E84.05

FINAL REPORT

EGRESS WINDOW TESTS

Robert Rood
Mechanical Engineering Department
School of Engineering
University of Alaska-Fairbanks
Fairbanks, AK 99775

August 1985

DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
RESEARCH SECTION
2301 Peger Road
Fairbanks, AK 99701

IMPLEMENTATION STATEMENT (by Department of Transportation and Public Facilities - DOT&PF)

The findings of this report are to be implemented by DOT&PF design personnel in preparing and approving specifications for windows in State buildings. The results of this research will be useful for designing buildings in northern and central Alaska that are considerably safer for occupants and more energy efficient. Significant savings in life cycle costs could also result from more extensive evaluation of products that appear promising in this limited, initial study.

This report should be used to help establish Statewide standards for windows in public facilities if it should become advantageous to have such specifications.

Stephen H. Kailing, P. E.
Project Manager, Research Section

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

In an arctic environment, building components are exposed to extreme conditions. The components chosen must be able to serve the function they were designed for even under these extreme conditions. In the case of windows, it is important for them to remain operable throughout the winter in order to provide a means of egress for the occupants of the building. The National Fire Code of 1984 requires that every living room and bedroom in one- and two-family residences have two means of egress, one of which may be a window.

The use of a window to meet the requirements may present a problem if there are cold outdoor temperatures, and the building is tightly constructed and/or humidified. These conditions in conjunction with each other often result in heavy ice buildup on window surfaces, rendering the window inoperable and unsuitable as a means of egress. In addition, the constant icing and thawing cycles on the window can cause maintenance problems and a decreased life expectancy of the window.

The intent of this study was to evaluate the performance of several types of window systems under simulated winter conditions as a means of gauging the relative susceptibility to icing of each window. Also, an investigation of air tightness and thermal resistance of the window systems was conducted.

The results of these tests are presented in this report.

SUMMARY

Three types of window systems were exposed to harsh environmental conditions, and to tests of resistance to heat transfer and air tightness. The three types of window systems tested were a Primo PVC casement window with both regular glazing and an insulating panel in place of the glazing; a Rockwell wood casement window with a Koroseal acrylic overlay; and a Caradco wood casement window.

The Primo window system remained operative under the most severe conditions applied during the cold room tests. The Rockwell without the Koroseal overlay and the Caradco both became inoperative due to icing. The Rockwell with the Koroseal suffered minor icing, but remained operable.

In addition, the Primo system had the highest resistance to heat transfer (lowest heat transmittance). When the glazing was replaced with the insulating panel, an overall heat transfer coefficient, or U value of 0.19 Btu/ft^2-hr-F was recorded. The Primo system with the glazing had a U value of 0.36. A U value of .37 was recorded for the Caradco window. The Rockwell without the Koroseal had a U value of 0.47, with the overlay, its U value was reduced to 0.32.

The Primo system also had the lowest air infiltration rate at 0.00987 cfm per foot of crack. The Caradco had a rate of 0.0275 cfm per foot of crack. A value of .0561 was recorded for the Rockwell without the acrylic overlay and 0.043 with the overlay. All windows tested well below the industry standard of 0.5 cfm per foot of crack.

TEST WINDOWS

Three types of windows which are suited for use in the cold regions were tested. These windows were a Primo casement/awning window, a Rockwell casement window with a Koroseal overlay and a Caradco casement window.

The Primo window sash and frame are fabricated from extruded polyvinyl chloride (PVC) plastic. The extruded sections are available in four different profiles. Each plastic section has a hollow core in which either an aluminum or galvanized steel insert is fitted to provide structural support. The weatherstripping and glazing gaskets are made of EDPM, a low temperature rubber.

Figure 1 illustrates a cross section of the window system with triple glazing. The glazing is spaced 1/2 inch apart. If fenestration is not needed, but if it is still desirable to provide a means of egress for the occupants in the room; the glazing can be replaced with a polyurethane panel.

The Primo system has a 180 degree quick throw handle that has two locking positions. At 90 degrees the window is allowed to swing freely as a casement window, while at 180 degrees the window opens as an awning window. The window is locked shut by four sliding cam action metal fittings.

The Rockwell is a wood sash and frame casement window. The weatherstripping and glazing gaskets are made of vinyl. The window is double-glazed with 1/2 inch spacing between panes. The Rockwell is operated by a rotating crank mechanism that opens the window to a maximum of 90 degrees from the closed position. The window is locked shut by one cam action lock on the center of the sash.

