RATING THE THERMAL PERFORMANCE OF SWINGING DOORS: THE CANADIAN EXPERIENCE

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ABSTRACT

This paper discusses the recent development of the Canadian standard for rating the thermal performance of swinging doors. This standard (CSA A453) defines the methodology for determining the U-factor, solar heat gain coefficient and annual energy performance (energy rating, or ER). The door standard defines the products to be evaluated and the computer simulation and physical testing procedures to determine the performance parameters. A research program was undertaken to support the development of the standard. Guarded heater plate measurements were made on the thermal conductivity of common door insulating materials. The solar optical properties of sandblasted and frosted glass were evaluated using a spectrophotometer. The final part of the research program compared total door system U-factors produced by computer simulation and guarded-hot-box testing for three door systems. This standard will be called up in the Canadian National Energy Code and will be in force as early as 1996.

INTRODUCTION

Over the past few years considerable effort has gone into the development of procedures and standards for rating the performance of windows. The energy conservation arguments for energy labeling of windows are just as valid for doors. Although doors represent a small portion of the building shell, their thermal resistance usually is many times smaller than that of walls or ceilings. Contrary to common perception, there is a wide range in the design and, therefore, thermal performance of doors. Performance claims by manufacturers are unregulated and difficult to check and enforce.

Recently, a Canadian standard has been developed for rating the thermal performance of swinging doors. This standard (CSA A453) defines the methodology for determining the U-factor, solar heat gain coefficient (SHGC), and annual energy performance (energy rating, or ER). This paper reviews three aspects of the standard:

- its development and key features,
- results of research performed to support the standard, and
- application of the standard.

OVERVIEW OF THE STANDARD

After the successful introduction in 1993 of CSA's Standard A440.2 for the energy performance of windows and sliding glass doors, it was felt that the methodology could be extended to cover other areas, including swinging doors. As with windows, the standard needed to cover all (or almost all) door systems (including residential, commercial, glazed, and unglazed), be simple to use, be accurate, and not be unduly onerous for manufacturers to comply with. The three main factors that affect these issues are

- properties to be assessed,
- product variations that require evaluation, and
- method of determining properties.

Door Properties

The standard calls for three properties to be assessed: U-factor, SHGC, and annual energy performance of total doors (slab and frame). These are the same thermal properties as required for windows. Infiltration and nonenergy door properties (e.g., strength, durability) are covered in other door standards (CGSB 1985). Although the SHGC for an unglazed door is close to zero, the SHGC for a fully glazed door is on par with that of windows. The standard does not specify minimum values for these properties; that is left to the discretion of the National Energy Code and provincial code bodies (see "Application of the Standard").

A unique feature of the CSA standard is the determination of an ER for each door system. The energy rating is simply an energy balance on the door over the heating

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season: solar gains, less heat transmission, less air infiltration heat losses. The ER is evaluated at an average Canadian weather condition assuming equal probability of the door facing in each of the cardinal directions. The energy rating is intended as a means of allowing consumers to compare the total energy performance of doors in residential buildings. Mathematically, the ER is written:

Energy Rating = Solar Heat Gain − Transmission Heat Loss − Infiltration Heat Loss

or, for the Canadian heating season,

$$ER = 72.2 \cdot SHGC_t - 21.9 \cdot U_t - 0.54 \cdot I/A_t \quad \text{(in W/m}^2\text{)}$$

where

72.2 = average solar radiation over the heating season in W/m^2,
$SHGC_t$ = solar heat gain coefficients of the *total* door,
21.9 = average indoor-to-outdoor temperature difference (°C),
U_t = total door heat loss coefficient ($W/m^2 \cdot °C$),
0.54 = constant to account for the average pressure and temperature difference seen by the door,
I = door air infiltration at 75 Pa pressure difference in m^3/hr, and
A_t = area of the door in m^2.

The energy rating is computed using door properties already evaluated and thus requires no additional testing or simulation costs.

Product Variations

A typical door manufacturer could have two product lines (wood, steel), two embossment profiles, six panel configurations (flush, 6, 8, 9, 12, and 18 panels), three door widths (800 mm, 850 mm, and 900 mm), three frame depths, four glazing types (single, double, double with low-e, and triple), 12 glazing sizes and shapes (from no glass to full glass, square to oval), and four decorative glazing treatments (clear, stained glass, sandblasted glass, and grilles). All of these products would be available as single doors, double doors, and sidelites. Thus, in this example, the total number of products that could require individual evaluation is 124,000. Clearly a standard that required all of these options to be evaluated would be unworkable.

A study was undertaken to determine which of the above factors have the greatest influence on door performance (Carpenter and Baker 1994). Sidelites and double doors have ratings similar to those of a single door. Frame depth, slab width, and number of panels have a minor effect on door performance. By referencing the most common option, the effect of these factors can be minimized. The committee selected options of 900-mm (36-in.) slab width, 168-mm (4 9/16-in.) frame depth, and flush and six-panel configurations.

