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AIR LEAKAGE OF NEWLY INSTALLED RESIDENTIAL WINDOWS

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PREPARED FOR

UNITED STATES DEPARTMENT OF ENERGY

AND

LAWRENCE BERKELEY LABORATORY

PREPARED BY

THE MINNESOTA ENERGY AGENCY

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AIR LEAKAGE OF NEWLY INSTALLED RESIDENTIAL WINDOWS

John Weidt and Jenny Weidt

ABSTRACT

The air-leakage characteristics of five major window designs were measured in a field survey conducted in Twin Cities, Minnesota. A total of 192 windows (16 manufacturers) were tested at 58 sites representing a cross-section of single-family homes, townhouses, low- and high-rise apartments, and condominiums. Air-leakage measurements of the installed windows were compared with the current standard used by industry and government of 0.50 cubic feet per minute per linear foot of crack. Other parameters studied were: effect of sash and frame material, effect of leakage between window frame and wall, differences among the product lines of a single manufacturer and between manufacturers, effect of installation practices, effect of cold weather on performance, change in performance over time for older windows, and performance of fixed glazing. Based on industry and government standards, 40% of all windows tested showed air-leakage characteristics higher than the 0.50 cfm/lfc standard, and 60% exceeded manufacturers' specifications for performance which in some cases were lower than the general industry standard. Analysis of the impact of various parameters on air-leakage performance showed that the operational design of the window was the most critical determinant although the ranking changes if performance is expressed in cfm/unit area or cfm/opening area. Air leakage was measured using a portable pressurization chamber. Smoke pencils, thermographic techniques and extensive photographic documentation provided additional data as to the location and cause of air leakage problems.

The work described in this report was funded by the Office of Buildings and Community Systems, Assistant Secretary for Conservation and Solar Applications of the U.S. Department of Energy under contract No. W-7405-ENG-48.

ACKNOWLEDGEMENTS

This project focused upon determining the field air leakage performance of new residential windows. The project received advise from two committees, individuals of which represent window design, research, installation, testing and regulatory agencies and hold membership in the associations listed. 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 persons listed.

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 Laboratory, Inc.; Richard Spronz, Architect; George Tamura, National Research Council of Canada; Robert Rogers, State of Minnesota, Building Codes Division (deceased)

Additional persons who contributed a great deal to the success of this project and whom we wish to acknowledge are:

-The window manufacturers, distributors and area builders who volunteered their time and testing sites for this program.

-Al Mazig of Twin City Testing and Engineering Inc. for his expertise in testing each window.

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-Richard Depta for his input as Contract Project Manager for the Minnesota Energy Agency.

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1.0 PROJECT ABSTRACT

This project studied a variety of aspects of the air leakage performance of windows as installed, focusing on new windows installed in new residential construction. The project tested a cross-section of windows representative of most commonly installed new residential window units in the Twin Cities Area. A total of 192 windows made by 16 manufacturers were tested between 7 September and 16 November 1978. The field testing was performed at 58 new construction sites; single family homes, townhouses, low and high rise apartments and condominiums. The major operation types tested were casement, double slider, double hung, single slider and single hung windows.

The air leakage data obtained in the field were compared to industry and government standards and manufacturer's reports for reference. This comparison revealed that 40% of all windows tested possessed air leakage characteristics higher than the industry and government standards of .50 cubic feet per minute per linear foot of crack, (cfm/lfc) and 60% of the windows tested exceeded the specifications published by their manufacturers. The field air leakage performance of the windows ranged from .01 cfm/lfc (an extremely tight window) to 2.28 cfm/lfc (an extremely leaky window). Window operation type, manufacturer, installation, construction material and window defects were analyzed in detail to determine their affects on air leakage.

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. Casement windows substantially out-performed the other operation types; it appeared that this performance could be attributed to its inherent design. The casement window is more rigid than the other operation types; that combined with compression type weatherstripping and positive locking hardware makes a tighter seal. The average air leakage performance of casement windows was .23 cfm/lfc, double sliders was .61 cfm/lfc, double hung was .72 cfm/lfc, single sliders was .79 cfm/lfc, and single hung was .96 cfm/lfc. Casement windows far out-performed sliders, and sliders generally out-performed hung windows, irrespective of all other observed variables, such as the frame and sash material, 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.

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 tendency of one material type to out-perform the other material type.

The manufacturer appeared to have an impact on the range of performance within each operation type. It appeared that certain manufacturers produced product lines with lower or higher air leakage rates than the average. There also appeared to be a trend for certain manufacturers to out-perform other manufacturers within a specific operation type. The pattern of performance of the product lines of the manufacturers 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.

A series of tests investigated the decline in performance of a window between the time it was manufactured and the time it was installed. The results of these tests indicate an average decline in performance of approximately 29% between factory and field.

The installation of the window was compared with the installation procedures recommended by the manufacturer. A ratio of installation steps taken by the installer to installation steps recommended by the manufacturer was established. There was little evidence of correlation between the installation ratio of the window and air leakage performance.

The project measured air leakage rates in three different ways; per linear foot of crack, per square foot of window sash area, and per square foot of ventilating area. All standards and specifications for evaluating window air leakage are based on a per linear foot of crack of operable sash calculation. Large shifts in relative performance occur when the above mentioned expressions of leakage are compared. For example, a double slider will appear to have less leakage than a single slider when the air flow is calculated by the linear foot of crack method, however, the single slider has less leakage than the double slider when the air flow is calculated by either of the other two methods. Measurement of air leakage by the per linear foot of crack method can be misleading if it is used as criteria when selecting between two window types.

Six fixed window units were tested for their installed air leakage performance. The fixed windows exhibited relatively high air leakage.

An important consideration in evaluating the air leakage performance of the total installed window unit is the amount of air passing between the window unit and the wall opening. The frame/wall crack leakage, although significant, was not found to have the impact of the sash/frame leakage of the window unit itself in these limited number of tests.

Window units which had been tested during the new window portion of the program were retested during the winter months to investigate the possibility of poorer performance during cold weather. The results obtained do not indicate a significant trend for the air leakage performance to deteriorate during cold weather.

The ability of a window to maintain its air leakage performance over a period of years is an important energy conservation attribute. Ten tests were made on windows which had been installed 2 to 8 years ago. The performance of 7 of the 10 older windows tested compared favorably with the performance of new windows of the same operation type. There was substantial degradation of performance in 3 of the older windows tested due to a design flaw.

A limited amount of work was done testing the performance of old windows and the retrofit windows designed to replace them. The results of the tests show that the existing old windows tested had very high levels of air leakage while the tests performed on their replacement windows indicate a considerable improvement in air leakage performance.

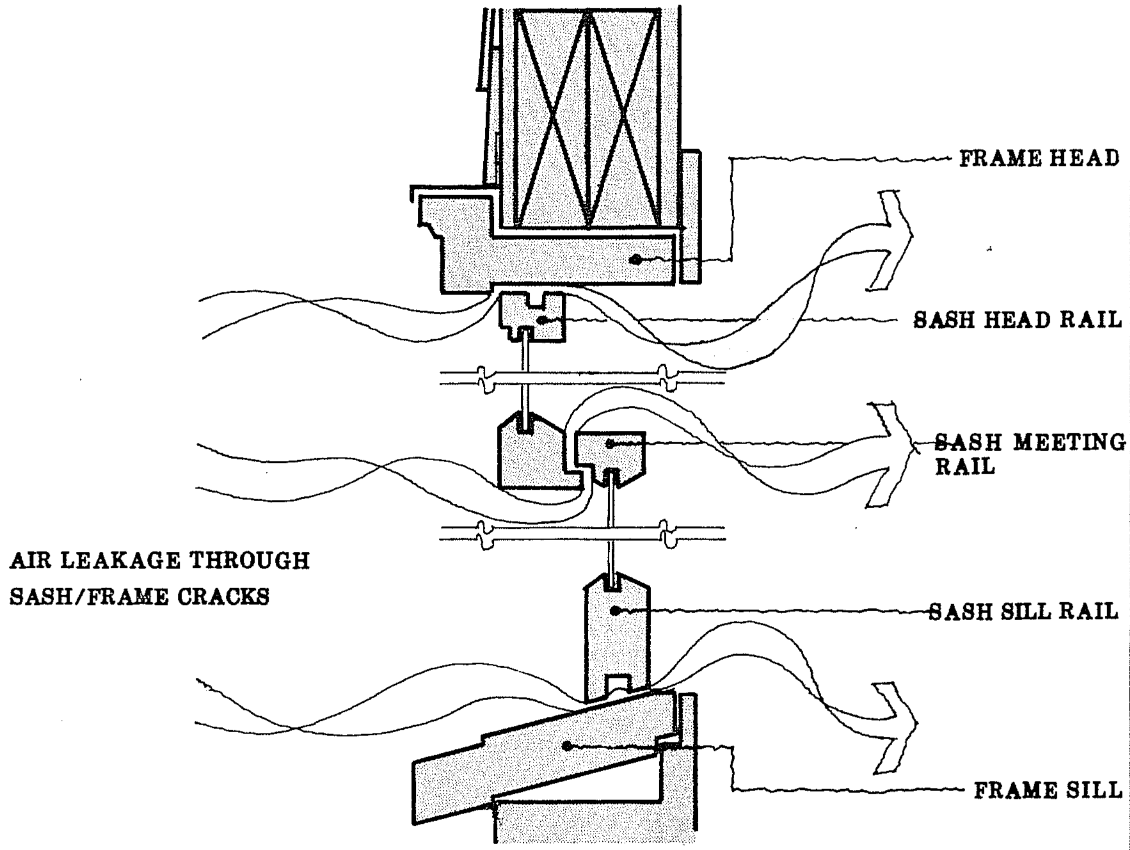


FIGURE 2.0.1 AIR LEAKAGE THROUGH SASH/FRAME CRACKS
Sash/frame air leakage passes through the cracks between various window sash parts and between the sashes and frame.

2.0 THE AIR LEAKAGE PERFORMANCE OF NEWLY INSTALLED RESIDENTIAL WINDOWS

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 sashes and frame as illustrated in Figure 2.0.1. 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 impact of such factors as window design, manufacturer and installation on installed air leakage.

The project tested a cross-section of windows representative of the most commonly installed new residential window units in the Twin Cities Area. The tested windows represented all major operation types and included tests of windows made by all major manufacturers of windows of each type. A total of 192 windows made by 16 manufacturers were tested between 7 September and 16 November 1978. The field testing was performed at 58 new construction sites; single family homes, townhouses, low and high rise apartments and condominiums.

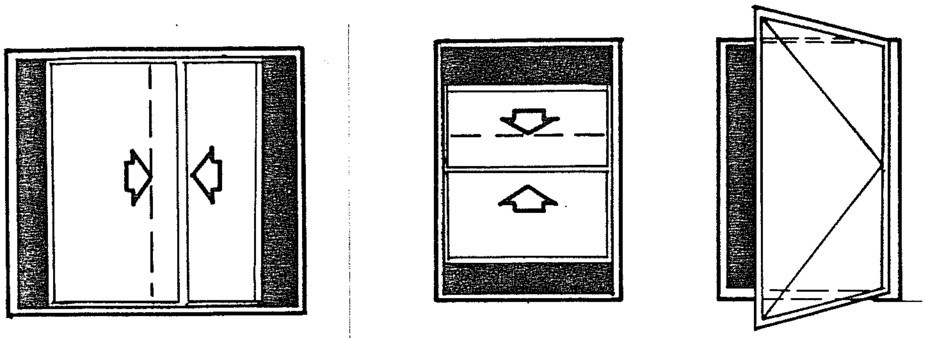


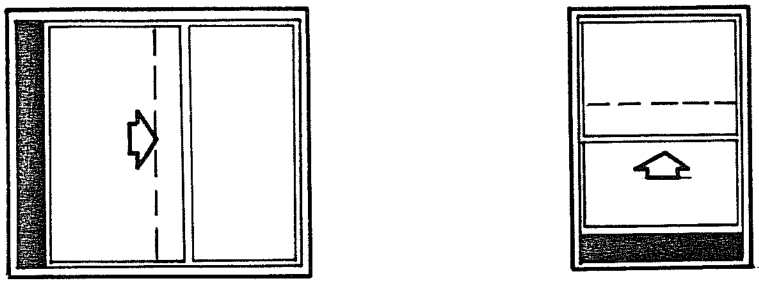
FIGURE 2.0.2a WINDOW OPERATION TYPES

The major operation types tested were casement, double slider, double hung, single slider and single hung windows. (Figure 2.0.2a and b.) these operation types were classified as single or double units according to each manufacturer's definition of his product.

CASEMENT WINDOWS
Casement windows are side-hinged sash units opening outwards from the building. 100% of the sash area is available for ventilation. The sash area of the tested units ranged from 5.5 to 11.5 square feet, with an average of 8.5 square feet. Two awning windows were grouped with the casement windows, these were identical to the casement windows except that they were top-hinged, out-swinging units. All casement windows tested were wood or clad wood (wood sheathed in metal or plastic) units. Aluminum casement windows were not typically being installed in residential construction during the test period and thus were not tested. Seventy-nine casement windows produced by 11 manufacturers were tested.

DOUBLE SLIDER WINDOWS
Double slider windows typically have two moveable sashes, each with track and hardware to allow full operation. All window types tested during this study were identified according to the manufacturer's definition of his product. Slightly less than 50% of the area of the window is available for ventilation. The sash area of the tested windows ranged from 10.5 to 19 square feet with an average area of 16 square feet. Thirty-three aluminum and wood double slider units produced by eight manufacturers were tested.

DOUBLE HUNG WINDOWS
Double hung windows are units whose sashes are free to move vertically; the lower sash upwards, the upper sash downwards. Slightly less than 50% of the window area is available for ventilation. The sash area of the tested units ranged from 8.5 to 16 square feet with an average of 13 square feet. Aluminum double hung windows were not typically being installed in residential construction during the test period and thus were not tested. In all, 38 wood and clad wood units produced by nine manufacturers were tested.



SINGLE SLIDER SINGLE HUNG

FIGURE 2.0.2 WINDOW OPERATION TYPES (continued)

SINGLE SLIDER WINDOWS

Single slider windows are constructed with one moveable and one fixed sash. The fixed sash may be sealed in place or retarded from movement by some physical design element such as set screws or stops. All window types tested during this study were identified according to the manufacturer's definitions which in some instances were modifications of a double slider. Slightly less than 50% of the area of the window is available for ventilation. The sash area of the tested windows ranged from 14 to 22.5 square feet with an average of 18 square feet. Thirty-one aluminum, wood and clad wood units produced by five manufacturers were tested.

SINGLE HUNG WINDOWS

Single hung windows are similar in operation to double hung windows except that the upper sash is fixed and only the lower sash is moveable. Slightly less than 50% of the window area is available for ventilation. The sash area of the tested windows ranged from 9 to 12 square feet, with an average of 10.5 square feet. All single hung windows tested were aluminum units as wood single hung units were not typically being installed in residential construction during the test period. Eleven single hung windows produced by two manufacturers were tested.

The air leakage of the sash/frame portion of the window unit was measured in this project by simulating a pressure difference equal to a 25mph wind and determining the volume of air flow through the unit. All field work and tests of leakage and exfiltration were made according to the testing procedures outlined in the Standard Test Method (STM), Appendix A, which was based upon American Society for Testing and Materials ASTM E-283 modified for field conditions; and the Standard Operating Procedure (SOP), Appendix B. 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 25 mph wind blowing against 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 was measured on site and test conditions were systematically recorded. Air leakage and exfiltration values were standardized by compensating for the affects of barometric pressure and temperature. After testing was completed, the data were input into a computer and compiled for analysis.

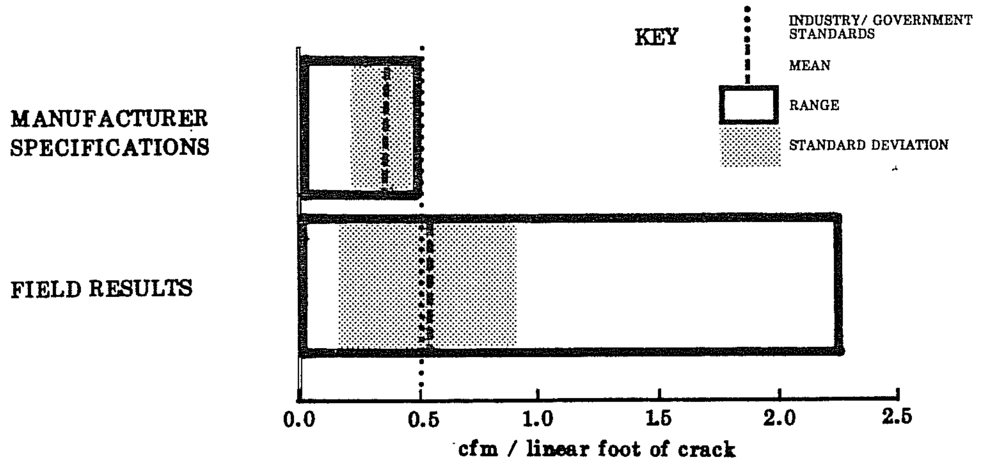


FIGURE 2.1.1 AIR LEAKAGE OF INSTALLED WINDOWS
The graphs compare the range and mean of manufacturer's published air infiltration rates and industry/government standards for air infiltration with results of tests performed on installed windows.

2.1 Field Tests - Comparison With Reference Values

The air leakage data obtained in the field were compared to industry and government standards and manufacturers 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). 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, Housing and Urban Development Minimum Property Standards (HUD MPS) and Federal Housing Administration Minimum Property Standards (FHA MPS) require certification of a product line through laboratory testing. Manufacturers frequently relate to 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 do not usually 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 capabilites and make their decisions accordingly. The purpose of this portion of the study was to relate the actual measured field air leakage performance of installed windows with these laboratory test based reference values.