The Koroseal magnetic interior overlay is an acrylic sheet that has a molded PVC extrusion fitted around the edges. The PVC extrusion also has magnetic stripping fitted on one side. This matches a steel strip that is fitted to the frame of the window; in this case, a Rockwell casement window. Figure 2 shows the Koroseal overlay.

The Caradco window is a wood sash and frame casement window. It is fitted with vinyl weatherstripping and glazing baskets. The glazing is 1/4 inch spaced and hermetically sealed. The window is operated by a worm-gear rotating type crank that opens the sash and glazing a full 90 degrees from its closed position. The window is locked by one cam action lock located on the center of the sash. Figure 3 depicts the Caradco window (the window shown is a double pane; the window tested was a tri-pane).

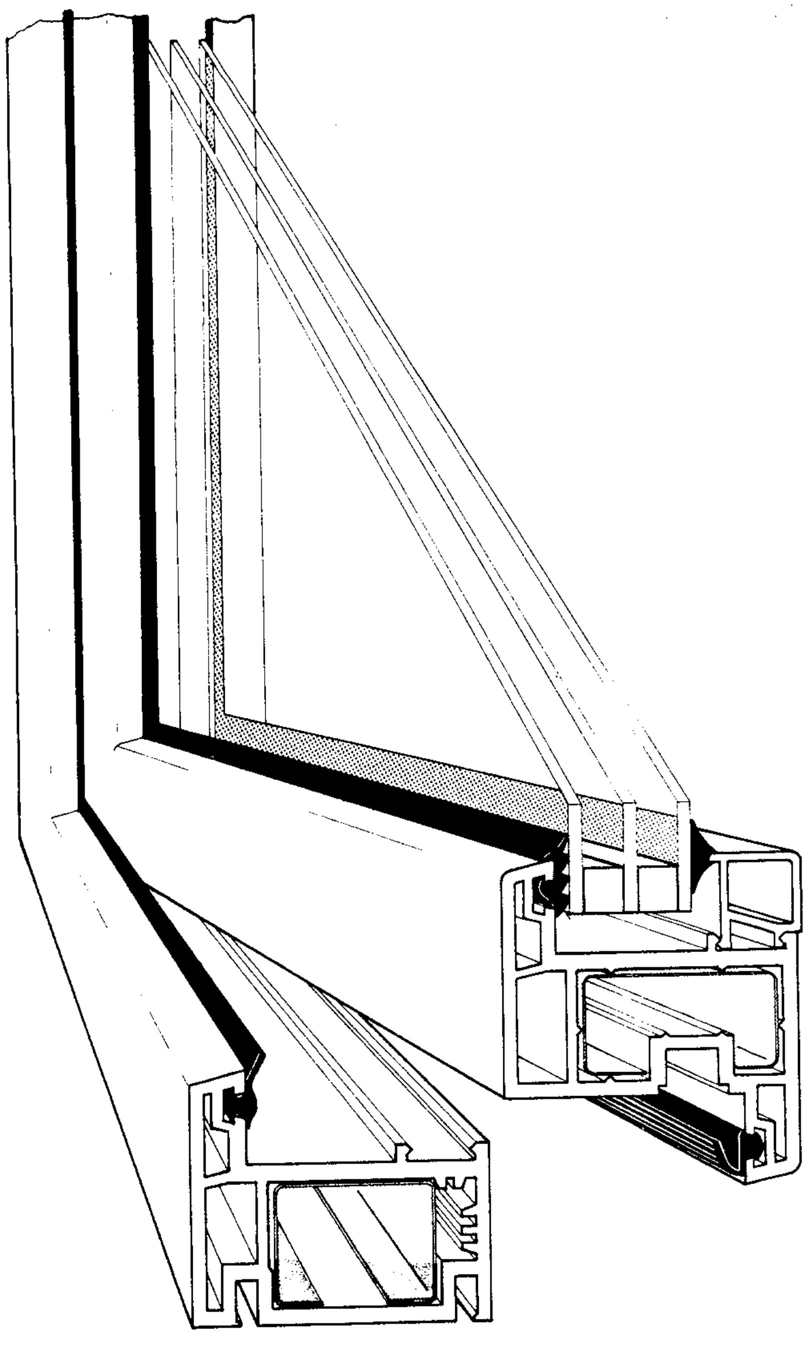


Figure 1. Primo window (from manufacturer's brochure).

