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Evaluation of Thermal Insulating Shutters by Means of a Guarded/Calibrated Hot Box Facility

R.G. Miller R.I. Carey

ABSTRACT

Full-scale guarded/calibrated hot box tests were conducted on two insulated residential walls. One wall contained a double-hung, double-glazed window and the other had a sliding glass door. Both walls were tested alone and with thermal insulating shutters. Tests were run under simulated winter and summer test conditions. Results indicate that the use of thermal insulation shutters reduces heat gain or loss through a noninsulated window/wall system by about 40 percent and through a noninsulated glass door/wall system by about 70 percent.

INTRODUCTION

With the high cost of heating and cooling energy, it has become imperative for the homeowner to look for ways of reducing fuel consumption. Typically, such reductions have been accomplished by adding insulation in the attic, caulking around window and door frames, insulating opaque walls, lowering thermostats, etc. All contribute to reducing the homeowner's fuel usage. However, these methods ignore one of the major areas of heat loss or gain i.e., windows and similar glassed areas. Typically, in houses in the northern half of the United States, about 15 to 35 percent of the total heat loss in winter is through windows.[1] This number may be even higher in passively solar-heated houses since the percentage of window area is usually greater.

There is clearly a need for a thermally effective material that can be incorporated into a thermal shutter to help reduce heat loss or gain through windows. One such product that has found acceptance in the marketplace is the fiberglass-reinforced polyisocyanurate thermal-insulating shutter. This paper discusses the results of large-scale guarded/calibrated hot box tests and compares the effectiveness of these insulating shutters in reducing heat loss or gain through a window/wall system and a sliding glass door/wall system.

DESCRIPTION OF HOT BOX TEST FACILITY

A detailed description of the guarded/calibrated hot-box facility has previously been reported.[2] A brief overview of the facility will be given here.

R. Gerry Miller and Richard I. Carey, Research Associate and Research Technologist, respectively, Jim Walter Research Corporation, 10301 Ninth Street North, St. Petersburg, Florida

The hot-box test facility can operate in either a guarded or a calibrated mode. When operating in the guarded mode, the apparatus is in accordance with ASTM C236-80, Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box.[3] When operating in the calibrated mode, the apparatus is in accordance with the proposed ASTM Test for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box.

The basic design consists of a cold chamber, a hot chamber, a meter box, test specimen frames, a refrigeration unit, and control and data-acquisition equipment, Fig. 1. The hot and cold chambers are insulated with approximately 12-in. (30.5-cm) foil-faced polyurethane foam. The hot-box facility can provide horizontal or vertical (upward or downward) heat flow.

Test specimen size is 8 by 8 ft (2.4 by 2.4 m) with a metered area, in the guarded mode, of 6 by 6 ft (1.8 by 1.8 m). The metered area in the calibrated mode is 8 by 8 ft (2.4 by 2.4 m). The temperature range on the cold side is approximately 80 to -50°F (27 to -46°C), and on the hot side is approximately 50 to 150°F (10 to 66°C). Air velocity (parallel to test specimen) in the hot chamber is approximately 0.5 mph (0.8 km/h) in the guarded mode; in the calibrated mode, it may vary from 0.5 to 15 mph (0.8 to 24 km/h), as it may in the cold chamber in either mode.

Temperatures (hot air and surface, cold air and surface, and inside and outside surfaces of the hot chamber) are measured with 24-gauge multistrand type T (copper-constantan) thermocouples. A total of 120 thermocouples are used to measure hot and cold air and surface temperatures (30 for each). In the guarded mode, 25 of the 30 thermocouples are in the metered area, and five in the guarded area. In the calibrated mode, all 30 are used in the metered area.

The cumulative Watt-hours of electrical energy, required to maintain steady hot-side temperature conditions in the area under test, are measured with a Watt-hour meter. This instrument utilizes two Hall-effect Watt transducers; one measures the heater power and the other the fan power. All temperature and power data are read by a data-acquisition unit, which, in turn, supplies the data to a minicomputer. The computer performs all the required calculations and supplies a hard copy of the final report through a line printer. In the calibrated mode, the computer is also used to control the hot-chamber temperature.

