FIELD AIR LEAKAGE OF NEWLY INSTALLED RESIDENTIAL WINDOWS

By

J. L. Weidt, J. Weidt, S. Selkowitz

ABSTRACT

Air leakage characteristics of 192 new windows installed in new residential construction representative of those units commonly installed in the Minneapolis/St. Paul Metropolitan Area have been measured and evaluated. The tested windows represented all major operation types, window material types and manufacturers represented in this market segment.

The air leakage data obtained in the field were compared to industry and government standards and manufacturers reports for reference. Window operation type, manufacturer, installation, construction material and window defects were analyzed in detail to determine their effects on air leakage.

The results of the project indicate that the air leakage of installed windows can be significantly higher than might be expected from laboratory tests. Window operation type was the prime variable in explaining the air leakage performance.

(1) John L. Weidt; John Weidt Associates; Chaska, Minnesota
(2) Jenny Weidt; John Weidt Associates; Chaska, Minnesota
(3) Stephen Selkowitz; Lawrence Berkeley Laboratory; Berkeley, California

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INTRODUCTION

Recent events underlining the dependence of the United States on dwindling energy resources has increased the need to identify areas in which energy wastes can be curtailed. Historically, little consideration has been given the energy effectiveness of windows in the design and construction of buildings. Little is known about the installed performance of windows and no regulations or standards exist that mandate specific performance requirements of windows once installed. Little data is available relating laboratory performance of a window to its installed performance in the field. A pilot program was begun by the United States Department of Energy (USDoE) and Lawrence Berkeley Laboratory (LBL) to investigate the air leakage performance of new windows being installed into new construction in the Minneapolis/St. Paul area. This paper describes work performed by John Weidt Associates, Inc. and Twin City Testing & Engineering Inc. for the Minnesota Energy Agency (MEA), under contract to Lawrence Berkeley Laboratory as a part of the US DoE/LBL Energy Efficient Windows Program. The project focused on the air leakage performance of new residential windows and compared the field test results with industry and government standards and manufacturers reports for reference.

A cross-section of wood and aluminum windows representative of the most commonly installed new residential window units in the Minneapolis/St. Paul Metropolitan Area was tested. The tested windows represented all major operation types and included tests of windows made by all major manufacturers marketing residential windows in the test area. The field testing was performed at 58 new construction sites; single family homes, townhouses, low and high rise apartments and condominiums. 192 windows were field tested for sash/frame leakage.

FIELD PROCEDURES

Pressure and temperature differences between the exterior and interior of a building induce air leakage through its envelope. Prime locations for this leakage are the cracks between the various parts of the window unit such as between the sash and frame. The purpose of this study was to determine the amount of air passing through these locations in the window unit and to obtain a better understanding of the relative contribution of such factors as window design, manufacturer and installation.

All field work and tests of leakage and exfiltration were made according to a standard test method based on American Society for Testing and Materials ASTM E-283 modified for field conditions. All results were standardized to account for atmospheric temperature and pressure conditions. The test process involved construction of a test chamber by sealing a sheet of plastic to the interior window frame. A negative pressure between the plastic and the window was then created to simulate a pressure difference equivalent to that of a 25 mph wind on the exterior of the unit. The amount of air flowing through the sash/frame crack of the window unit was then measured and the leakage rate calculated. While under pressure, the exterior perimeter of the window unit was examined with smoke to help determine areas of leakage. The window was examined before and after testing for flaws such as missing or damaged weatherstripping. Weather data, site and test conditions were systematically recorded. After testing was completed, the data were input into a computer and compiled for analyses.

Field Tests - Comparison With Reference Values

The air leakage data obtained in the field were compared to industry and government standards and manufacturer's reports for reference. Window associations such as National Woodwork Manufacturers Association (NWMA) and Architectural Aluminum Manufacturers Association (AAMA) have certification requirements that a window, when tested in a laboratory, perform within the specified maximum limit of .50 cfm/lfc (cubic feet of air per minute per linear foot of crack of operable sash). A number of public standards such as National Council of States on Building Codes and Standards (NCSBS) Model Energy Code, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90-75, U.S. Department of Housing and Urban Development Minimum Property Standards (HUD MPS) and U.S. Federal Housing Administration Minimum Property Standards (FHA MPS) require certification of a product line through laboratory testing. Manufacturers frequently reference these air leakage testing results in their advertising by either stating that they meet or exceed the standards of .50 cfm/lfc or by publishing laboratory test results for a particular model of their product line.