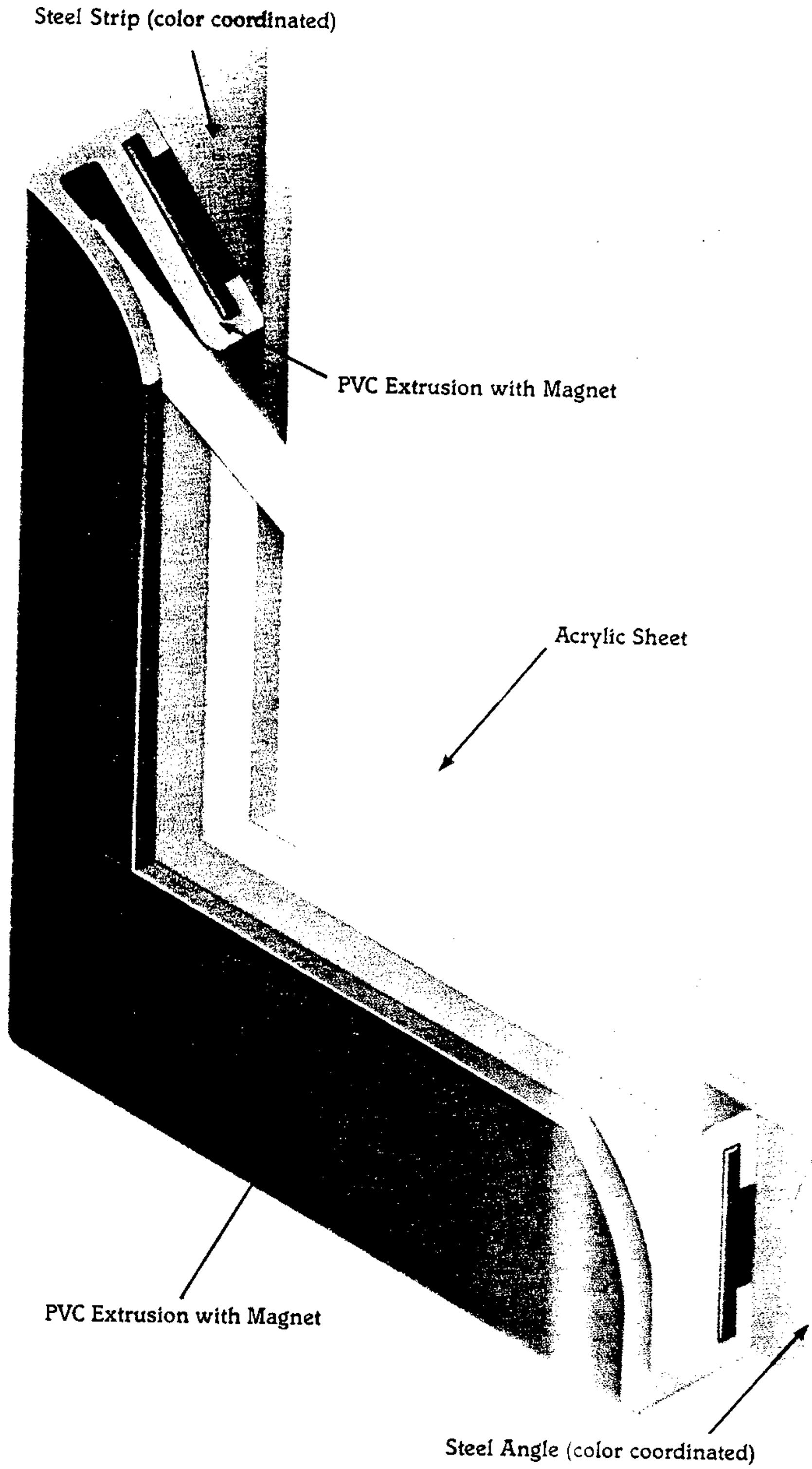


Figure 2. Koroseal (from manufacturer's brochure).

