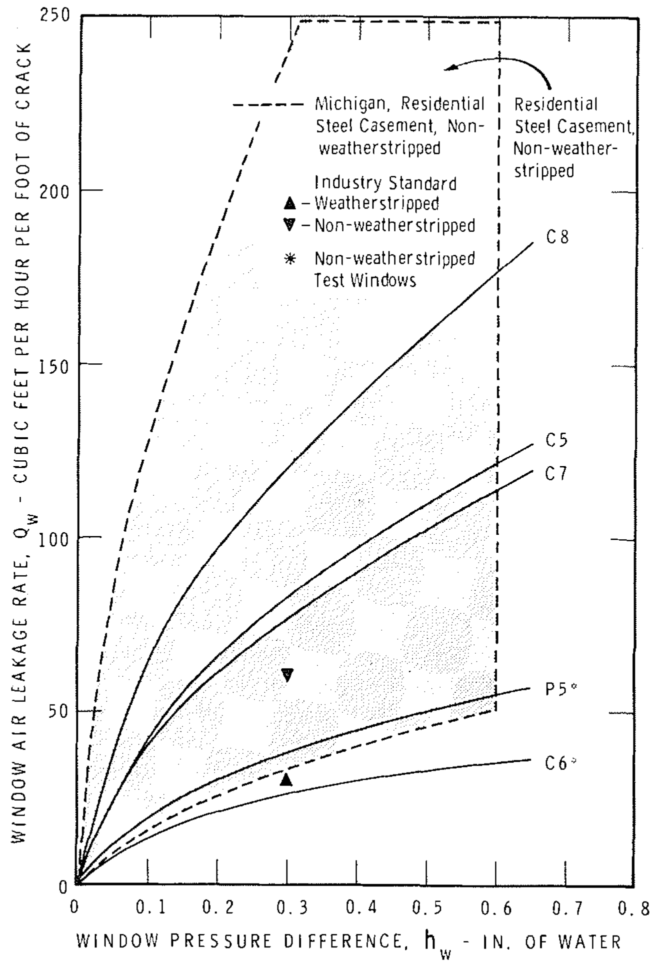

Fig. 6 Air infiltration characteristics of weatherstripped and non-weatherstripped metal hinged windows

types not referenced in the table. Some of the casement, projected, and sliding residential types are included in the present tests; the sliding types have leakage values comparable to those for the weatherstripped and non-weatherstripped wood double-hung windows; as a group the weatherstripped wood casement and projected windows have somewhat lower values.

There is a lack of published test information on most of the new types of metal windows. Where a major building is involved, the windows are often custom-made and it is desirable to have leakage tests made on specimens of those installed. In other situations, the values given in industry standards for the specific window type (Table I) provide some guidance; these values can be modified by a safety factor according to the judgment of the designer.

The large variation in air leakage characteristics of windows of a given type, particularly when not weatherstripped, has been noted. Great precision in establishing the appropriate air leakage value is, therefore, usually not possible. It would seem desirable to indicate the probable range of values in a design table so that the engineer can exercise judgment in his selection.

Air leakage values for double-hung windows in the Guide And Data Book are given for the unlocked condition; values for other windows are given for the locked configuration, or both. For purposes of uniformity, and to be consistent with the conditions of test in industry standards, it is suggested that all leakage data be given for the locked arrangement. The effect of locking varies with the window design. Based on information in the reference from which Guide And Data Book values for double-hung windows were developed, the effect of locking is generally small with weatherstripped windows; the ratio of leakage for unlocked and locked arrangements is usually less than 1.2. For non-weatherstripped double-hung windows, the difference between locked and unlocked arrangements generally increases with increasing looseness; the ratio of unlocked to locked values is as large as 1.8. Similar results were obtained for the windows reported in this study.

The current Guide And Data Book tabulates design window leakage values for various wind speeds. These values are 20% less than the leakages measured at pressure differences equivalent to the stagnation pressures of the tabulated wind speeds. This reduction in leakage was made to account for the fact that the pressure drop across windward walls is usually numerically less than the stagnation pressure of the wind. Pressure differences causing air leakage also result from building chimney action and imbalance