DESCRIPTION OF TEST WALL CONSTRUCTIONS

Two basic walls were tested in this study: one contained a double-hung, double-glazed window and the other a sliding glass door.

Double-Hung Window Test Wall

The test wall containing the double-hung, double-glazed window was constructed of nominal 2- by 4- in. (5- by 10- cm) studs, 16 in. (40.6 cm) on center with a double top plate (attached to the studs and each other with 16d nails) and a single sole plate into which the studs were toenailed with 8d nails. A framed opening for the window was located in the center of the wall. A nominal 2- by 6- in. (5- by 15- cm) header, consisting of two 2- by 6- in. (5- by 15- cm) members spaced 3/8 in. (1 cm) apart with wood strips was used to span the window opening.[4] The unit was held together with 16 d nails. The header was supported at the ends by the inner studs of the double-stud joint and nailed to the outer stud with 16d nails. A single 2- by 4- in. (5- by 10- cm) sill was used.

The wall was insulated with kraft-faced fiberglass batts [R-11, nominal 3-1/2 in. (1.94 $\frac{Km^2}{W}$, nominal 8.9 cm)]. The paper tabs were stapled approximately 8 in. (20.3 cm) apart to the inside surface of the studs.

The small spaces between the rough window framing and window head and between the jambs and sill were stuffed with fiberglass. These insulated cracks were then covered with a 4-mil (0.10 mm) polyethylene vapor barrier.

The interior of the wall was covered with 1/2-in. (1.3-cm) gypsum board. These boards were installed horizontally and attached to the studs with GWB-54 drywall nails spaced 6 in. (15.2 cm) on center. Joint compound was used to cover the nail heads and joint tape covered the horizontal tapered joint. Two coats of white latex paint were applied to the gypsum boards. Molding was then installed around the window frame.

The exterior of the wall was covered with 19/32-in. (1.5-cm) siding. It was installed with 8d wood siding nails spaced 6 in. (15.2 cm) on the perimeter and 12 in. (30.5 cm) in the field.

The completed assembly (test specimen and frame) was placed between the hot and cold chambers. Thermocouples were installed to measure air and surface temperatures at appropriate locations on the window and window frame.

Sliding-Glass-Door Test Wall

The sliding-glass-door test wall was also constructed of 2- by 4- in. (5- by 10- cm) studs, 16 in. (40.6 cm) on center, double top plate, and a single sole plate. The framed opening for the sliding glass door was located in the center of the wall. A nominal 2- by 10- in. (5- by 25- cm) header, made up of two 2- by 10- in. (5- by 25- cm) members spaced 3/8 in. (1 cm) apart with wood strips was used to span the door opening.[5] The whole unit was held together with 16d nails. The header was supported as in the window test wall.

The wall cavity contained kraft-faced fiberglass batts [R-11, nominal 3-1/2 in. (1.94 $\frac{Km^2}{W}$, nominal 8.9 cm)]. The paper tabs were stapled approximately 8 in. (20.3 cm) apart to the inside surface of the studs.

The interior of the wall was covered with 1/2-in. (1.3 cm) gypsum board. Joint compound was used to cover the nail heads and butt joints, and two coats of white latex paint were then applied. The exterior of the wall was covered with 19/32-in. (1.5 cm) siding. Nails and nailing schedules for both sides of the wall were the same as used in the window wall.

The completed assembly was then placed between the hot and cold chambers, and thermocouples were installed to measure air temperatures and appropriate surface temperatures on the glass door.

DESCRIPTION OF THERMAL INSULATING SHUTTERS

The fiberglass-reinforced polyisocyanurate thermal-insulating shutters come in do-it-yourself kits. These kits contain shutter board, plastic framing, and knobs. Adhesive (for attaching plastic framing to shutter board) and knife (for cutting shutter board to installation dimensions) are available separately. Detailed assembly instructions are included in each kit.