Although these standards and reports are based on a laboratory testing situation and do not necessarily relate to the performance of a window once it has been installed, designers and builders who specify and purchase windows frequently assume that these laboratory test results are indicative of the window's field performance capabilities and make their selections accordingly. The purpose of this portion of the study was to compare the actual measured field air leakage performance of installed windows with these laboratory test based reference values.

The average air leakage rate of all windows tested was .52 cfm/lfc. 40% of all windows tested possessed air leakage characteristics higher than the industry and government standards of .50 cfm/lfc. The field air leakage performance of the windows ranged from .01 cfm (an extremely tight window) to 2.28 cfm/lfc (an extremely leaky window) while manufacturers' performance specifications ranged from .01 cfm/lfc to .50 cfm/lfc. The leakage rate of 60% of the windows tested exceeded the specifications published by their manufacturers. Figure 1 compares the actual field performance of each window to manufacturer, industry and government references.

After ascertaining the field performance of the tested windows the data were analyzed to find reasons for the range and level of air leakage performance. Window operation type, manufacturer, installation, construction material and window defects were analyzed in detail to determine their relationships on air leakage.

ANALYSIS OF VARIABLES

Field Air Leakage Performance Related to Window Operation Types

Results of the field tests were grouped by window operation type to identify patterns of air leakage performance. Analysis of the data indicated that the primary operation type of the window (casement, slider, or hung) was the most important variable in explaining a window's air leakage performance. Figure 2 illustrates the relative performance by window operation type, and shows the average air leakage performance of casement windows to be .23 cfm/lfc, double sliders to be .61 cfm/lfc, double hung to be .72 cfm/lfc, single sliders to be .79 cfm/lfc, and single hung to be .96 cfm/lfc. Table 1 lists the range, mean and standard deviation of the field results.

When compared on the basis of air leakage expressed in cfm/lfc, casement windows far out-performed sliders, and sliders generally out-performed hung windows, irrespective of all other observed variables, such as the material the window was made of, the manufacturer of the window, or the installer of the window. Manufacturers who made casement, slider and hung windows generally produced casement windows with lower air leakage rates than their sliders, while their slider windows generally had a lower air leakage rate than their hung windows. A comparison between the field air leakage data and the manufacturer's reference specifications showed that, with the exception of casement windows, the majority of all operation types tested had higher air leakage rates than indicated by the manufacturers' reference. In all, 33% of the casement windows, 70% of the double slider windows, 79% of the double hung windows, 84% of the single slider windows, and 100% of the single hung windows had higher field air leakage rates than the manufacturer's laboratory report.

Air Leakage Performance of Window Construction Material

Field window performance data were grouped by window operation type and then material subtype - aluminum, wood or clad wood - to identify patterns of performance. When more than one material type populated an operation type, such as a mix of aluminum and wood single sliders or wood and clad wood casements, there was no particular pattern of one material type to out-perform the other material type. Table 2 lists the range, mean, standard deviation and air leakage performance of the various window types studied. Shown under each major operation type is the performance of the window material subtype. Particular care should be exercised when examining relative performance by material type within the single and double slider window categories. Breaking these categories down further by manufacturer, it appears that shifts in relative performance between groups of windows within any operation type appears to be more a function of manufacturer than of construction material. Table 3 illustrates this trend.

Field Air Leakage Performance Related to Window Manufacturer

Each operation type of each of the 16 manufacturers in the study was analyzed and its performance compared to the average performance of that operation type. All operation types of four of the manufacturers had better than average air leakage performance; all operation types of four of the manufacturers had average air leakage performance and four manufacturers produced windows whose performances were consistently worse than average. The product line of the remaining four manufacturers did not follow the above pattern; the performance of operation types produced by each of these manufacturers vacillated from below to above average. The pattern of performance of the product lines of the manufacturer could generally be ranked by the window design in that, each manufacturer's casement window normally out-performed his double slider and his double slider normally out-performed his double-hung window.