Figures 2.1.1 and 2.1.2 graphically compare the results of field tests with the reference values. Numerical reference for this figure and all figures

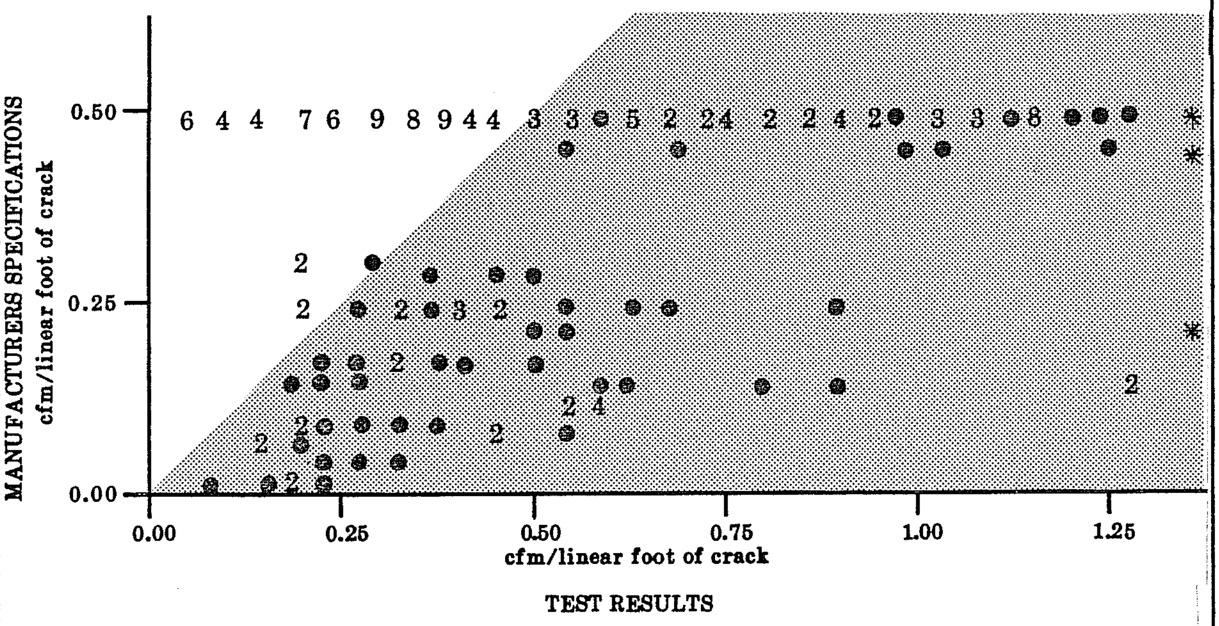


FIGURE 2.1.2 SCATTERGRAM OF FIELD RESULTS
Results of each test are plotted relating their field test performance to manufacturer's specifications. Each number indicates that more than one result occurred at a given point. As an example, a point occurring at X=.75, Y=.25 means that the window's manufacturer 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.

in this report may be found in Appendix C, DATA. Figure 2.1.1 illustrates that the average air leakage 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.

Figure 2.1.2 illustrates that the windows tested in the field had a very wide range of performance. 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.

After ascertaining the field performance of the tested windows the data was 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 to the air leakage.

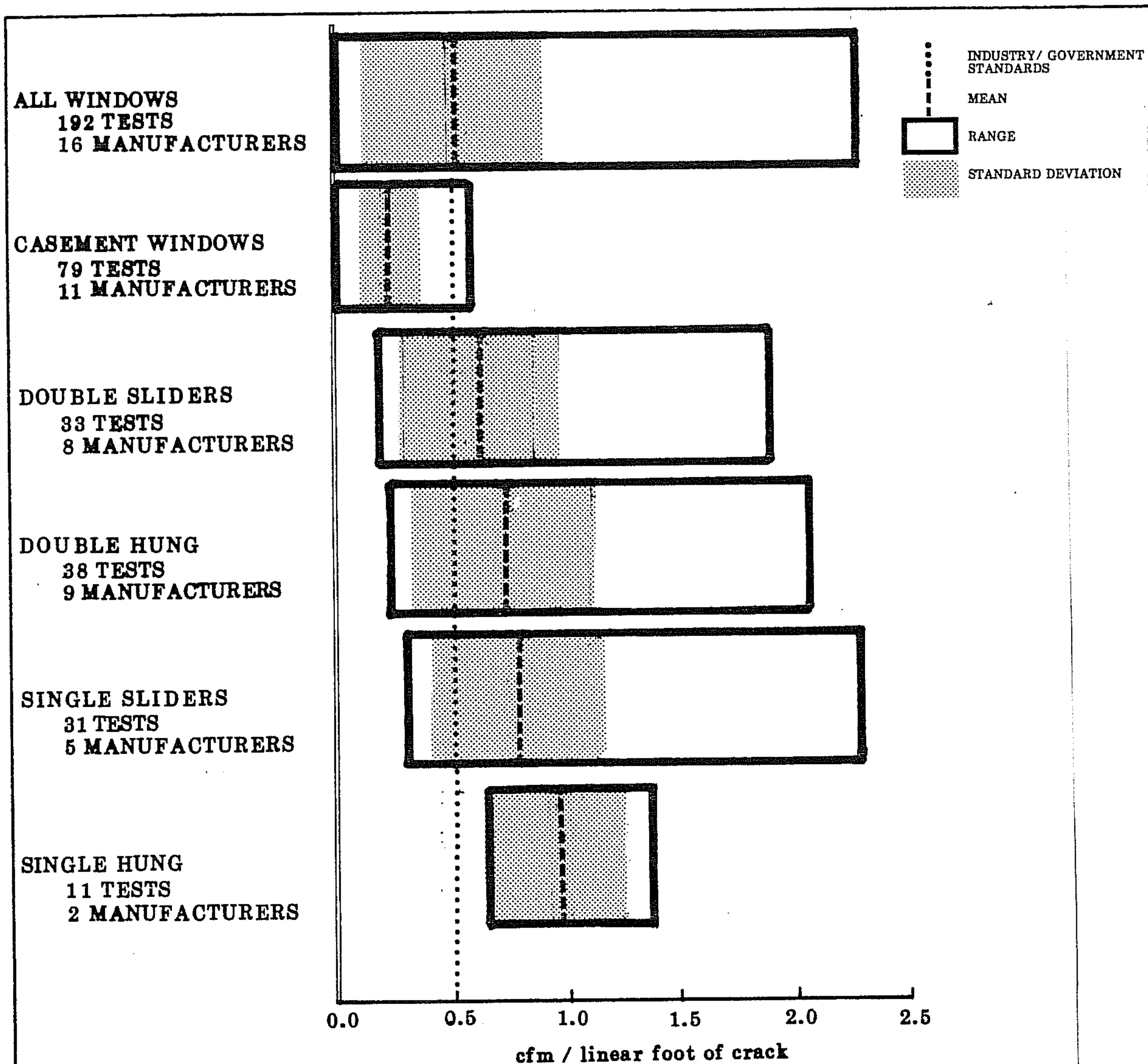


FIGURE 2.2.1 FIELD RESULTS: COMPARISON OF WINDOW TYPES

2.2 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 2.2.1 illustrates the relative performance of the studied window operation types, 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.

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

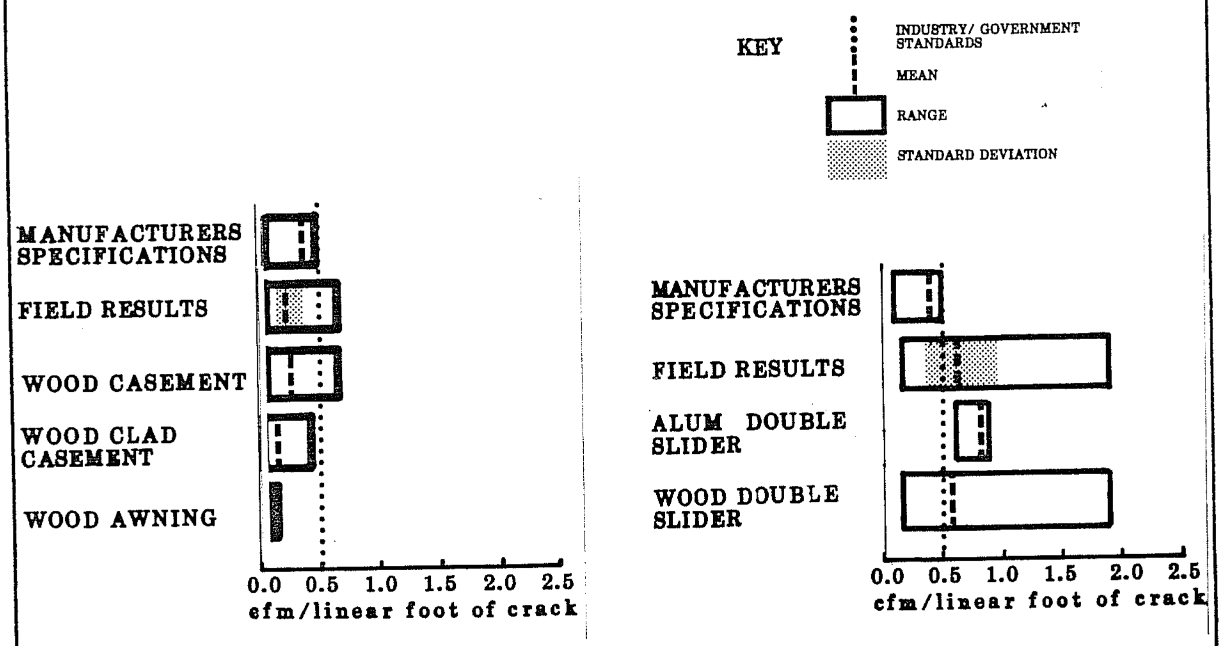


FIGURE 2.2.2 AIR LEAKAGE PERFORMANCE OF CASEMENT, DOUBLE SLIDER WINDOWS AND MATERIAL SUBTYPES

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, 84% of the single slider windows, 70% of the double slider windows, 100% of the single hung windows, 33% of the casement windows and 79% of the double hung windows had higher field air leakage rates than the manufacturer's laboratory report.

An attempt was made to determine why casement windows out-performed the other operation types. It was concluded that because of its rigid construction, the casement window needed less installation care to perform well. The slider and hung windows needed more attention to assure installation plumb, square and true. Casement windows with a compression spring-type weatherstripping and positive locking hardware appeared, on the average, to be able to be sealed tighter than windows that rely on a friction-type weather stripping and less positive sealing/locking mechanisms.

Field window data were grouped by window operation type and then material subtype - aluminum, wood or clad wood - to identify patterns of performance. Figures 2.2.2 and 2.2.3 illustrate the range, mean, standard

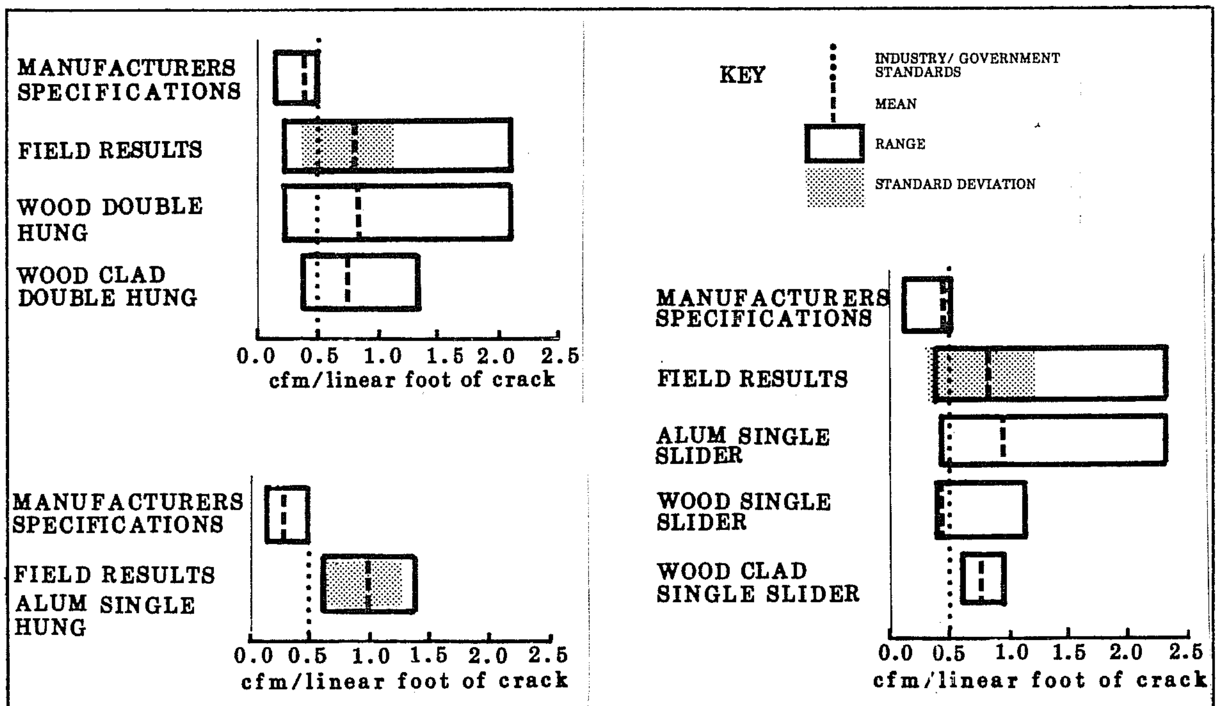


FIGURE 2.2.3 AIR LEAKAGE PERFORMANCE OF DOUBLE HUNG, SINGLE SLIDER AND SINGLE HUNG WINDOWS AND MATERIAL SUBTYPES

deviation and expected performance level of the air leakage performances of the various window types studied. 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. 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, shifts in relative performance between groups of windows within any operation type appears to be more a function of manufacturer than of construction material.

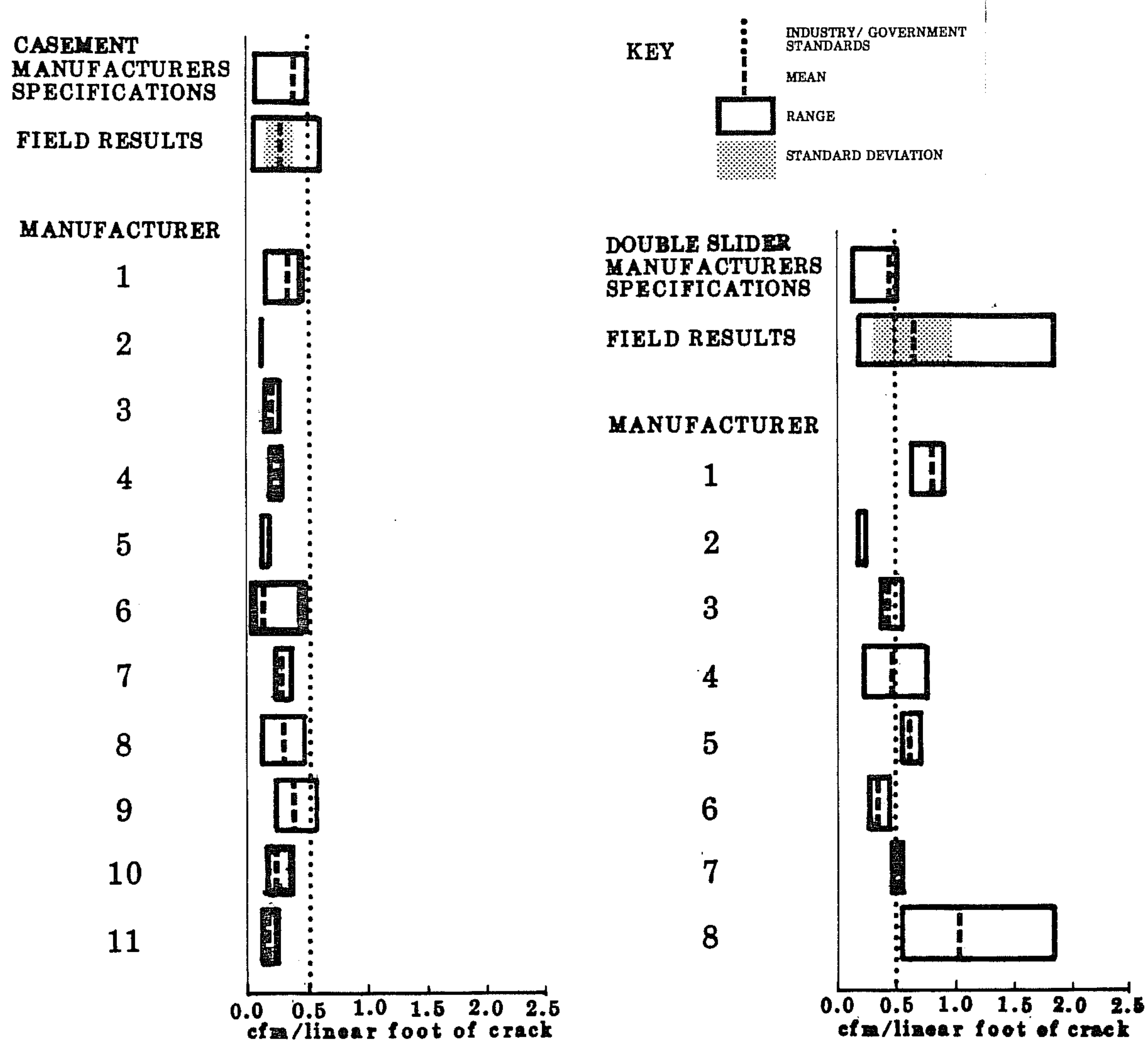


FIGURE 2.3.1 AIR LEAKAGE PERFORMANCE BY MANUFACTURER OF CASEMENT AND DOUBLE SLIDER WINDOWS (Note: The manufacturer number does not represent the same manufacturer from graph to graph.)