Figure 2 shows a cross section of the shutter board. The board consists of a fiberglass-reinforced polyisocyanurate foam core nominal 9/10-in. (2.3 cm) with aluminum foil facers on both sides and covered with a washable vinyl facer.

The window shutters tested were of two styles, a pop-in style and a two-piece movable style (sliding). Figures 3 and 4 show the pop-in and movable styles, respectively, shown installed for testing in the window test wall. The sliding glass door shutter consisted of three hinged panels. When installed, one panel is fixed and will not move. When the shutters are open, the middle and end panels fold back onto the fixed panel. Figure 5 shows the open shutter.

RESULTS OF HOT-BOX TESTS

Ten hot box tests were run in this study. Six were run in the guarded mode (ASTM C236, window test wall) and four, because of the size of the sliding glass door, were run in the calibrated mode.

Double-Hung, Double-Glazed Window Test Wall

Before tests were run on the window test wall, the window was opened and closed several times to ensure that it operated properly. The window was then locked before being tested.

The six tests consisted of a "winter" and a "summer" static temperature test condition for the bare window and for each shutter style (pop-in and sliding). The average air temperatures for the winter test condition were 74.6°F (23.7°C), interior and -1.1°F (-18.4°C), exterior. In the summer test condition, average air temperatures for the interior and exterior were 74.9°F (23.8°C) and 102°F (38.9°C), respectively. Air velocities in the hot and cold chambers were less than 0.5 mph (0.8 km/h) for both test conditions.

Table 1 contains average data for the bare window and for the pop-in and sliding shutter tests for both winter and summer test conditions. The column labeled power indicates the amount of power (in Watts) needed to maintain the specified temperature conditions in the 6- by 6- ft (1.8- by 1.8- m) metered area. This laboratory comparison documents the relative energy loss eliminated with the addition of the fiberglass-reinforced polyisocyanurate thermal-insulating shutters to the base wall assembly (bare window and involved opaque wall area). It is not intended to reflect actual power usage in the field. As can be seen from these data, in the winter test condition, the sliding shutter decreased power use by 38% (compared to the base wall assembly). For the pop-in shutter, power use decreased approximately 46 percent. Under the summer test conditions, the percentages of decrease were slightly greater but were similar to, those in the winter test conditions.

Figures 6 and 7 are pictorial representations of average surface and air temperatures measured during the test. In Fig. 6, the exterior temperature is -0.9°F (-18.3°C) and the interior glass temperature is about 55°F (12.8°C). With the pop-in shutter in place, and at the same exterior temperature, the interior glass temperature drops to about 16°F (-8.9°C) (Fig. 7). Obviously, the shutter is serving its purpose by retarding the heat loss through the window. Similar conditions exist for the sliding shutter.

In the summer tests, the air-temperature conditions are reversed. The addition of the shutters to the interior of the window increases the interior glass temperature. However, this increase is offset by the large temperature drop across the insulating shutter (reduction of heat gain to the interior).

Figure 8 graphically shows the approximate temperature profiles through the insulating shutter/window system for winter test conditions. The more effective insulating shutter is represented by the smaller temperature drop through the glazing. In these tests, the pop-in shutter performed slightly better than did the sliding shutter.

Table 1 also contains the U and R_t (total resistance) values for the three window and involved-wall systems tested. These values apply only to this specific opaque wall area and window system exposed to the specified test conditions. However, the data may be used for comparison, again showing pop-in shutter performance to be slightly better than that of the sliding shutter.

Sliding-Glass-Door Test Wall

The sliding glass door was opened and closed several times to ensure its proper operation and then was locked before testing began. Four tests were run on this wall system, two in a winter test condition and two in a summer test condition (with and without closed shutters). The average air temperatures for the winter test condition were an interior temperature of 75.0°F (23.9°C) and an exterior temperature of 27.6°F (-2.4°C). In the summer test condition, average air temperatures for the interior and exterior were 75.6°F (24.2°C) and 91.7°F (33.2°C), respectively. Air velocities in the hot and cold chambers were less than 0.5 mph (0.8 km/h) in both test conditions.

