THERMAL PERFORMANCE OF WOOD WINDOWS AND DOORS

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According to a recent study conducted by "Architectural Record," energy conservation is one of the highest ranking considerations, nationwide, when designers select building materials for new construction. Due to the energy crisis of 1974 and subsequent energy conservation codes and legislation, complete and detailed thermal performance data is being required for windows and doors, for use in analyzing their contribution to the energy load of the exterior building envelope. Much of this data is currently based on engineering calculation or glass performance tables.

NWMA has conducted controlled laboratory testing of modern window and door designs to verify their calculated or published design thermal performance. Tests were also conducted to explore how various testing techniques affected the measured performance of windows and doors. The generic window and door constructions used for this project were selected from the current manufacturers production or were purchased from local retail outlets. Each window was tested with one or more combinations of single glazing, insulated glazing, removable double glazing or storm windows. The various door constructions were tested as separate slabs, without being machined for hardware or installation. Additional tests were conducted with doors installed in wood or metal door frame assemblies. All units were tested in accordance with nationally recognized test methods for thermal transmittance and air infiltration. Several experimental tests were also conducted to more closely study the specific effects of unit design or test method variation.

The report itself is divided into separate sections on windows and doors. The results of this study form an overall view of the thermal transmittance performance capabilities of wood window and door designs. Comparisons are drawn among the various units and tests conducted in this study. The results of this study are also compared to the design performance data contained in the ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume. Detailed sample descriptions, test methods, calculation procedures and metric conversions are contained in the Appendix.

THERMAL PERFORMANCE OF WINDOWS

The thermal performance testing of windows was divided into four phases. Each phase was structured to study a particular modification, variation or effect of the testing method. A brief description of the windows tested during this study is contained in Table 1. All window units were approximately 3' wide by 4' high and were tested with only the glazing combinations supplied by the manufacturer. Whenever practical, however, factory installed storm panels or storm windows were removed to obtain data for the prime window with single glazing only. More complete descriptions of the test units and their glazing combinations are contained in Appendix A.

For ease of comparison within this study, and for comparison with published thermal design information, the results of each individual test have been corrected to ASHRAE Standard Winter Design conditions of still air on the interior (h_i = 1.46 BTU/hr.-sq.ft.-°F) and 15 MPH on the exterior (h_o = 6.0 BTU/hr.-sq.ft.-°F), unless otherwise noted.

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PHASE I - Thermal Transmittance of Windows Under Static Air Conditions

The Phase I tests were conducted to establish the base-line thermal performance of the sample windows under static wind conditions. The tests consisted of measuring the thermal performance of eleven generic wood and aluminum window designs with various combinations of single glazing, insulated glazing, removable double glazing (RDG) and wood or aluminum storm window. Tests for this phase were conducted in accordance with ASTM C-236-66(71), "Standard Test Method for Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot Box," with a cold chamber temperature of 18°F, a warm chamber temperature of 68°F, and an exterior and interior wind condition of essentially still air (40 to 60 ft. per min. velocity). The results of each test were then adjusted to the ASHRAE Standard Winter Design conditions described previously. In all, twenty-eight thermal tests were conducted during this phase.

The results from Phase I (Table 2) indicate that the performance of each window unit was basically dependent upon the glazing combination present in the unit during the test. The U-values for single glazed windows ranged from 0.72 to 1.06 BTU/hr.-sq.ft.-°F insulated glazed units ranged from 0.47 to 0.66 BTU/hr.-sq.ft.-°F.

In general, the addition of a storm window, either wood or aluminum framed over a single glazed prime window, increased the thermal efficiency of the prime window by 44% to 59%, depending on the design of the prime unit and the thickness of the enclosed air space. A 40% to 47% reduction in heat loss was also obtained by placing the storm window over an insulated glazed prime unit. It should be noted that all aluminum prime/storm window combinations did contain a thermal break in the window frame. This thermal break was by-passed in in some cases when the storm window was not in place.

For casement windows, conventional storm windows cannot be installed without impairing the operation of the unit. Thus, removable double glazed panels (RDG) were installed directly to the window sash. There the improvement in U-value was about 45% for single glazed prime windows, and 29% for insulated glazed prime windows. The RDG panel was also effective when installed on a single glazed wood double hung window, though not as effective as the storm window.

Table 3 shows a comparison between the results of the Phase I tests and the thermal design values listed in the ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume. Overall, the results from Phase I compared well with the ASHRAE values, with wood window test values averaging 12% better than the data listed for 80% glazed wood windows. Aluminum single glazed windows averaged 10% better than the ASHRAE metal window values, and double glazed and insulated glazed aluminum windows ranged from 6% better to 14% worse than the ASHRAE values for metal windows with thermal barriers.

PHASE II - Thermal Transmittance of Windows Under Dynamic Wind Conditions

The second phase of the project consisted of retesting three of the wood windows originally tested under Phase I (Units #9-77, #10-77, and #11-77), under a modified test procedure. The retests on these units were conducted under the same procedures used during Phase I, except that a 15 MPH wind horizontal and parallel to the plane of glazing was applied to the exterior of the unit. The Phase II tests were conducted to verify the calculation techniques and the air film co-efficients used for correcting the measured performance values to the Standard Winter Design conditions. Six thermal tests were performed under Phase II. Both the Phase I and Phase II tests were conducted on the same units without removing them from the chamber between tests.

Table 4 shows that the results from the Phase II testing were 17% to 45% worse than the results from Phase I. Since both sets of values were adjusted to the same Standard Winter Design conditions, and since panel conductance, (C), is theoretically independent of temperature and wind, both sets of values should have been approximately equal, allowing for testing error.

A closer look at the raw lab data revealed that while there was a significant increase in heat flow during tests conducted with the wind applied, there was not a corresponding change in the surface temperature readings to compensate for the increased heat flow. Consequently, the panel conductance values obtained during Phase II were significantly higher than those obtained from Phase I. Further, the exterior film conductance values, (h), calculated from the thermocouple readings and heat flow measurements, were much higher than could be justified by the measured wind velocities. (Exterior film conductances ranged from 5.7 to 9.7 BTU/hr.-sq.ft.-°F, while the wind varied only slightly from the prescribed 15 MPH). Interior film conductances also increased by about 40% during the Phase II tests, with no change in interior air velocity. These facts suggested that heat flow was occurring during the test by some mechanism other than transmission through the window glazing and frame.

PHASE III - Effect of Air Infiltration on the Measurement of Conductive Heat Loss

Additional tests were conducted to determine if air infiltration was an influencing factor during the previous thermal transmittance tests. Phase III consisted of removing some or all of the weatherstrip from Units #9-77, #10-77, and #11-77, and retesting each modified unit for thermal performance under both wind conditions described previously. The weatherstrip was removed as an easy and reproducable way of varying the air infiltration rate of the unit without changing its design or installation. Air infiltration tests were performed on each unit both before and after the weatherstrip was removed. Air infiltration tests were conducted in accordance with ANSI/ASTM E-283-73, "Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors," at static air pressure differentials of both 0.30 and 0.11 inches of water (equivalent to wind velocities of 25 and 15 MPH respectively). After the air infiltration tests were completed, the modified window units were again tested for thermal performance in accordance with the test methods used in Phase I and Phase II. A comparison of the results for each of the three window units, with and without weatherstrip, is listed in Table 5.