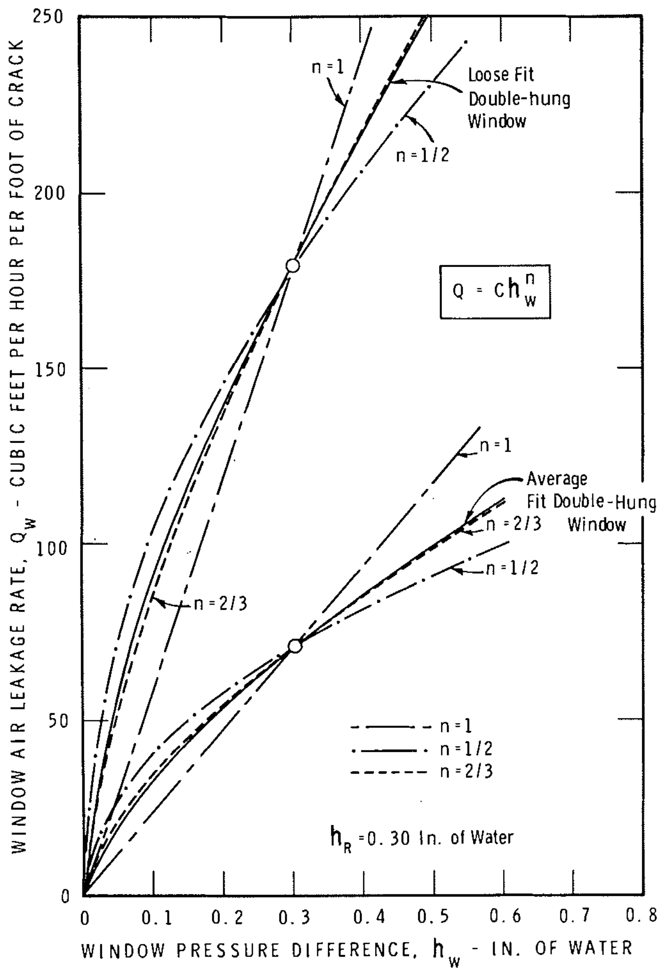

Fig. 7 Simplified air leakage characteristic

of supply and exhaust air systems; for tall buildings, these factors may be more important than wind. It would seem preferable, therefore, to present design air leakage values as a function of pressure difference.

Presentation of window leakage data can be simplified by giving leakage values for a standard reference pressure difference. Air leakage values for other pressure conditions can then be extrapolated using a relationship of the following form:

$$Q = C(h_w)^n = Q_r(h_w/h_r)^n$$

where Q = window air leakage rate
h_w = window pressure difference
C = proportionality constant = $Q_r/(h_r)^n$
Q_r = tabulated reference air leakage rate
h_r = reference window pressure difference

Similar methods for presenting air leakage characteristics have been proposed.[4,5] A logical choice for the standard reference pressure difference is h_r = 0.30 in. of water, or 1.56 psf, as this is the value most commonly used in window standards. Fig. 7 indicates that an exponent of 2/3 gives the best approximation of the air leakage characteristic of loose and average fit windows tested at the University of Wisconsin. Any discrepancy between the approximate and actual characteristics is minor, relative to the general variability of window leakage characteristics.

CONCLUSION

Results given in this paper indicate that air leakage characteristics of current designs of vertical and horizontal sliding residential-type windows, of both wood and metal construction, are similar to those for wood double-hung windows covered by the Guide And Data Book. Air leakage values obtained for residential-type, weatherstripped, wood casement, and projected-awning windows were somewhat lower than those for weatherstripped wood double-hung windows in the Guide And Data Book. Air leakage results for the metal casement and projected windows in this study demonstrate the importance of good fit in achieving tightness. An insufficient number of windows of this type was tested to warrant specific conclusions.

There are a number of new designs of metal windows not covered in this study for which there are little published air leakage data, but for which industry standards have been published. Air leakage values in these standards provide some guidance in developing Guide And Data Book data for these windows. In view of the great variety of types available and the difficulty of selecting representative samples, the value of a test program to provide such information is questionable.

It is suggested that some changes in the format of the Guide And Data Book table are desirable; a range of air leakage might be given for each type of window for which there are representative test results; air leakage should be expressed as a function of pressure difference; presentation can be simplified by giving air leakages for a single value of pressure differences and values at other pressure differences obtained from an appropriate exponential relationship.

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12. Recommended Standards for Steel Windows, Steel Window Institute, Cheltenham, Penn.
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15. Curtain Wall Specifications, National Association of Architectural Metal Manufacturers, 228 North LaSalle St., Chicago 1, Ill.
16. Window Specifications, Canadian Government Specifications Board, Ottawa, Canada.
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DISCUSSION

W. J. GRUBBS, Barberton, Ohio: I wish to compliment the authors on their fine paper. The window industry has need for this type of data, from which more meaningful industry standards can be developed.

Concerning the statement on page 4 of the paper, that "The window specifications of the Canadian Government Specifications Board require that double windows be tested in this manner. This requirement ensures a tight inner sash and permits a relatively loose outer or storm unit . . ." What do you consider a tight inner sash in terms of cfh/ft of crack?

AUTHOR SASAKI, (Written): Before answering this question, I should first like to expand on the significance of tightness on the performance of double windows. In addition to their effect on a building's heating and cooling loads, the overall window tightness and the relative tightness of the prime and storm units affect the heat transmission through the window, the minimum inside surface temperature, the window rain leakage resistance, and condensation on the inner surface of the storm. A double window with overall tightness exhibits greatest resistance to rain penetration and to condensation between the panes when the prime unit is tighter than the storm. It was to promote this resistance that the air tightness requirement, as quoted above, for double windows was written. Air infiltration through the window increases the heat transmission loss through that window and decreases the inside window surface temperature. Increasing the overall window tightness reduces these effects of infiltration. Inside surface temperatures and heat transmission are also adversely affected by the interchange, due to natural convection, of air between the prime-storm air space and the outside. This natural venting is decreased by an increase in storm unit tightness. The minimum inside surface temperature determines whether condensation will occur on the inside surface of the window. For most cold weather usage, especially in humidified buildings, the inside surface temperature should be kept as high as possible. A loose or vented storm unit, although minimizing rain penetration, lowers the inside surface temperatures on the window and increases the possibility of inside surface condensation. It will be seen that there is a potential conflict between the various window performance requirements; the overall and relative tightnesses of the prime and storm must be such that no one aspect of the window's performance suffers unduly at the expense of another.