2.3 Field Air Leakage Performance Related to Window Manufacturer

When the field data was grouped by major operation type and then subgrouped by manufacturer within each operation type as illustrated in Figures 2.3.1 and 2.3.2, some trends appeared which indicated that the manufacturer may have an impact on the range of performance within each operation type. 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 continuously 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

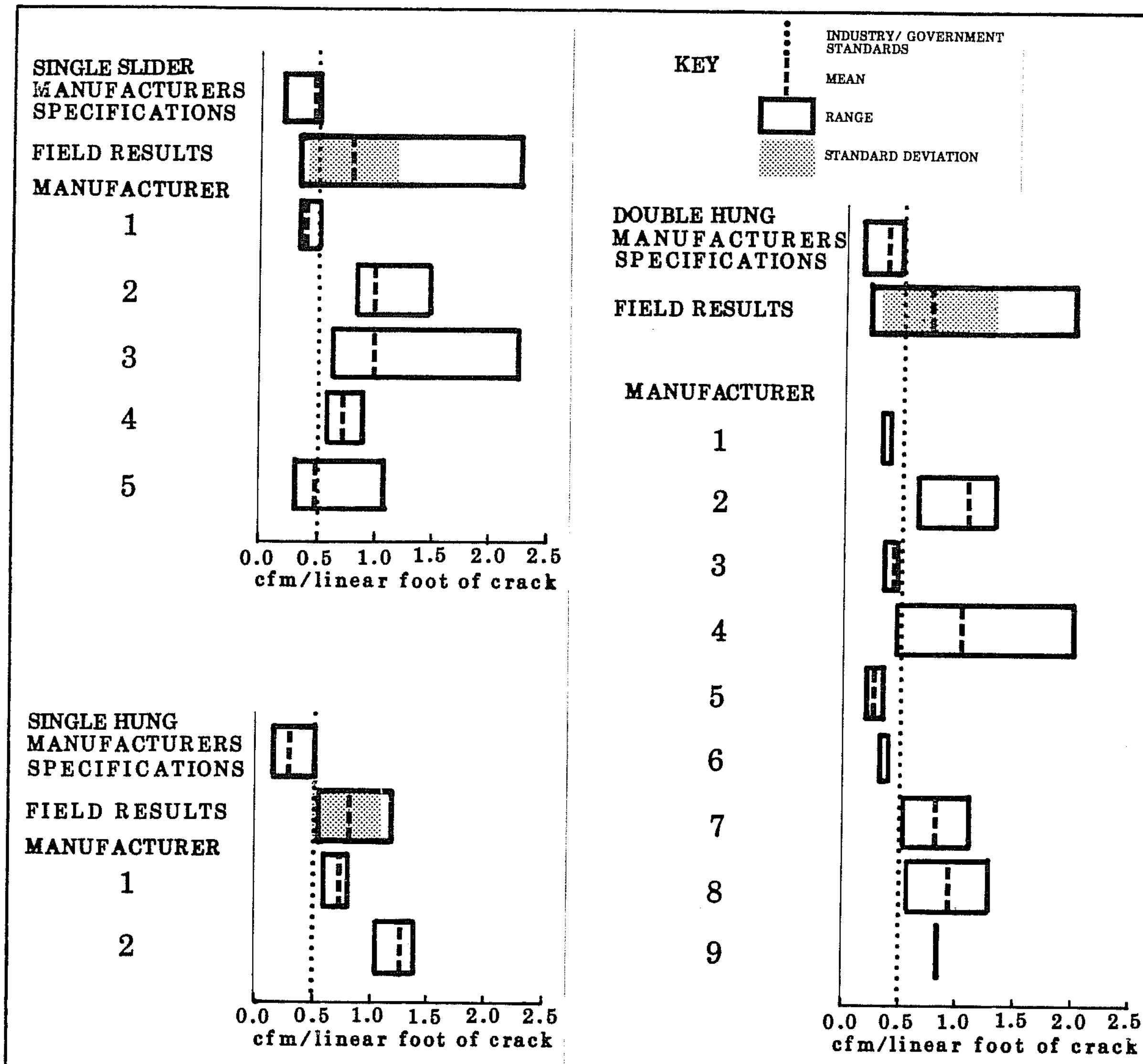


FIGURE 2.3.2 AIR LEAKAGE PERFORMANCE BY MANUFACTURER OF DOUBLE HUNG, SINGLE SLIDER AND SINGLE HUNG WINDOWS (Note: The manufacturer number does not represent the same manufacturer from graph to graph.)

pattern of performance within any manufacturer's set of windows was dictated by the window design in that, for instance, a 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 were 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

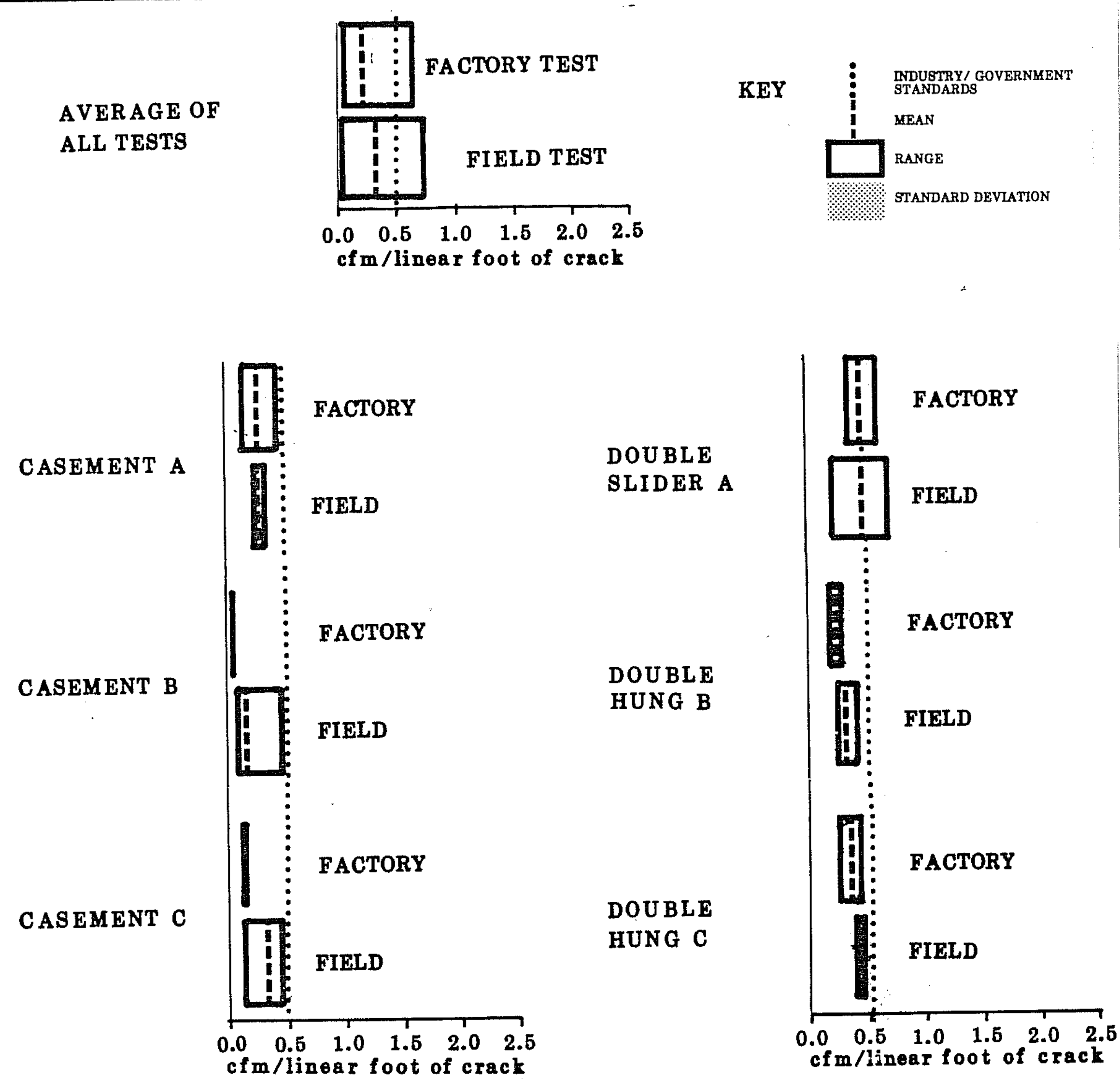


FIGURE 2.3.3 FACTORY/FIELD TEST RESULTS
A comparison of air leakage performance measured in the field with the air leakage rate of similar uninstalled windows tested in the factory.

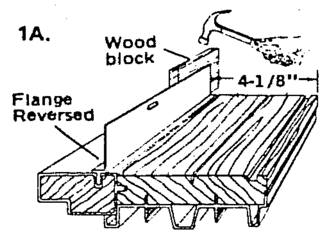
results obtained on similar windows tested in the field. Figure 2.3.3 illustrates the results of these tests which indicate an average decline in performance of approximately 29% between factory and field.

Ten window units were tested in the field in the company of a manufacturer's representative and the contractor's installer. The window unit was tested as installed, then the window unit and its installation was examined and any modifications suggested by the manufacturer were made. The window was then retested. In no instance was it possible to improve the performance of the installed window with field modifications to the installation or to the unit itself. These observations indicated that although quality control flaws and installation procedures could be identified as causes for air leakages, correction of these problems in the field can not be assumed to be a matter of routine.

SUGGESTED INSTALLATION IN FRAME WALLS

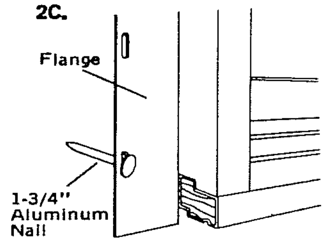
1. Remove protection blocks.
   a) For 4-1/8" wall thickness remove flanges and reverse (1a).
2. Make certain rough opening is correct. Sill plate should be level.
   a) Close and lock sash.
   b) Center window in opening, resting bottom on sill plate.
   c) 1-3/4" aluminum nails are furnished for installation.
   d) Nail one corner first, then level window unit and nail opposite corner.
3. Square the window, check reveal across bottom sash at the sill. Nail remaining two corners.
4. Shim and block as required. Check width at meeting rail to avoid inward or outward bow of unit. Complete nailing.
5. Staple sill windbreak to sheathing. Caulk around perimeter of window after exterior finish is applied.
6. Vjnyl trim strip, wood filler and instructions for narrow or support mullions are available

1A.



2D.

2C.



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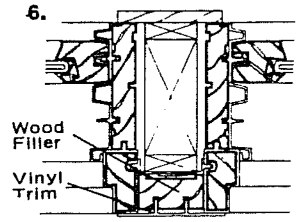


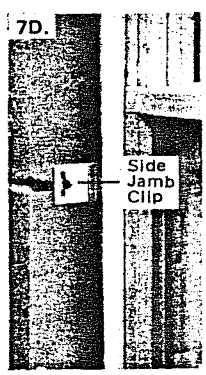
SUPPORT MULLION

SUGGESTED INSTALLATION IN MASONRY WALLS

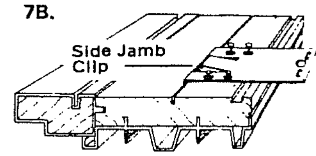
7. Six side jamb clips* (3 on each side) are recommended for securing window to masonry. For high rise construction see your Distributor for additional anchoring suggestions.
   a) Close and lock sash.
   b) Place bent end of metal clip in saw kerf in back of jamb and fasten with 5/8" nails. The spacer on the clip will help center the window.
   c) Position window in opening, level, square and plumb. Shim as required.
   d) Nail clips to wall with masonry fasteners.
   e) In brick veneer walls, leave adequate clearance for caulking around entire perimeter between the jambs and masonry.
   f) Acid solutions commonly used to wash brick do not affect vinyl, but they do affect glass. Wash acid splashed on glass surfaces with clear water to prevent etching.

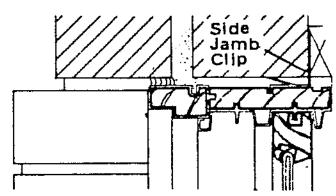
* Metal Side Jamb Clips are available

7D.



7B.





Owner maintenance manual for window available

IMPORTANT: Painting and staining may cause damage to white vinyl. Do not paint weatherstripping. Abrasive cleaners or solutions containing corrosive solvents should not be used on products. Creosote base stains should not come in contact

Apply interior finish on sash for protection as soon as possible. Lap all finish coats onto glass to provide seal and prevent glazing failure.

TO REMOVE THIS LABEL — Tear away as much label as you can...what is left can be quickly removed by soaking well with a wet sponge. Use a PLASTIC SCRAPER when cleaning glass — metal can scratch glass or break the glazing seal.

FIGURE 2.4.1 TYPICAL INSTALLATION RECOMMENDATIONS

2.4 Field Air Leakage Performance Related to Installation Techniques

During field testing, the installation of the window was compared with the installation procedures recommended by the manufacturer. Refer to Figure 2.4.1 for an example of a manufacturers installation instructions. Each window was examined for evidence that manufacturer recommended steps such as nailing, clearances, plumbing, squaring or levelling, had been taken by the installer. A ratio of installation steps taken by the installer to installation steps recommended by the manufacturer was then established for use in analyzing the impact of installation on window performance. The ratio across all window types was .81, indicating that the installers were completing 80% of the steps recommended by the manufacturer.

It must be emphasized that the ratio of installation steps taken to installation steps recommended, while a useful tool, is an imperfect indicator of the impact of installation on the performance of the window. There was no weight attached to any of the steps taken by the contractor or the steps suggested by the manufacturer, though presumably certain installation steps are more important to window performance than other steps. No credit was given for steps taken which were not specifically required by the manufacturer, nor was an attempt made to weigh the care with which a step was taken. There was little evidence of correlation between the installation ratio of the window and air leakage performance.

While the ratio of installation steps taken to installation steps recommended was not found to impact the air leakage performance of the tested windows, limited observations indicate that the installer may have a significant impact. The installation of the windows in the project was performed by 28 different contractors; of the 192 windows tested, the minimum number observed of a single contractor was 3, the maximum number of observations was 21.

Analysis was made of installations of specific manufacturers products when the model had been installed by more than one contractor - eleven situations, 39 tests. In ten of the eleven situations, there was no significant difference in the average performance of one contractor over another, however, in the eleventh situation, the air leakage was more than 50% greater than in the other similar installations. Thus the observations suggest that the installer can have a major impact upon the air leakage performance of a window but in 10 of the 11 cases studied, there was no significant difference.

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 2.5.1 PERFORMANCE OF WINDOWS WITH DEFECTS

2.5 Field Air Leakage Performance Related to Construction Defects

The performance of windows of each operation type with observed anomolies was compared to the average performance of that operation type. 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. The field data was organized by major operation type. Table 2.5.1 displays the results of this organization and indicates that anomolies impacted the performance of windows within each operator type.

The data indicated patterns in the location of observed excessive air leakage which varied from window operation type to window operation type. 28% of the casement windows tested had one or more observed anomolies. The majority of leakages were observed at the corners (Figure 2.5.2). The average air leakage rates of casement windows with anomolies was 45% greater than the mean performance of all casement windows. 45% of the double slider windows tested had one or more observed anomolies. Leakages were observed at the corners, at the meeting rail and at the sill. The performance of these windows was the same as the average of all double slider windows. 82% of the double hung windows tested had an observed defect. Leakages were observed at the corners, at the meeting rail and

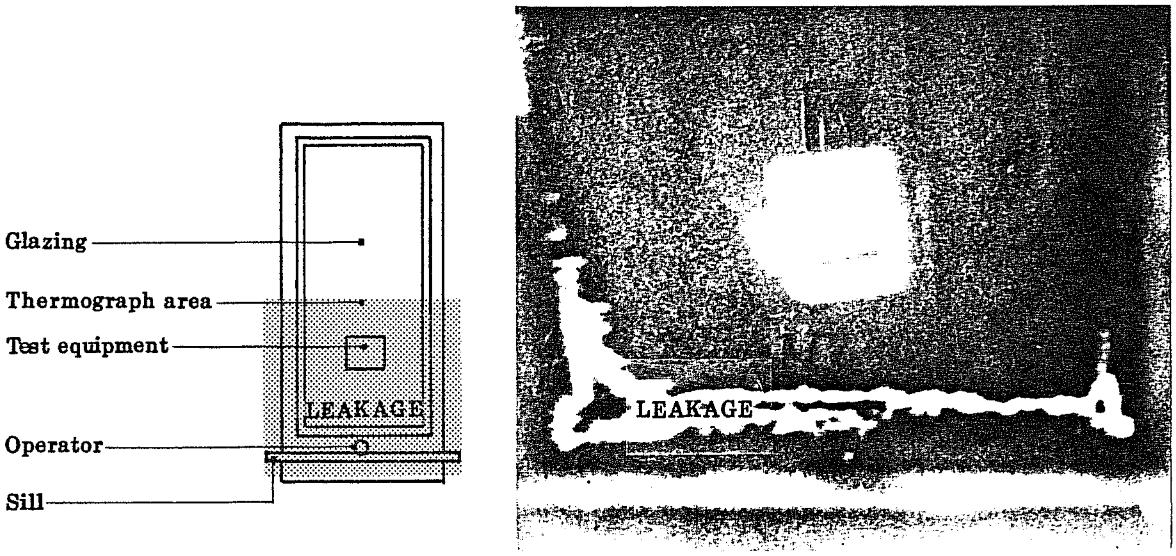


FIGURE 2.5.2 THERMOGRAPH AND SKETCH SHOWING TYPICAL CORNER LEAKAGE OF CASEMENT WINDOWS

along the sill length. The average air leakage rate of these windows was 7% above the average for all double hung windows. Single slider window anomolies were observed within a limited number of studied manufacturers of single slider windows and are not attributable to the window type in general. 65% of the single slider windows tested had one or more observed defects. The average air leakage rate of the single slider windows with anomolies was 12% greater than the mean of all single slider windows. Single hung window anomolies were observed within a limited number of manufacturers and should not be attributed to the window type in general. 55% of the tested single hung windows had an observed defect. The air leakage rate of these windows was 24% greater than the mean of all single hung windows.

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 construction, the majority appeared to have been the result of the manufacturing process. Three particular defects were most commonly observed.

1. 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

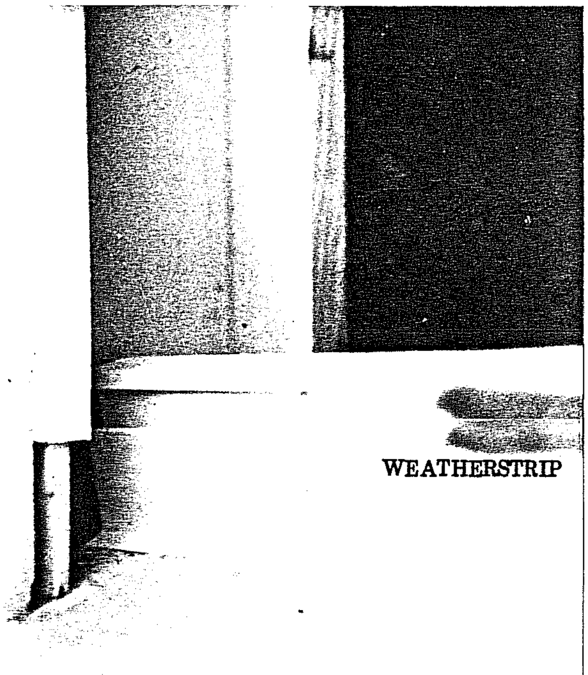


FIGURE 2.5.3 AIR LEAKAGE DUE TO WEATHERSTRIP DISCONTINUITY
Pile weatherstripping at sill cut short, leaving 2½" gap to jamb.

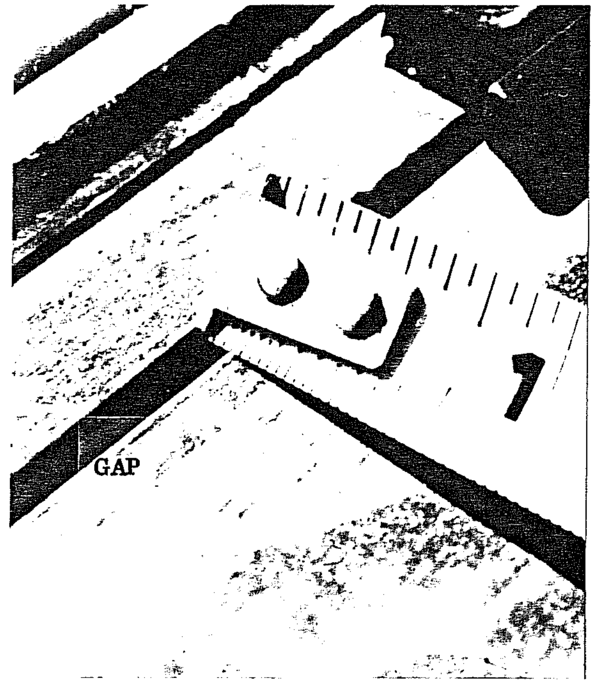


FIGURE 2.5.4 AIR LEAKAGE DUE TO HARDWARE SEAL
Hardware on double hung moved sash away from each other when locked.

weatherstrip was cut shorter than the sash, allowing a gap to occur at the corners (Figure 2.5.3).

2. 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.

3. 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 (Figure 2.5.4).