With only one exception, the thermal transmittance measured for units without weatherstrip was essentially the same as that measured for the unit with weatherstrip, even though there was a two to four-fold increase in the air infiltration rates of the units when the weatherstrip was removed. Pressure measurements taken during these and all previous thermal transmittance tests showed that the differential across the unit never exceeded 0.02 inches of water. Thus, air infiltration was probably not occurring during the tests, and even if it was, at such low pressure differentials the effect on the total heat flow would have been too small to account for the large discrepancy between the Phase I and Phase II tests.

PHASE IV - Effect of Test Temperature on the Measurement of Conductive Heat Loss

The fourth and final phase of the project consisted of testing one wood window unit (Unit #9-77) at warm and cold chamber temperatures other than 68°F and 18°F. These tests were conducted to determine if extreme differences in chamber temperatures affected measured thermal transmittance. The temperature combinations selected represent extremes in mean air temperature and total air temperature difference. Tests were conducted in accordance with procedures established under Phase I.

Table 6 contains the results of this testing and includes the results of Unit #9-77 when tested at 68°F and 18°F.

These tests show that the choice of chamber temperatures used during the test had little effect on the measured thermal performance of the unit. However, when the difference between the warm and cold chamber temperatures is small, steady-state heat flow is difficult to maintain, and accurate readings of heat flow and surface temperatures are difficult to obtain. The magnitude of these values is also small, and slight variations in surface temperature, air temperature, and heat flow readings can introduce significant error in the final results.

Conclusions on Window Testing

The following conclusions were drawn from the data obtained from the four phases of this window study and from the analysis of that data, as described in preceding sections.

1. The most important determining factor in the thermal transmittance of the modern window is the combination of glazing materials in that unit, as evidenced by the tests conducted during Phase I and Phase II of this project.

2. The application of storm windows is an effective means of reducing conductive heat loss for both single glazed and insulated glazed prime windows. Phase I and Phase II testing indicated that the installation of a storm window over single glazing was more effective in reducing conductive heat loss than was the use of insulating glass. This may be due to the increased air space thickness created by the addition of the storm window or to the additon of air space over portions of the sash and frame.

3. In window designs where the application of conventional storm windows is impractical, such as casements or awnings, the use of a removable double glazing panel effectively reduced the conductive heat loss, though not as effectively as the use of a storm window.

4. The thermal transmittance (U-value) of wood windows, obtained from the Phase I testing, averaged 12% better than the design data contained in the ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume, Chapter 22, Table 8. The measured U-values for single glazed aluminum windows were about 10% better than the metal window values from ASHRAE, but in some instances were worse than the ASHRAE values adjusted for thermal barrier design.

5. The results from the Phase II tests, which included the application of an exterior 15 MPH wind were on the average 28% worse than the results for identical units tested without an exterior wind, even though both sets of data had been corrected to the ASHRAE Standard Winter Design conditions and should have been equal.

6. The Phase III tests indicate that the air infiltration rate of a unit is not an influencing factor in the measurement of thermal transmittance by either the Phase 1 or Phase II test methods, provided little or no air pressure differential exists across the unit during the thermal transmittance test.

7. Testing window units at chamber temperatures other than 68°F and 18°F has little influence on the results of the tests, as evidenced by the results from Phase IV.

THERMAL PERFORMANCE OF DOORS

A three stage testing program was developed for evaluating the thermal transmittance of wood doors and door assemblies. The overall testing program was designed to enable substitution of any of five generic door constructions into either a wood or steel door frame. Data was developed for the thermal transmittance of the doors as slabs, and for the doors as installed in the frame assemblies.

A brief description of the various doors and door/frame assemblies tested during this study is contained in Table 7. All doors were 3'0" x 6' 8" x 1-3/4" thick and were built to minimum NWMA I.S.-1 and ANSI/NWMA I.S.-5 requirements. Detailed descriptions of the test doors, door frames and hardware are contained in Appendix A.

For ease of comparison within this study and for comparison to published thermal design information, the results of each individual test have been corrected to ASHRAE Standard Winter Design conditions of still air on the interior (h_i = 1.46 BTU/hr.-sq.ft.-°F) and 15 MPH wind on the exterior (h_o = 6.0 BTU/hr.-sq.ft.-°F), unless otherwise noted.

STAGE I - Thermal Transmittance of Door Slabs Under Static Air Conditions

Stage I consisted of testing each of five generic wood door constructions as separate slabs, without being machined for hardware or installation. The tests were conducted in accordance with SDI 113 "Standard Thermal Performance Test for Steel Door and Frame Assemblies," with cold chamber temperatures of 10°F, warm chamber temperatures of 80°F, and an exterior wind condition of essentially still air (40-60 feet per minute velocity). It should be noted that the SDI 113 test method measures only the center five feet of door height, due to limitations in thermal testing equipment design, and also includes portions of the test chamber wall on either side of the door. The results from the first stage of testing and a comparison to the calculated design performance data from the ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume, are listed in Table 8.

The data from the Stage I tests indicate that the thermal performance of solid wood block core, hollow core, and pine panel doors agrees closely with the values calculated from the data found in the ASHRAE 1977 Fundamentals Volume. However, test data for the particleboard core door was 19% worse than the calculated value. Closer examination of the calculation for the particleboard core door revealed that the thermal conductivity, (k), for particleboard material listed in the ASHRAE 1977 Fundamentals Volume did not apply to the low density material (27 pounds per cubic foot) used in the tested door. Accurate thermal conductivity data for this low density core material could not be obtained.

While the test data and the calculated data for doors were in close agreement, the test data did not agree with the design thermal transmittance values listed for doors in Table 9, Chapter 22 of the 1977 ASHRAE Fundamentals Volume. This ASHRAE table lists the U-value of 1-3/4" thick solid wood slab doors as 0.47 BTU/hr.-sq.ft.-°F, (interpolated), regardless of core construction. The Stage I test results indicate that the U-values of wood doors do vary with core construction, and that most core constructions are considerably better than the ASHRAE table would suggest.

STAGE II - Thermal Transmittance of Door Slabs Under Dynamic Wind Conditions

For this stage, two door designs (Doors "A" and "E") were retested under the same procedures used during Stage I, except that an exterior 15 MPH wind was applied vertically upward and parallel to the plane of the door during the test. These tests were conducted to verify the calculation techniques used for correcting measured performance values to the ASHRAE Standard Winter Design conditions. Table 9 contains the results from the Stage II portion of this study, along with a comparison to the Stage I results. The tests from both stages were conducted on the same doors without removing them from the chamber between tests.

The results of these tests indicate that the application of the exterior 15 MPH wind had little effect on the measured U-value performance. The slight discrepancy between the Stage I and Stage II results for the pine panel door (Door "E"), was primarily due to a poor seal between one edge of the door and the test chamber wall.