Table 2 contains the average data for the bare door and shutter tests in both winter and summer test conditions. In the winter test condition, with the insulating shutter in place, there was a 70% decrease in power required to maintain the same temperature conditions as in the bare door test. In the summer test condition, the percentage of decrease was approximately the same.

Figures 9 and 10 are pictorial representations of the average temperature data measured during the test. The addition of the insulating shutter in the winter test condition decreased the interior glass temperature by retarding the heat loss through the glass door. When the shutter was installed in the summer test condition, the interior glass temperature increased because the heat gain to the interior was reduced by the shutter.

Figure 11 shows the approximate temperature profiles through the glass door system with and without the installed thermal insulating shutters for winter test conditions.

Table 2 also contains the U and R_t values for the two sliding-glass-door and involved-wall systems tested. These values apply only to this specific opaque wall area and sliding glass door system exposed to the specified test conditions.

CONCLUSIONS

A series of full-scale guarded/calibrated hot box tests were conducted on a double-hung, double-glazed window/wall system and a glass door/wall system under laboratory simulated winter and summer static temperature test conditions. Tests were conducted both with and without thermal insulating shutters. In the window/wall system, two styles of shutters, pop-in and sliding, were tested. The pop-in shutter, which reduced the heat gain/loss through the bare window/wall system by about 40 percent, performed slightly better than the sliding shutter. In the glass door/wall system, a bifolding insulating-shutter style was tested. Heat gain/loss was reduced by about 70 percent, compared with the bare door, when the thermal insulating shutter was installed.

REFERENCES

1. W. A. Shurcliff, Thermal Shutters and Shades (Andover, MA: Brick House Publishing Co., 1980).

2. R. G. Miller, E. L. Perrine, and P. W. Linehan, "A Calibrated/Guarded Hot Box Test Facility," Thermal Transmission Measurements of Insulation [ASTM STP 660], R. P. Tye, Editor (New York: American Society for Testing and Materials, 1978), pp. 329-341.

3. 1981 Annual Book of ASTM Standards, Part 18 (New York: ASTM 1981), pp. 77-88.

4. U. S., Department of Agriculture, Wood-Frame House Construction [Handbook No. 73] by L. O. Anderson (Washington, D.C.: Government Printing Office, 1975).

5. Anderson, 1975.

TABLE 1

Window/Wall Test Data

Test description	Condition	Hot air[a] °F	Cold air[a] °F	Mean[a] °F	Power (watts)	Power usage vs. base wall (%)	Reduction (%)	U-value[b] $\frac{Btu}{°F\ ft^2\ h}$	R_t-value[c] $\frac{°F\ ft^2\ h}{Btu}$
Bare window	winter	74.7	-0.9	36.9	149.9	100.0		0.188	5.34
Pop-in shutter	winter	74.8	-1.1	36.9	80.1	53.4	46.6	0.100	9.99
Sliding shutter	winter	74.5	-1.1	36.7	92.4	61.6	38.4	0.116	8.63
Bare window	summer	101.8	74.7	88.2	55.0	100.0		0.192	5.22
Pop-in shutter	summer	101.7	75.2	88.4	28.8	52.4	47.6	0.102	9.71
Sliding shutter	summer	102.6	74.8	88.7	32.2	58.5	41.5	0.109	9.08

TABLE 2

Sliding Glass Door/Wall Test Data

Bare door	winter	75.0	27.9	51.4	486.8	100.0		0.549	1.82
Shutter	winter	75.0	27.3	51.1	144.7	29.7	70.3	0.162	6.19
Bare door	summer	92.1	75.7	83.8	169.7	100.0		0.548	1.82
Shutter	summer	91.2	75.6	83.5	44.7	26.3	73.7	0.151	6.59