The results of the analyses indicate that the greatest observed leakages occurred primarily at the corners of the windows and along the head, meeting rail and sill, and that these observed leakages usually related to a window with greater air leakage than average. Excessive observed leakage related to weatherstrip discontinuity, sash fit and hardware seal in a number of cases.

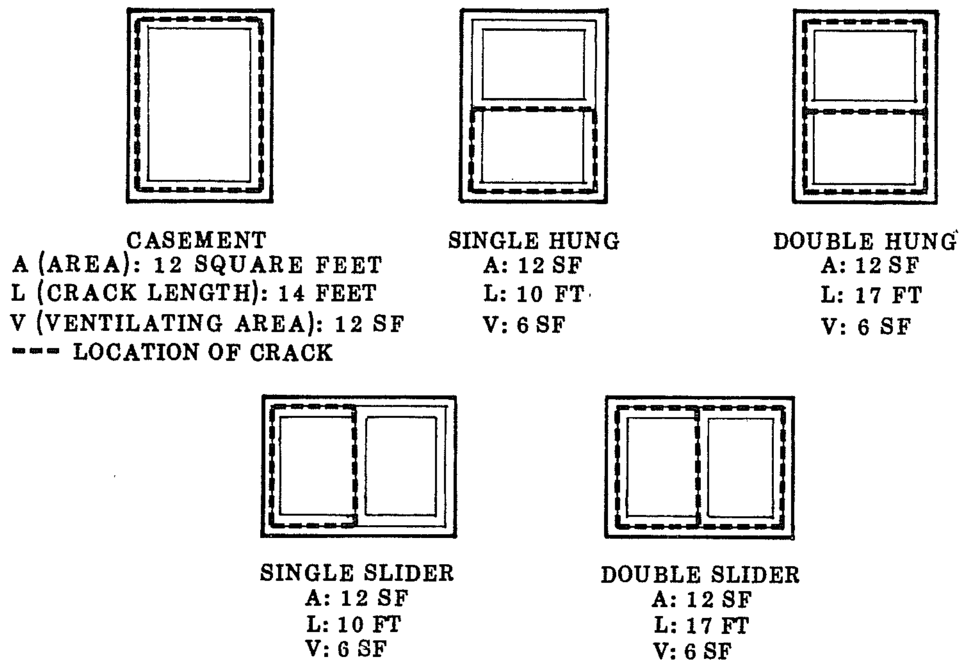


FIGURE 3.0.1 COMPARISON OF CRACK LENGTH, SASH AREA AND VENTILATING AREA OF TYPICAL OPERATION TYPES

3.0 Field Performance Expressed by Varying Air Leakage Rates

The project computed air leakage rates in three different ways; per linear foot of crack, per square foot of window sash area, and per square foot of ventilating area.

Windows serve the basic purposes of providing light, view and, in the case of operable windows, ventilation. 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 amount of air in cubic feet that is capable of passing through the operable sash/frame crack under a simulated 25 mph wind. Because the crack length of different window operation types varies greatly in relation to unit, glazed or ventilating area, the designer or buyer needs to do some translating to get an understanding of the total volume of infiltration to be expected. Evaluation of the window's air infiltration performance should not be made solely on the basis of leakage per linear foot of crack, because the total volume of air leakage for certain types of windows which have inherently longer crack length (double slider and double hung) is considerably higher than for other windows. Crack length 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 may have exactly the same overall dimensions and capacities for ventilation. When the flow of air leakage is calculated via the crack length method, and the leakage per linear foot of crack is the same, the double slider will appear to equal the performance of the single slider when, in fact, the total volume of air leakage through the double slider will be over 60% greater due to its additional crack length. Refer to Figure 3.0.1 which relates the crack lengths of various window types of equal area.

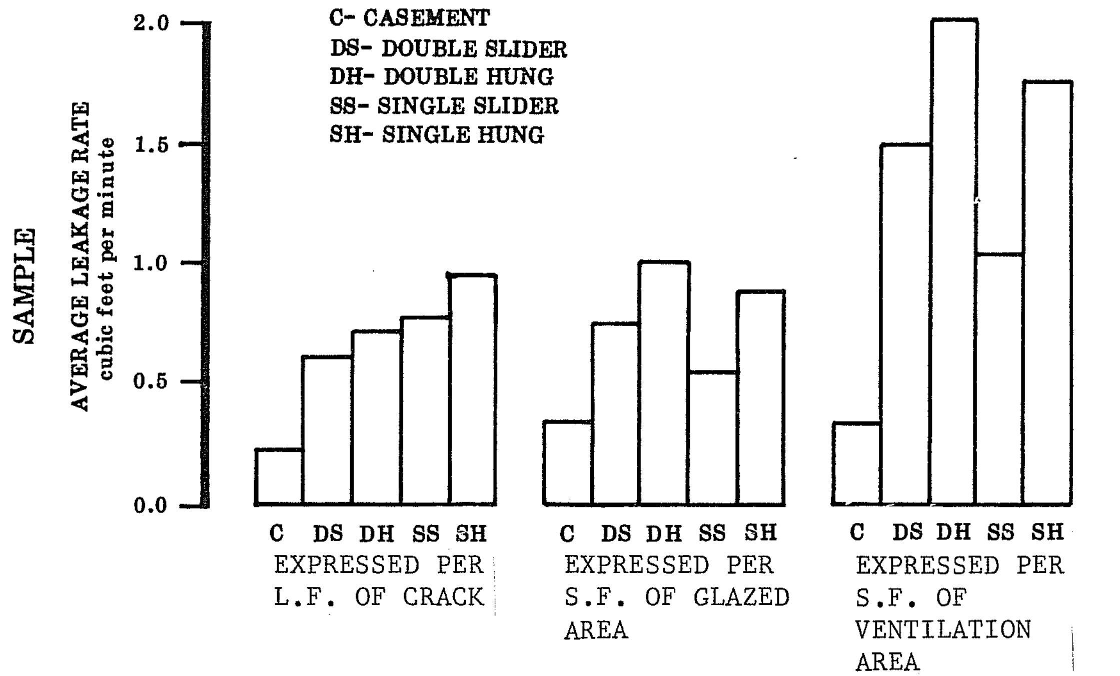


FIGURE 3.0.2 EXPRESSIONS OF AIR LEAKAGE RATE
The results of field testing new windows in new construction were calculated via the three methods displayed above.

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, thus the air leakage of the two windows above was 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 infiltrating 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.

Figure 3.0.2 illustrates the 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. 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 performance 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 performance 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.

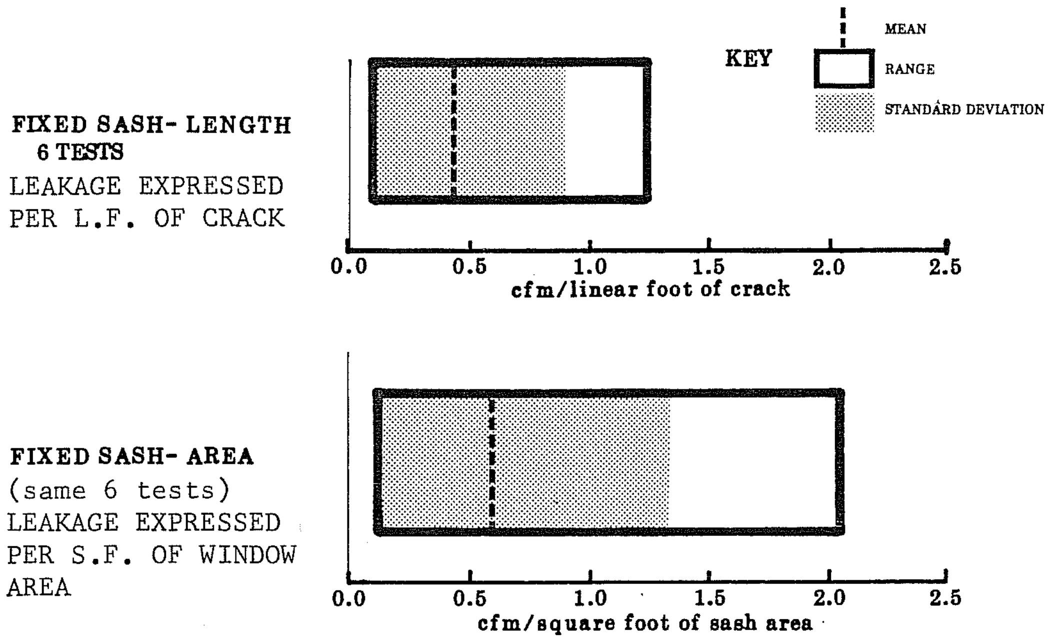


FIGURE 4.0.1 RESULTS OF TESTING FIXED SASH RELATED VIA CRACK LENGTH AND SASH AREA METHODS OF CALCULATING AIR LEAKAGE

4.0 **AIR LEAKAGE PERFORMANCE OF FIXED SASH**

Six fixed window units were tested for their installed air leakage performance. Figure 4.0.1 illustrates the results. The fixed windows tested exhibited relatively poor air leakage characteristics, especially 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.

There are currently no standards for fixed residential wood or aluminum windows. Observations from this study indicate that there is a definite need to establish air leakage standards for such windows.

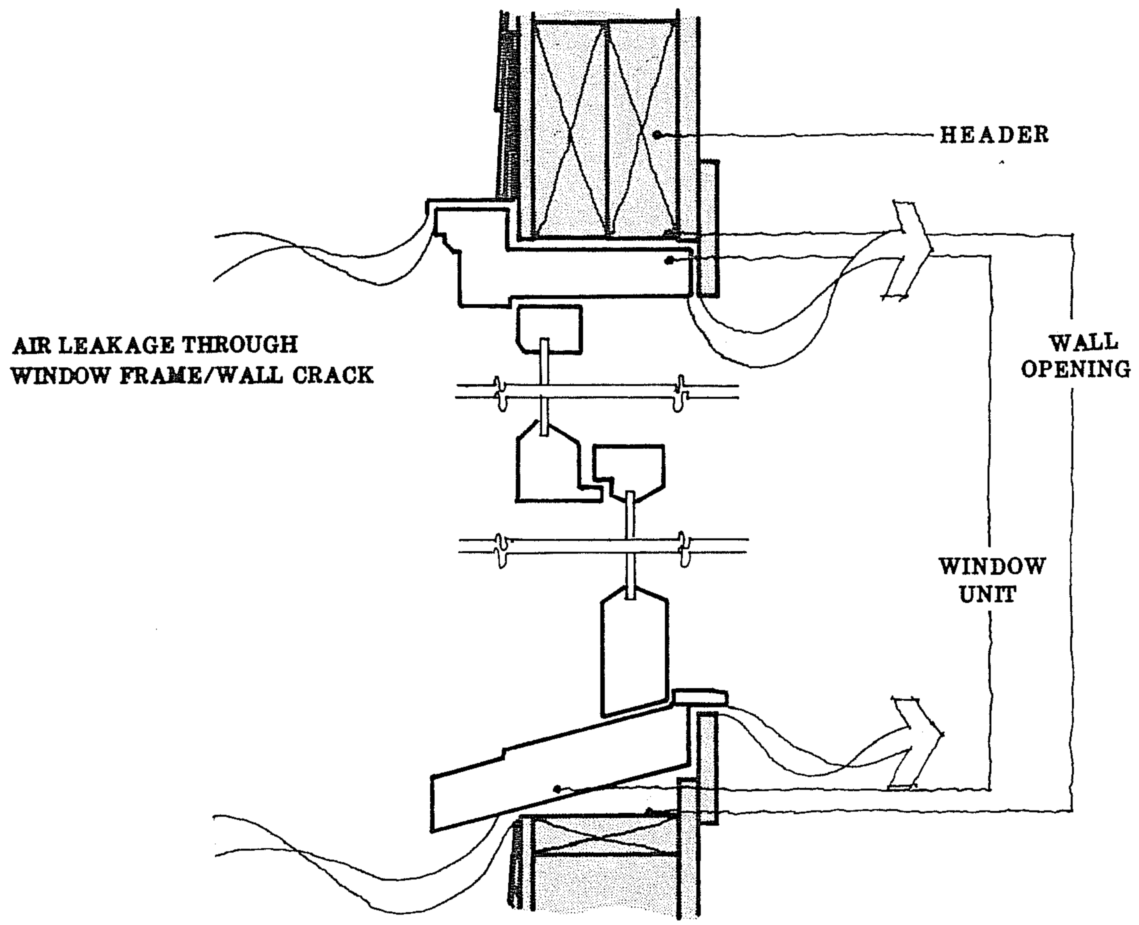


FIGURE 5.0.1 AIR LEAKAGE THROUGH FRAME/WALL CRACKS
Frame/wall air leakage passes through the cracks between the window frame and the wall.

5.0 AIR LEAKAGE BETWEEN THE WINDOW UNIT AND WALL

An important consideration in evaluating the air leakage performance of the total installed window unit is the amount of air passing between the window unit and the wall opening as diagrammed in Figure 5.0.1. The project undertook to obtain a better understanding of the magnitude of this leakage through application of some experimental testing techniques. Although the techniques proved imperfect, they nonetheless can be used in a qualitative way to define the importance of the installation of the window unit in the wall as a function of energy performance.

The technique for measuring frame/wall leakage is explained in detail in Appendix A. The technique employed the use of two fans, one large fan to

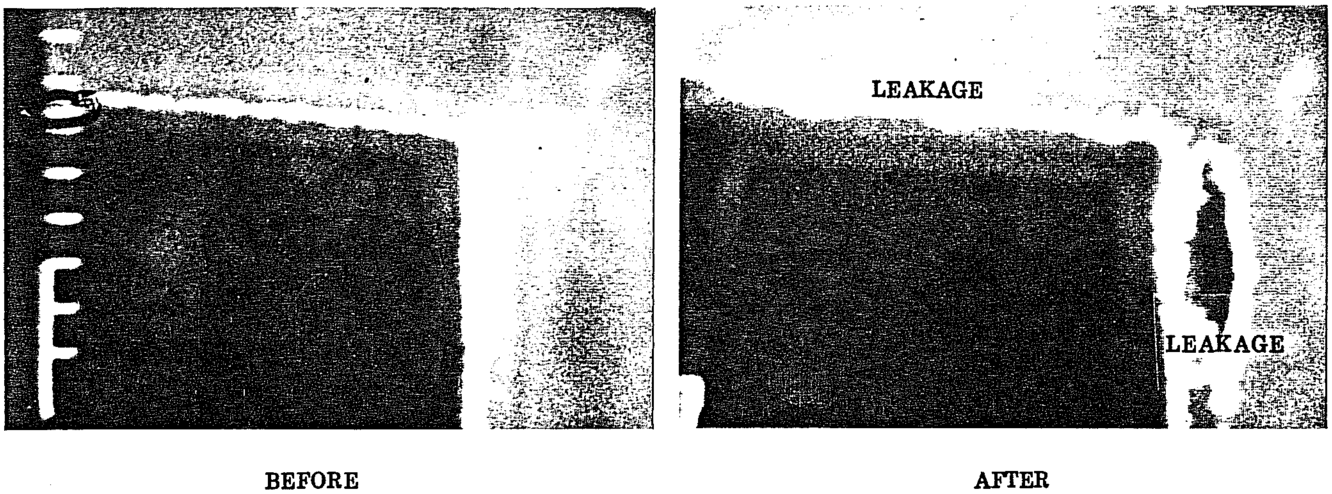


FIGURE 5.0.2 THERMOGRAPH OF FRAME/WALL LEAKAGE
Thermograph before and after room pressurization, cold area above and to right of window unit due to frame/wall leakage.

pressurize the room in which the window was installed and another to pressurize a chamber attached to the wall immediately adjacent to the window. The window unit was sealed, exposing only the crack between the window trim and wall. The room was brought to a negative pressure approximating a 25 mph outside wind and the frame/wall chamber was pressurized until its pressure was balanced with room pressure. The flow of air from the chamber into the room was then measured. This two-fan arrangement prevented air from "short circuiting" from the room interior into the frame/wall chamber thus avoiding the possibility of measuring interior air from the room as leakage. It did not, however avoid the problem of interior air from adjacent rooms entering the cavity and being measured at the frame/wall crack. During three of the four frame/wall tests, the temperature differential between inside and outside was great enough to employ infrared thermography during testing. The thermography indicated dramatically the areas and relative amount of air leakage at the frame wall crack (see Figures 5.0.2). On some of these same tests, however, it was noted that the temperature of the chamber did not drop during the test creating speculation that there was warm air from inside adjacent rooms entering the frame/wall chamber.

TEST NUMBER	AIR LEAKAGE AT THE FRAME WALL CRACK Per Foot	Total	AIR LEAKAGE AT THE SASH/FRAME CRACK Per Foot	Total
1/1	.43	10.71	.25	10.9*
1/2	.24	5.91	not measured	
1/3	.38	6.61	.51**	10.2**
1/4	.23	4.09	.45**	8.9**

TABLE 5.0.3 FRAME/WALL LEAKAGE DATA

* Total leakage through combination of operator and fixed sash.
** Figures from similar units tested as installed by same contractor.

It is interesting to note the relative impact of total air leakage as measured through the frame/wall crack when compared to the leakage through the sash/frame crack of the installed window unit as displayed in Table 5.0.3. Although the test method allows some degree of imprecision in the absolute measurement of the volume of outside air flowing through the sash/frame crack, it nonetheless indicates that the air leakage performance of the crack between the window unit and the wall has a significant affect on the air leakage performance of the entire window unit as installed. The air flow measurements at the frame/wall crack indicate that air leakage at this location can be nearly that of the window unit itself. Control of air leakage at the frame/wall crack is relatively easy during window installation but cannot be controlled successfully after the window is installed. It is, therefore, imperative that window installers pay close attention to limiting air leakage at the frame/wall crack.