STAGE III - Thermal Transmittance of Installed Door/Frame Assemblies

The last stage of testing, Stage III, involved preparing and installing one door (Door "A") separately into a wood and metal door frame. The door was machined for and installed with standard cylinder lock.hardware and butt hinges. The door and door frame were then installed into a test wall as described in the SDI 113 test method. Each assembly was then tested for thermal transmittance both with and without the application of the 15 MPH exterior wind. The results of Stage III testing under each wind condition are contained in Table 10 along with a comparison to the results for the door slab alone. Again, comparison is made to the U-values calculated from the ASHRAE 1977 Fundamentals Volume.

The results in Table 10 indicate that the thermal transmittance values obtained during the tests without an exterior wind (Stage 1 method) were in close agreement with values calculated from the ASHRAE data. When the wind was applied, however, the U-value for the door installed in the metal frame was slightly higher than for the test without the wind. Conversely there was a drastic change in measured U-value for the two tests conducted on the door and wood frame combination. Again, the adjusted U-values for a specific door and frame combination should have been the same under either wind condition.

A close examination of the detailed test data and the calculations for these door combinations and tests did not identify any specific cause for the discrepancy between tests. However, the installation of the door/frame assembly into the test wall may have influenced the results. The door/frame assembly is installed into a 2 x 4 frame wall construction for testing. A portion of that wall is included in the 4' x 5' metering area of the test appartus. Heat flow through this wall is included as part of the total measured heat flow, and is thus included in the final test results for the door/frame combination. While thermocouples are placed on both the inside and the outside surfaces of the wall, their readings may not have accurately estimated the average temperature of the entire wall, and thus may have affected the calculation of the average temperature of the entire sample. Since heat flow through the wall cannot be isolated from the total heat flow, the effect of the wall cannot be separted from the final test results.

The metering chamber used for the door tests was only 5' high and was centered on the doors during the tests. Thus, the top and bottom 10" of the door and door frame were not included in the test measurements. The possibility exists that lateral heat flow was occurring within the door or the door frame members, in the cracks between the door and the frame, or between the frame and the wall. Lateral heat flow could also occur within the test wall. This heat flow, whether by conduction or convection, would raise the total measured heat flow, but would not affect the thermocouple readings of surface temperatures. Consequently, the test would indicate a higher transmittance than was actually occuring through the door/frame assembly.

Conclusions on Door Testing

The following conclusions are drawn from the data obtained during the three stages of the door study and from the analysis of the results as described in the preceding sections.

1. The values obtained from the transmittance tests conducted using the Stage I testing procedure agree closely with the performance values calculated in accordance with the ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume.

2. The results of the Stage I study indicate that the measured thermal transmittance of solid wood block core and particleboard core doors is significantly better than the general wood door performance data listed in the ASHRAE 1977 Fundamentals Volume, Chapter 22, Table 9.

3. The application of a 15 MPH exterior wind during the test had little effect on the adjusted transmittance values of wood door slabs, measured during the Stage II portion of this study.

4. The application of the 15 MPH wind may have affected the performance of door/frame assemblies installed in the 2 x 4 frame construction test wall.

5. The frame and wall surround apparently does have a bearing on the results of the thermal performance testing of wood doors. However, the limited number of tests in this area were not sufficient to conclusively determine the reason for this affect.

COMMENT ON WINDOW AND DOOR TESTING

This study has attempted to show the relationship between the thermal performance of modern wood windows and doors and the design performance data obtained from the ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume. The various windows and doors chosen for this study were selected to represent the basic designs, constructions and glazing combinations available for use in residentail construction. These windows and doors were tested for thermal performance, using several different testing methods, to obtain information on the effects of exterior wind condition, air infiltration and temperature and to correlate that information with performance data predicted by calculation.

Several important facts have been discovered by this study. Of greatest concern is the discrepancy between the U-values obtained by the tests conducted with still air and those conducted with a 15 MPH wind on the exterior. On the one hand, the tests conducted with essenially still air on the exterior provided data that was consistent with ASHRAE design values, and, in fact, indicated that the ASHRAE values may be somewhat conservative. On the other hand, when an exterior 15 MPH wind was applied during the test, the results were considerably worse than those predicted by the ASHRAE 1977 Fundamentals Volume. Research to examine the cause of this discrepancy provided useful data on the effect of air infiltration and variations in test chamber temperature, but could not fully explain the reasons for the discrepancy between the tests. Data obtained by this study has evidenced the need for uniform testing methods for all windows and doors. Uniform test methods would not only provide consistent data for the comparison of products, but would also minimize confusion with interpreting the results for application to the total building heating load. The test method should prescribe, or at least give guidance, toward determining the effects of each parameter of the method, specifically in regard to exterior wind velocities and film coefficients. The test method should also detail calculation and conversion practices for adjusting measured values to standard (or non-standard) design conditions. Further, the test should be structured to measure the performance on full size test samples, especially in the testing of doors.

The design performance tables for windows and doors contained in ASHRAE publications should also be reviewed, specifically as they apply to the thermal mechanics of combination glazing systems, framing materials and core constructions. The tables should be realligned to more closely simulate those sizes, constructions or combinations of products most commonly manufactured.

It is the recommendation of the National Woodwork Manufacturers Association, based on the results of this study, that the development of such uniform testing and evaluation methods be actively pursued, and that other studies be conducted to assess the effects of air films, exterior wind, and other test variables on the measured test results. Other aspects of total energy performance, such as air infiltration and solar heat gain, need to be studied so that the total energy loss or gain of the product as installed in the field can be measured and evaluated for a broad spectrum of products, locations, and environmental conditions.

APPENDIX A - DETAILED SAMPLE DESCRIPTIONS

Window Units

All wood window units used in this study were manufactured in conformance to ANSI/NWMA I.S.2-73. All aluminum window units were manufactured in conformance to ANSI/AAMA A 134.1. All window units were purchased from local retail outlets or were supplied at no cost by a manufacturer from his standard product line.

Unit #1-76 Wood double hung window, 37-5/16" wide by 49-5/16" high. Overall area: 12.78 sq. ft. The unit contained metal jamb liners, and was primed white on the exterior. Both sash were glazed with single glass. The unit was submitted with a wood framed storm window and an aluminum framed storm window. Both storm windows were glazed with single glass, and when mounted, created an enclosed air space of 2"-3". Both storm windows contained screens on the lower portions.

Unit #2-76 Wood double hung window, 37-5/16" wide by 49-2/16" high. Overall area: 12.78 sq. ft. The unit contained vinyl jamb liners, and was primed white on the exterior. Two sets of sash were submitted: one set glazed with single glass, and the other set glazed with 1/2" insulating glass consisting of two sheets of single glass fabricated into a sealed unit with an enclosed air space of 1/4". The unit was also submitted with removable double glazing panels, a wood framed storm window, and an aluminum framed storm window. The removable double glazing panels were glazed with single glass, and when mounted created an enclosed air space of approximately 3/8". Both storm windows were glazed with single glass, and when mounted created an enclosed air space of 2"-3". Both storm windows contained screens on the lower portions.

