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COLD-WEATHER PERFORMANCE OF HINGED EXTERIOR DOORS

BY

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LE COMPORTEMENT PAR TEMPS FROID DES PORTES D'ENTREE SUR CHARNIERES

SOMMAIRE

Les portes d'entrée traditionnelles sur charnières utilisées dans les constructions résidentielles sont constituées presque exclusivement de bois. Les portes d'entrée isothermiques à parement d'acier offrent une autre possibilité, mais une condition importante de leur adoption est leur comportement par temps froid. Puisqu'il n'existe actuellement aucune norme de fonctionnement permettant d'évaluer les portes de ce genre, la Société centrale d'hypothèques et de logement a demandé à la Division de recherches en bâtiment de mettre au point des directives pour l'évaluation du comportement par temps froid des portes d'entrée sur charnières d'une part et des portes à parement d'acier en particulier. La Division a entrepris une étude en laboratoire d'un certain nombre de portes en bois et à parement d'acier en vue de caractériser le comportement par temps froid des portes d'entrée sur charnières.

Cold-weather performance of hinged exterior doors

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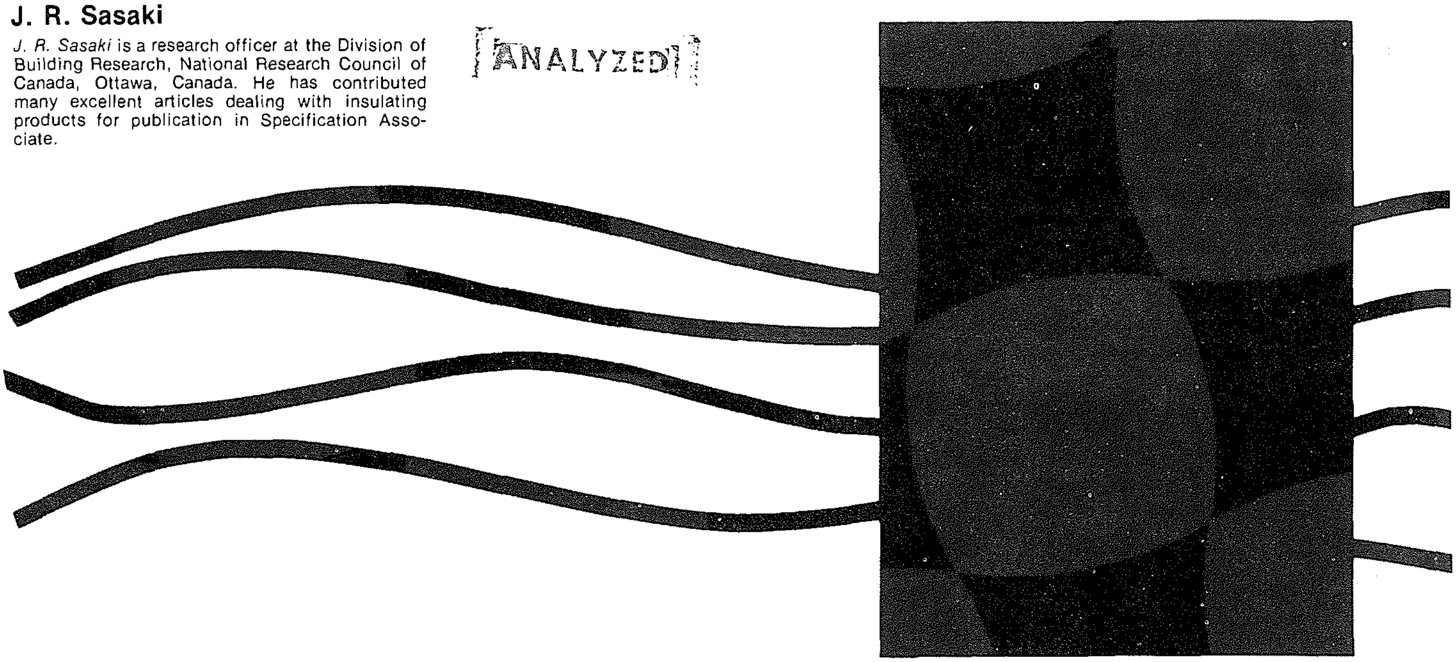


Traditionally, hinged exterior doors used in residential construction have been made almost exclusively of wood. An alternative has recently been offered in the form of insulated steel-clad exterior doors, but a prime consideration of their acceptance is their performance in cold weather. As there is currently no performance standard for assessing such doors, the Division of Building Research was asked by Central Mortgage and Housing Corporation to develop guidelines for evaluating the cold-weather performance of hinged exterior doors in general, and steel-clad doors in particular. The Division initiated a laboratory investigation on a number of steel-clad and wood doors to determine the factors that describe the cold-weather performance of hinged exterior doors.

Cold-weather performance

The cold-weather performance of an openable element such as a hinged exterior door is described by its resistance to heat loss, condensation and air leakage.

(1) The over-all heat-loss resistance is controlled primarily by the thermal resistance of the core of the door panel and by the number of panes of glass used in any glazed opening. It is also affected by the construction of the edge of the door panel, especially where the edge of the panel is covered with sheet metal that can provide a continuous heat-flow path between the indoor and outdoor environments.