a $°C = 5/9\ (°F-32)$

b $1\ W/Km^2 = 0.1761\ Btu/°F\ ft^2\ h$

c $1\ Km^2/W = 5.678\ °F\ ft^2\ h/Btu$

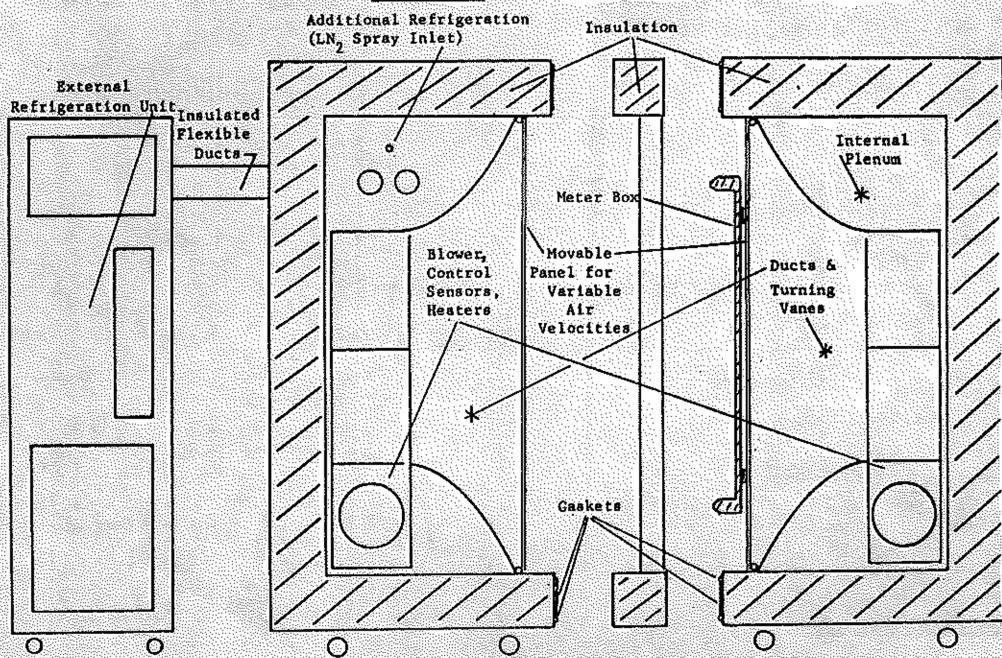

Figure 1. Schematic of JWRC Hot Box Facility

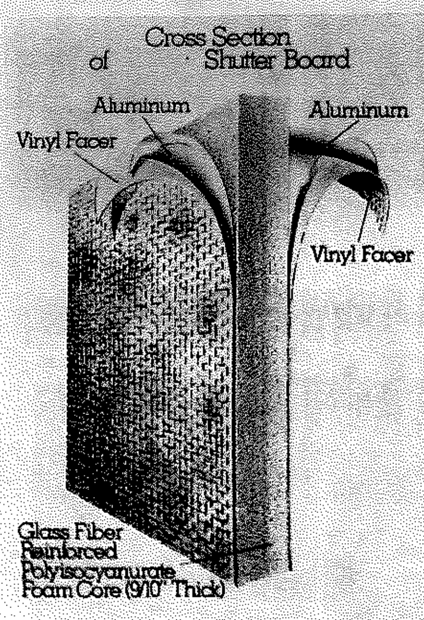

Figure 2. Cross-Section of Thermal Shutter