Unit #3-76 Wood casement window, 49-12/" wide by 41-5/8" high (two single sash units, side by side). Overall area: 14.24 sq. ft. The unit was primed white on the exterior. Two sets of sash were submitted: one set glazed with single glass, and the other set glazed with 1/2" insulating glass consisting of two sheets of single glass fabricated into a sealed unit with an enclosed air space of 1/4". The unit was also submitted with removable double glazing panels, glazed with single glass. When mounted, the double glazing panels created an enclosed air space of approximately 1/2". The unit was also submitted with an interior mounted screen panel.

Unit #4-76 Aluminum single hung window, 35-9/16" wide by 47-9/16" high. Overall area: 11.75 sq. ft. The prime window contained no specific thermal barrier. The top lite was glazed into the frame with single glass. The bottom sash was glazed with single glass. The unit was submitted with an aluminum framed storm window, glazed with single glass in both sash. The storm window contained no specific thermal barrier. The storm window was attached to the prime window by a rigid plastic extrusion, separating the two metal frames by approximately 3/8". When mounted, the storm window created an enclosed air space of 1-1/8" to 1-13/16". The storm window contained a screen on the lower portion.

Unit #5-76 Wood framed, aluminum sash, horizontal sliding window, 35-7/16" wide by 47-1/2" high, both sash operable. Overall area: 11.69 sq. ft. The unit was submitted unfinished. Both sash were glazed with single glass. The unit was submitted with an aluminum framed storm window. The storm window was glazed with single glass, and when mounted to the wood frame, created an enclosed air space of 1-1/2" to 2-1/2" The prime window sash and storm window contained no specific thermal barrier. The storm window contained a screen panel on the interior left hand side.

Unit #6-76 Aluminum single hung window, 31-1/8" wide by 35-1/2" high. Overall area: 7.67 sq. ft. The unit was finished white on the interior and exterior. The top lite was glazed into the frame with single glass. The bottom sash was glazed with single glass. The bottom sash was separated from the frame and interlock by weatherstrip or rigid plastic extrusion. The frame contained a solid plastic thermal barrier, separating the two metal frame extrusions by approximately 1/4". The unit was submitted with aluminum storm sash that mounted directly to the frame at the interior, creating an enclosed air space of 1-78" to 2-9/16". The storm sash were glazed with single glass. The prime window sash and storm window sash contained no specific thermal barrier. A screen sash for the lower portion was also submitted.

Unit #7-76 Aluminum horizontal sliding window, 35-11/16" wide by 47-3/8" high, both sash operable. Overall area: 11.74 sq. ft. The unit was finished white on the interior and exterior. The frame contained a hollow plastic extrusion, separating the two metal frame extrusions by approximately 1/4". This plastic extrusion also served as parting stop and sill track. The left hand sash was clad on the interior with a rigid plastic extrusion, and the right hand sash was clad on the exterior with the same plastic extrusion, combining to form a plastic to plastic joint at the frame thermal barrier and the sash interlock. The plastic cladding also created an enclosed air space of approximately 3/8" within the sash frame. Both sash were glazed with welded insulating glass, with an enclosed air space of 1/4".

Unit #8-76 Aluminum casement window, 42" wide by 48-1/4" high (two single sash units, side by side). Overall area: 14.07 sq. ft. The unit was finished white on the interior and exterior. Both the frame and the sash were clad on the interior with rigid plastic extrusions, creating enclosed air spaces of between 1/4" and 1/2". There was no exposed metal visible on the interior of the unit. Both sash were glazed with welded insulating glass, with an enclosed air space of 1/4".

Unit #9-77 Wood double hung window, 37-3/8" wide by 49-1/4" high. Overall area: 12.78 sq. ft. The unit contained vinyl jamb liners, and was primed white on the exterior. Both sash were glazed with 1/2" insulating glass, consisting of two sheets of single glass fabricated into a sealed unit with an enclosed air space of 1/4". The unit was submitted with a wood framed storm panel, glazed with single glass. When mounted, the storm panel created an enclosed air space of 2" to 3". The storm panel also contained a screen on the lower portion.

Unit #10-77 Wood double hung window, 34-1/4" wide by 48" high. Overall area: 11.42 sq. ft. The unit contained metal jamb liners, and was painted dark brown. Both sash were glazed with 1/2" insulating glass, consisting of two sheets of single glass fabricated into a sealed unit with an enclosed air space of 1/4". The unit was submitted with a wood framed storm panel, painted dark brown, and glazed with single glass. When mounted, the storm panel created an enclosed air space of 1-1/2" to 2-3/4". The storm panel also contained a screen on the lower portion.

Unit #11-77 Wood casement window, 42-13/16" wide by 41-7/8" high (two single sash units, side by side). Overall area: 12.45 sq. ft. The unit was primed white on the exterior. Both sash were glazed with 1/2" insulating glass, consisting of two sheets of single glass fabricated into a sealed unit with an enclosed air space of 1/4". The unit was submitted with removable double glazing panels, glazed with single glass. When mounted, the double glazing panels created an enclosed air space of 5/16".

Doors

All wood flush doors were manufactured in conformance to NWMA I.S.1-78. The ponderosa pine door was manufactured in conformance to ANSI/NWMA I.S.5-73. All doors were supplied at no cost by manufacturers from their standard product line.

Door "A": Solid wood block core flush door, 3068 by 1-3/4", Type I. The door was framed block glued core construction with 3 ply lauan plywood face panels. The door was prefit in width 3/16" with a 3° bevel on the lockstile only. The door was not machined for hardware and was submitted unfinished.

Door "B": Solid wood block core flush door, 3068 by 1-3/4", Type I. The door was framed block glued core construction with 1/8" thick tempered hardwood face panels. The door was prefit in width 3/16" with a 3° bevel on the lockstile only. The door was not machined for hardware and was submitted unfinished.

Door "C": Solid particleboard core flush door, 3068 by 1-3/4", Type I. The door was mat-formed particleboard core construction with 3 ply lauan plywood face panels. The door was prefit in width 3/16" with a 3° bevel on the lockstile only. The door was not machined for hardware and was submitted unfinished.

Door "D": Hollow core wood flush door, 3068 by 1-3/4", Type I. The door was honeycomb cellular core construction with 3 ply lauan plywood face panels. The door was prefit in width 3/16" with a 3° bevel on the lockstile only. The door was not machined for hardware and was submitted unfinished.

Door "E": Ponderosa pine panel door, Style 110, 3068 by 1-3/4". The door contained 11/16" thick raised panels of ponderosa pine. The door was prefit in width 3/16" with a 3° bevel on the lockstile only. The door was not machined for hardware and was submitted unfinished.

Door Frames and Hardware

All door frames and hardware were purchased from local retail outlets or were supplied at no cost by manufacturers from their standard product line.

Metal Frame: 16 gage metal door frame, 3068, for a 1-3/4" thick door. The frame was constructed for right hand swing, and included a plastic leaf type edge weatherstrip. The frame was primed grey.