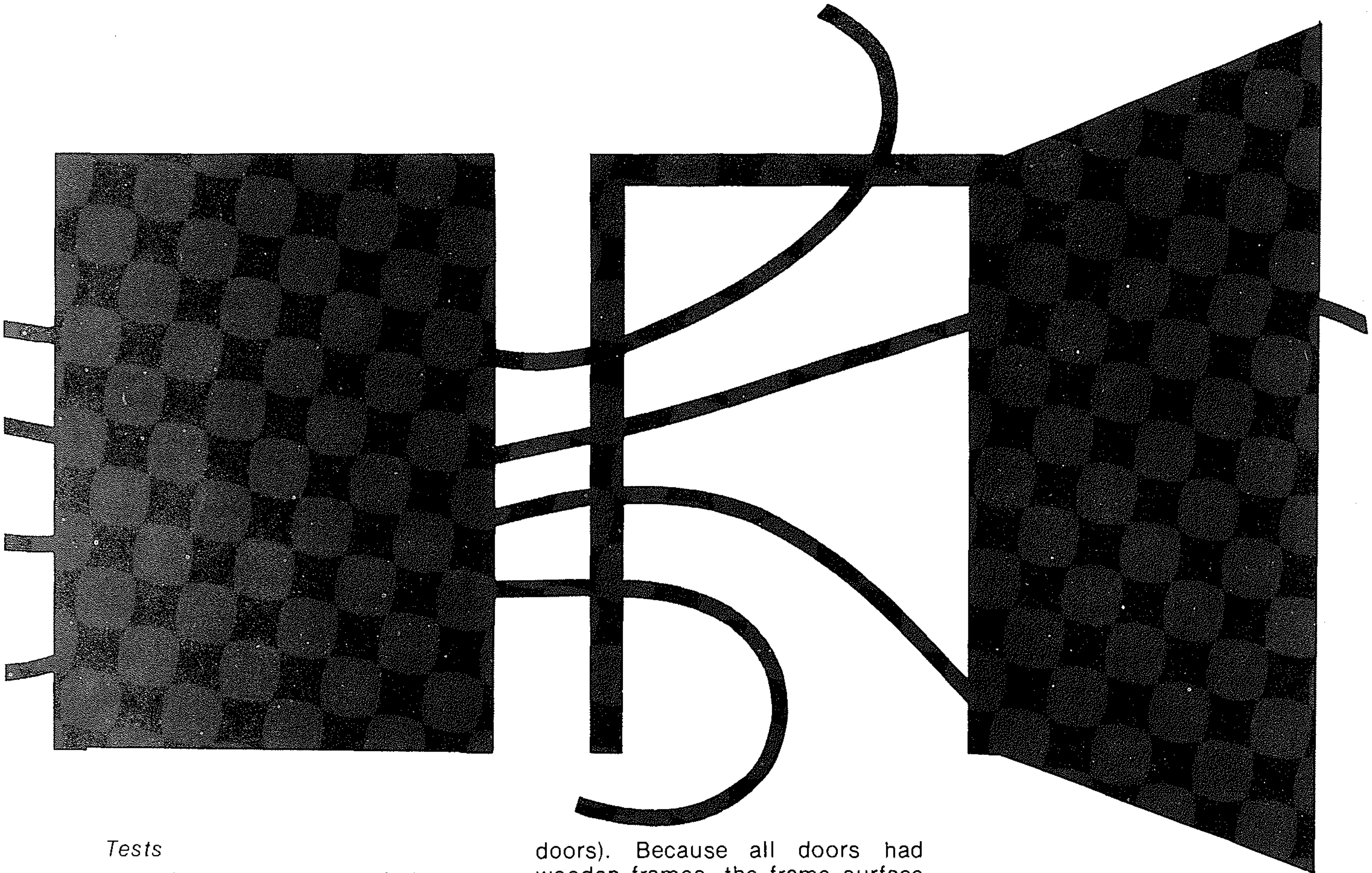
(2) Condensation resistance is controlled by the construction of the edge of the door panel, the thermal conductivity of the inner skin of the door panel, and the number of panes of glass in any glazed opening.

(3) The air leakage resistance is affected by the warpage characteristic of the door panel under a temperature difference and by the type of weatherstripping used between door panel and door frame. The warpage characteristic of the door panel is dependent on the thermal expansion coefficient of the inner and outer skins of steel-clad door panels; and on the moisture content of the core of wood door panels. The performance of the weatherstripping is dependent on its type — it can be either a "face" weatherstrip or an "edge" weatherstrip; on its resiliency under cold conditions; and on its resistance to cracking and tearing under extremely cold conditions.

The cold-weather performance that should be required of a door depends to a large extent on the way the door is to be used in a building. One that is to be used in combination with an outer storm door does not require the same levels of performance as one that is to be used alone. Similarly, a door that is to be used in conjunction with a vestibule and inner door does not require the same performance as one that is to be used alone. In the current study it is assumed that the door provides the only separation between indoors and outdoors, regardless of whether it is steel clad or wood. That is, the door is intended to provide the maximum resistance to heat loss, condensation and air infiltration.

Test specimen

Three steel-clad doors were obtained as factory-assembled units, including door panel, wood door frame and weatherstripping. Four wood door panels and the wood door frames and weatherstripping were assembled in the laboratory (Table I). The features of the test doors are shown in Figures 1 and 2; types of weatherstripping, in Figure 3. Wood door W1 was tested with four different weatherstripping arrangements, and the remaining doors with only one weatherstripping arrangement. Wood doors, W2, W3, and W4, were said to conform to the Canadian Standards Association wood door standard, CSA 0132.2-1969; this standard contains no performance requirements.



Tests

The doors were tested in the DBR/NRC environmental facility. Each door assembly was subjected to the following test sequence:

(a) measurement of the air leakage through the door with both faces of the door exposed to air at 72°F. (isothermal conditions);

(b) measurement of the warpage of the door panel relative to the frame, with room-side air at 72°F. and weather-side air lowered to and held at —10°F. for one to three weeks;

(c) measurement of the temperatures on the exposed room-side face of the door panel, with room-side air at 72°F., weather-side air at —10°F., and no air leakaage;

(d) measurement of the air leakage through the door after exposure to room-side air at 72°F. and weather-side air at —10°F. for more than one week;

(e) measurement of warpage of the door panel with the weather-side air at —40°F.; and

(f) determination of the physical behavior of the weatherstripping with the weather-side air at —40°F. and the room-side relative humidity in excess of 20 per cent.