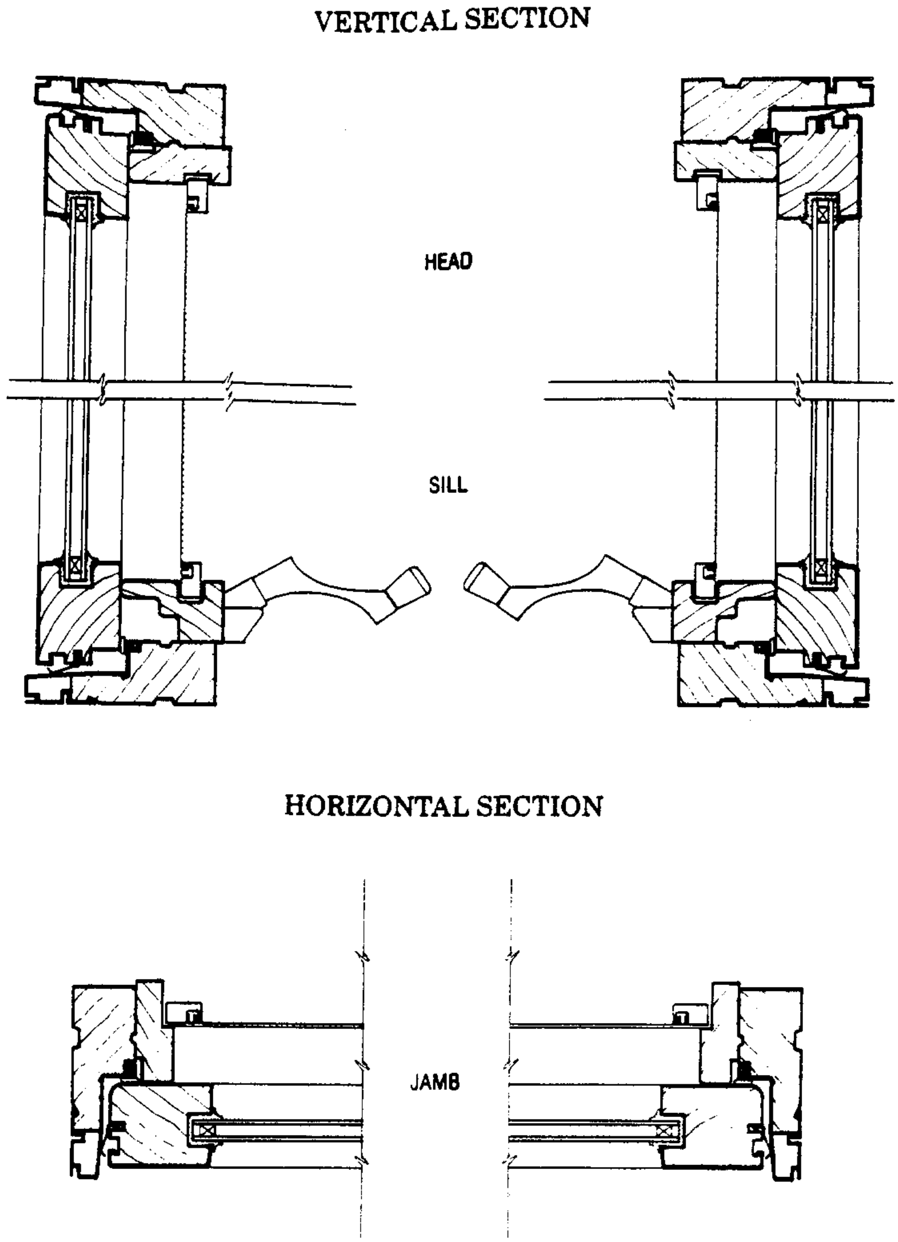


Figure 3. Caradco window (from manufacturer's brochure).

COLD ROOM TESTS

The cold room tests were used to study the window system's performance under hostile conditions. Two tests were conducted; test #1 at -40° for 48 hours and test #2 at -20°F for 24 hours.

An Associated Environmental Systems environmental chamber was used to simulate winter outdoor temperatures. The indoor, or warm environment, was simulated by building a plastic film tent around the indoor face of the window. A small humidifier was placed inside the tent. For each of the two tests a relative humidity (R.H.) of 30% was maintained.

A Hewlett-Packard 3054 Datalogger-Control Unit, with two 44422A1T-couple acquisition boards and a 44431A A.C. actuator board, was used to record data and control the humidity.

Pressure was supplied to the interior of the environmental chamber from an exterior air supply line. The pressure on the outside, or cold side, of the window was to simulate the pressure actually encountered on the lower story of a two-story house due to stack effect and wind pressure. The stack pressure can be calculated as follows (ASHRAE, 1981):

$$Ps = (r_o - r_i)gh$$

where

Ps = stack pressure
g = gravitational acceleration
r_o and r_i = air density, outside and inside.

The wind pressure can be calculated by:

$$Pv = 0.5\ rv^2$$

where

Pv = pressure due to wind

r = air density

v = wind velocity.