Figure 3. Installation of Pop-In Shutter

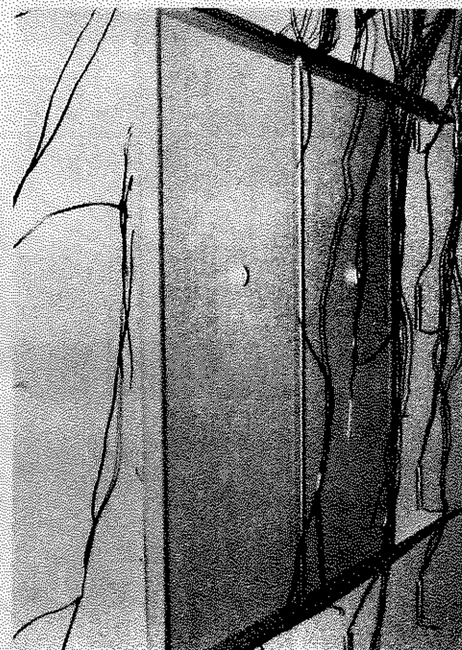

Figure 4. Installation of Sliding Shutter

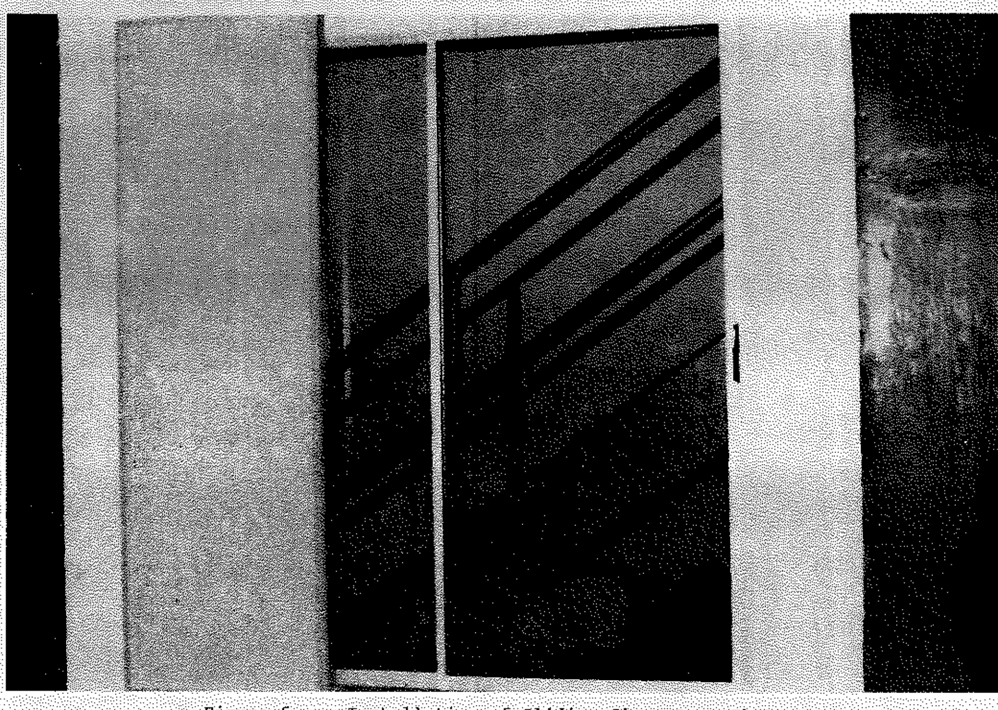

Figure 5. Installation of Sliding Glass Door Shutter

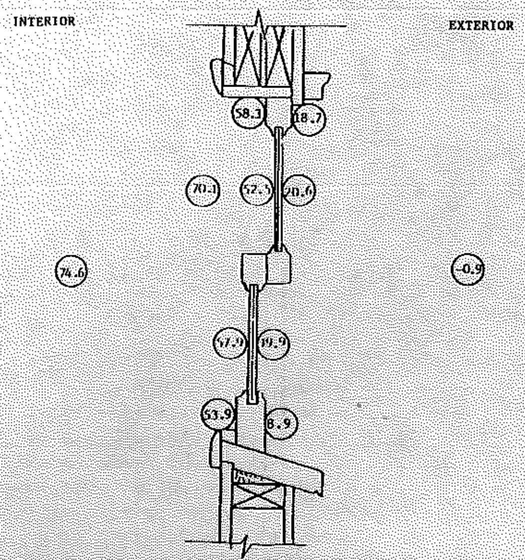