Room-side surface temperatures were measured with copper-constantan thermocouples attached to the inside face of each door panel (zero air leakage through the doors). Because all doors had wooden frames, the frame surface temperatures are not reported. Surface conductance values at the room-side and weather-side faces of the doors were approximately 2 and 5 Btu/hr. ft.^{2}°F., respectively, when the weather-side air temperature was controlled at —10°F. or —40°F.

Door air leakage was measured as follows: an airtight chamber was sealed to the room-side face of the door frame. The chamber was connected by an air hose to a laminar flow meter, connected in turn by an air hose to the intake side of an air blower. The blower sucked air from the weather-side box through the door into the chamber and then through the flow meter. Door air leakage measured with a weather-side air temperature of —10°F. was corrected to flows that would have occurred with an air temperature of 72°F. in order that these leakage values would be comparable to those obtained under isothermal conditions. Correction was as follows:

$$\text{Leakage at } 72°\text{F.} = (\text{Door leakage at } -10°\text{F.}) \times \sqrt{\frac{532°\text{R}}{450°\text{R}}}\ \text{cfm}$$

Warpage of the door panel was measured with dial gauges mounted on steel bars. These, in turn, were anchored to the door frame. (Warpage is the movement of the door panel that occurs when the weather-side air temperature is changed from 72°F. to —10°F.)

The resiliency of weatherstripping at extremely cold outdoor temperatures was determined visually and by touch. The tear and cracking resistance of the weatherstripping was determined by opening and closing the door hard 10 to 20 times after frost had formed between the edge of the door panel and the door frame.

Test results

A summary of the test results is given in Table II; and examples of the variations in surface temperature over the room-side surface of four door panels are shown in Figure 4. Typical warpage values for one steel-clad door and one wood door are shown in Figure 5.

Thermal resistance

Thermal resistance values listed in Table II are estimates only, based on the conductances of the core materials. The heat-loss resistance values of the steel-clad door panels are more than twice those of the wood door panels. This is reflected in the high surface temperatures over the central portion of the steel doors compared with the centre surface temperatures of the wood doors (Figure 4).

Minimum surface temperatures

Minimum surface temperatures measured on the wood door panels were relatively warm, varying from 44.5 to 51°F. It should be noted (Figure 4) that the minimum temperatures on the hollow-core door occurred a few inches above the bottom edge of the door panel and not at the edge, illustrating the typical surface temperature depression that occurs at the bottom of a vertical air space experiencing convective heat loss.

Minimum temperature on the steel door S3 was higher than the minimums on the wood doors, although the construction of the edge of the door panel was similar to that of the wood doors. This is explained by the fact that the steel inner skin conducted heat from the warm central portion to the edge. Steel door S2 was slightly colder along the bottom edge than were the wood doors because the aluminum weatherstrip holder at its bottom edge acted as a partial thermal bridge from the outer to the inner steel skin. The coldest minimum surface temperature was measured on steel door S1, which had almost no thermal separation at the edges between the inner and outer steel skins.

A useful comparison can be made between the minimum temperatures measured on the doors and the minimum temperature permitted by current window standards on the inside surface of residential aluminum windows. Under the same conditions of test the minimum inside-surface temperature permitted by the Canadian Government Specifications Board residential window standard (CGSB 63-GP-3a) is approximately 30°F. The minimum temperatures measured on all the doors except S1 were well above this limit.

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TABLE 1 DESCRIPTION OF TEST DOORS

DESIGNATION	CONSTRUCTION OF DOOR PANELS	WEATHERSTRIPPING (w/s)
S1	Steel-clad panel, with core of paper honeycomb and foam urethane	Plastic face w/s (1)* along head and jambs Plastic wiper (7) along sill
S2	Steel-clad panel, with foam urethane core	Aluminum edge w/s (5) along head and jambs Plastic wiper (8) along sill
S3	Steel-clad panel, with foam urethane core	Plastic magnetic face w/s (3) along head and lock jamb Plastic corner w/s along hinge jamb Plastic wiper (9) along sill
W1	Wood door with hollow core and horizontal wood spacers	(a) Plastic edge w/s (6) along head and jambs Plastic wiper (10) along sill (b) Bronze edge w/s (4) along head and jambs Plastic face w/s (11) along sill (c) Plastic face w/s (2) along head and jambs Plastic face w/s (11) along sill (d) Aluminum edge w/s (5) along head and jambs Aluminum and plastic threshold (12)
W2	Wood door with hollow core and horizontal wood spacers	Aluminum edge w/s (5) along head and jambs Aluminum and plastic threshold (12)
W3	Wood door with solid core of platewood (or chipwood) with horizontal tubular holes	Aluminum edge w/s (5) along head and jambs Aluminum and plastic threshold (12)
W4	Wood door with solid core of wood planks	Aluminum edge w/s (5) along head and jambs Aluminum and plastic threshold (12)

*Numbers in parenthesis refer to the type of weatherstripping installed in the door (see Figure 3).