In addition to the tendency of certain manufacturers to produce product lines with lower or higher air leakage rates than the average, there appeared to be a trend for certain manufacturers to out-perform other manufacturers within a specific operation type. This trend was not necessarily consistent across window operation types; manufacturer A's casement may out-perform manufacturer B's casement, while manufacturer B's double-hung may out-perform manufacturer A's double hung.

A series of tests was designed to investigate the decline in performance, if any, of a window between the time it is manufactured and the time it is installed. Twenty-five windows were tested randomly at three different manufacturer's plants. The results of these factory tests were compared to results obtained on similar windows tested in the field. Table 4 illustrates the results of these tests which indicate an average decline in performance of approximately 29% between factory and field.

Field Air Leakage Performance Related to Installation Techniques

The 192 windows in this study were installed by 28 different contractors, a minimum of three and a maximum of 21 window tests per contractor. In eleven situations, encompassing 39 window tests, one manufacturer's window type was installed by more than one contractor. In eight of these eleven cases there was no significant difference in the average performance of three window units installed by one contractor compared to three similar units installed by the second contractor. In the remaining three sets of tests, one manufacturer's model was installed by three different contractors. The performance of two of these three sets of windows were very similar, but the set of windows installed by the third contractor had over 50% more air leakage than the windows installed by the first two contractors.

Field Air Leakage Performance Related to Construction Defects

The field inspection of the tested windows revealed a number of anomolies such as areas of excessive leakage and physical defects in weatherstripping, hardware, and sash fit that the testing personnel felt may have significant impact on the performance of the windows tested.

Physical defects in the tested window units were observed to relate to locations of excessive air leakage. Although a few of the defects appeared to be a result of abuse of the window during installation, the majority appeared to have been the result of the manufacturing process. Three particular defects were most commonly observed.

Weatherstrip Discontinuity. The weatherstripping seal around leaky windows was frequently discontinuous. Most commonly this occurred at sash corners, where the weatherstrip at the jamb was not in the same plane as the weatherstrip at the head or sill. There were also cases where the weatherstrip was cut shorter than the sash, allowing a gap to occur at the corners.

Sash Fit. The "tightness" by which the sash held the weatherstrip in contact with its meeting surface had particular significance in leakage at the sill and meeting rail. A loose sash allowed gaps between the sashes or sash and frame which could not be sealed by the weatherstrip. The squareness of the sash in the frame affected leakage at corners, particularly in double slider windows, where out-of-square sash allowed large corner leakage.

Hardware Seal. In certain instances, locking hardware failed to seal the window shut and, instead, forced the sash away from the frame or meeting rail, creating poor weatherstrip contact.

The performance of windows of each operation type with observed anomolies was compared to the average performance of that operation type. The results of this analysis indicate that the greatest observed excess leakages occurred primarily at the corners of the windows and along the head, meeting rail and sill, and that these observed excess leakages usually related to a window with greater air leakage than average. Table 5 illustrates this trend. Excessive observed leakage was related to weatherstrip discontinuity, sash fit and hardware seal in a number of cases.

Field Performance Expressed by Varying Air Leakage Rates

At the current time, all standards and specifications for evaluating window air leakage are based on a per linear foot of crack calculation which expresses the air leakage (in cubic feet per minute) that will pass through the sash/frame crack under a pressure equivalent to a simulated 25 mph wind. Although this measurement of a window's air leakage performance is reasonable in an absolute sense, it can be misleading if used as criteria when selecting between two window types such as single sliders and double sliders. These two types of windows, as an example, may have exactly the same dimensions, however, when the air leakage is calculated via the crack length method, the double slider will appear to perform much better than the single slider merely because allowance is given for the additional crack length. Refer to Figure 3 which compares the crack lengths of various window types of equal area.