Wood Frame: 1-15/16" rabbet wood door frame, 3068, for a 1-3/4" thick door. The frame was constructed for right hand swing, and was supplied without weatherstrip. The frame was unfinished.

Door Lock: Standard cylinder door lock, keyed through the knob, 2-3/8" backset, 5/8" latch throw, brass finish.

Door Hinges: Three (3), 4 x 4 square corner butt hinges, mounted with appropriate wood or machine screws, brass finish.

APPENDIX B - TEST PROCEDURES AND CALCULATION METHODS FOR WINDOWS

Test Apparatus, Sample Installation, and Test Procedures

Each window unit, with its various glazing combinations, was tested for thermal transmittance in accordance with ASTM C-236-66(71), "Standard Test Method for Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot Box." Basically, the guarded hot box consisted of two chambers with a common wall. One chamber was heated and the other cooled. A metering box of sufficient size to encompass the entire test sample was mounted to the common wall within the heated chamber and was maintained at the same temperature as the heated chamber. (The purpose here was to obtain no net heat transfer between the metering box and the heated chamber.) The test unit was installed vertically, plumb, square and level, into the common wall between the cold chamber and the metering box. The perimeter of the unit was sealed and insulated using expanded polystyrene of known thermal resistance. (Preliminary tests were performed to determine this resistance.) Fifteen 30 gage copper-constantine thermocouples were attached to each side of the test unit at various, uniform locations on the glass, sash and frame, to measure surface temperatures. Thermocouples were also suspended within the chambers to measure air temperatures.

Upon completion of the installation of the test unit and thermocouples, the chambers were brought to operating temperatures of about 68°F for the heated chamber and metering box, and 18°F for the cold chamber. The air movement on both sides of the test unit was very slow (40-60 fpm), and was directed parallel to the plane of glazing. No provisions were made to artificially produce an air pressure differential across the test unit. As a result, any heat flow due to air leakage occurred only through the forces developed by the difference in air densities between the heated and cooled chambers.

The test unit was allowed to stabilize under these test conditions for a time period sufficient to assure that steady-state heat flow had been achieved. After this period, the surface temperatures, air temperatures, and total heat input to the metering box were measured and recorded. Differential air pressure, relative humidity and the radiation component of heat were also measured and recorded. All measurements were obtained and averaged over a test period of approximately two hours.

In addition to the "still air" tests above, window units #9-77, 10-77, and 11-77 were tested with their various glazing combinations, under an actual 15 MPH exterior wind. This was achieved by placing a wind machine within the cooled chamber. Air flow was directed through a baffel 4" away from the plane of the wall containing the test unit, and was adjusted to provide an average 15 MPH wind velocity at the plane of the wall as the wind approached the unit itself. The wind was directed horizontal and parallel to the plane of glazing. The air flow could move about the unit uncontrolled after approaching the unit, and could provide turbulence by its own force. The velocity of the wind was measured using an Alnor Velometer and appropriate accessories. Other conditions remained as described in the still air tests mentioned previously.

In another series of tests, window units #9-77, 10-77, and 11-77, with insulated glass only, were tested for air infiltration performance. Air infiltration tests were conducted in accordance with ANSI/ASTM E-283-73, "Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors." Each unit was tested using differential air pressure of 0.30" of water column (equivalent to 25 MPH wind velocity or 1.57PSF) and 0.11" of water column (equivalent to 15 MPH wind velocity or 0.57PSF). The air infiltration rate was calculated as a function linear foot of sash crack. Each of these units was then modified by removing some or all of their sash crack weatherstrip, to vary their air infiltration rate. These modified units were then retested for air infiltration per methods as described above. After completion of the air infiltration tests, each of these units were tested for thermal transmittance under both the "still air" and "15 MPH wind" thermal tests described previously.

A fourth series of tests were performed on window unit #9-77. This unit, glazed with insulating glass and with storm panel installed, was again tested for thermal transmittance under the "still air" test method described before, except that the warm and cold chamber temperatures were varied in accordance to the following schedule. The unit was allowed to stabilize under each of these conditions before measurements were recorded.

a. 55°F warm air temperature and 35°F cold air temperature

b. 50°F warm air temperature and 0°F cold air temperature

c. 85°F warm air temperature and 5°F cold air temperature

d. 90°F warm air temperature and 40°F cold air temperature

Calculations

The following parameters were measured directly during each test:

1. total heat input to the metering box during the test period
2. average warm chamber air temperature
3. average cold chamber air temperature
4. average temperature of each thermocouple located on the warm and cold surfaces of the test unit
5. average speed and direction of the air movement on each side of the test unit
6. differential air pressure between the cooled chamber and the metering box
7. relative humidity in each chamber during the test period
8. radiation component of heat transfer

The final results for each test were calculated using the equations and methods described below. (REF: ASTM C-236 and ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume for these and other equations and methods not listed.)

(1) Heat Flow Rate (BTU/hr.-sq.ft.): the average heat flow through the unit as tested.

$$\text{Heat Flow Rate} = \frac{\text{(Total Heat Input)} - \text{(Heat Flow Through Perimeter Insulation)}}{\text{Area of the Test Unit}}$$

(2) Thermal Transfer, "as tested" (BTU/hr.-sq.ft.-^{o}F): the average heat flow through the unit as tested, as a function of the difference between the air temperatures on both sides of the unit.

$$\text{Thermal Transfer, "as tested"} = \frac{\text{Heat Flow Rate}}{\text{(warm air temp.)} - \text{(cold air temp.)}}$$

(3) Average Surface Temperatures (^{o}F): inside and outside surface temperatures of the unit, calculated by "weighing" each thermocouple reading by the material and area it represented.

(4) Panel Conductance (C) (BTU/hr.-sq.ft.-^{o}F): the average heat flow through the unit as tested, as a function of the difference between the surface temperatures of both sides of the unit.

$$\text{Panel Conductance (C)} = \frac{\text{Heat Flow Rate}}{\text{(warm surface temp.)} - \text{(cold surface temp.)}}$$

(5) Thermal Transmittance, Winter Design, (U-value) (BTU/hr.-sq.ft.-^{o}F): the average heat flow through the unit, as a function of the air temperature difference, calculated to adjust to a standard 15 MPH wind on the outside and standard still air on the inside. This calculation allows for the direct comparison between the results of this project and the design thermal transmission values in the ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume.

$$\text{Thermal Transmittance, Winter Design (U)} = \frac{1}{(1/1.46) + (1/C) + (1/6.0)}$$

Where: 1.46 = the ASHRAE standard film or surface conductance (h_i) for still air. (BTU/hr.-sq.ft.-^{o}F)

6.0 = the ASHRAE standard film or surface conductance (h_o) for a 15 MPH wind. (BUT/hr.-sq.ft.-^{o}F)

APPENDIX C - TEST PROCEDURES AND CALCULATION METHODS FOR DOORS

Test Apparatus, Sample Installation and Test Procedures

Each door slab was tested for thermal transmittance in accordance with ASTM C-236-66(71) "Standard Test Method for Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot Box." Basically, the guarded hot box consisted of two chambers with a common wall. One chamber was heated and the other cooled. A metering box of approximately 4' wide by 5' high was mounted to the common wall within the heated chamber and was maintained at the same temperature as the heated chamber. (The purpose here was to obtain no heat transfer between the metering box and the heated chamber.) The test unit was installed vertically, plumb, square and level, into the common wall between the two chambers and was centered on the metering box. The perimeter of the unit was sealed and insulated using expanded polystyrene board of known thermal resistance. (Preliminary tests were performed to determine this resistance.) Fifteen 30 gage copper-constantine thermocouples were attached to each side of the test door in a uniform grid pattern to measure surface temperatures. Thermocouples were also suspended within the chambers to measure air temperatures.