For test #1, a cold side pressure of .17 to .25 inches of water was maintained. This would be equivalent to the stack pressure experienced by a two-story house and a wind velocity of 18 MPH. The wind accounts for 0.197 inches of water and the stack effect for 0.02 inches of water, pressure. Test #2 had a cold side pressure of .12 to .20 inches of water. This would be equivalent to the stack pressure experienced by a two-story house with a 16.5 MPH wind. The wind pressure amounts to 0.15 inches of water and the stack effect to 0.015 inches of water, pressure. The results of test #1 are presented in Table 1 and of test #2 in Table 2.

The condition of each of the window systems at the conclusion of test #1 were as follows:

Caradco

There was a significant amount of ice formation completely across the base of the sash and frame, and the lower portion of the glazing. Icing also occurred from the base three quarters of the way up the sash and frame. Due to this ice buildup the window was inoperable until the ice had been removed. Also, a considerable amount of force then had to be applied to open the window. The glazing, where not covered with ice, was covered with a layer of condensed water.

Primo

Slight icing occurred across the base of the sash and frame. Around the edges of the glazing, where it meets the sash, there was light condensation. There was no resistance to operation of the window. All of the moving parts were free of ice and the window opened easily.

TABLE 1. Results of Test #1 (-40°F outside, 30% RH and 75°F inside, outside pressure = 0.17 to 0.25 inches of water).

Type	Location	Air °F	Glazing °F	Frame °F	Humidity %RH
Primo	Indoor	74.0	51.2	48.8	30.2
	Outdoor	-40.1	-31.0	-33.6	----
Caradco	Indoor	76.1	42.6	60.8	29.2
	Outdoor	-39.3	-25.4	-35.8	----
Rockwell	Indoor	78.8	42.3	61.2	29.1
	Outdoor	-41.0	-25.5	-34.7	----
Rockwell w/ Koroseal	Indoor	79.5	54.5	59.6	30.2
	Outdoor	-41.3	-31.3	-36.0	----

TABLE 2. Results of Test #2 (-20°F outside, 30% RH and 75°F inside, outside pressure = 0.12 to 0.20 inches of water).

Type	Location	Air °F	Glazing °F	Frame °F	Humidity %RH
Primo	Indoor	73.4	54.0	50.3	30.5
	Outdoor	-22.0	-15.1	-17.1	----
Caradco	Indoor	78.7	47.6	64.8	29.1
	Outdoor	-22.1	-11.0	-18.4	----
Rockwell	Indoor	79.3	46.7	62.4	29.6
	Outdoor	-21.3	-10.1	-18.1	----
Rockwell w/ Koroseal	Indoor	79.4	53.7	61.3	30.7
	Outdoor	-22.0	-13.7	-17.5	----

Rockwell

Heavy ice formed across the sash and frame, and the lower one-eighth of the glazing. There was also ice buildup along the vertical parts of the sash and frame, approximately three-fourths of the way to the top. The glazing surface was completely covered with condensate. The window was not operable until all of the ice was removed from the sash-frame intersection.

Rockwell with Koroseal

There was very slight ice formation inside the overlay on the glazing surface and on the sash-frame intersection. The edges of the Koroseal overlay where it was in contact with the frame had some condensation. The window was easily operated, there was no hindrance due to the slight icing.

The condition of each window system at the conclusion of test #2 was:

Caradco

There was slight icing at the base of the glazing and on the sash-frame intersection. Condensation occurred over the entire glazing surface. The force needed to operate the window crank was slightly more than normal. The window did not completely close after opening due to ice in the operating mechanism.

Primo

There was light condensation around the edge of the glazing where it makes contact with the sash. Also, the sash and frame were covered with condensate. The window operated easily without any hindrance whatsoever.

Rockwell

The sash-frame intersection on the base of the window was completely iced over. The condensation had formed over the entire glazing surface. The window had to be forced open and would not close completely after opening.

Rockwell with Koroseal

There was slight condensation on the Koroseal overlay and slight icing on the edges of the window glazing next to the sash. The window opened and closed easily.

GUARDED HOT BOX TESTS

The guarded hot box owned jointly by the University of Alaska-Fairbanks and DOT&PF Research Section was used to determine the overall heat transfer coefficient, or U value, for the window systems. See Figure 4 for a diagram of the guarded hot box.

The windows fit into the mask wall, which is then sandwiched between the cold box and meter box. The mask wall is composed of 4 inches of expanded polystyrene extruded with a smooth skin surface, and two 3/8 inch sheets of plywood. The guard box protects the meter box from the surrounding environment by maintaining the same temperature as the meter box. Therefore, all energy introduced to the meter box goes through the mask wall. For a more thorough treatment of the operation and theory of the guarded hot box refer to Reference 5.