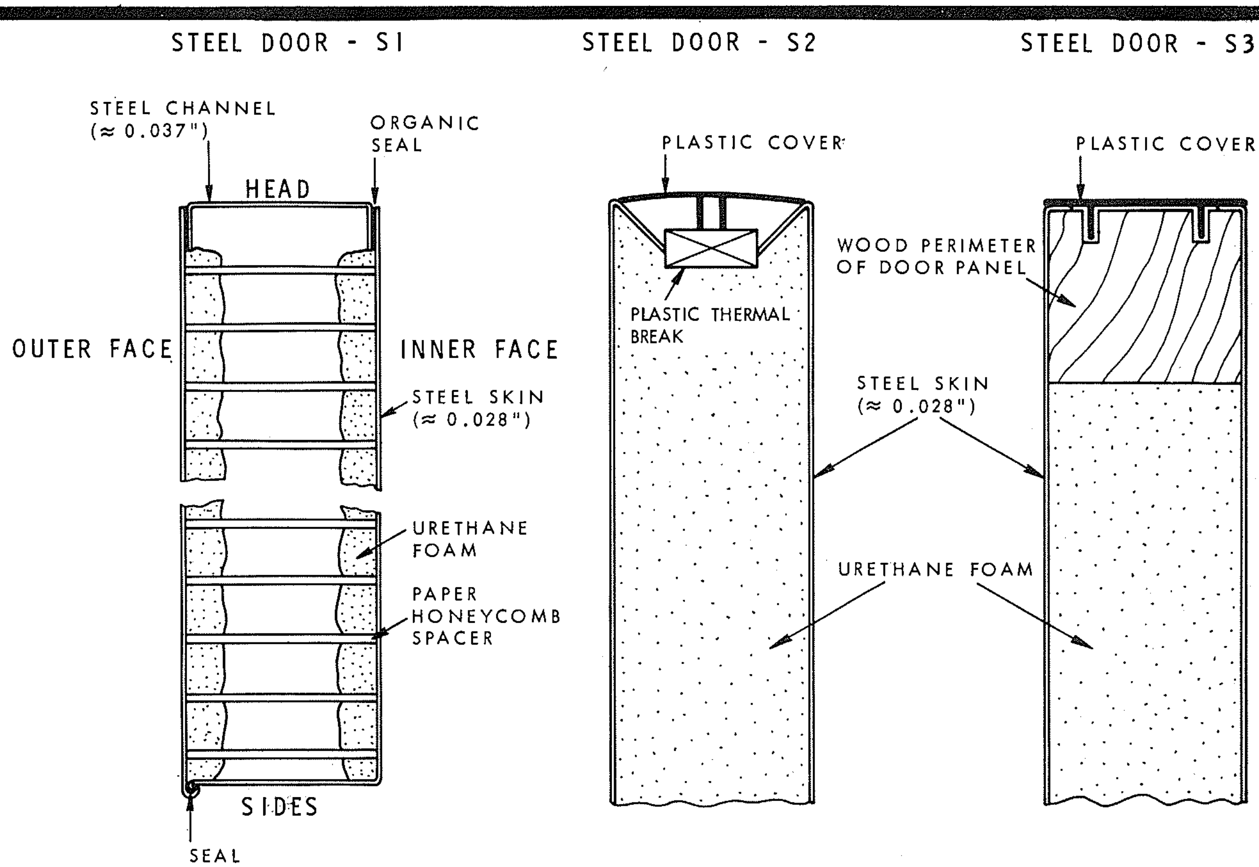

FIGURE 1 DETAILS OF STEEL-CLAD DOOR PANELS (CROSS-SECTIONAL VIEWS)