Upon completion of the installation of the test unit and the thermocouples, the chambers were brought to operating temperatures about 80^{o}F for the heated chamber and metering box, and 10^{o}F for the cold chamber. The air movement on both sides of the test unit was very slow (40-60 fpm), and was directed parallel to the plane of the door. No provisions were made to artificially produce an air pressure differential across the test door. As a result, any heat flow due to air leakage occurred only through the forces developed by the difference in air densities between the heated and cooled chambers.

The test door was allowed to stabilize under these test conditions for a time period sufficient to assure that steady-state heat flow had been achieved. After this period, the surface temperatures, air temperatures, and total heat input to the metering box were measured and recorded. Differential pressure and relative humidity were also measured and recorded. All measurements were obtained and averaged over a test period of approximately two hours.

In addition to the "still air" thermal tests above, doors "A" and "E" were tested with an actual 15 mph exterior wind. This was achieved by placing a wind machine within the cooled chamber. Air flow was directed through a baffle 4" away from the plane of the wall containing the test door, and was adjusted to provide an average 15 mph wind velocity at the plane of the wall as the wind approached the door itself. The wind was directed vertically upward and parallel to the plane of the door. The air flow could move about the door uncontrolled after approaching the door, and could provide turbulence by its own force. The velocity of the wind was measured using an Alnor Velometer and appropriate accessories. Other conditions remained as described in the still air tests mentioned previously.

After these tests had been completed, door "A" was machined for lock and hinges and was installed separately into each of the two door frames using three (3) 4 x 4 steel butt hinges and a 2-3/8" backset cylinder lock. This assembly was then installed plumb, square and level into a test wall which had been substituted for the expanded polystyrene used in the tests on the door slabs. The test wall and other test parameters are specified in the SDI 113 "Standard Thermal Performance Test for Steel Door and Frame Assemblies."

The test wall was approximately 6' wide by 7' 2" high and was constructed using stud grade 2 x 4's. The frame contained single top and bottom plates and double studs around the rough opening for the door. The stud cavities were filled with friction fit expanded polystyrene insulation board with a "k" of 0.25 @ 75°F m.t. The test wall was sheathed interior and exterior with 1/2" plywood. The metal door frame cavities were filled with nominal 0.6 pcf fiberglass insulation. After the installation was completed, each assembly was tested under both the "still air" and "15 MPH wind" condition described above, per SDI 113 "Standard Thermal Performance Test for Steel Door and Frame Assemblies."

Calculation Methods

The following parameters were measured directly during each test. All measurements were made only on that portion of the test door slab or door/frame/wall assembly that was within the metering box area.

1. Total heat input to the metering box during the test period.
2. Average warm chamber air temperature.
3. Average cold chamber air temperature.
4. Average temperature of each thermocouple located on the warm and cold surfaces of test door.
5. Average speed and direction of the air movement on each side of the test door.
6. Differential air pressure across the test door.
7. Relative humidity in each chamber during the test period.

The final results for each test were calculated using the equations and methods described below. (REF: ASTM C-236, SDI 113, and ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume for these and other equations and methods not listed.)

(1) Heat Flow Rate (BTU/hr.-sq.ft.): the average heat flow through the sample as tested.

$$\text{Heat Flow Rate} = \frac{(\text{Total Heat Input}) - (\text{Heat Flow Through Perimeter Insulation})}{\text{Area of the Test Sample Within Test Chamber}}$$

(2) Thermal Transfer, "as tested" BTU/hr.-sq.ft.-°F): the average heat flow through the sample as tested, as a function of the difference between the air temperatures on both sides of the sample.

$$\text{Thermal transfer, "as tested"} = \frac{\text{Heat Flow Rate}}{\text{(warm air temp.)} - \text{(cold air temp.)}}$$

(3) Average Surface Temperatures (°F): inside and outside surface temperatures of the sample, calculated by "weighing" each thermocouple reading by the area it represented.

(4) Panel Conductance (C) (BTU/hr.-sq.ft.-°F): the average heat flow through the sample as tested, as a function of the difference between the surface temperatures of both sides of the sample.

$$\text{Panel Conductance (C)} = \frac{\text{Heat Flow Rate}}{\text{(warm surface temp.)} - \text{(cold surface temp.)}}$$

(5) Thermal Transmittance, Winter Design, (U-value) (BTU/hr.-sq.ft.-°F): the average heat flow through the sample, as a function of the air temperature difference, calculated to adjust to a standard 15 mph wind on the outside and standard still air on the inside. This calculation allows for the direct comparison between the results of this project and the transmission values listed in the ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume.

$$\text{Thermal Transmittance, Winter Design (U)} = \frac{1}{(1/1.46) + (1/C) + (1/6.0)}$$

Where: 1.46 = the ASHRAE standard film or surface conductance (h_i) for still air. (BUT/hr.-sq.ft.-°F)

6.0 = the ASHRAE standard film or surface conductance (h_o) for a 15 mph wind. (BTU/hr.-sq.ft.-°F)

APPENDIX D - CONVERSION FACTORS TO SI METRIC UNITS

Physical Quantity	To Convert From	To	Multiply By
Length	inches (in.)	meter (m)	2.540×10^{-2}
	feet (ft)	meter (m)	3.048×10^{-1}
	mile (mi)	kilometer (km)	1.609
Area	square feet (ft^2)	square meter (m^2)	9.290×10^{-2}
Volume	cubic feet (ft^3)	cubic meter (m^3)	2.832×10^{-2}
Temperature	Farenheit (°F)	Centigrade (°C)	C = (F-32)/1.8
Pressure	inches of water	Pascal (Pa)	2.484×10^{2}
Velocity	feet per minute (ft/min)	meter per second (m/s)	5.080×10^{-3}
	mile per hour (MPH)	kilometer per hour (km/h)	1.609
Air Flow	cubic feet per minute per foot of crack (CFM/ft)	cubic meter per second per meter of crack ($m^3/s \cdot m$)	1.439×10^{-4}
Heat Flow (g)	BTU/hr-sq.ft.	W/m^2	3.154
Thermal Conductance (C)	BTU/hr-sq.ft.-°F	$W/(m^2 \cdot C)$	5.678
Thermal Transmittance (U)	BTU/hr-sq.ft.-°F	$W/(m^2 \cdot C)$	5.678
Air Film Coefficent (h)	BTU/hr-sq.ft.-°F	$W/(m^2 \cdot C)$	5.678

REFERENCES

1. ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume, Chapters 22 & 26, published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

2. 1977 Annual Book of ASTM Standards, Part 18; C-236-66(71), "Standard Test Method for Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot Box," published by the American Society for Testing and Materials.