Figure 6. *Bare Window - "Winter"*

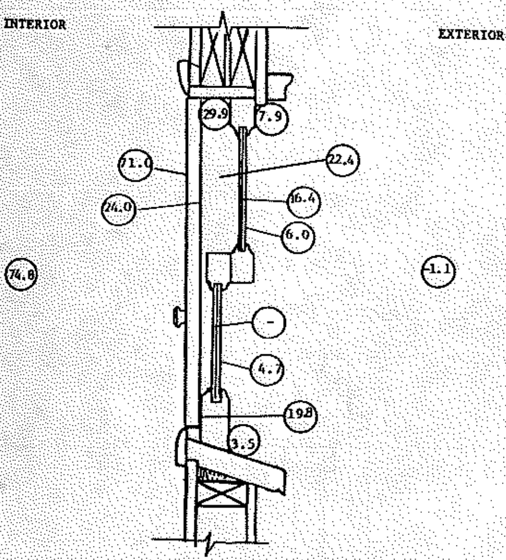

Figure 7. *Pop-In Shutter - "Winter"*

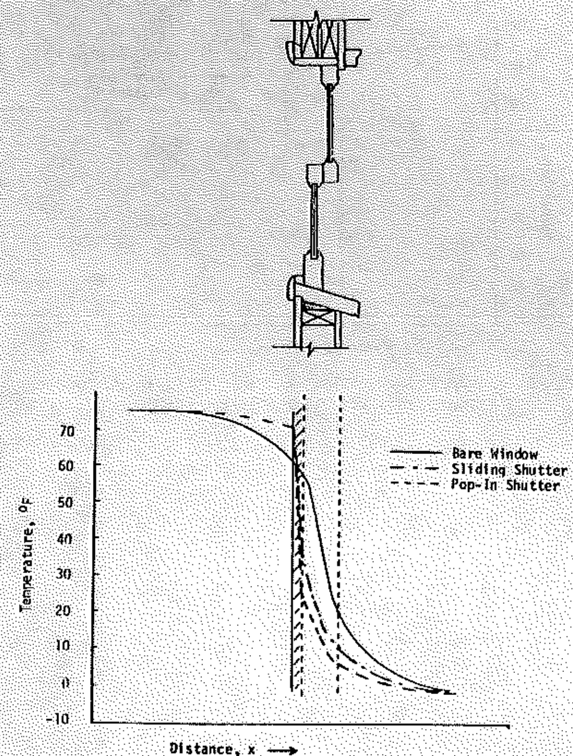

Figure 8. *Approximate Temperature Profiles through Shutter/Window System -"Winter"*