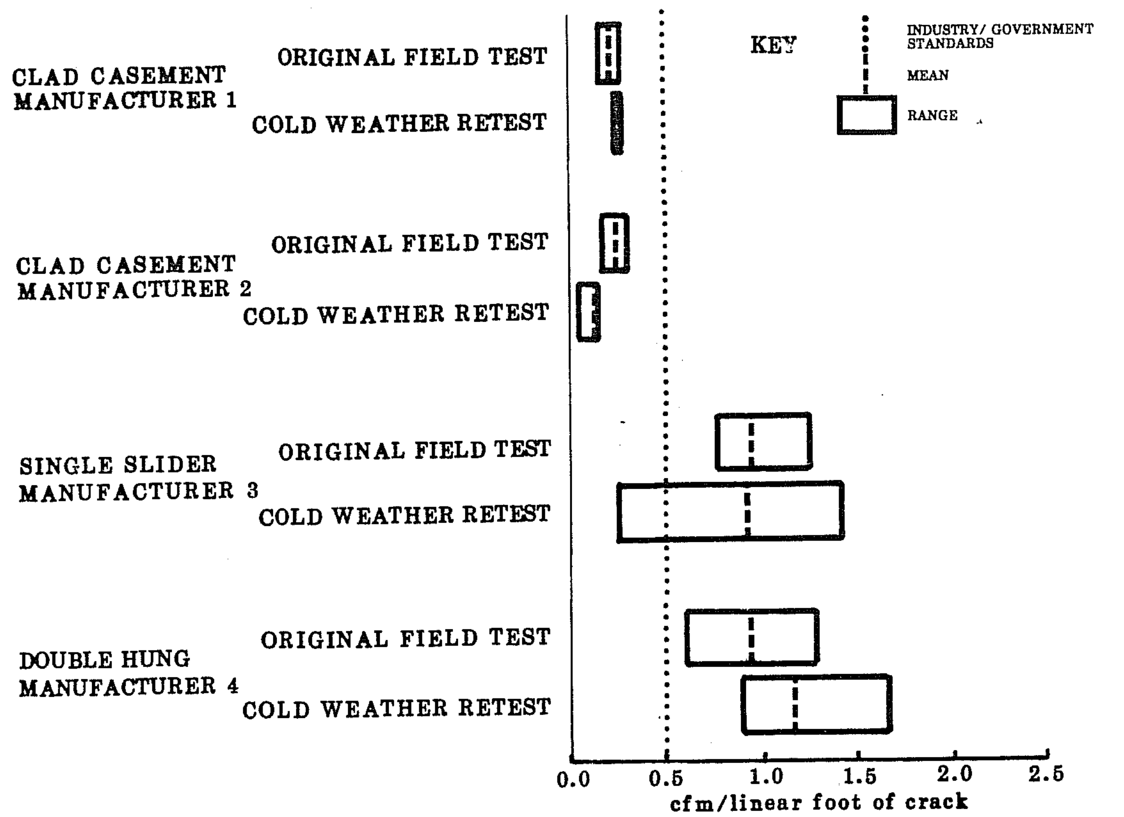


FIGURE 6.0.1 COLD WEATHER RETESTS
A sampling of windows which had been tested during the summer months were retested in the winter to observe performance differences.

6.0 PERFORMANCE OF NEW WINDOWS DURING COLD WEATHER

A number of window units which had been tested during the new window portion of the program were retested during the winter months to investigate the possibility of poorer performance during cold weather. The average outdoor temperature encountered during the initial testing was 60.2 F, while the average outdoor temperature encountered during cold weather retesting was 7.8 F. Figure 6.0.1 displays the results of the retesting work. The results obtained indicate no significant degradation in the air leakage performance during cold weather. After each opening and closing of a window unit, its performance will vary since factors such as dirt and the care of the operator in closing the unit can greatly affect its seal; the difference of the two results (original versus cold weather) could be attributed to the variation in performance that is to be expected with normal operation of the unit.

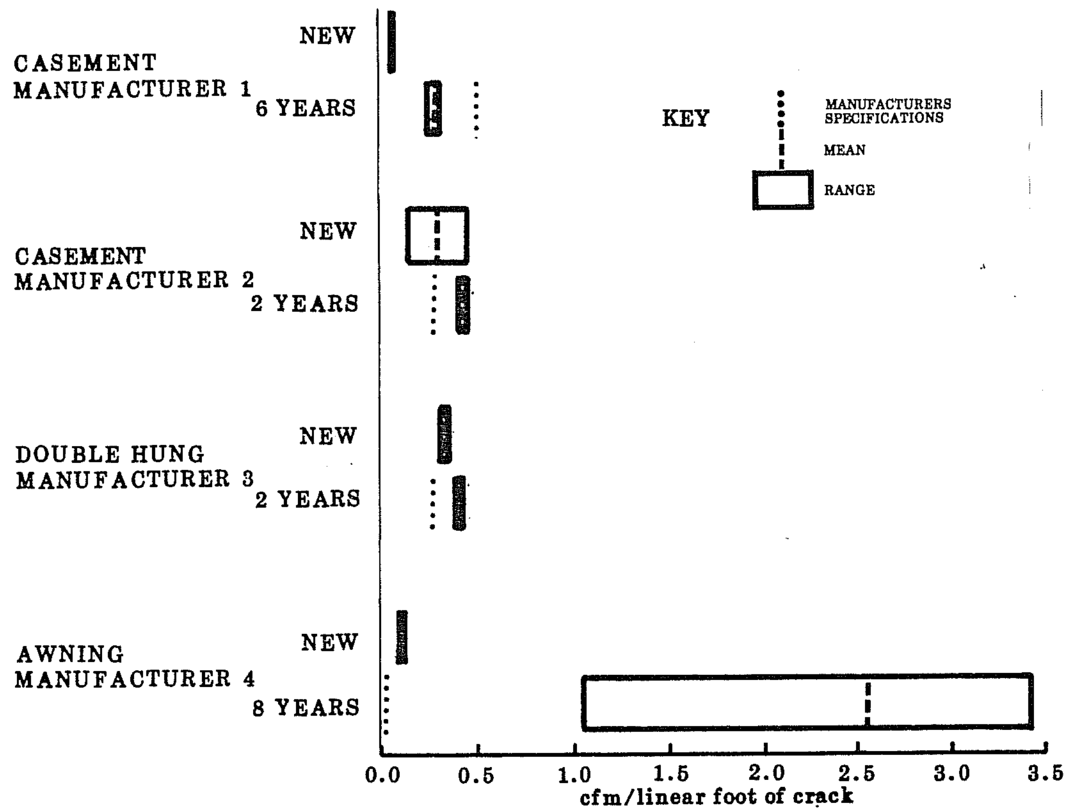
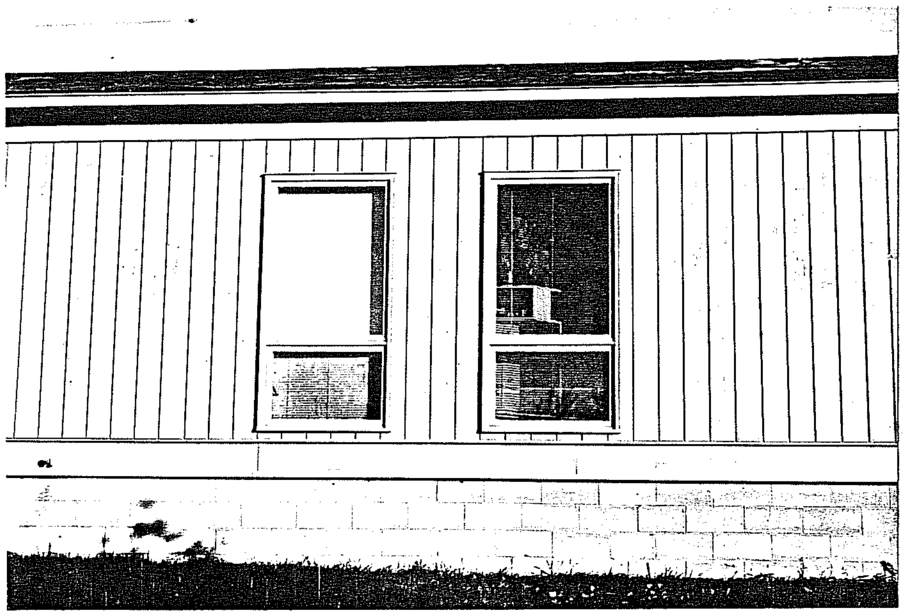


FIGURE 7.0.1 PERFORMANCE OVER TIME
A relation of the performances of new windows to their counterparts two to eight years earlier.

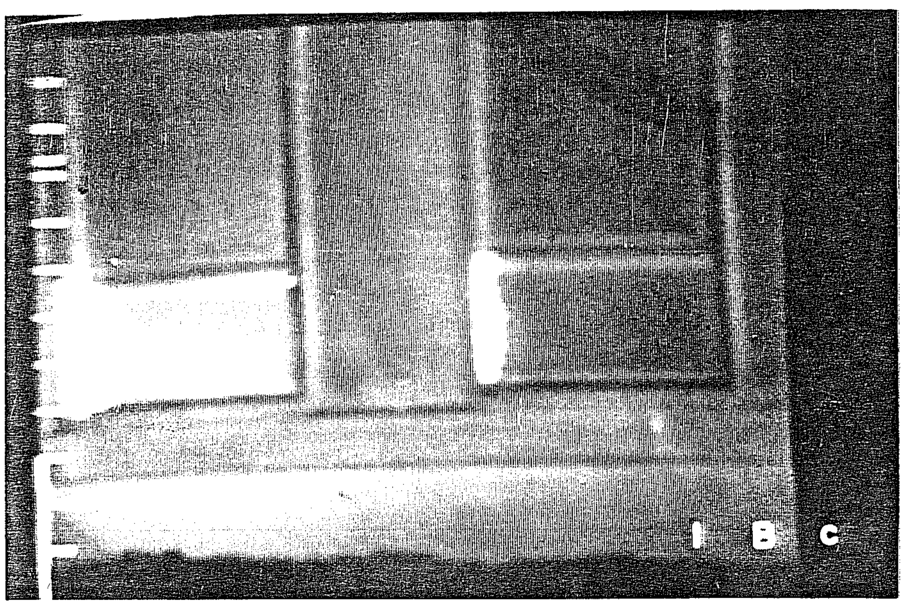
7.0 WINDOW AIR LEAKAGE PERFORMANCE OVER TIME

The ability of a window to maintain its air leakage performance over a period of years is an important energy conservation attribute. In this project, ten tests were made on windows which had been installed for from 2 to 8 years, and for which manufacturers' specifications from the installation year were available. The results of these tests were compared to the performance of new windows of the same operation type as illustrated in Figure 7.0.1. The performance of 7 of the 10 older windows tested did not degrade appreciably from the performance of new windows of the same operation type, although none performed as well as may have been anticipated from the manufacturers specifications.

There was substantial degradation of performance in 3 of the older windows tested, which were awning units. The sash was equipped with a roto operator at the center of the right jamb and a locking mechanism at the center of the left jamb. Ice, resulting from condensation on the unit, built up between the sill stop and the sash and, as it expanded, pushed the sash outward until the teeth on the roto operator snapped and the sash warped. Although only 3 of these units were tested, this condition was observed in a total of 22 similar window units. It appears that this degradation in performance can be attributed to a design flaw of the manufacturer; no positive lock was provided at the window sill.



AREA OF THERMOGRAPH



THERMOGRAPH

FIGURE 7.0.2 EXTERIOR THERMOGRAPH OF UNIT WITH POOR PERFORMANCE OVER TIME
Light areas show air leaking from interior, especially at roto operator jamb.

Figure 7.0.2 is an interior thermograph of one of the leaky awning window units under pressure. The lightest areas are zones of exfiltration and are typically at the roto operator side of the sash.

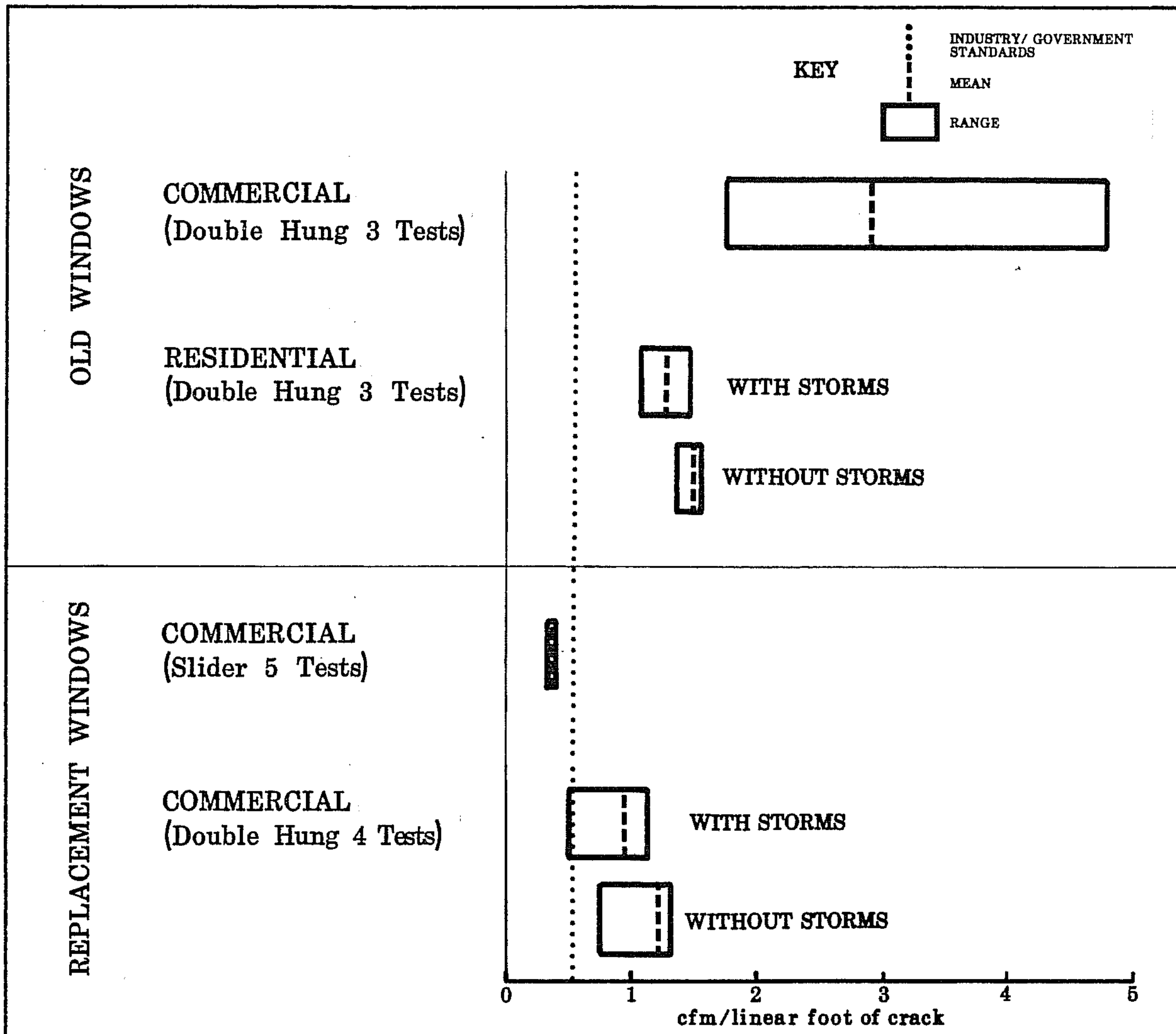


FIGURE 8.0.1 FIELD AIR LEAKAGE PERFORMANCE OF OLD AND RETROFIT WINDOWS

8.0 OLD AND RETROFIT WINDOWS

Although the major focus of the testing program was oriented to determining the air leakage performance of new windows, a limited amount of work was done on testing the performance of old windows and retrofit windows designed to replace them.

Field air leakage measurements were made on six older residential and commercial windows 25-50 years old and on nine commercial replacement windows made by three manufacturers. The results of the tests are displayed in Figure 8.0.1. The old commercial windows lacked weatherstripping and were in generally poor condition, contributing to their considerable air leakage. These older commercial windows tested were being refitted with new replacement windows, and tests performed on the replacement windows indicate a considerable improvement in air leakage performance. Where tests were performed on old and retrofit windows each both with and without storms, the storms reduced the rate of air leakage.

It should be noted that the volume of air leakage of the old commercial double-hung windows exceeded the capacity of the test equipment, and that the data displayed in the table is extrapolated and therefore approximate. Conversion of air infiltration at one pressure to air infiltration at another pressure should not be done - it was done here for graphic comparison only. The actual air leakage of the three tested units was:

Unit 1: 1.35 cfm/lfc at .15" water pressure difference
Unit 2: 1.34 cfm/lfc at .20" water pressure difference
Unit 3: 1.51 cfm/lfc at .05" water pressure difference

This data was extrapolated to the standard pressure by the following process:

$$Q = C(\Delta P)^{.65}$$

where: Q is the air flow volume (cfm)
ΔP is the pressure differential applied to the window
C is a constant

9.0 CONCLUSIONS AND RECOMMENDATIONS

The focus of this project was to establish a base of information on the air leakage performance of windows after installation. Statistically valid information, representative of the market distribution for the Minneapolis/St. Paul metropolitan area was compiled on new windows being installed into new construction. The results of these tests were analyzed in an attempt to relate the design, manufacture and installation of the windows to the performance ratings observed. Comparisons were made between the field performance of a unit and the industry and federal standards set for its performance in the laboratory.

Additional testing was done to further explore the potentials for energy conservation through the use of windows and to aid in explaining the air leakage performance measured in the field. New windows were tested in the factory as well as observed in the field, windows originally tested in warm weather were retested in the winter to observe their performance under different climatic conditions, examples of old and retrofit windows were tested and thermography was used to expand and explain the data being collected.

9.1 THE FIELD AIR LEAKAGE PERFORMANCE OF NEW WINDOWS INSTALLED IN NEW CONSTRUCTION

9.1.1 Conclusions

9.1.1.1 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. (Figure 2.1.1). A large percentage of the windows tested had air leakage in excess of these standards and reports (Figure 2.1.2). 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.

9.1.1.2 The performance of a window is primarily affected by its operation type. Casement windows far outperform sliding and hung windows (Figure 2.2.1).

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

9.1.1.4 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.

9.1.1.5 The data indicate trends in performance relative to the manufacturer and installer.

The impact of manufacturer and installer are far less important than the window operation type. For instance, even the poorer performance, marginally installed casement windows outperformed the majority of all other hung and sliding windows, even those made by the higher performing manufacturers and installed according to recommendations.

It appears that, although both manufacturer and installer impact window performance, the manufacturer has more impact than the installer. As an example, the very best installation of a poorly designed or manufactured window may not equal the performance of a well designed and manufactured window poorly installed.

A limited number of tests indicate that the window declines in air leakage performance between factory and field (Figure 2.3.3).

9.1.1.6 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 (Figure 3.0.2).

9.1.2 Recommendations

9.1.2.1 To have more meaning to the design and construction industry, window air leakage performance as determined in the laboratory should have a more direct relationship to the performance one might expect in the field. Laboratory tests should be made on windows representative of the manufacturer's product line and should be made randomly and frequently.

9.1.2.2 Expression of air leakage rate should be changed from crack length to one more meaningful to designers and builders and one which more accurately portrays the total air leakage impact of the window unit. The performance of fixed windows, used primarily for light and view, would most appropriately be expressed in cfm per square foot of sash, while operable windows, used for ventilation as well as light and view, might have their performance expressed in terms of free ventilating area.

9.1.2.3 Additional testing of new windows in new construction should be performed to further isolate the areas of greatest leakage. Such testing might focus on weatherstripping, and testing parts of the window such as jamb, sill and meeting rail separate from the entire opening. More data is necessary to provide definitive information on the impact of design, manufacture, shipping and installation of the air leakage performance of new residential window units. The data base should be expanded to include windows representative of different national construction zones. Data on the performance of windows in commercial construction is also required.

9.2 THE PERFORMANCE OF NEW WINDOWS IN COLD WEATHER

9.2.1 Conclusion

9.2.1.1 Windows retested during this project in cold weather that had been tested during warm weather showed no significant tendency to decrease in over-all performance levels. The windows retested during cold weather represented less than 10% of the total number of windows tested (Figure 6.0.1).