3. 1977 Annual Book of ASTM Standards, Part 18; ANSI/ASTM E-283-73, "Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors," published by the American Society for Testing and Materials.

4. NWMA I.S.1-78, Series Standard for Wood Flush Doors, published by the National Woodwork Manufacturers Association.

5. ANSI/NWMA I.S.5-73, Industry Standard for Ponderosa Pine Doors, published by the National Woodwork Manufacturers Association.

6. SDI 113, Standard Thermal Performance Test for Steel Door and Frame Assemblies, published by the Steel Door Institute.

7. ANSI/NWMA I.S.2-73, Industry Standard for Wood Window Units, published by the National Woodwork Manufacturers Association.

8. ANSI/AAMA A134.1-72, Specifications for Aluminum Prime Windows, published by the Architectural Aluminum Manufacturers Association.

ACKNOWLEDGEMENTS

1. National Woodwork Manufacturers Association
2. Dynatherm Engineering, Lino Lakes, Minnesota

TABLE 1
Windows Tested During This Study

Unit #1-76	Wood double hung window unit with metal jamb liners
Unit #2-76	Wood double hung window unit with vinyl jamb liners
Unit #3-76	Wood casement window unit; two sash side by side
Unit #4-76	Aluminum single hung window unit; thermal barrier design
Unit #5-76	Combination wood and aluminum framed, horizontal sliding window unit
Unit #6-76	Aluminum single hung window unit; thermal barrier design
Unit #7-76	Aluminum, vinyl clad horizontal sliding window unit
Unit #8-76	Aluminum, vinyl clad casement window unit; two sash side by side
Unit #9-77	Wood double hung window unit with vinyl jamb liners
Unit #10-77	Wood double hung window unit with metal jamb liners
Unit #11-77	Wood casement window unit; two sash side by side

TABLE 2
Test Results from Phase I

Thermal Transmittance (U)* of Windows With Various Glazing Combinations

Unit I.D.	Single Glazed	Single Glazed + RDG	Single Glazed + Wood Storm	Single Glazed + Alum Storm	Insulated Glazed	Insulated Glazed + RDG	Insulated Glazed + Wood Storm	Insulated Glazed + Alum Storm
1-76	0.90	---	0.39	0.39	---	---	---	---
2-76	0.86	0.46	0.36	0.38	0.55	---	0.29	0.30
3-76	0.72	0.40	---	---	0.48	0.34	---	---
4-76	1.06	---	---	0.57	---	---	---	---
5-76	0.83	---	---	0.47	---	---	---	---
6-76	1.05	---	---	0.55	---	---	---	---
7-76	---	---	---	---	0.66	---	---	---
8-76	---	---	---	---	0.66	---	---	---
9-77	---	---	---	---	0.52	---	0.31	---
10-77	---	---	---	---	0.53	---	0.32	---
11-77	---	---	---	---	0.47	0.34	---	---

* BTU/hr.-sq.ft.-°F. All reported U-values corrected to ASHRAE Standard Winter Design conditions of 15 MPH exterior wind velocity and still air inside.

TABLE 3
Comparison of Results from Phase I Tests to ASHRAE Thermal Design Data

Glazing Description	Phase I Results		ASHRAE Handbook Values(1)			
	Wood Window	Aluminum Window	Glass Only	Wood 80%	Aluminum non-TB	Aluminum TB(2)
Single Glazed	0.72-0.90	0.83-1.06	1.10	0.99	1.10	1.10
Single + RDG	0.40-0.46	-------	0.50	0.45	0.60	0.50
Single + Storm(3)	0.36-0.39	0.47-0.57	0.50	0.45	0.60	0.50
Insulated Glazed	0.47-0.55	0.66	0.58	0.55	0.70	0.58
Insulated + RDG	0.34	-------	0.39	0.37	0.47	0.39
Insulated + Storm(3)	0.29-0.32	-------	0.39	0.37	0.47	0.39

(1) Values from ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume, Chapter 22, Table 8

(2) Multiplier taken as 1.0 from footnote "m" of above reference

(3) Wood and aluminum framed storm windows combined

TABLE 4
Comparison of Phase I and Phase II Thermal Transmittance Tests

Unit I.D.	Window Description	Glazing Description	Tested U-values*	
			Phase I Adjusted 15 MPH Exterior Wind	Phase II Actual 15 MPH Exterior Wind
9-77	Wood Double Hung	Insulated Glazed	0.52	0.68
10-77	Wood Double Hung	Insulated Glazed	0.53	0.64
11-77	Wood Casement	Insulated	0.47	0.59
9-77	Wood Double Hung	Insulated + Storm	0.31	0.45
10-77	Wood Double Hung	Insulated + Storm	0.32	0.41
11-77	Wood Casement	Insulated + RDG	0.34	0.40

* BTU/hr.-sq.ft.°F. All reported U-values corrected to ASHRAE Standard Winter Design conditions of 15 MPH exterior wind velocity and still air inside.

TABLE 5
Phase III Thermal Transmittance Test Results

Unit	Description	Weatherstrip	Air Infiltration Rate (CFM/ft. of Crack) at 1.57 PSF	Thermal Transmission U-value* (Still Air Test)	Thermal Transmission U-value* (15 MPH Wind Test)
9-77	Wood Double Hung	In Place	0.59	0.52	0.68
9-77	Wood Double Hung	Removed	0.95	0.52	0.68
10-77	Wood Double Hung	In Place	0.27	0.53	0.64
10-77	Wood Double Hung	Removed	1.05	0.53	0.67
11-77	Wood Casement	In Place	0.19	0.47	0.59
11-77	Wood Casement	Removed	0.31	0.47	0.68

* BTU/hr.-sq.ft.-°F. All reported U-values corrected to ASHRAE Standard Winter Design conditions of 15 MPH exterior wind velocity, and still air inside.

TABLE 6

Phase IV Thermal Transmittance Test Results

Warm Chamber Temperature (F°)	Cold Chamber Temperature (F°)	Air Temperature Difference (F°)	Mean Air Temperature (F°)	Thermal Transmittance, (U)* (BTU/hr.-sq.ft.-°F)
55	35	20	45	0.32
50	0	50	25	0.33
90	40	50	65	0.34
85	5	80	45	0.33
68	18	50	43	0.31

* BTU/hr.-sq.ft.-°F. All reported U-values corrected to ASHRAE Standard Winter Design conditions of 15 MPH exterior wind velocity, and still air inside.

TABLE 7

Doors Tested During This Study

Door "A"	Solid wood block core flush door with lauan plywood face panels
Door "B"	Solid wood block core flush door with 1/8" tempered hardboard face panels
Door "C"	Solid particleboard core flush door with lauan plywood face panels
Door "D"	Hollow core wood flush door with lauan plywood face panels
Door "E"	Ponderosa pine panel door, Style 110 (6 panel)
Wood Door Frame:	3'0" x 6'8" wood frame, 1 15/16" rabbet, right hand swing, without weatherstrip.
Metal Door Frame:	3'0" x 6'8" metal frame, 16 gage, right hand swing, with plastic leaf type weatherstrip.