Thermal tests were performed on an idealized double window at the Division of Building Research to determine quantitatively the adverse effect of natural venting around the storm and infiltration through the window on the window heat transmission loss and on inside surface temperatures. As the infiltration of air through the window was increased from zero, the inside surface temperatures dropped and the heat transmission through the window increased.

When the air leakage exceeded approximately 30 cfh/ft of crack, the inside surface temperature dropped below what was considered acceptable and the increase in heat transmission loss became significant. Taking this leakage rate as the maximum permissible at a pressure difference equivalent to the stagnation pressure of wind at 15 mph, the overall window air leakage, rated at a pressure difference equivalent to a 25 mph wind, must not exceed approximately 50 cfh/ft of crack.

The natural venting measurements indicated that the tightness of the storm unit must be such that air leakage through the storm unit alone must not be much in excess of 120 cfh/ft of crack (at 25 mph wind pressure), if the decrease in inside surface temperature and the increase in heat transmission loss are to remain within acceptable limits, regardless of the prime unit tightness. If the storm unit leakage characteristic is limited to 120 cfh/ft of crack (at 25 mph wind pressure), and the overall window leakage is limited to 50 cfh/ft of crack (at 25 mph wind pressure), then the leakage characteristic of the prime unit alone must not exceed 60 cfh/ft of crack (at 25 mph wind pressure).

With these limits on the leakage characteristics of the prime and storm, the pressure drop across the storm unit will only be one-fifth of that across the whole window when both are locked, and a reasonable degree of resistance to rain penetration is provided. When the leakage characteristic of the storm is decreased to 60 cfh/ft at 25 mph wind pressure (i.e. equal to the prime unit), the overall leakage characteristic of the window becomes 40 cfh/ft (at 25 mph wind pressure); the pressure drop across the storm is one-half the total drop and the possibility of rain penetration is increased.

Tests have shown that, under design conditions, interpane condensation can be eliminated only when the storm unit tightness is a small fraction of the prime tightness. Since the leakage characteristic of the storm is limited by thermal considerations, elimination of interpane condensation is only practical for windows with extremely tight prime units. Windows having a prime unit leakage characteristics of 60 cfh/ft (at 25 mph wind pressure) may have some condensation between the panes.

The above discussion suggests that, from the standpoint of window thermal performance and rain leakage considerations, the leakage characteristic of the prime unit alone should not exceed 60 cfh/ft of crack (rated at a pressure difference equivalent to a 25 mph wind), while that of the storm unit alone should not be less than that of the prime unit and should not exceed 120 cfh/ft of crack (at 25 mph wind pressure); and that leakage through the double window with both prime and storm units closed should not exceed 50 cfh/ft of crack (at 25 mph wind pressure). Greater overall window tightness may, however, be indicated by such considerations as building heating economy and comfort.

MR. GRUBBS: This paper should prove to be a service to engineers, builders and home owners because it points out that far too many primes now offered for sale fail to meet the generally accepted maximum air leakage standards. Actually, only eight of the 26 windows tested for this paper did so. Further, this wide disparity was difficult to determine by visual examination and verbal description, indicating a need for further testing as the only means whereby performance can be determined.

G. Y. ANDERSON: Pocatello, Idaho (Written): The paper suggests that the ASHRAE Guide And Data Book table "be simplified by giving air leakages for a single value of pressure differences and values at other pressure differences obtained from an appropriate exponential relationship." While I agree that the exponential relationships be included in the ASHRAE Guide And Data Book, I do not think that they should replace the table, because most heat loss and seasonal energy consumption calculations are made for wind velocities other than 25 mph. It may, however, be wise to delete some of the wind velocity columns in the table to provide space for a column of exponential equations within in the table itself.

I also recommend that the exponent for the approximate exponential relationships be expressed as a decimal, rather than as a fraction.

AUTHOR SASAKI, (Written): The use of an exponential relationship in conjunction with air leakage values given at a reference pressure difference is suggested only as a simplification for cross tabulation of leakage vs pressure difference. The more important change called for in the paper is the expression of window air leakage as a function of air pressure difference, since factors other than wind do contribute to the pressure difference causing air leakage. Even if wind were the only contributing force, the designer making the heat load calculation still must decide what fraction of the total design wind velocity head acts across the window. Because this fraction varies according to exposure and building configuration, it would be incorrect to list a single value of air leakage for any given design wind speed.