Technical differences in the definitions of single and double operating units can lead to additional confusion. For instance, some side sliding windows observed during the field testing appeared to be double slider windows as both sashes were equipped with hardware and track; one sash, however, was held in place with set screws. The manufacturer defined this window as a single slider. Other side sliding windows were observed in which only one sash was equipped with a full width track, the track for the second sash extended to only 1/2 the width of the frame and the sash had no hardware (handles, etc.) for operation. Nonetheless, the sash was unrestrained - the manufacturer defined the unit as a double slider. Identification and performance calculations of all windows tested in this project were based upon the manufacturer's definitions of his window types. The air leakage rates of the two windows above were thus related to the appropriate crack length for single and double slider windows, respectively. In analyzing the performance of these two particular types of windows, the "double" slider out-performed the "single" slider on the basis of air leakage per linear foot of crack (the double slider had over 69% more crack length and thus the total air leaking through the unit could be divided by this substantially greater crack length). When these two windows were compared on the basis of air leakage per glazed or ventilating area, however, the single slider substantially out-performed the double slider.

The air leakage rates were calculated in three different ways; per linear foot of crack, per square foot of window sash area, and per square foot of ventilating area. Table 6 lists the average air leakage performance of the major operation types measured in this study expressed in terms of linear foot of crack, square foot of sash area, and square foot of free ventilating area. A graphic representation varying the expression of air leakage performance is given in Figure 4. Large shifts in relative performance, dependent on the expression of leakage used, can be observed, particularly in the following areas:

Single Slider Relative to Double Slider Windows. When air leakage is expressed per linear foot, the leakage rate of the double slider is 72% that of the single slider. When the air leakage is expressed as a function of either sash or vent area, the roles reverse and the leakage of the single slider is 62% and 60% that of the double slider, respectively.

Single Hung Relative to Double Hung Windows. When air leakage is expressed per linear foot, the leakage rate of the double hung is 66% that of the single hung. When the air leakage is expressed as a function of either sash or vent area, the roles reverse and the leakage of the single hung is 81% and 84% that of the double hung, respectively.

Casement Windows Relative to All Other Windows. Whether the leakage is expressed per linear foot, sash area or ventilating area, the average casement window out-performs the average of the next highest performing window operation type.

AIR LEAKAGE PERFORMANCE OF FIXED SASH

Six fixed window units were tested for their installed air leakage performance. Table 6 illustrates the results. The fixed windows tested exhibited relatively poor air leakage characteristics considering the relative ease with which fixed sash should be able to be sealed into their frames. Leakage of the units was usually located with smoke and occurred near corners both at the glazing/sash and the sash/frame interface. The poorest performer did not appear to have continuous sealant between the glazing and the sash, as a strip of cardboard could easily be inserted between the sash and lite in several places.

CONCLUSIONS

Conclusions and recommendations have been based upon experimental results and observations made during this project. It must be emphasized that these observations are based upon a sample window population in a specific geographical location, although we believe the results to be broadly applicable to similar populations in other locales.

A comparison of the performance of the windows studied to the laboratory based manufacturer's published air infiltration data, NWMA & AAMA certification specifications, HUD, FHA MPS, and the Minnesota State Building Code (based on ASHRAE 90-75) clearly indicate that the field performance of a unit can be far different from these reports. A large percentage of the windows tested had air leakage in excess of these standards and reports. The contractors and installers participating in the study expressed that they relied upon these reports to give an indication of field performance and that they used this information as a basis for window selection.

The performance of a window is primarily affected by its operation type. Casement windows far out perform sliding and hung windows.

The material of the window; that is wood, clad wood or aluminum, did not have significant impact on the measured performance of the windows.

Air leakage observed through the use of smoke and/or infrared thermography indicated that air leakage was not uniform around the sash perimeter. Areas of excessive air leakage occurred most frequently at corners, sills and meeting rails. Areas of excessive air leakage could frequently be related to weatherstrip, sash fit and hardware irregularities.

Varying the expression of air leakage rate between crack length, sash area and free ventilating area dramatically shifts the relative performance of the tested window operation types. Expressions of air flow per linear foot of crack do not give a ready understanding of the total leakage performance of a window relative to the more common way of thinking of windows - area. Technical variations in the definition of window operation types between manufacturers, and thus the definition of crack length, adds to the confusion when a designer or contractor chooses a window.

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This project focused upon determining the field air leakage performance of new residential windows. Two committees were formed with representation of window design, research, installation, testing and regulatory agencies; we would like to give acknowledgement to the committee members for their generous contributions of direction and technical expertise. The conclusions in this report do not necessarily reflect the opinions of the committee members.