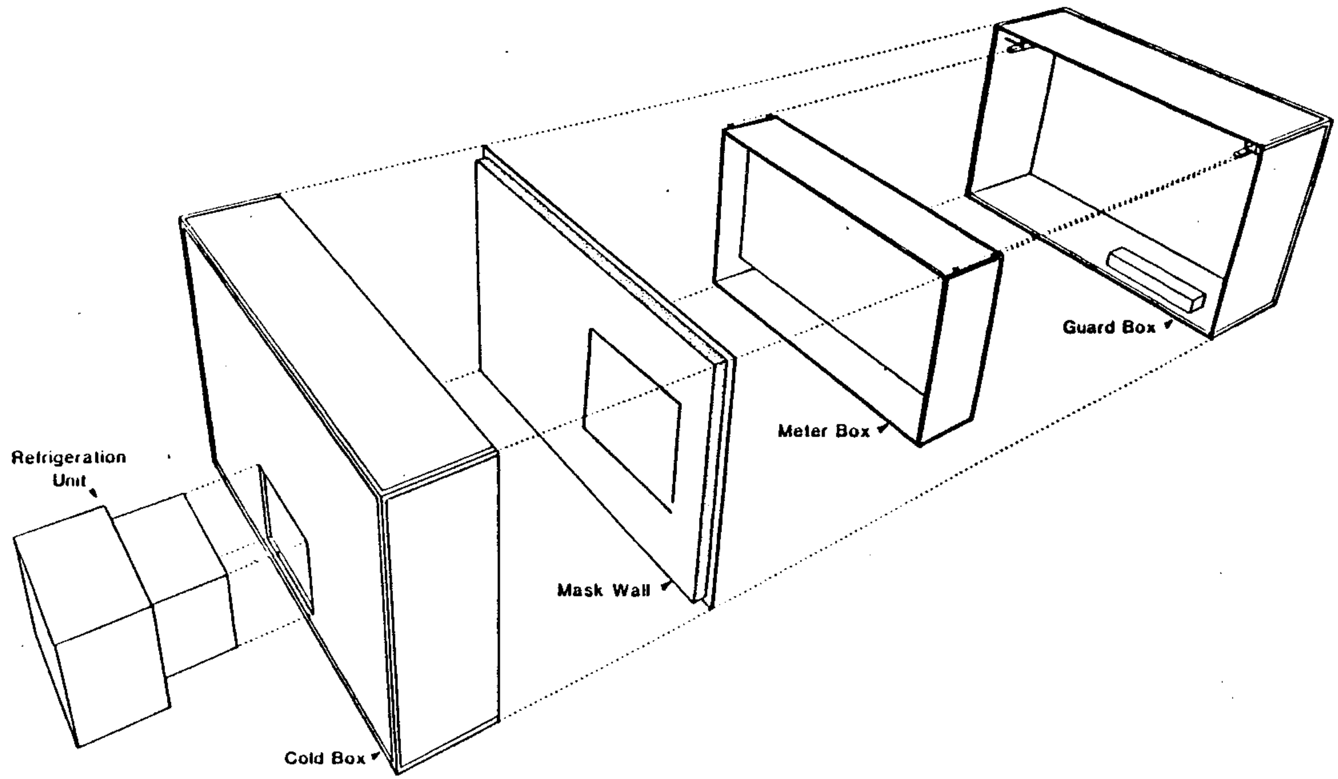
The window systems were tested at a cold box temperature of approximately 0 degrees F, and a meter and guard box temperature of 80 degrees F. The typical test duration was approximately 8 hours.

With the data collected from the guarded hot box an insulating, or R value, for the window systems can be determined. The energy exchanged between the meter and guard boxes can be calculated by:

$$Qmeter/guard = (T\text{-}time)(temp.\ diff)(A1)(.29287)/Rm$$

GUARDED HOT BOX : EXPLODED VIEW

used for testing of thermal conductance



where

Qmeter/guard = total energy exchanged between meter and guard boxes (watt-hours)
T-time = total elapsed time of test (hours)
A1 = area of meter/guard box contact (ft^2)
.29287 = Btu/hr to watt conversion
Rm = R value of meter box wall (5.31 ft^2-hr-°F/Btu)
temp. diff = average temperature difference between meter and guard boxes (°F).