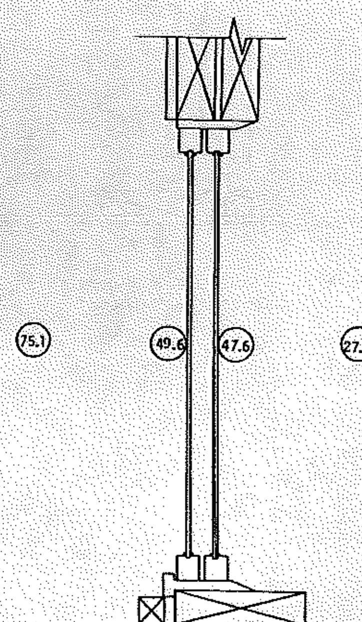

Figure 9. *Bare Sliding Glass Door - "Winter"*

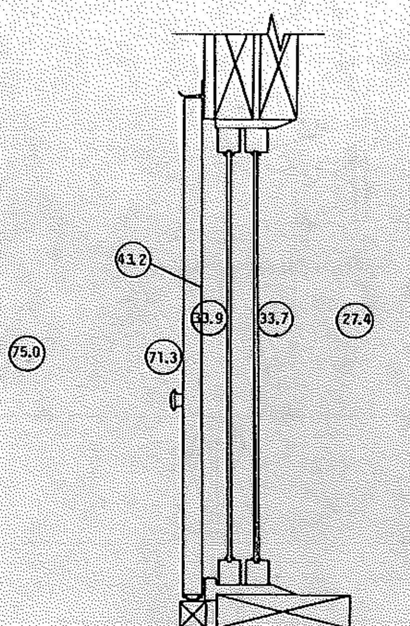

Figure 10. *Sliding Glass Door Shutter - "Winter"*

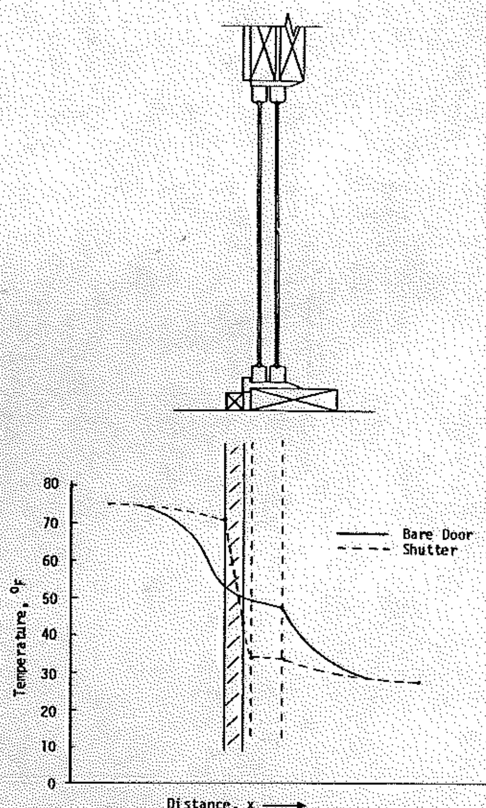

Figure 11. *Approximate Temperature Profiles through Shutter/Glass Door System -"Winter"*

Discussion

S. Selkowitz, Lawrence Berkeley Lab., Berkeley, CA: Please comment on the possibility of glass breakage with tight-fitting, highly insulated interior shutters under two conditions:

1. Summer, with direct sun on the window, with shutter in place; and
2. Winter, under very cold outdoor conditions, with shutter suddenly removed, exposing cold glass to indoor air at 70°F.

Miller:

1. No tests were conducted under these conditions.

2. The "winter" tests reported on in this paper were for exterior air temperatures of approximately 0°F and 27°F (Tables 1 and 2), respectively. Interior air temperature for both systems was about 74°F. Under these conditions, removing the shutters after the tests and exposing the cold glass to the warm indoor air did not result in any damage to the glass. Tests were not run under colder conditions.

G.M. Hughes, Bonneville Power Administration, Seattle, WA: What U-or R-value did you assign to the shutter material?

Miller: One inch of shutter material has an R-value at 75°F of 7.20 h ft 20 F/Btu.

R.R. Jones, National Bureau of Standards, Washington, D.C.: Could you comment on air movement on each side of the test specimen?

R.G. Miller: In the guarded mode (window/wall), the air movement on the cold surface was horizontal, (left to right). In the meter box the air moved from top to bottom and in the guard box, air moved gently over the meter box in a horizontal direction (right to left).

In the calibrated mode (sliding glass door/wall), air movement on the cold surface was the same as above. On the hot surface, air movement was opposite to that on the cold surface, right to left.

In all cases, air velocities were less than 0.5 mph.

For more information: "A Calibrated/Guarded Hot-Box Test Facility", by R.G. Miller, E.L. Perrine and P.W. Linehan, Thermal Transmission Measurements of Insulation, ASTM STP 660, pp. 329-341.

J.H. Klems, Lawrence Berkeley Lab., Berkeley, CA: What was the size of heat flow through the wall relative to that through the window for your wall window test? What is the accuracy of your power measurement? How big is the heat flow through the walls of the metering box?

R.G. Miller:
a. Only the total heat flow through the window/wall and sliding glass door/wall systems was measured. See Tab 1 and 2.
b. The accuracy of the watt hour meter is $\pm$ 0.5 percent.
c. The heat flow through the walls of the metering box is kept to a minumum by use of a null balance differential controller. A temperature difference across the insulated walls of the meter box isused to control the temperature of the hot chamber (guard area) to the meter box temperature. The actual heat flow through the walls was not measured.