Ad Hoc Project Review Committee

Jerome Blomberg, Blomberg Window Systems; Rodney L. Erickson, Construction Specification Institute; Frank W. Hetman, DeVac, Inc; Jeffrey Lowinski, National Woodwork Manufacturer's Association; David S. Miller, National Institute of Building Sciences; Roger O'Shaughnessy, Insulating Glass Certification Council; Heinz Trechsel, National Bureau of Standards; Henry Wakabayashi, National Conference of States on Building Codes and Standards; Alan Wessel, American Society of Heating, Refrigerating, and Airconditioning Engineers

Ad Hoc Technical Panel

Curtis Johnson, Pella Products, Inc.; Robert Michaud, Michaud, Cooley, Hallberg, Erickson & Associates; Mechanical Engineers; A.A. Sakhnovsky, Construction Research Laboratories, Inc.; Richard Spronz, Architect; George Tamura, National Research Council of Canada; Robert Rogers, State of Minnesota, Building Codes Division (deceased)

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Table 1
Field Results: Comparison of Window Types
(Data for Figure 2)

Window Type	No of Tests	Range	Range of St. Dev.	Mean
All Windows	192	.01 - 2.28	.13 - .92	.52
Casements	79	.01 - .58	.11 - .35	.23
Double Sliders	33	.17 - 1.90	.27 - .96	.61
Double Hung	38	.22 - 2.06	.31 - 1.14	.72
Single Sliders	31	.30 - 2.28	.38 - 1.19	.78
Single Hung	11	.68 - 1.37	.67 - 1.25	.96

Table 2
Air Leakage Performance of Casement, Double Slider, Double Hung, Single Slider and Single Hung Windows and Material Types

CASEMENT

Window Type	No of Tests	Range	Range of St. Dev.	Mean
All Casements	79	.01 - .58	.11 - .35	.23
Wood Casement	47	.04 - .58	.14 - .37	.26
Wood Clad Casement	30	.01 - .49	.07 - .32	.19
Wood Awning	2	.10 - .15	.09 - .16	.13

DOUBLE SLIDER

Window Type	No of Tests	Range	Range of St. Dev.	Mean
All Double Sliders	33	.17 - 1.90	.27 - .96	.61
Aluminum Double Sliders	6	.64 - .88	.71 - .89	.80
Wood Double Sliders	27	.17 - 1.90	.20 - .94	.57

DOUBLE HUNG

Window Type	No of Tests	Range	Range of St. Dev.	Mean
All Double Hung	38	.22 - 2.06	.31 - 1.14	.72
Wood Double Hung	29	.22 - 2.06	.29 - 1.16	.72
Wood Clad Double Hung	9	.31 - 1.30	.33 - 1.10	.72

SINGLE SLIDER

Window Type	No of Tests	Range	Range of St. Dev.	Mean
All Single Sliders	31	.30 - 2.28	.38 - 1.19	.78
Aluminum Single Sliders	22	.30 - 2.28	.46 - 1.29	.88
Wood Single Sliders	6	.30 - 1.09	.18 - .78	.48
Wood Clad Single Slider	3	.60 - .89	.56 - .86	.71

SINGLE HUNG

Window Type	No of Tests	Range	Range of St. Dev.	Mean
Aluminum Single Hung	11	.68 - 1.37	.67 - 1.25	.96

Table 3
Air Leakage performance of single and double slider windows as a function of both material type and manufacturer.

DOUBLE SLIDER

Window Type	No of Tests	Range	Mean
All Double Sl.	33	.17 - 1.90	.61
Aluminum	6	.64 - .88	.80
Wood	3	.17 - .24	.20
	3	.35 - .51	.42
	6	.21 - .76	.49
	3	.55 - .72	.63
	3	.28 - .44	.34
	3	.46 - .53	.48
	6	.51 - 1.90	1.04

SINGLE SLIDERS

Window Type	No of Tests	Range	Mean
All Single Sl.	31	.30 - 2.28	.78
Aluminum	4	.30 - .50	.38
	6	.85 - 1.15	.97
	12	.62 - 2.28	.99
Wood	3	.60 - .89	.71
	6	.30 - 1.09	.48