The energy transferred through the mask wall can be calculated by:

$$Qwall = (T\text{-}time)(T_{hot}-T_{cold})(A_w)(.29287)/Rma$$

where

Qwall = energy transferred through the mask wall (watt-hours)
A_w = area of mask wall (ft^2)
.29287 = watt to Btu/hr conversion
Rma = R value of mask wall (20.94 ft^2-hr-F/Btu)
T-time = total elapsed time (hours)
T_{hot} and T_{cold} = skin temperatures of mask wall.

In addition, by calculating the energy transferred through the glazing of the window system by the same method listed above the R value of the window sash and frame can be determined as shown below:

$$Rs\text{-}f = \frac{(T\text{-}time)(T_{hot}-T_{cold})(As\text{-}f)(.29287)}{(Qt-Qm/g-Qwall-Qg)}$$

where

Rs-f	= R value of sash and frame (ft^2-hr-°F/Btu)
As-f	= area of sash and frame (ft^2)
T-time	= total elapsed time of test (hours)
Qt	= total energy supplied to meter box (watt-hours)
Qm/g	= energy through meter/guard box interface (watt-hours)
Qwall	= energy through mask wall (watt-hours)
Qg	= energy through glazing (watt-hours).

The overall heat transfer coefficient, or U value, can then be found by:

$$Uoa = \frac{[1/(Rg+1/1.47+1/6)](Ag) + [1/(Rs\text{-}f+1/1.47+1/6)](As\text{-}f)}{A_t}$$

where

Uoa	= U overall of window system (Btu/ft^2-hr-F)
Rg	= R value of glazing (ft^2-hr-F/Btu)
Ag	= area of glazing (ft^2)
Rs-f	= R value of sash-frame (ft^2-hr-F/Btu)
As-f	= area of sash-frame (ft^2)
A_t	= total area of window system (ft^2)
1.47	= convection coefficient, still air (BTU/hr-ft^2-F)
6	= convection coefficient, 15 mph wind (Btu/hr-ft-F)

See the Appendix for an example calculation.

The results of the guarded hot box tests are listed in Table 3. The Primo window system with the insulating panel had the lowest overall U value. The Rockwell with the Koroseal overlay had the best heat transfer characteristics of the window systems with fenestration.

TABLE 3. Results of the guarded hot box tests (80°F meter/guard box temperature, 0°F cold box temperature).

	Primo w/ glazing	Primo w/ insul. panel	Caradco	Rockwell	Rockwell w/ koroseal
Elapsed time (hrs)	7.9	7.94	8.12	8.17	8.11
Meter box air (°F)	79.4	78.7	80.1	79.9	79.7
Cold box air (°F)	-3	-1.6	0.31	-0.14	-0.54
Temp. diff. m/g box (°F)	-0.25	-0.52	-0.038	0.09	0.17
Power (watt-hrs)	703	465	565	610	506
Wall/meter box area (ft^2)	22.26	22.26	24.91	25.75	25.75
Window/meter box area (ft^2)	8.49	8.49	5.84	5	5
Meter/guard box area (ft^2)	73.71	73.71	73.71	73.71	73.71
R value of test wall*	5.31	5.31	5.31	5.31	5.31
R value meter/ guard box*	20.94	20.94	20.94	20.94	20.94
U value of windows*	0.364	0.190	0.370	0.469	0.320

* Units of :Btu/hr-°F-ft^2.

AIR INFILTRATION TESTS

The air infiltration tests were conducted in accordance with guidelines specified by ASTM (1980) E283. These guidelines require 0.3 inches of water pressure and a complete seal around the test specimen. The windows, for this test were sealed in a half of mylar bag that had used previously for gas sample collection. The bags were sealed on the window frames with adhesive caulking and tape. A flow meter was connected into the air supply line. A Dywer manometer was linked to the mylar bag by plastic tubing.

The air supply was adjusted so a pressure of 0.3 inches of water was maintained in the mylar bag. Readings were then taken from the flow meter. From the flow meter data, a determination of the air leakage rate for the window systems at that pressure was possible. Table 4 is a summary of the data collected from the air infiltration tests.

The Primo window system had the lowest air leakage rate due to the nature of the seals and locking mechanism on the window. The Koroseal overlay improved the performance of the Rockwell window, but care must be taken in attaching the Koroseal. The magnetic stripping must be free of all debris and the stripping should be continuous. All of the window systems were well below the maximum allowed by industry standards which is 0.5 cfm per foot of crack.

CONCLUSIONS

By evaluating the performance in each test it is possible to draw conclusions about which window system is best suited for each individual circumstance. It should be kept in mind, however, that the cold room tests provide only a comparative analysis of the window systems over a limited range of conditions and time. Actual long-term performance should not be directly extrapolated from the data given.