TABLE 8

Results of Stage I testing and comparison to ASHRAE thermal design data

Door I.D.	Description	Stage I Results (U-value)*	ASHRAE Design U-value**
A	Wood block core, lauan face panels	0.33	0.33
B	Wood block core, hardboard face panels	0.36	0.34
C	Particleboard core, lauan face panels	0.31	0.26
D	Hollow core, lauan face panels	0.47	0.46
E	Pine panel door, Style 110	0.47	0.47

* BTU/hr.-sq.ft.-°F. All reported U-values corrected to ASHRAE Standard Winter conditions of 15 MPH exterior wind velocity and still air inside.

** Calculated values based on formula and data in ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume, Chapter 22. Calculated values are based only on that portion of the door that would be included in the 4' wide by 5' high metering area of the testing apparatus, centered on the test specimen.

TABLE 9

Comparison of Stage I and Stage II Test Results

Door I.D.	Description	Stage I U-value* (Still Air Test)	Stage II U-value* (15 MPH Wind Test)
A	Wood block core flush lauan plywood face panels	0.33	0.33
E	Pine panel door, Style 110	0.47	0.49

* BTU/hr.-sq.ft.-°F. All reported U-values corrected to ASHRAE Standard Winter Design conditions of 15 MPH exterior wind velocity and still air inside.

TABLE 10

Stage III Results

	Measured U-Value* Exterior Wind Condition		
Sample Description	Still Air	15 MPH Wind	ASHRAE Design U-value**
Door "A" alone	0.33	0.33	0.33
Door "A" in metal frame with weatherstrip	0.34	0.37	0.34
Door "A" in wood frame without weatherstrip	0.27	0.41	0.28

* BTU/hr.-sq.ft.-°F. All reported U-values corrected to ASHRAE Standard Winter Design conditions of 15 MPH exterior wind velocity, and still air inside.

** Calculated values based on formula and data in ASHRAE Handbook and Product Directory, 1977 Fundamentals Volume, Chapter 22. Calculated values are based only on that portion of the door and door/frame/wall assembly that would be included in the 4' wide by 5' high metering area of the test apparatus, centered on the assembly.

DISCUSSION

HENRY F. MOYER, Resch. Supervisor, Libby-Owens-Ford Co., Toledo, OH: Has an effort been made to determine the U-value of the products tested at the same conditions under which the U-values published in the ASHRAE HANDBOOK of Fundamentals were determined? (72°F inside temperature; 0°F outside temperature 15 mph wind).

J.F. LOWINSKI: Yes. Several portions of this testing project were specifically conducted to determine the effect of varying environmental conditions on the measured test results. The first series of tests (Phase I) were conducted using a warm chamber temperature of 68°F, a cold chamber temperature of 18°F, and an interior and exterior wind condition of essentially still air. The results for these tests were adjusted to the Standard Winter Design conditions used in the ASHRAE HANDBOOK of Fundamentals to determine glazing U-values, namely h_i= 1.46 Btu/h·ft^2·°F and h_i- 6.0 Btu/h·ft^2·°F. The second series of tests (Phase II) were conducted under the same set of chamber temperatures, but with an actual 15 mph wind applied to the exterior of the window unit, horizontal and parallel to the plane of glazing. The results from these tests were also adjusted to the Standard Winter Design conditions described above. Comparison of both sets of results (Ref Table 4) indicate the use of an actual 15 mph wind during the test randomly increased the apparent U-value of the test unit between 17% and 45%, though theorectically, both sets of results should have been equal. Further, the adjusted results from the Phase I tests correlate well with the U-values derived from the 1977 ASHRAE HANDBOOK of Fundamentals, Chap. 26, Table 13 (Ref Table 3).

Under Phase IV, additional tests were conducted on one unit (Unit #9-77) at warm and cold chamber temperatures other than 68°F and 18°F. The warm and cold chamber temperatures selected were: 75°F and 35°F; 50°F and 0°F; 90°F and 40°F; and 85°F and 5°F. These sets of temperatures were selected to represent extremes in total air temperature difference, and in mean air temperature. All tests were conducted with essentially still air on the interior and exterior of the test unit. The results of these tests were within 0.03 Btu/h·ft^3·°F of each other, including the results from the original test conducted at 68°F and 18°F, indicating that variations in warm or cold chamber temperatures have little influence in the overall U-value of the product.

From the results of these tests, it is my opinion that tests conducted using warm and cold chamber temperatures of 68°F and 18°F respectively, and which include the calculated effect of a 15 mph exterior wind, approximate the U-values contained in the ASHRAE HANDBOOK of Fundamentals. However, the physical application of an exterior 15 mph wind does not correlate with the calculated exterior air film coefficient of 6.0 Btu/h ·ft^2·°F. Further research into the actual effect of exterior winds is needed before such a relationship can be developed.

LESTER SCHUTRUM, Research Dept., PPG Industries, New Kensington, PA: The convection coefficient of a 15 mph wind is much reduced because of the lower velocities near the window. The combination of this reduced velocity and the radiation coefficient approximate a U-value accepted by ASHRAE.

C.A. MORRISON, Assoc. Prof., ME Dept., Univ. of Florida, Gainesville, FL: Wind velocity perpendicular to surface of 15 mph will give h_o (exterior air film coefficients) greater than 6.0 published by ASHRAE.

LOWINSKI: Some of the tests conducted for this study include the effects of an actual 15 mph wind, applied horizontal and parallel to the plane of the window. The application of this wind during the test caused a significant increase in the measured U-value of the window, over the calculated effect of that wind. Exterior air film coefficients calculated from these tests ranged from 5.7 to 9.7 Btu/h

·ft^3·°F (avg: 7.6), though wind speeds varied only slightly from the prescribed 15 mph. Window tests conducted by others, with the wind applied perpendicular to the plane of glazing, have shown similar variations in exterior air film coefficients. These variations are apparently influenced by the many recesses, protrusions, and overall flatness of the window. The air film coefficients used by ASHRAE, however, are derived from tests on flat surfaces with the wind direction unspecified.

For a window, the exterior air film coefficient is dependent not only on the velocity of the wind, but also on the direction of the wind and on the flatness of the window. The three options we have under test situations are: 1) To test under a given wind speed and direction; 2) To test under a specified uniform air film coefficient; or 3) To test under still air conditions and calculate the effects of exterior wind and air films. Since none of these three options is entirely representative of actual field exposure, selection of an appropriate test method should be based not only on the technical accuracy of the results, but on the reproducibility of those results, the ability to compare apparent strenghts and weaknesses to test samples, and the ability to adjust or correct the results to represent conditions other than those under which the tests were conducted. However, until the influence of wind on the exterior of a window is understood from both a testing and field service viewpoint, controversy over film coefficients and testing methodology will persist.