Table 4
Factory/Field Test Results

Manufacturer	Factory		Field	
Window Type	Mean	Range	Mean	Range
A - Casement	.26	.15 - .45	.29	.26 - .34
- Double Slider	.46	.37 - .62	.49	.21 - .76
B - Clad Casement	.03	.01 - .04	.14	.01 - .49
- Double Hung	.22	.19 - .26	.27	.22 - .35
C - Clad Casement	.14	.12 - .16	.31	.15 - .46
- Clad Double Hung	.30	.24 - .37	.34	.31 - .39

Table 5
Performance of Windows with Defects

WINDOW OPERATION TYPE	NUMBER OF WINDOWS WITH ONE OR MORE OBSERVED DEFECTS	AIR LEAKAGE PERFORMANCE OF WINDOWS WITH DEFECTS TO AVERAGE PERFORMANCE WITHIN OPERATION TYPE
CASEMENT	28%	45% ABOVE AVERAGE
DOUBLE SLIDER	45%	AVERAGE
DOUBLE HUNG	82%	7% ABOVE AVERAGE
SINGLE SLIDER	65%	12% ABOVE AVERAGE
SINGLE HUNG	55%	24% ABOVE AVERAGE

Table 6
Expression of Air Leakage Rate
(Data for Figure 4)

Method of Calculation	Mean Results Casement	Double Slider	Double Hung	Single Slider	Single Hung
cfm/lfc	.23	.61	.72	.78	.96
cfm/sf	.34	.76	1.02	.55	.88
cfm/vsf	.34	1.57	2.10	1.14	1.77

Table 7
Results of Fixed Sash Related Via Crack Length and Sash Area

Method Of Calculation	Range	Range Of Std. Deviation	Mean
cfm/lfc	.11 - 1.21	.11 - .81	.39
cfm/sf	.12 - 2.04	.12 - 1.34	.60

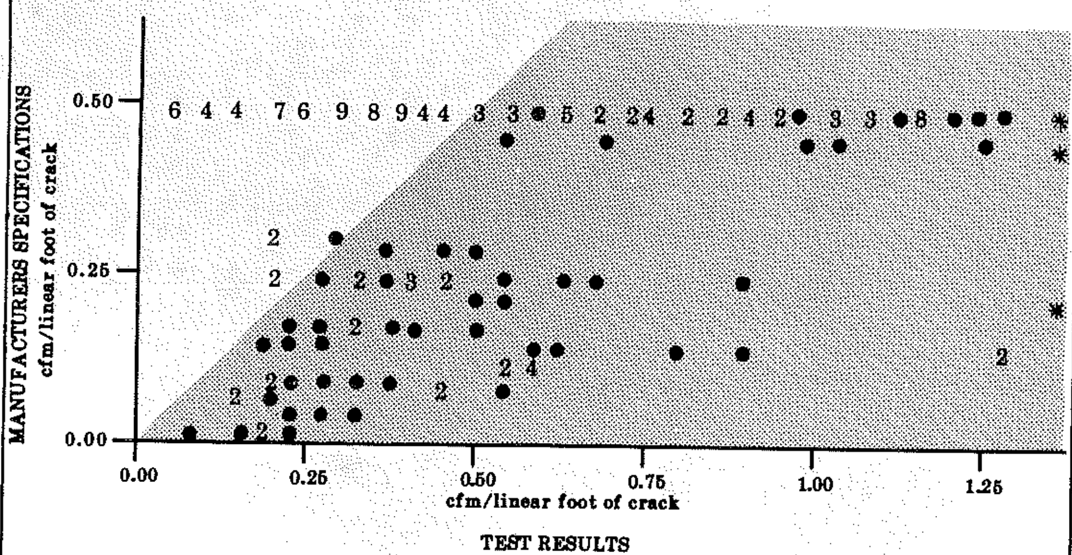

FIGURE 1 SCATTERGRAM OF FIELD RESULTS
Results of each test are plotted relating their field test performance to manufacturer's specifications. Each number indicates that more than one result occurred at a given point. As an example, a point occurring at X=.75, Y=.25 means that the window's manufacturer reported a lab test at .25, the field-measured leakage of the unit was .75. Points within the grey area relate to windows whose field air leakage were greater than reference. The * designate outliers.