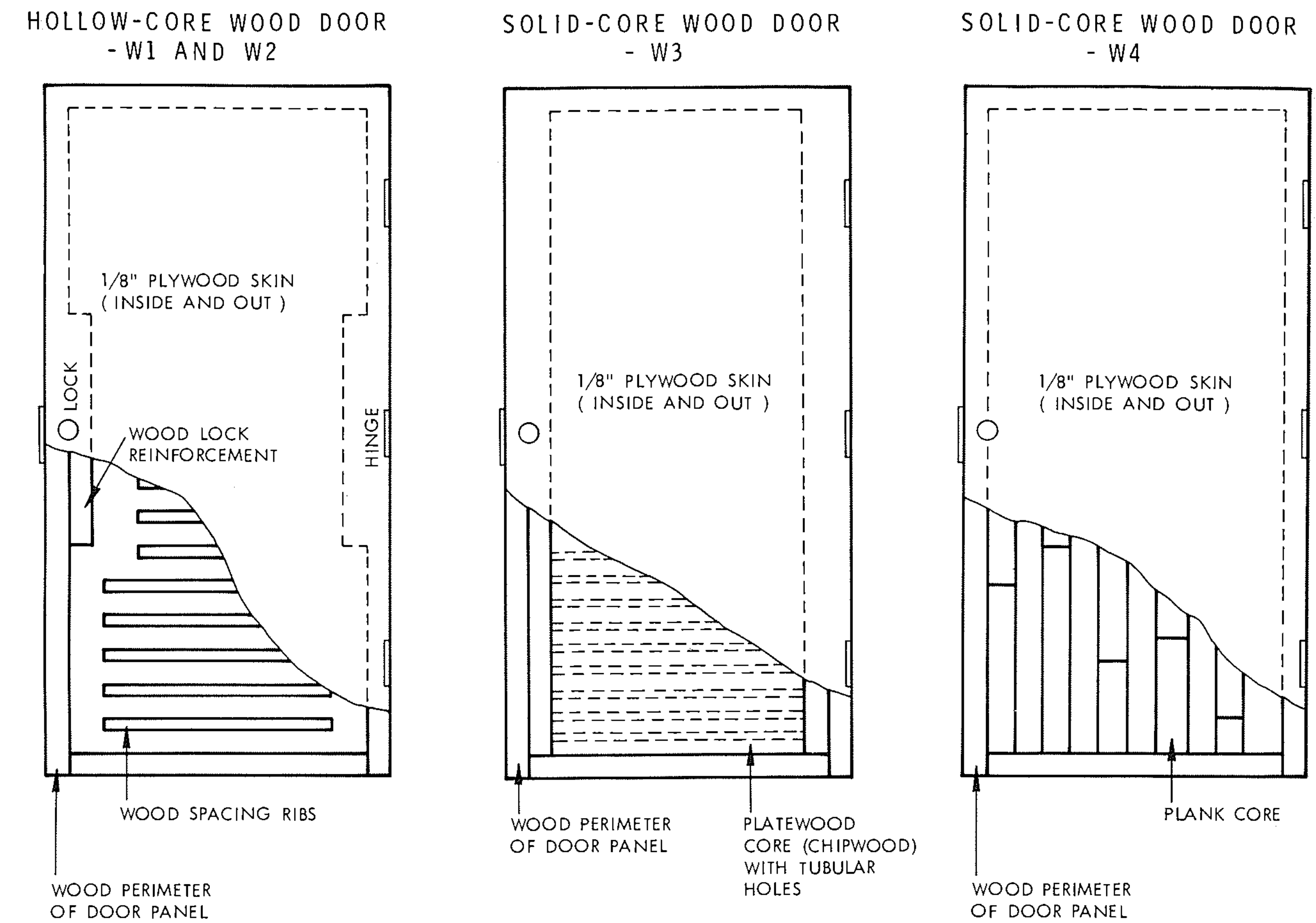

FIGURE 2 DETAILS OF WOOD DOOR PANELS (VIEWED FROM ROOM SIDE)

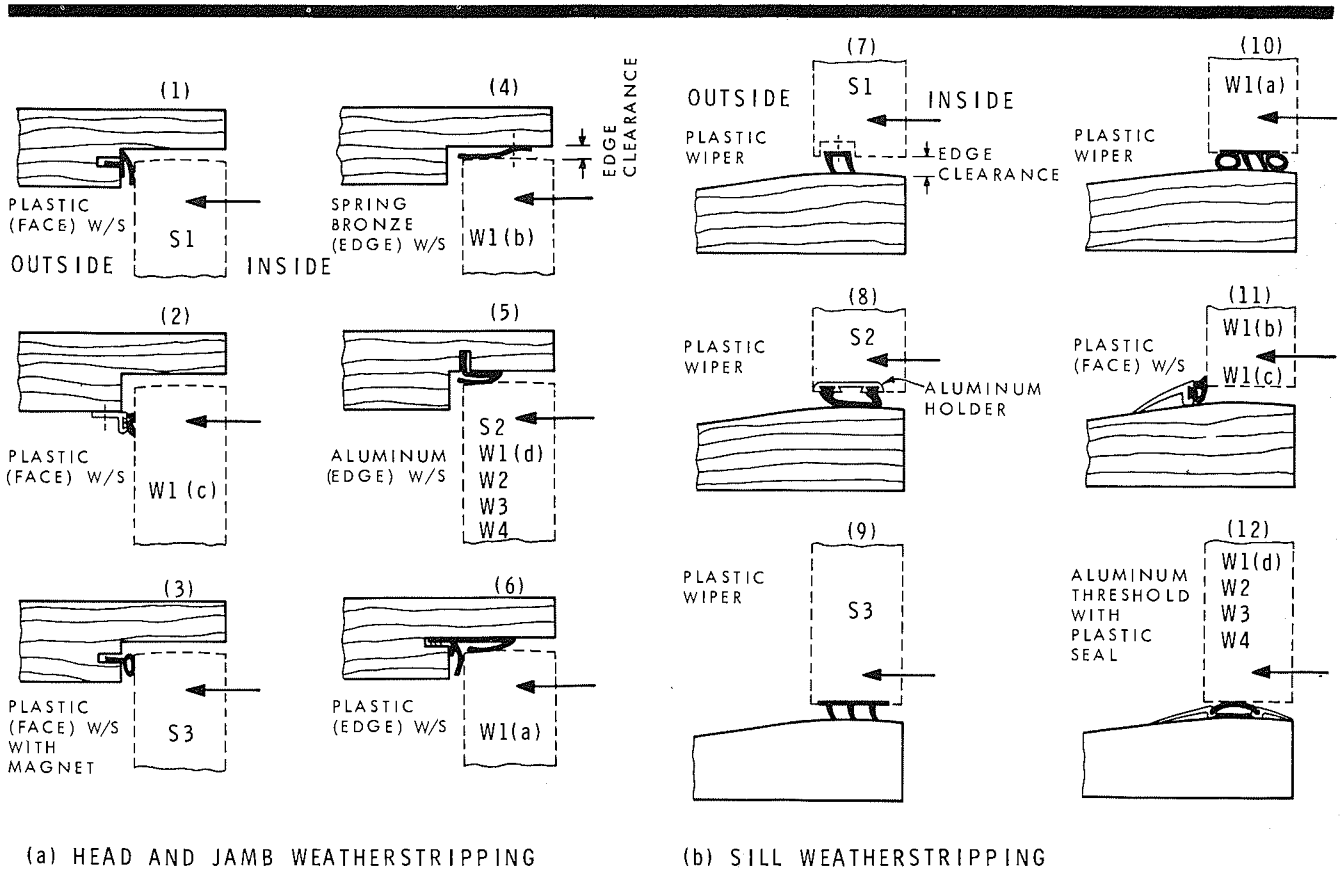

FIGURE 3 DETAIL OF WEATHERSTRIPPING

Warpage, weatherstripping and airtightness

The warpage characteristic of the steel-clad door panels differed in many respects from that of the wood door panels. Steel-clad panels warp as a result of differential thermal contraction of the inner and outer steel skins. As it is colder than the inner skin, the outer skin undergoes greater contraction and this difference in contraction cups the door panel outwards; that is, the top and bottom edges of the panel are pushed into the door frame while the middle of the door is pushed into the room (Figure 5). Warpage from thermal contraction occurs as rapidly as the change in skin temperature. Another characteristic feature of steel-clad doors is the small warpage experienced; the largest measured was less than 0.10 in. As a consequence of the relatively small warpage and of its direction, the air leakage characteristic of the steel-clad doors under cold outdoor conditions is not too different from the leakage characteristic under isothermal conditions.