9.2.2 Recommendation

9.2.2.1 In cold climate such as the test area, the prime air leakage concern is during the winter months. Although the limited data obtained on cold weather testing is encouraging, more data is required to confirm that current specified test temperatures can give a true indication of a window's performance during cold weather.

9.3 THE AIR LEAKAGE OF THE FRAME/WALL CRACK

9.3.1. Conclusions

9.3.1.1 The number of tests made and the experimental nature of the testing process allows only general observations to be made regarding the relative impact of the frame/wall crack on air leakage when compared to the sash/frame crack. The air leakage performance of the crack between the window unit and the wall has a significant affect on the air leakage performance of the entire window unit as installed. This location of air leakage is easily controllable during window installation but cannot be controlled successfully after the window is installed. It is, therefore, imperative that window installers pay close attention to limiting air leakage at the frame/wall crack.

9.3.1.2 The measurement of air leakage at the frame wall crack is difficult. The data obtained on the limited number of tests run indicates that the frame/wall crack has significant air leakage, but that this leakage was somewhat less significant than the leakage through the sash/frame crack of the window unit itself.

9.3.2 Recommendation

9.3.2.1 The limited data obtained indicates that the frame/wall crack is an area of significant air leakage. Installation techniques to control leakage at this location require documentation and dissemination. Data should be developed that can be applied by installing contractors to insure maximum affectiveness of the air leakage seal at this location.

9.4 WINDOW AIR LEAKAGE PERFORMANCE OVER TIME

9.4.1 Conclusion

9.4.1.1 Ten older windows, representing four manufacturers, were tested during the project. The performance of the products of three of the manufacturers had similar air leakage characteristics to those of new windows of the same manufacturer and operation type, the performance of the product of the fourth manufacturer was far worse than the similar new windows tested. The results indicate that window air leakage performance does not have to substantially degrade over time, but may degrade due to improper window design. (Figure 7.0.1).

9.4.2 Recommendation

9.4.2.1 A window that cannot maintain its air leakage performance over a period of years is a poor investment as well as an energy waster. Work is required to document the severity in decline in window performance over time, to identify the reasons for such decline, and to investigate means of correcting the problems causing the degradation in performance.

9.5 OLD AND RETROFIT WINDOWS

9.5.1 Conclusion

9.5.1.1 A number of the old windows tested were very leaky; so much so that the capacity of the measuring equipment was exceeded during the test. The retrofit windows which were tested in the same buildings as the old windows substantially increased the performance of those window openings formerly containing the older windows.

9.5.2 Recommendation

9.5.2.1 The stock of existing windows in residential and commercial construction represents a dramatic potential for energy conservation. Data similar to that developed during this project for new windows should be generated for replacement retrofit and storm windows and other devices currently marketed to reduce air leakage through existing window openings.

APPENDIX A

STANDARD TEST METHOD

MODIFICATIONS TO STANDARD TEST METHOD

Nominal changes in the Standard Test Method were agreed to during negotiations with the contracted testing laboratory, Twin City Testing:

1) Manometer: has divison of .01 inches of water, readings are interpolated to .005 inches of water.
2) Fan: utilized in standard sash/frame crack test: 50 cfm capacity

As the test process developed, further modifications to the Standard Test Method were made:

1) Equipment Tare Leakage: The field test equipment was periodically checked for tare leakage.

STANDARD TEST METHOD FOR RATE OF AIR LEAKAGE THROUGH:

INSTALLED EXTERIOR WINDOWS

UNINSTALLED WINDOWS AT FACTORY AND JOBSITE

THE JOINT BETWEEN THE WINDOW FRAME AND ADJACENT WALL ASSEMBLIES

WINDOW EVALUATION PROJECT

Minnesota Energy Agency
Lawrence Berkeley Laboratories
U.S. Department of Energy

13 July 1978

STANDARD TEST METHOD FOR:

1. RATE OF AIR LEAKAGE THROUGH INSTALLED EXTERIOR WINDOWS

1.1 SCOPE

1.1.1 This method covers the determination of the resistance of exterior windows installed in a building to air infiltration resulting from air pressure differences.

1.1.2 This method is applicable to window assemblies alone and is not intended for measuring the leakage through openings between the window and adjacent wall assemblies.

1.1.3 The proper use of this method requires a knowledge of the principles of air flow and pressure measurements used in this method.

1.2 SUMMARY OF METHOD

1.2.1 The test consists of providing a sealed air chamber against one face of the test specimen, supplying air to and exhausting air from the chamber at the rate required to maintain the specified test pressure difference across the specimen, and measuring the resultant air flow through the specimen.

1.3 SIGNIFICANCE

1.3.1 This test method is a standard procedure for determining the air leakage characteristics under specified air pressure differences.

1.3.2 The rates of air leakage of similar windows determined in the laboratory, in the factory and in the field can be compared. The field values, however, can vary with indoor and outdoor conditions which can cause dimensional changes in the window assembly.

1.4 DESCRIPTION OF TERMS AND UNITS OF MEASUREMENT

1.4.1 The specimen is the assembled unit installed in the exterior wall of a building.

1.4.2 Standard conditions for the test method are defined as dry air at

Pressure: 29.92 in. Hg(101.3 kPa)
Temperature: 69.4° F, 20.8° C
Air Density: 0.075 lb/ft^3 (1.202 kg/m^3)

1.4.3 Test pressure difference is the specified difference in static air pressure across the closed and locked or fixed specimen, expressed in inches of water (Pa).

1.4.4 Air leakage (Q) is the volume of air flowing per unit time through the closed and locked specimen under a test pressure difference, expressed as ft^3/min (m^3/s).

1.4.5 Rate of air leakage is the air leakage per unit of specimen area, expressed as $ft^3/min.ft^2$ ($m^3/s \cdot m^2$); and the air leakage per unit of operating sash crack length, expressed as $ft^3/min. ft$ ($m^3/s.m$).

1.4.6 Length of crack (L) is the sum of all perimeters of all sash contained in the test specimen, based on overall dimensions of such parts, expressed as ft (m). Where two such operable parts meet, the two adjacent lengths of perimeter shall be counted as only one length.

1.4.7 Specimen area (A) is the area determined by the overall dimensions of the test specimen expressed as ft^2 (m^2).

1.5 APPARATUS

1.5.1 The description of apparatus in this section is general in nature and any arrangement of equipment capable of performing the test procedure within the allowable tolerances is permitted.

1.5.2 Major components (see Figure 1)

1.5.2.1 Test Chamber - A chamber is formed by sealing an impermeable sheet against the prime window window frame. At least one static pressure tap shall be provided to measure the chamber pressure and shall be located at mid-height of the test specimen. The air supply into or air exhaust from the air chamber shall be located so that it is centered on the glass located furthest from the test chamber.

The impermeable sheet shall be 6 mil. polyethylene (without powder treatment) or painted or varnished plywood. At no time during the test shall the impermeable sheet, or any other part of the testing assembly, come in contact with nor be allowed to exert pressure upon the operating or fixed sash; either under positive or negative pressures.

The test chamber shall be of sufficient size to have approximately uniform pressure distribution throughout.

1.5.2.2 Fan - The fan is a controllable blower, exhaust fan or reversible blower, designed to provide the required air flow at the specified test pressure difference. The system should provide essentially constant air flow at a fixed pressure for the period required to obtain readings of air flow and pressure difference. The fan shall have a capacity of 100cfm at a static pressure difference of (.5 + duct resistance + flow meter resistance) inches of water and shall be equipped with a speed control or control valve.

1.5.2.3 Pressure Measuring Apparatus - A device to measure the test pressure within a tolerance of $\pm$ 0.005 inches of water, such as an inclined manometer with a range of 0-0.50 inch of water and with the smallest division of 0.005 inches of water or other suitable instrument.

1.5.2.4 Air Flow Metering System - A device to measure the air flow within the tolerances set forth in 1.5.3. Such device may be a variable area flow meter capable of measuring leakage of 0-100 cubic foot per minute in the approximate ranges of 1.5 ft^3/min to 15 ft^3/min. and 10 ft^3/min to 100 ft^3/min.

1.5.3 Accuracy - The air flow through the test specimen shall be determined with an error not greater than ± 5% when this flow equals or exceeds 2 ft^3/min or ± 10 % when the air flow rate is less than 2 ft^3/min, but more than ½ ft^3/min.

1.6 CALIBRATION

1.6.1 The air flow metering system as installed in the test shall be calibrated in the laboratory using the standard orifice meter, venturi meter, nozzle or laminar flow meter.

1.6.2 The pressure measuring apparatus as installed in the test shall be calibrated in the laboratory with a micromanometer.

1.6.3 The above calibrations shall be conducted every three months at a minimum.

1.7 PROCEDURE

1.7.1 Open, close, and lock each sash five times prior to testing. Verify that all holes are not plugged by dirt, paint.

1.7.2 Fit the impermeable sheet to the window frame to cover the window frame and sash assembly. Provide suitable support for the sheet without contacting the sash. Seal the joint between the window frame and the sheet at the perimeter; seal the air supply or exhaust entrance to the chamber and seal around the openings for the pressure tap.

1.7.3 Adjust air flow through the test chamber to provide a pressurization of 0.30 inch of water (75 Pa). Check the sheet and all sealed joints for extraneous air leakage. Leakage may be checked by soap solution, smoke pencil or other positive sensitive means. Eliminate all extraneous air leakage sources.

1.7.4 Adjust the air flow through the test chamber to provide the specified test pressure difference across the test specimen. When the test pressure has stabilized to within ± .005 inch of water, record the air flow through the flowmeter and the test pressure difference (outside wind above 5 to 10 mph may not permit stabilized conditions).

Measure and record the air temperature in the duct work. This can be accomplished thru measurement of the temperature of fan air exhaust (suction pressure mode) or fan air intake (positive pressure mode).

Identify and record leakage sources and qualitative leakage rates in the window assembly from outside with the test chamber under .3 inch of water suction pressure using a smoke pencil.

1.7.5 Repair any marking or damage to window unit or wall caused by testing.

1.8 CALCULATIONS

1.8.1 With all extraneous leakage sources eliminated, the metered air flow is equal to the air leakage, Q, at the test condition.

1.8.2 Express air leakage, Q, at standard condition:

$$Q_s = \left(\frac{B}{29.92}\right) \left(\frac{530}{T + 460}\right) Q$$

Q_s = air leakage rate at standard condition, cubic ft per minute.
B = barometric pressure, in. of Hg
T = duct air temperature, ^{o}F

1.8.3 Calculate the air leakage in accordance with the following methods:

Rate of air leakage per unit length of crack = Q_s/L

and

Rate of air leakage per unit area = Q_s/A

1.9 REPORT

1.9.1 The report shall include the following information.

1.9.1.1 General - date and time of test, building and window location and date of report.

Identification of the specimen (manufacturer and model code, operation type, dimensions, materials and other pertinent information).

1.9.1.2 Detailed drawings

1.9.1.2.1 Window Unit - general
From typical drawings provided- verification and dimensions of the section profile, sash outline and arrangement.

From site observations -drawings of window installation procedures and details, window anchorage, framing location (as possible), panel arrangement.

Identification of sealants used and location.

Note any deviations observed from typical window unit.

1.9.1.2.2 Hardware and locking mechanism - Identification of the hardware and locking arrangement, and type and location of locking mechanism.

1.9.1.2.3 Glazing - Identification of the glass thickness and type and method of glazing.

1.9.1.2.4 Weatherstripping - Identification of type, location, condition, installation, spacing and anchorage of weather-stripping. Note any gaps or discontinuities.

1.9.1.3 Ambient Test Conditions - From testing contractor's data, note the duct temperature.

From Minnesota Energy Agency data, note the indoor and outdoor temperatures, the indoor and outdoor relative humidity, the outdoor windspeed and direction, the outdoor barometric pressure and time of the test.

1.9.1.4 Pressure Difference and Leakage - A statement or tabulation of the pressure difference exerted across the specimen during the test and the corresponding measured rate of air leakage Q, and the air leakage Q_s, Q_s/L, and Q_s/A as calculated in Section 1.8.

1.9.1.5 Compliance Statement - A statement that the tests were conducted in accordance with this method, or a complete description of any deviations from this method.

1.9.1.6 Signature - The test report shall be signed by the testing official.

STANDARD TEST METHOD FOR:

2. RATE OF AIR LEAKAGE THROUGH EXTERIOR WINDOWS IN FACTORY OR FIELD PRIOR TO INSTALLATION.

2.1 The same test procedure as for the installed windows can be used. A support (adjustable to take different size test specimen) is required to hold the test specimen in a vertical position.

STANDARD TEST METHOD FOR:

3. RATE OF AIR LEAKAGE THROUGH OPENING BETWEEN WINDOW UNIT AND ADJACENT WALL ASSEMBLIES.

3.1 SCOPE

3.1.1. This is an experimental methodology to determine the leakage through the openings between the window and adjacent wall assemblies.

3.2 SUMMARY OF METHOD

3.2.1 The test arrangement to be used in this method is shown in Figure 2. The building is subjected to a pressure difference specified for the frame-wall leakage test. The leakage of air into the air chamber will cause its pressure to rise. The fan is operated to reduce the air chamber pressure until it is equal to the building pressure. At this point, the frame-wall joint is subjected to the specified pressure difference and the metered flow is equal to the frame-wall leakage.

3.3 SIGNIFICANCE

3.3.1 Reserved

3.4 DESCRIPTION OF TERMS AND UNITS OF MEASUREMENT

3.4.1 The specimen is the assembled unit installed in the exterior wall of a building.

3.4.2 Standard conditions for the test method are defined as dry air at

Pressure: 29.92 in. Hg(101.3 kPa)
Temperature: 69.4° F, 20.8° C
Air Density: 0.075 lb/ft^3 (1.202 kg/m^3)

3.4.3 Test pressure difference is the specified difference in static air pressure across the closed and locked or fixed specimen, expressed in inches of water (Pa).

3.4.4 Air leakage (Q) is the volume of air flowing per unit time through the closed and locked specimen under a test pressure difference, expressed as ft^3/min. (m^3/s).

3.4.5 Rate of air leakage is the air leakage per unit of specimen area, expressed as ft^3/min.ft^2 (m^3/s·m^2); and air leakage per unit length of window/wall crack length expressed as ft^3/min.ft.

3.5 APPARATUS

3.5.1 The description of apparatus in this section is general in nature and any arrangement of equipment capable of performing the test procedure within the allowable tolerances is permitted.

3.5.2 Major Components (see Figure 2)

3.5.2.1 Test Chamber - An impermeable sheet is placed against the window assembly to eliminate air leakage. A chamber is formed by placing an impermeable shallow box over the window assembly including the window frame - wall joint and sealed. One static pressure tap shall be provided to measure the pressure difference between air chamber and room.

3.5.2.2 Fan - The fan is a controllable blower, exhaust fan or reversible blower designed to provide the required air flow at the specified test pressure difference. The system should provide essentially constant air flow at a fixed pressure for the period required to obtain readings of air flow and pressure difference. The fan shall have a capacity of 100 cfm at the static pressure difference of (.5 + duct resistance + flow meter resistance) inches of water and shall be equipped with a speed control or control valve.

3.5.2.3 A separate fan to obtain a specified pressure difference across the exterior walls of the building is required. It can be connected to a window, door or vent opening of the building. One static pressure tap in the exterior wall adjacent to the frame-wall leakage apparatus is required.

The fan shall have the capacity of 3,000 cfm minimum at static pressure difference of 0.50 in. of water and speed control or control damper.

3.5.2.4 Pressure Measuring Apparatus - A device to measure the test pressure within a tolerance of $\pm$ 0.005 inches of water, such as an inclined manometer with a range of 0-0.50 inch of water and with the smallest division of 0.005 inches of water or other suitable instrument.

3.5.2.5 Air Flow Metering System - A device to measure the air flow within the limitation set forth in 3.5.3.

3.5.3 Accuracy - The air flow through the test specimen shall be determined with an error not greater than $\pm$ 5% when the flow equals or exceeds 2 ft^3/min. or $\pm$ 10% when the air flow rate is less than 2 ft^3/min, but more than ½ ft^3/min.

3.6 CALIBRATION

3.6.1 The air flow metering system as installed in the test shall be calibrated in the laboratory using the standard orifice meter, venturi meter or nozzle or laminar flow meter.

3.6.2 The pressure measuring apparatus as installed in the test shall be calibrated in the laboratory with a micromanometer.

3.6.3 The above calibrations shall be conducted every three months at a minimum.

3.7 PROCEDURE

3.7.1 From indoor, fit the impermeable sheet over the window assembly. Seal the joint between window frame and sheet at the perimeter.

3.7.2 Place the impermeable box which extends beyond the window frame over the window assembly. Seal the joint between box and wall.

3.7.3 Adjust air flow through the test chamber to provide a pressurization of 0.30 inch of water (75 Pa). Check sealed joints of the box for extraneous air leakage and eliminate all leakage sources.

3.7.4 Adjust the air flow through fan No.1 to provide the specified test pressure difference across the exterior wall containing the test specimen.

Operate fan No.2 to balance the pressures of the air chamber and room. When the test conditions are stabilized, record the air flow through the flow meter and the test pressure difference (outside wind above 5 to 10 mph may not permit stabilized condition).

Measure and record the air temperature in the duct work. This can be accomplished thru measurement of the temperature of fan air exhaust (suction pressure mode) or fan air intake (positive pressure mode).

Identify and record leakage sources and qualitative leakage rates in the window assembly from outside with the test chamber under .3 inch of water suction pressure using a smoke pencil.

1.7.5 Repair any marking or damage to window unit or wall caused by testing.

3.8 CALCULATIONS

3.8.1 With all extraneous leakage sources eliminated, the metered air flow is equal to the air leakage, Q, at the test condition.

3.8.2 Express air leakage, Q, at standard condition:

$$Q_s = \left(\frac{B}{29.92}\right) \left(\frac{530}{T + 460}\right) Q$$

Q_s = air leakage rate at standard condition, cubic foot per minute
B = barometric pressure, in. of Hg
T = duct air temperature, ^oF

3.8.3 Calculate the air leakage in accordance with the following methods:

Rate of air leakage per unit length pf crack = Q_s/L

and

Rate of air leakage per unit area = Q_s/A

3.9 REPORT

3.9.1 The report shall include the following information.

3.9.1.1 General - date and time of test, building and window location and date of report.

3.9.1.2 Identification of the specimen (manufacturer and model code, operation type, dimensions, materials and other pertinent information).

3.9.1.2 Detailed drawings

3.9.1.2.1 Window Unit - general

From typical drawings provided - verfication and dimensions of the section profile, sash outline and arrangement.

From site observations, drawings of window installation procedures and details, window anchorage, framing location (as possible); panel arrangement, wall materials & construction.

Identification of sealants used and location.

Note any deviations observed from typical window unit.

3.9.1.2.2 Hardware and locking mechanism - Identification of the hardware and locking arrangement, and type and location of locking mechanism.

3.9.1.2.3 Glazing - Identification of the glass thickness and type and method of glazing.

3.9.1.2.4 Weatherstripping - Identification of type, location, condition, installation, spacing and anchorage of weatherstripping. Note any gaps or discontinuities.