The Primo window system with the insulating panel was the most energy efficient way to provide a reliable means of egress, if fenestration is not needed. If fenestration is desired, the Rockwell in conjunction with the Koroseal had the greatest insulating value of the

TABLE 4. Results of air infiltration tests (0.3 inches water of pressure on exterior face of window.

Type	Lineal ft. crack	Flow (CFM)	CFM per ft. crack
Caradco (wood)	7.83	0.215	0.028
Primo (PVC)	10.83	0.106	0.0098
Rockwell (wood)	8.19	0.459	0.056
Rockwell w/ koroseal	8.19	0.353	0.043

window systems with glazing. Unfortunately, it also had the highest infiltration rate.

Each window application must be evaluated on a life cycle cost basis, with consideration given to the egress safety aspect. Life cycle costs which include first cost, long term energy use and maintenance costs are beyond the scope of this report.

ACKNOWLEDGEMENTS

I would like to acknowledge and thank Steve Kailing of DOT&PF Research Section for his assistance during the study and for editing the final report. Also, I wish to thank Rick Briggs of DOT&PF Research Section for his invaluable technical assistance.

REFERENCES

1. American Society of Heating, Refrigerating and Air Conditioning Engineers. 1981. ASHRAE Handbook of Fundamentals. Atlanta, GA.

2. American Society for Testing Materials. 1980. Annual Book of ASTM Standards, Pt. 18 Thermal Insulation; Building Seals and Sealants. Philadelphia, PA.

3. McQuiston, C.F., and J.D. Parker. 1982. Heating, Ventilating and Air Conditioning. John Wiley and Sons, New York.

4. National Fire Protection Association. 1984. National Fire Codes, Vols. 1-16. Quincy, MA.

5. Zarling, J.P., W.A. Braley, J.S. Strandberg and S.V. Bell. 1984. Thermal properties of metal stud walls. State of Alaska, Department of Transportation and Public Facilities Report No. AK-RD-85-05.

APPENDIX

EXAMPLE CALCULATION

CARADCO WINDOW

Hot box and window temperature (F)

	Warm	Cold
Avg. air temp.	80.1	0.312
Avg. glazing temp.	58.1	18.9
Avg frame temp.	72	11.76
Avg mask wall temp.	77.7	1.986

Temp. diff. meter/guard box = -.038
Total elapsed time of test = 8.125 hours
Total metered energy = 565 watt-hours

R value of test wall

4" polystyrene at 5 ft^2-hr-F/Btu	= 20
Two 3/8 inch plywood at 0.47 ft^2-hr-F/Btu	= .94
ER	= 20.94

R value of meter/guard box wall

1" polystyrene at 5 ft^2-hr-F/Btu	= 5
1/4 inch plywood at .31 ft^2-hr-F/Btu	= .31
ER	= 5.31

R value of glazing

3 panes glazing	= neg.
One 1/4 inch airspace at 30°F 0.746 ft^2-hr-F/Btu	= .746
One 1/4 inch airspace at 60°F 0.692 ft^2-hr-F/Btu	= .692
ER	= 1.438

Area meter/guard box (ft^2)	=	73.71
Area of window glazing (ft^2)	=	3.326
Area of window frame (ft^2)	=	2.51
Area of meter/test wall (ft^2)	=	30.75

$$Qm/g = \frac{(73.71\ ft^2)(.29287\ watt/Btu/hr)(-.038F)(8.125\ hr)}{5.31\ ft^2\text{-hr-F/Btu}}$$

$$Qm/g = -1.26 \text{ watt-hours}$$

$$Qwall = (24.91\ ft^2)(.29287)(77.7-1.986)(8.125)/20.94$$

$$Qwall = 214.3 \text{ watt-hours}$$

$$Qglaze = (3.326)(.29287)(58.12-18.9)(8.125)/(1.438)$$

$$Qglaze = 215.9 \text{ watt-hours}$$

$$Rs\text{-}f = \frac{(2.51)(.29287)(72-\ 11.76)(8.125)}{[565 - (-1.26) - 214.3 - 215.9]}$$

$$R = 2.65\ ft^2\text{-hr-F/Btu}$$

$$Uoa = \frac{[1/(2.65+.68+.17)](2.51) + [1/(1.438+.68+.17)](3.326)}{5.836}$$

$$Uoa = 0.37\ (Btu/hr\text{-}ft^2\text{-F})$$