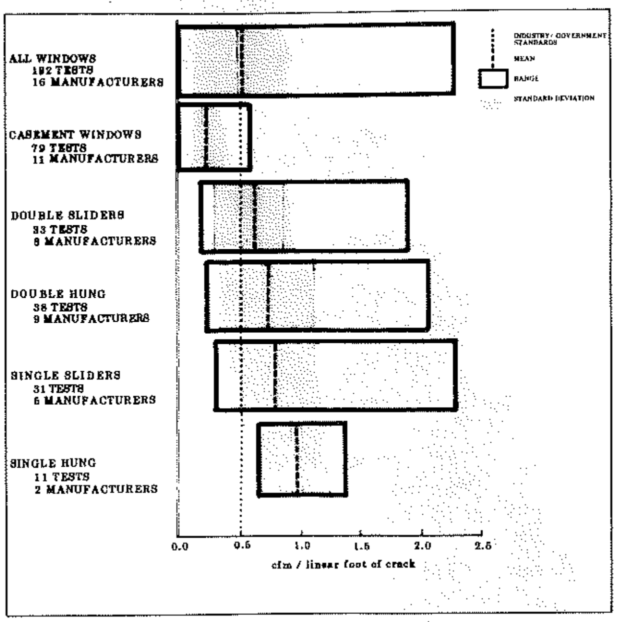

FIGURE 2 FIELD RESULTS: COMPARISON OF WINDOW TYPES

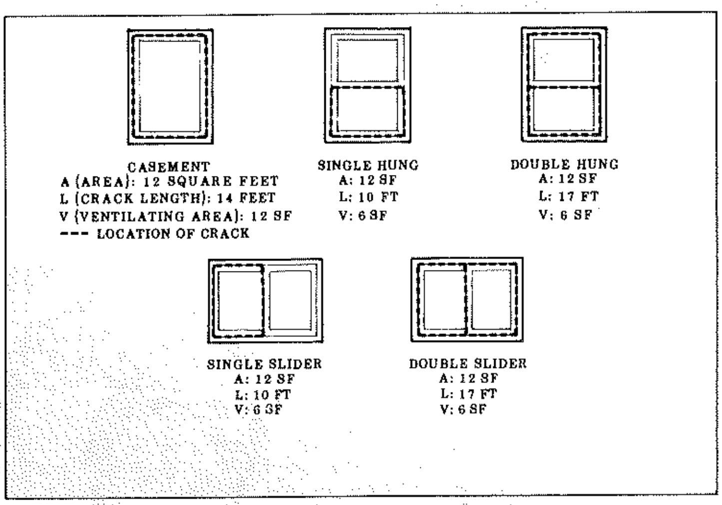

FIGURE 3 COMPARISON OF CRACK LENGTH, SASH AREA AND VENTILATING AREA OF TYPICAL OPERATION TYPES

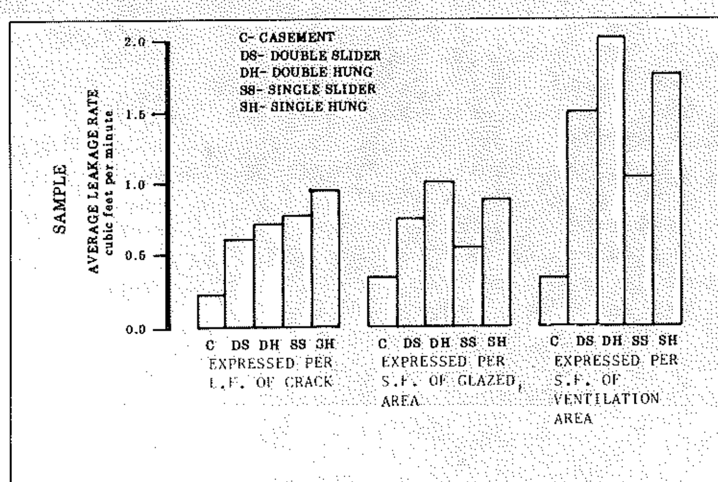

FIGURE 4 EXPRESSIONS OF AIR LEAKAGE RATE
The results of field testing new windows in new construction were calculated via the three methods displayed above