3.9.1.3 Ambient Test Conditions - From testing contractor's data, note the duct temperature.

From Minnesota Energy Agency data, note the indoor and outdoor temperatures, the indoor and outdoor relative humidity, the outdoor windspeed and direction, the outdoor barometric pressure and time of the test.

3.9.1.4 Pressure Difference and Leakage - A statement or tabulation of the pressure difference exerted across the specimen during the test and the corresponding measured rate of air leakage Q, and the air leakage Q_s, Q_s/L and Q_s/A as calculated in Section 1.8.

3.9.1.5 Compliance Statement - A statement that the tests were conducted in accordance with this method, or a complete description of any derivations from this method.

3.9.1.6 Signature - The test report shall be signed by the testing official.

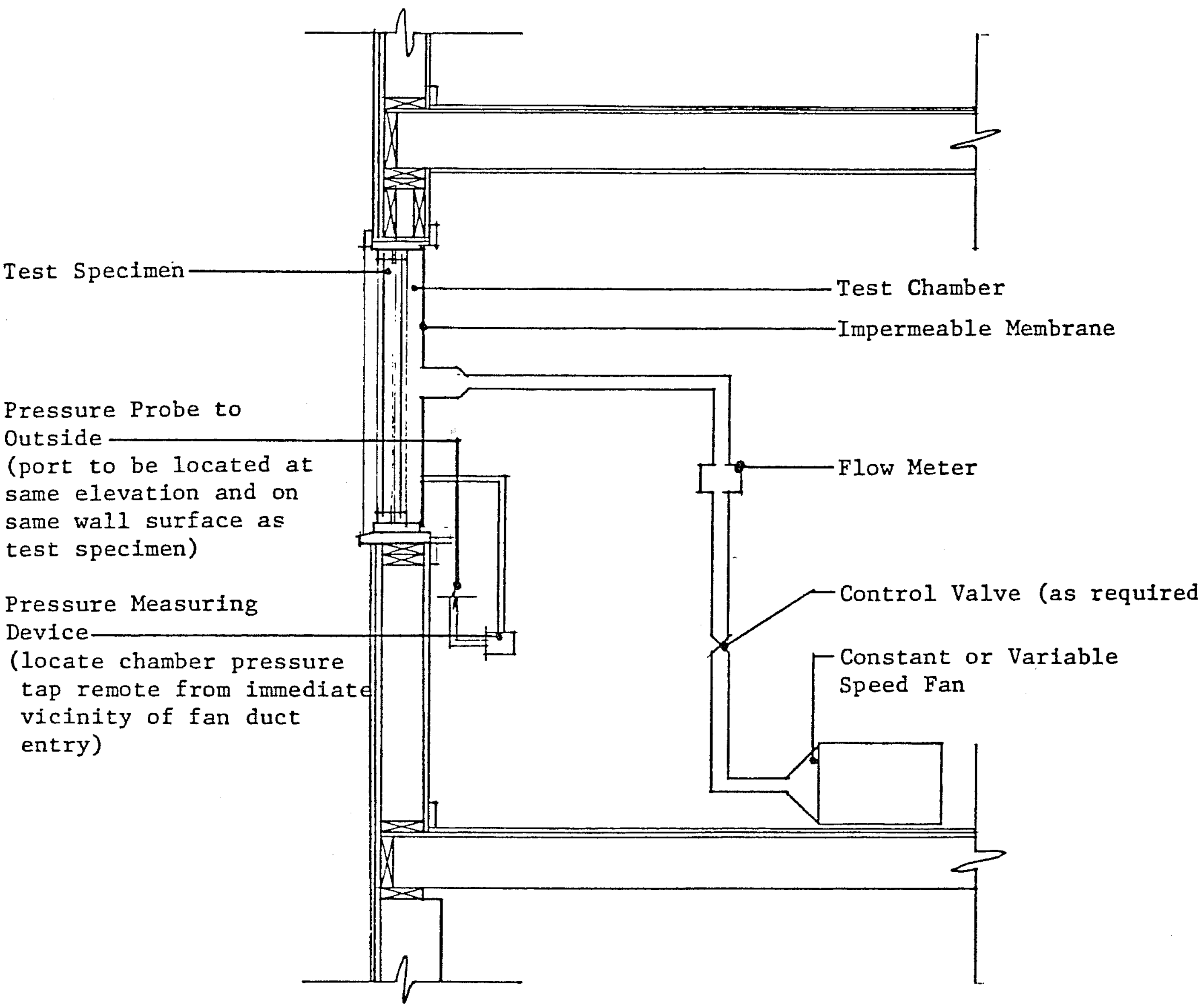


FIGURE 1 - General Arrangement of the Apparatus for Air Leakage Test

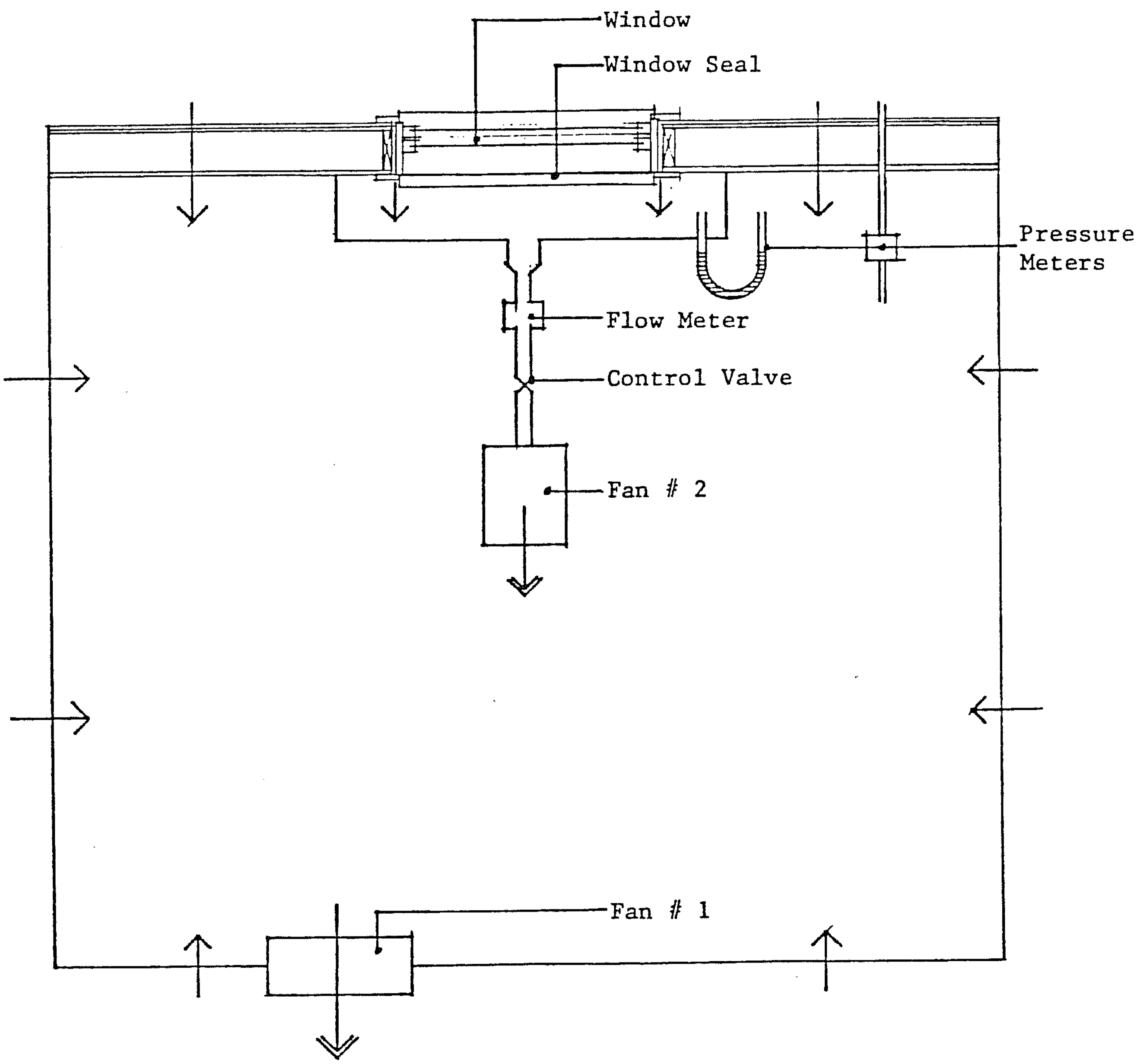


FIGURE 2 - General Arrangement for Window Frame-Wall Air Leakage Test

APPENDIX B

STANDARD OPERATING PROCEDURES

STANDARD OPERATING PROCEDURES

The purpose of this project is to report on the air infiltration characteristics of new wood and aluminum windows after their installation into residential construction. Operating procedures for the tester will follow those outlined in the Standard Test Method, procedures for John Weidt Associates personnel are as follows:

Test Observations/Sketches/Recordings

The responsibility for identification of the window, checking and preping the window and testing for air infiltration is that of the tester. John Weidt Associates personnel will have the following responsibilites during the testing process.

1) The area surrounding the test unit is to be examined and the following noted:
   a) Method of installation and anchorage of window unit
   b) Wall materials and condition of structure
   c) Any unit to wall sealants and their locations

2) Record pertinent information: addresses, window identification, weather data, construction/installation/testing observations

3) Take photographs and notes of all test information
   a) window defects - damaged/discontinuious weatherstripping, missing/broken hardware, etc
   b) areas of identified leakages
   c) installation details - general techniques, any irregularities in sash fit, etc

4) Sketch plan of structure, note test window orientation

5) Set up, process and record weather data
   a) Interior and exterior wet and dry bulb temperatures will be recorded
   b) Wind speed and direction will be recorded

6) Assist the tester at his direction

7) Leave test area in as good as, or better condition as before testing process.

DETAILED FIELD PROCEDURES

Upon arrival at jobsite, make initial contact with the job supervisor, if necessary,he will assist you in locating the test area and power source. After the tester has completed the routine window check outlined in Standard Test Method and approved the unit for testing:

1) Set up weather station directly outside the unit to be tested - advance tape and mark new area with test number and date.

2) Take interior and exterior wet/dry bulb temperatures - record

3) Refer to field manual - if in checking the window, the tester identifies design features or materials that differ from manual, note differences on field copy.

4) Sketch floor plan of structure and designate the location and orientation of unit to be tested.

5) Set data back with test number and take preliminary photographs of surrounding area.

6) Attempt to identify installation procedures - if they differ considerably from manufacturer's recommendations, sketch the actual details on worksheet.

7) identify and note sealants used around window unit.

8) Construction observations/notes to be taken
   a) Construction status of structure
   b) Sheathing material
   c) Structural details
   d) Interior wall finish

9) Assist tester, if necessary, in preparing area for testing - tester is responsible for all taping and construction of test chamber.

After window has been prepared for testing and pressurization has begun:

1) As stabilization is reached, flip switch which will activate strip chart recorder attached to aenometer, record wind speed and direction at time of test, de-activate recording device at termination.

2) Sketch window unit noting:
   a) Operation type
   b) Areas of leakages
   c) Window defects i.e. missing hardware, weatherstripping, etc.

3) From the exterior of the window unit, use smoke pencil to help identify areas of leakage
   a) check perimeter, corners and meeting rails;

   b) if leakages appear, concentrate on those areas and with the testers expertise, attempt to determine why leakages are occuring (whether weatherstripping, caulking etc.)

4) Document photographically all defects, areas of leakages and general test procedures on each test

5) Make certain that the test area is left in a clean condition.

FIELD WORKSHEETS

MEAINFIL 5.01	SITE BACKGROUND

DATE: TIME:

1. Manufacturer ______

2. Site: Name ______ builder, owner

Address Morraine Way

Eden Prairie

______

Contact (above)

______

3. Phone Contact (above)

4. Installer ______

5. Building Status: Complete X Completion Date ______

CONSTRUCTION	OPERATOR TYPES		
	Casement	Double Hung	Sliders
Frame	X		
Masonry			
Masonry Veneer			

NOTES:

6. Power: x yes ______ no
7. Interior finish ______ rough X finished
7.a. If interior finished, what is on the window trim?
X varnish ______ wall paint ______ other

MEAINFIL

2.03 Installation Techniques

Window: Mfg: ________ Type: wood casement

Construction: 2 X 4 wood frame

Site: ________ Location:

Eden Prairie, Mn.

Contacts:

Installation Details:

2 X header

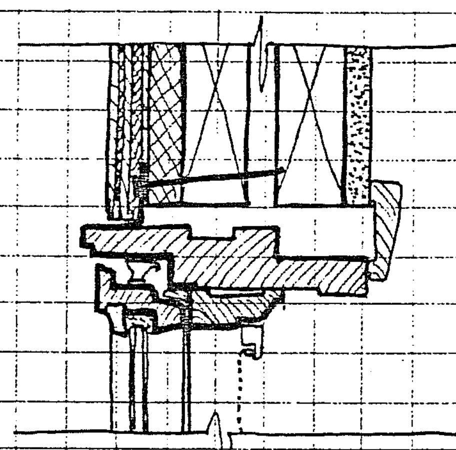
3/4" fiberboard sheathing

25/32" cedar siding

vinyl cladding nailed to framing

wood frame (vinyl clad)

(jamb detail similar)



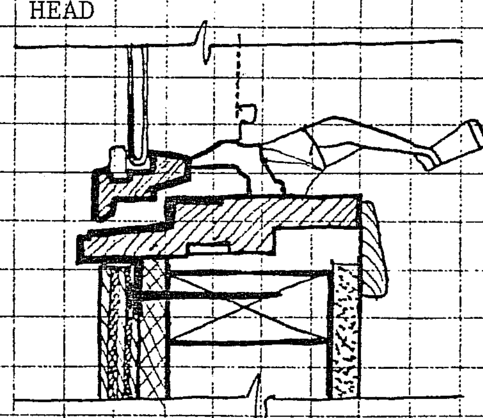
HEAD

insulating glass

wood frame

3/8" space

cladding nailed to framing



SILL

Note: no shims, frame not set on sill-- window suspended by cladding

MEAINFIL — SITE SURVEY

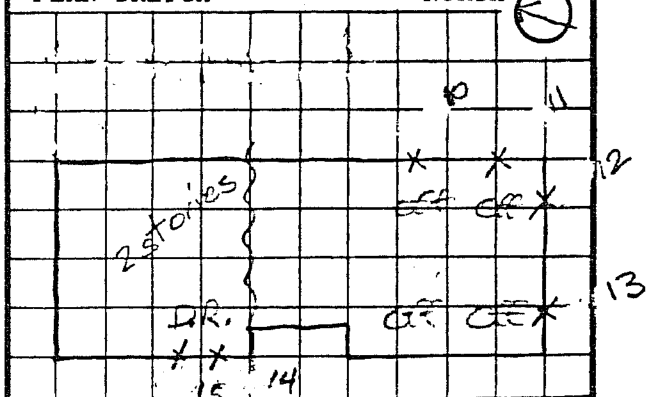
ADDRESS: Carnelian Drive Eagen, MN.	DATE: November 16, 1978
	WINDOW CODE:
	MODEL CODE: CDH

INSTALLATION & ANCHORAGE: nailed through nailing fin

WALL MATLS/CONST.: drywall - 2"x4" studs - sheathing - aluminum clad siding

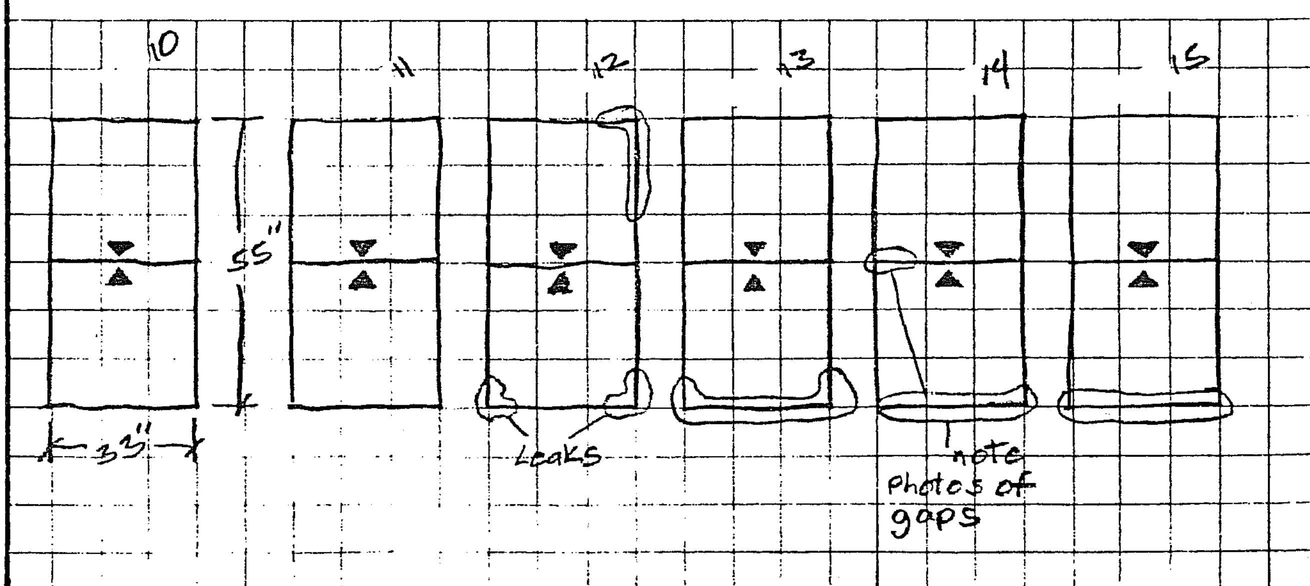
SEALANTS/LOCATION: caulked perimeter

PLAN SKETCH — NORTH



DATA BACK NUMBER	TIME	TEMPERATURE				WIND SPEED	WIND DIRECTION
		EXTERIOR		INTERIOR			
		WB	DB	WB	DB		
10	12:25	37	40	50	63	0-3	SW-S
11	12:47	38	42	50	63	0-2	NE-W-S
12	1:13	40	45	50	63	0-4	W-SE
13	1:55	39	42	50	63	0-3	E-N
14	3:55	37	38	49	65	0	NW-W
15	4:20	37	38	49	65	0-2	N-W

WINDOW SKETCHES (Note operation, areas of and reason for leakages, dimensions)



CHECK LIST FOR SITE VISIT (pre-test)

SUBJECT: SINGLE SLIDER

ADDRESS: Morgan Avenue, Brooklyn Park

TESTS TO
BE PERFORMED: 2 frame/wall

3 site fix-up

FRAME WALL TEST CHECK LIST

1. Heat YES ± 70°
2. Wall finish (paper, paint, etc) SKETCH location of any paper

   paper - vinyl

3. "Sealable" room - need 2 at Swanco SKETCH

   NOTES: bedroom sketched are small, look easy to seal

SITE FIX-UP CHECK LIST

1. Heat YES + 60°
2. Installed window, unfinished area Yes - insulation exposed
3. Verify operation type: c cc ss ds dh
4. Check size of units: equal 3 unequal 1 slightly smaller
5. # of units in unfinished area 4

NOTES:

LOOK FOR FIXED SASH UNITS TO TEST AT ALL LOCATIONS NONE

Number of units ______

APPENDIX C

DATA

DATA APPENDIX

All test results displayed in this report have been standardized.