The wood door panels experience much greater warpage than the steel doors.Warpage also occurs more slowly, and in the opposite direction; that is, the top and bottom edges of the panel pull away from the door frame into the room. Warpage of wood door panels is due to moisture movement caused by a temperature gradient rather than by thermal expansion and contraction. Residual water in the door and water vapour from the room move through the door towards the cold side so that the outer or cold skin of the door achieves a higher relative humidity than the inner skin. As wood expands with an increase in relative humidity, the outer skin of the wood door expands in relation to the inner skin and warps the panel inwards. Moisture migration through wood is very slow, and warpage therefore continues to change for many weeks. Most of the air leakage tests on the wood doors were performed within three weeks of the commencement of warpage. The doors did not, therefore, indicate as much leakage as they might have done if the tests had been conducted after a longer period of exposure to the conditions that cause warping.

Because of its large warpage potential, the airtightness of a hinged wood door under cold weather conditions depends very much on the type of weatherstripping installed on it. To provide good airtightness, a weatherstrip must be capable of maintaining contact with the door panel when the panel warps. The tests show that, in general, "edge" weatherstripping maintains better contact with a warping door than "face" weatherstripping. Doors S2, W1(d), W2, W3 and W4, with edge weatherstripping, show much smaller changes in leakage characteristics with changes in outdoor temperature than doors W1(a) and W1(c) with face weatherstripping.

Exceptions were doors S3 and W1(b). Steel door S3 had a very flexible plastic face weatherstrip which had a magnetic insert. The magnet maintained contact between the weatherstrip and the steel skin of the door panel as it warped so that the leakage characteristic remained unchanged at cold outdoor conditions. Wood door W1(b) had an edge weatherstrip, but it experienced a noticeable change in leakage characteristic with changing outdoor temperature because the edge clearance between the door panel and the door frame was too large to be properly sealed with the spring bronze weatherstrip, even at isothermal conditions. Warpage resulting from a drop in outdoor temperature was enough to reduce contact between weatherstrip and door panel to a point where extensive leakage resulted.

It is important to recognize that face weatherstripping will provide greater airtightness than edge weatherstripping if the door exhibits very little warpage. For warping doors such as the wood doors tested, however, edge weatherstripping will give better airtightness under cold weather conditions.

Regardless of the type of weatherstripping, an important factor in the ultimate tightness of hinged doors is proper edge clearance between the door panel and the frame. Too small a clearance will cause binding of the door panel in the frame and tend to tear wiper-type sill weatherstripping. Too large a clearance will cause excessive leakage. As a better fit can be made between door panel and frame in a factory-assembled door than in a site-assembled door, it is desirable to market doors as an assembled unit of panel, frame and weatherstripping rather than as separate components.

The relative magnitude of the door air leakage values measured in this study can be better appreciated by comparing them with the leakage permitted in residential windows. The Canadian Government Specifications Board standard, CGSB 63-GP-3a, for residential aluminum sliding windows and the Canadian Standards Association standard, CSA 0132.1, for wood windows both permit a leakage rate of 3/4 cu. ft. per min. per ft. of sash perimeter at a pressure difference of 0.30 in. of water. If this same limitation were applied to a door with a perimeter of 20 ft. 8 in., the maximum leakage permitted would be 15.2 cfm. With the exception of wood doors W1(a), W1(b) and W1(c), all the door and weatherstripping combinations tested were as airtight as the windows currently accepted for use in Canadian residential construction.

Extreme cold-weather behavior of weatherstripping

The final test performed on all doors was to open and close each one repeatedly, with the weather-side air temperature at —40°F. and frost formation between the door panel and door frame. None of the weatherstripping showed a tendency to tear away from the frame when the frosted doors were opened and closed repeatedly.

The flexible vinyl weatherstrips (w/s 1, 2, 3, 7, 8, 9, 11 and 12) lacked resiliency at —40°F. and their effectiveness as an air sealer was reduced. Lack of resiliency, however, did not cause the weatherstrips to crack. Although cracking did not accur in this study, however, it is conceivable that plastic weatherstrips will be torn or cracked in actual installations. A plastic sill weatherstrip installed with insufficient clearance between the sill and the bottom edge of the door panel can be squeezed too tightly on closing. With loss of resiliency at very cold outdoor temperatures the weatherstrip will be unable to withstand squeezing and may, therefore, be torn or cracked.

Summary of test results

(1) An insulated steel-clad door has a much greater resistance to heat loss and has generally a warmer inside surface than a wood door. With the exception of steel door S1, the condensation resistance of the steel-clad doors that were tested is comparable to that of the wood doors tested and is much higher than the condensation resistance of metal windows

currently used in residential construction.

(2) The warpage experienced by steel-clad doors under cold weather conditions is much less than that of wood doors. Satisfactory airtightness can be achieved, therefore, with either edge weatherstripping or face weatherstripping.

(3) The warpage of wood doors under cold weather conditions is so large that satisfactory airtightness can only be achieved with edge weatherstripping. Good airtightness also requires a door panel that fits the door frame without excessive edge clearance.

(4) Steel-clad doors with either edge or face weatherstripping and wood doors with edge weatherstripping are as airtight as windows currently used in residential construction.

(5) Extremely cold outdoor air temperatures (approximately —40°F.) do not appear to have a deleterious effect on the airtightness of metal weatherstripping.

(6) Vinyl plastic weatherstrips tend to harden at extreme outdoor temperatures, thereby losing some of their effectiveness as a weather seal. In a door with proper edge clearance between the door panel and door frame, however, there does not appear to be a high risk of cracking or tearing of the weatherstrip.

Conclusions

The current study conducted at DBR/NRC shows that the cold-weather performance of steel-clad door panels with some form of thermal break at the edges is equal to or better than that of wood doors now used in residential construction. The study also shows that the heat-loss resistance, condensation resistance, and airtightness of the majority of the doors investigated are equivalent to or better than the performance of windows used in residential construction.

There is an evident need for a performance standard for factory-assembled, hinged, exterior doors, both wood and steel clad, that are intended to be used alone, that is, without a storm door or an inner vestibule and door. The cold-weather performance requirements that should be included in such a standard are a minimum permissible thermal resistance for the door panel, a minimum permissible inside-surface temperature, and a maximum permissible air leakage value. The door frame should be required to meet the same surface temperature limit as the door panel. Glazed openings should be required to have double glazing and should be restricted in area.

The airtightness of wood doors with face weatherstripping should be required to be evaluated with a temperature difference across the door. The airtightness of wood

TABLE II

SUMMARY OF TEST RESULTS*

TEST DOOR	THERMAL RESISTANCE OF DOOR PANEL (hr ft² °F/Btu)	MINIMUM INSIDE SURFACE TEMPERATURE (°F) t_c = -10°F	WARPAGE (in.) t_c = -10°F	AIR LEAKAGE (cfm ΔP = 0.30 in. water) t_c = 72°F	t_c = -10°F
S1	> 4	26.5°F at bottom hinge-side corner	-0.050 in.	9	11.7
S2	> 6	44°F at bottom lock-side corner	-0.09 in. at top lock-side corner	5.8	9.2
S3	> 6	52.5°F at bottom lock-side corner	-0.09 in.	2.1	2.2
W1(a)	1.5	45.5°F along centreline, 1 in. above bottom edge	0.19 in. prior to leakage test (20 days) 0.24 in. maximum (26 days)	2.6	16.2
W1(b)	1.5	46°F along centreline, 6 in. above bottom edge	0.12 in. prior to leakage test (6 days) 0.17 in. maximum (9 days)	13.6	38
W1(c)	1.5	46°F along centreline, 6 in. above bottom edge	0.17 in. prior to leakage test (22 days) 0.19 in. maximum (29 days)	2.2	>65
W1(d)	1.5	44.5°F along centreline, 1 in. above bottom edge	0.12 in. prior to leakage test (5 days) 0.13 in. maximum (12 days)	12.7	14.6
W2	1.5	45°F along centreline, 6 in. above bottom edge	0.335 in. prior to leakage test (22 days) 0.35 in. maximum (29 days)	8.2	10.7
W3	1.5	46.5°F along centreline, at bottom edge	0.19 in. prior to leakage test (13 days)	9	11.4
W4	2.0	51°F along centreline, at bottom edge	0.04 in. prior to leakage test (5 days) 0.16 in. maximum (12 days)	10.3	11.0

*Notes: (1) Door air leakage (corrected to flow at 72°F) = cubic feet per minute
Total permissible leakage ≃ 15.2 cfm (assuming permissible rate for windows, 3/4 cfm/ft, and leakage perimeter of 20 ft 8 in.)

(2) Warpage = movement of door panel when weather-side air temperature changed from 72°F to -10°F
= (+ ve), when movement towards room-side
= (- ve), when movement towards weather-side
Warpage greatest at bottom lock-side corner, except for S2
Warpage of steel doors stabilized in less than 1 day
Warpage of wood doors continued to increase; number of days at -10°F indicated in bracket

(3) Weather-side air temperature = t_c
Room-side air temperature = 72°F

doors with edge weatherstripping and the tightness of steel-clad doors can be evaluated under isothermal conditions. The thermal resistance to be required of a door should be based on the severity of the climate in the region in which the door is to be used; that is, a door used in the mild climate of Southern Ontario need not have as large a thermal resistance as one used in Western Canada where the winters are more severe.

A door to be used in combination with an outer storm door or inner vestibule and door will generally not require the same high level of performance as one used alone. The airtightness of such a door should, however, be comparable to that of a door used alone, since the second inner or outer door cannot be depended on to add to overall airtightness. A door used in combination with a second door can also be permitted to have single-glazed openings. ■