The manufacturer reference numbers displayed in the figures are not consistently the same manufacturer from figure to figure.

Figure 2.1.1
Air Infiltration of Installed Windows

Description	Range	Standard Deviation	Mean
Industry/government standards: .50 cfm/lfc			
Manufacturer Specifications:	.04 to .50		
Field Results:	.008 to 2.279	.130 to .920	.524

Figure 2.2.1
Field Results: Comparison of Window Types

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

Figure 2.2.2
Air Infiltration 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

FIGURE 2.2.3
Air Infiltration Performance of Casement, Double Slider, Double Hung, Single Slider and Single Hung Windows and Material Types

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

Figure 2.3.1 Air Infiltration Performance by Manufacturer of Casement and Double Slider Windows

CASEMENT

Manufacturer	No. Tests	Range	Mean
All Casements	79	.01 - .58	.23
1	9	.15 - .46	.28
2	3	.14 - .14	.14
3	3	.17 - .29	.24
4	7	.16 - .29	.22
5	3	.13 - .18	.15
6	17	.01 - .49	.12
7	3	.26 - .34	.29
8	11	.17 - .47	.30
9	9	.28 - .58	.37
10	9	.16 - .35	.22
11	5	.10 - .20	.16

DOUBLE SLIDER

Manufacturer	No. Tests	Range	Mean
All Double Sliders	33	.17 - 1.90	.61
1	6	.64 - .88	.80
2	3	.17 - .24	.20
3	3	.35 - .51	.42
4	6	.21 - .76	.49
5	3	.55 - .72	.63
6	3	.28 - .44	.34
7	3	.46 - .53	.48
8	6	.51 - 1.90	1.04

Figure 2.3.2 Air Infiltration Performance by Manufacturer of Double Hung, Single Slider and Single Hung Windows

DOUBLE HUNG

Manufacturer	No. Tests	Range	Mean
All Double Hung	38	.22 - 2.06	.72
1	3	.31 - .39	.34
2	7	.69 - 1.32	1.10
3	3	.36 - .48	.42
4	3	.47 - 2.06	1.02
5	5	.22 - .35	.27
6	3	.30 - .39	.35
7	6	.52 - 1.19	.82
8	6	.56 - 1.30	.91
9	2	.81 - .82	.82

SINGLE SLIDER

Manufacturer	No. Tests	Range	Mean
All Single Sliders	31	.30 - 2.28	.78
1	4	.30 - .50	.38
2	6	.85 - 1.15	.97
3	12	.62 - 2.28	.99
4	3	.60 - .89	.71
5	6	.30 - 1.09	.48

SINGLE HUNG

Manufacturer	No. Tests	Range	Mean
All Single Hung	11	.68 - 1.37	.96
1	6	.68 - .76	.72
2	5	1.04 - 1.37	1.25

Figure 2.3.3 Factory/Field Test Results

Manufacturer/Witype	Factory Mean	Factory Range	Field Mean	Field Range
A - Casement	.26	.15 - .45	.29	.261 - .344
- Double Slider	.46	.37 - .62	.49	.210 - .760
B - Clad Casement	.03	.01 - .04	.14	.008 - .486
- Double Hung	.22	.19 - .26	.27	.221 - .354
C - Clad Casement	.14	.12 - .16	.31	.153 - .459
- Clad Double Hung	.30	.24 - .37	.34	.307 - .388

Figure 3.0.2 Expression of Air Infiltration Rate

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	1.015	.55	.88
cfm/vsf	.34	1.57	2.097	1.14	1.77

Figure 4.0.1 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 6.0.1 Cold Weather Retests

Manufacturer	Window Type	Original/ Retest	Range	Mean
1	Clad Casement	Original	.16 - .27	.20
		Retest	.24 - .27	.25
2	Clad Casement	Original	.01 - .49	.14
		Retest	.14 - .17	.16
3	Single Slider	Original	.62 -2.28	.99
		Retest	.54 -1.41	.91

Figure 7.0.1 Performance Over Time

Manufacturer	Window Type	New/ Over Time	Mfgr. Spec.	Range Of Performance	Mean
1	Casement	New		.04 - .08	.05
		Over Time	.50	.23 - .32	.27
2	Clad Casement	New		.15 - .46	.31
		Over Time	.25	.39 - .46	.43
3	Double Hung	New		.31 - .39	.40
		Over Time	.25	.41 - .44	.43
4	Awning	New		.10 - .15	.12
		Over Time	.04	1.17 -3.42	2.56

Current manufacturer's specifications have not been listed to maintain confidentiality.

Figure 8.0.1 Old and Retrofit Windows

Description	Range	Mean
OLD WINDOWS		
Commercial Double Hung	1.76 - 4.84	2.91
Residential Double Hung w/storms	1.02 - 1.37	1.20
Residential Double Hung w/o storms	1.24 - 1.49	1.38
RETROFIT WINDOWS		
Commercial Sliders	.34 - .36	.35
Commercial Hung w/storms	.45 - 1.12	.92
Commercial Hung w/o storms	.79 - 1.24	1.16

APPENDIX D

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BIBLIOGRAPHY

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APPENDIX E

THERMOGRAPHY

THERMOGRAPHY

The thermographic portion of the project was divided into two parts. The initial portion of the project, done in the Spring of 1978, was done by ECC (Energy Conservation Consultants) using an AGA 750 camera and involved scanning two residences for air infiltration characteristics. No attempt was made to pressurize the residences with other than furnace fans, exhaust fans and the ambient wind conditions. These limited scans gave little qualitative data relating to air infiltration characteristics, except on one residence where a small leak in the siding material itself was identified. Scanning was discontinued due to inappropriate weather conditions.

The primary portion of the thermographic study was done in January 1979. The inframetrics 510 camera used was supplied by Packer Engineering of Chicago, Illinois and the personnel using the camera were trained by Dr. Charles Roberts of Packer Engineering.

The purpose of this portion of the window testing program was to determine the value of infrared thermography in assessing the air infiltration characteristics of the following conditions:

1) The crack between the window sash and the frame
2) The crack between the window frame and wall.
3) Air leakage around fixed windows.
4) The characteristics of old windows relative to air infiltration.

The value of the camera was studied in relationship to its ability to detect the location of air infiltration of various portions of the window, to determine the relative volume of that infiltration and to determine the air infiltration characteristics of the window/wall system.

Thermographic scans were made of 67 different site situations:

59 individual windows
12 windows retested during cold weather
10 windows during site fix-up
4 fixed windows
10 windows over time
13 retrofit windows
10 older windows

Specialized thermographic scans were made:

3 frame/wall under pressurization
2 separate scans of frame/wall conditions under ambient conditions
1 total building exfiltration scan
1 single room infiltration scan
1 neighborhood scan

The sash/frame test methods employed during the thermographic phase of the project were very similar to those used during the major project work - new residential windows. All window tests were performed using the portable testing equipment (pressurization to .3 inches of water pressure differential). All site observations such as temperature, relative humidity, wind speed and direction were recorded. The infrared camera was used to scan the condition of the window, (both prior to and during the pressurization process) observing the differences between the ambient and pressurized window. Three frame/wall tests were also thermographically scanned to observe the affects of pressurization and the various modifications to the standard test method.

The room infiltration, building exfiltration and the neighborhood scans were performed in manners other than described above. The following thermographic pocesses were standardized, but the test pressurization was unique to each case.

1) The room infiltration scan was made; a) prior to room pressurization to obtain an ambient condition and b) after room pressurization to observe any altered characteristics (patterns of cooler temperatures along the walls, floors and ceiling of the room).

   The room was pressurized to the capacity of the 1000 cfm fan (pressurization did not equal .3 inches of water pressure differential), the volume of air flow at that time was not measured. The thermographic scans were made to determine a qualitative difference between infiltration due to the window unit and infiltration or thermal transmission due to the other components of the building

2) The building exfiltration scan was made; a) from the exterior prior to pressurization to obtain an ambient condition b) from the exterior after pressurization to observe altered characteristics.

   The building was not pre-prepared; all openings were left as would ordinarily exist and pressurization applied to the capacity of the 1000 cfm fan. Given this condition, less than .02 inches of water pressure differential between ambient and pressurized conditions were able to be obtained.

3) The neighborhood scan was done in an area of moderate development which has taken place over the last 10 years. The thermographic camera was mounted in the back of a vehicle and driven slowly from house to house, scanning for air leakage or other thermal transmission characteristics.

The building exfiltration and neighborhood scans were made in the early morning before dawn, prior to the possibility of solar gain affecting the results.

The thermographic scans were recorded on video tape for review, analysis and condensation. In all, approximately 16 hours of video tape recordings were made of the 67 scan conditions. From the video tapes, a series of photographs representative of the characteristics between ambient and pressurized scans of each test was made.

CONCLUSIONS

Under a variety of circumstances, the use of infrared thermography was very valuable in locating air infiltration:

1) Neighborhood Scans - These were the most generalized techniques used to locate air leakage and were performed under an early morning condition when the only driving force for air exfiltration was ambient condtions. The locations of air leakages were readily identified when those air leakages were of a gross nature.

2) Whole Building Pressurization - The ability to locate areas of moderate air exfiltration during whole building pressurization were surprisingly successful Areas of major air exfiltration were readily identifiable when the building was under pressurization of no more than .02 inches of water pressure differential. It is assumed that an increased pressurization on the building would result in the ability to read smaller and finer areas of air exfiltration.

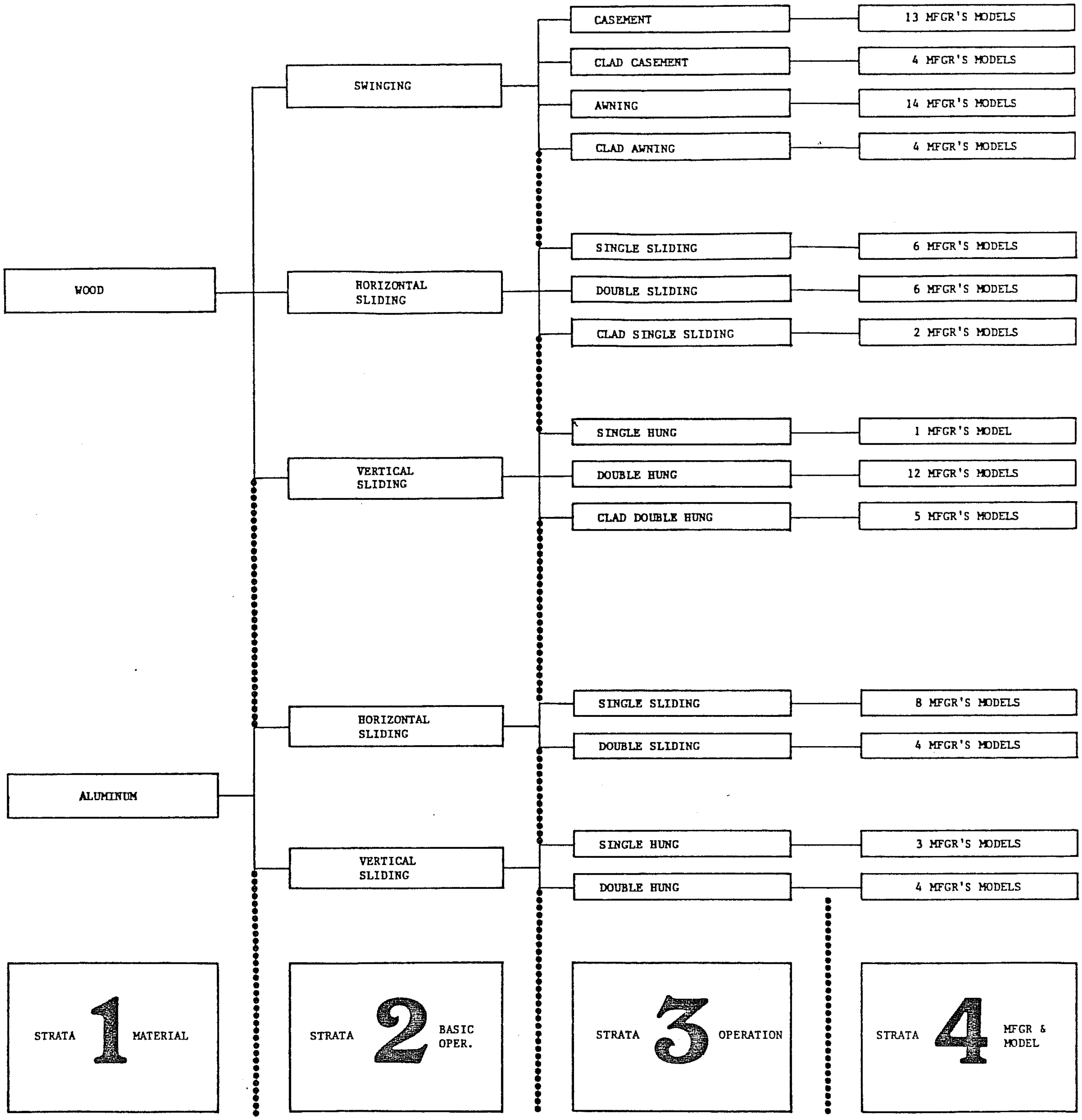
3) Frame/wall - The purpose of this test is to identify the amount of outside air that can infiltrate through the crack between the window unit and the wall. Once under pressurization, there is a potential for warm air to be short-circuited from other areas of the building which makes identification of exterior infiltration difficult (short-circuited air is air pulled through the wall cavities from other portions of the building such as the floor below or above). Thermography was particularly valuable when used in conjunction with the frame/wall pressurization tests. The camera indicated that cool exterior air was being drawn through this crack rather than being short circuited from adjacent rooms. However, it was not possible - with the limited number of tests performed - to discover a method with which to determine how much of the air flow being measured was attributable to actual iniltration and how much to short-circuited air.

   The camera was also useful in highlighting air infiltration locations of specifc window units. Becaue the photographs were able to be taken over a period of time, it was very obvious those areas of window air infiltration that contributed most significantly to the overall air infiltration of the unit. These locations were confirmed with smoke as well as being scanned with the camera. Alone, the smoke can only give a relative idea of the location and amount of air flow and can usually only give indications for one side of the window unit; used in conjunction with the thermography which can be applied from the opposite side of the window, it was possible to get a more accurate picture of the location and relative volume of air flow in the window units. The air infiltration characteristics of casement, slider and double hung windows were observed through use of the camera to correlate fairly well with earlier observations made with the use of smoke.

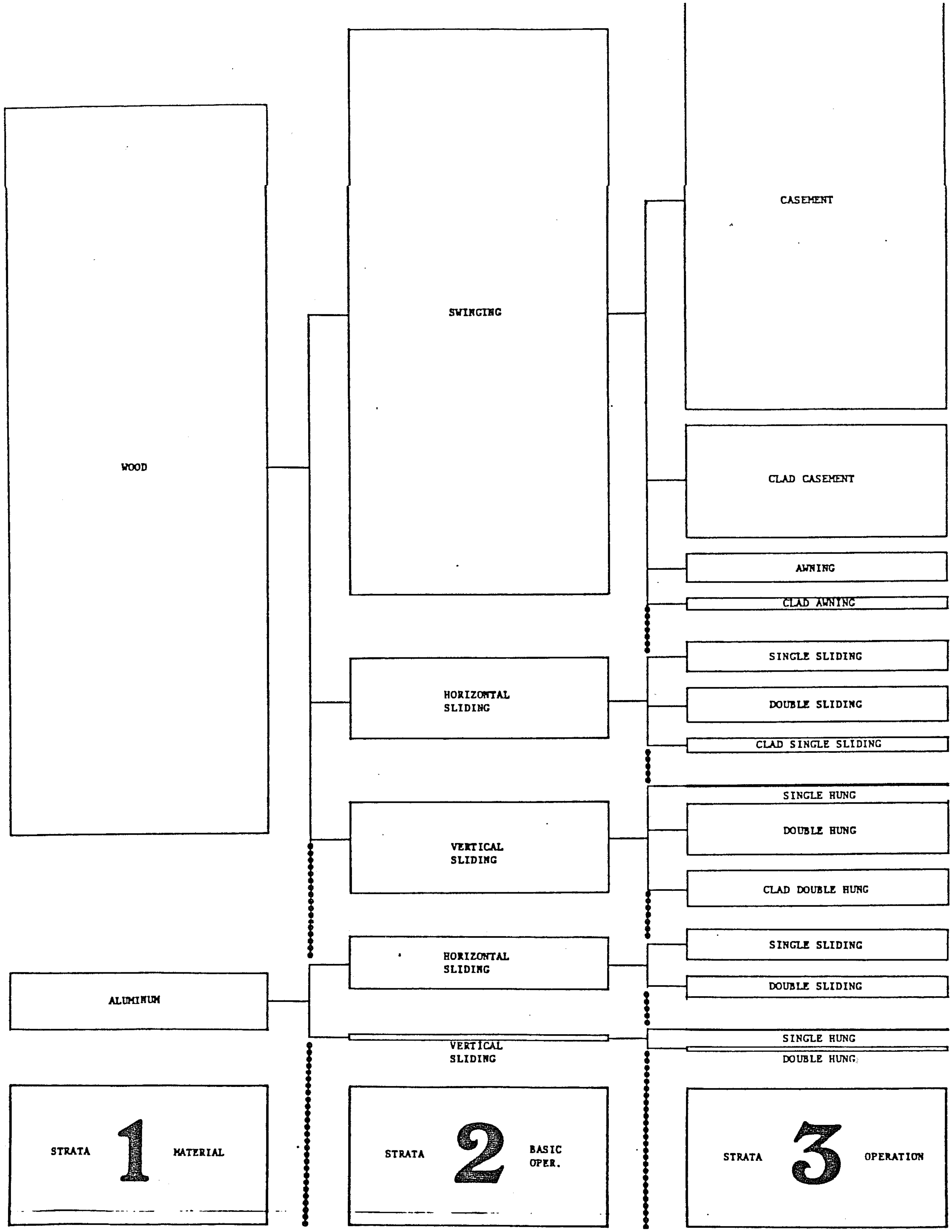
   The use of thermography to relate to the quantity of air flow is much more difficult to determine from the data available. The relative leakages of windows examined under similar conditions was qualitatively apparent to the testers, however, the volume of data collected with the camera would have to be analyzed carefully to determine whether a quantifyable relationship exists between the volume and temperature of the air flow scanned relates to the volume of air flow measured with the testing device. If this is possible, importance of certain design features of individual windows in conjunction with suggested design alterations of said windows to improve their performance by a significant amount.

APPENDIX F

SAMPLE DISTRIBUTION



DISTRIBUTION OF WINDOW OPERATION TYPES.



DISTRIBUTION OF WINDOW OPERATION TYPES BY