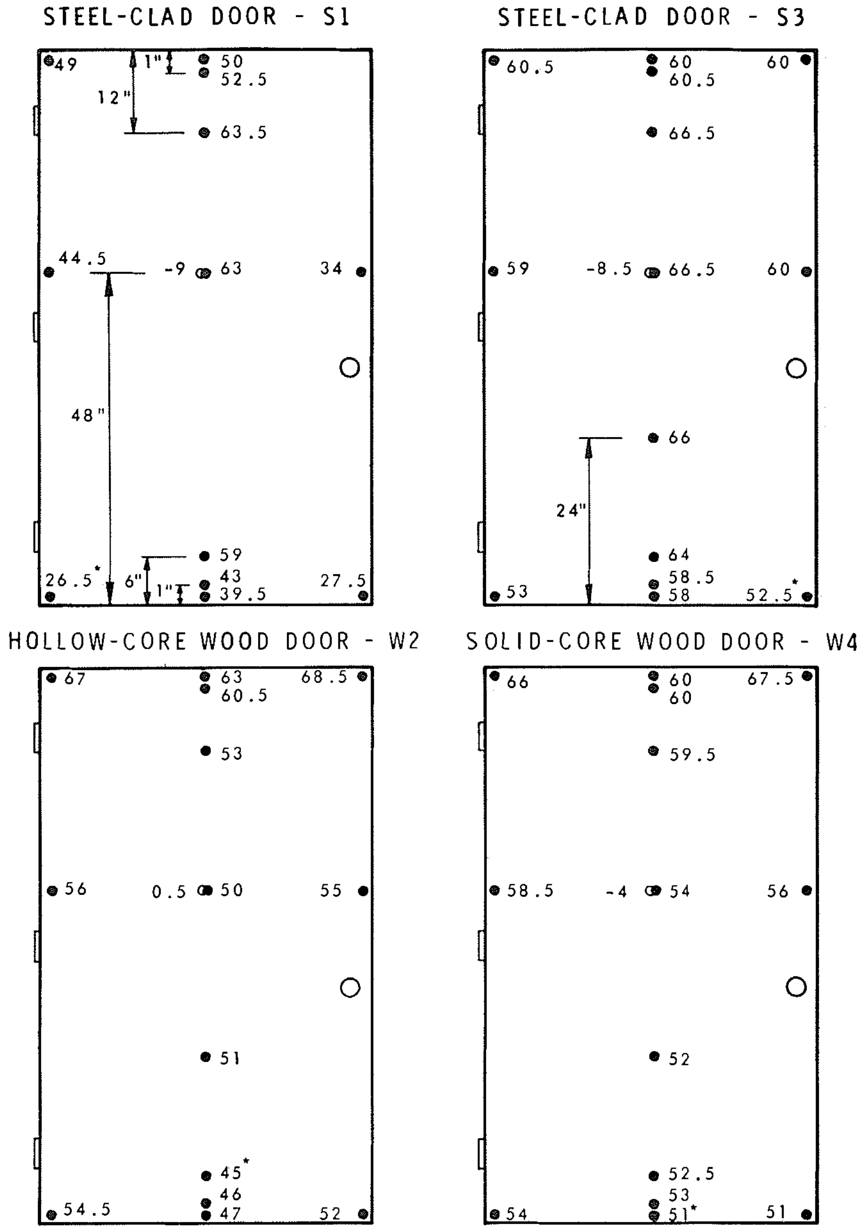

FIGURE 4

ROOM-SIDE SURFACE TEMPERATURES ON FOUR REPRESENTATIVE DOOR PANELS, °F

- WARM-SIDE SURFACE THERMOCOUPLES (* MINIMUM VALUE)
- COLD-SIDE SURFACE THERMOCOUPLES

ROOM-SIDE AIR TEMPERATURE = 72°F
WEATHER-SIDE AIR TEMPERATURE = -10°F
NO AIR LEAKAGE THROUGH DOORS

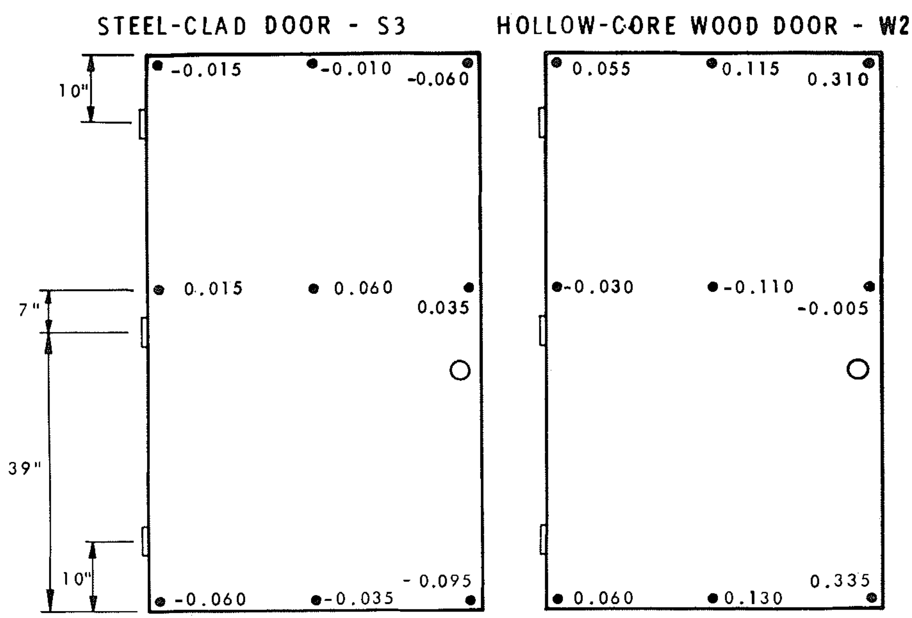

FIGURE 5

WARPAGE MEASUREMENT ON A STEEL-CLAD AND ON A WOOD DOOR (IN.)

- LOCATION OF WARPAGE MEASUREMENTS ON INSIDE SURFACE OF DOOR PANELS

ROOM-SIDE AIR TEMPERATURE = 72°F
WEATHER-SIDE AIR TEMPERATURE = -10°F
NO AIR LEAKAGE THROUGH DOORS

NOTE:

A POSITIVE WARPAGE INDICATES A MOVEMENT TOWARDS ROOM SIDE (OUT OF DOOR FRAME)

A NEGATIVE WARPAGE INDICATES A MOVEMENT TOWARDS WEATHER SIDE (INTO DOOR FRAME)