Glass size and type have a significant impact on door performance. To keep the number of options manageable, four glazing shapes and sizes were selected: no glass, 1/4 glass, 1/2 glass, and full glass. A computer program was developed to automatically generate properties for these four sizes from a single set of simulations (EE 1995). Solar/optical measurements showed that most glazing decorative treatments (tints, sandblasting, and frosting) result in a similar reduction in solar transmission (see "Solar/Optical Properties" section). The standard requires that a sandblasted lite can be used to represent all glazing decorative treatments.

Rationalizing the range of door products as described here reduced the number of evaluations from 124,000 to 96 for a typical manufacturer.

Evaluation Techniques

According to the standard, door U-factors can be determined either by computer simulation (using FRAME EE 1992; and VISION UW 1992) or by physical testing in accordance with ASTM C1199 (ASTM 1991). The solar heat gain coefficient can likewise be determined using the computer programs or by physical testing using an indoor solar simulator and an SHGC test procedure (CANMET 1993). The total-door SHGC is the glazing SHGC calculated using VISION, with a correction to account for door slab and frame solar heat gain effects. The SHGC for partially glazed doors will be relatively low because of the small glass area. Although two evaluation techniques are permitted, it is expected that most product ratings will be determined using the computer simulation approach because it is faster and costs only 5% to 15% that of physical testing.

The standard does not require cross-checking, or "validation," of simulation and test results. It was felt that the extra testing costs would provide little benefit provided that the work was performed by a competent professional engineer from an independent company. Training and accreditation procedures have been developed to ensure consistent simulation results.

Comparison With NFRC Door Standard

The National Fenestration Rating Council standard for rating the U-factor of doors, which was developed at about the same time, is similar to the Canadian standard. In fact, attempts were made to keep the CSA standard as similar as possible, with differences only to accommodate Canadian market conditions, testing capabilities, and more recent research results. The major differences between the two standards are summarized in Table 1.

TABLE 1 **Differences Between CSA and NFRC Procedures**

Issue	CSA Requirement	NFRC Requirement
Properties Rated	U-factor, SHGC, Infiltration and Energy Rating	U-factor, SHGC and Infiltration
Evaluation Procedure	Testing OR simulation by professional engineer	Simulation with testing of best and worst products
Aging of Foam Insulations	Use five-year aged value (aged conductivity value in simulation or adjustment to test)	Use initial (non-aged) value
Rating the Door System	Rating is for entire door: slab and frame	Rating is for slab in a default frame

RESEARCH IN SUPPORT OF THE STANDARD

A research program was undertaken during the development of the standard. The purpose of the research was threefold:

- to aid in understanding the performance of doors,
- to determine thermal characteristics of materials found in doors for use in computer simulation, and
- to establish whether computer simulation and physical testing provide similar results for the same products.

This section summarizes the results of this research.

Thermal Conductivity

If computer simulation is to be used to determine the thermal conductance or U-factor of door systems, it is imperative that the thermal conductivities of door materials be accurately known. Thermal conductivity measurements of common door insulating materials, such as HCFC-blown polyurethane, pentane-blown polystyrene, and cardboard honeycomb, were made.

Additional tests were conducted to determine if there were either product-to-product variations or manufacturer-to-manufacturer variations. The results showed little variability.

These tests were conducted using a guarded heater plate apparatus in accordance with ASTM C177-85 (ASTM 1985). To ensure that the material samples were representative, entire door slabs were obtained from door manufacturers and 625-mm by 625-mm (25-in. by 25-in.) samples were cut from the center of the slab. The insulation samples were tested shortly after the date of manufacture to minimize any offgassing effects. The samples were evaluated at hot- and cold-side temperatures of 0°C and 20°C, respectively, for a mean temperature of 10°C.

Foam insulations produced using refrigerants as the blowing agent are known to exhibit an increase in thermal conductivity over time as the blowing agent diffuses out of the insulation. The addition of facer materials (e.g., aluminum foil on board insulation) can slow down the diffusion of the blowing agent. It is not clear, however, how effective fiberglass or steel skins are in retarding the diffusion of the blowing agent, especially after cutting the door slab to insert glazing systems, peep holes, and operating hardware. A testing program was set up to assess the effect of aging in polyurethane foams. Additional door slabs were tested after six months and one year of aging at room temperature.

Table 2 summarizes the results of the conductivity testing program. The test values for polyurethane fall almost midway between conductivity measurements of unfaced board-stock polyurethane foam and fully encapsulated (i.e., unaged) foam (ORNL 1992). Thus, it would appear that the door skins offer some resistance to blowing agent diffusion, but it appears that there would still be a 15% increase in conductivity over five years. Based on these measurements, the thermal conductivity is expected to be 0.021 W/m·°C after five years of aging. This value is recommended as representative of the long-term performance of HCFC-141b polyurethane foam. The thermal conductivity of the polystyrene foam is consistent with previously published values for board stock (ASTM 1992). The cardboard honeycomb has a relatively high thermal conductivity: five times the value of polystyrene.

TABLE 2 **Thermal Conductivity Measurements of Insulating Materials**

Sample	Thermal Conductivity[1] (W/m·°C)	Density (kg/m³)
Polyurethane[2]-Initial	0.0182 ± 3.1%	32.9
Polyurethane-6 month aged	0.0198 ± 3.0%	32.9
Polyurethane-1 year aging	0.0201 ± 3.1%	32.9
Polystyrene[3]	0.0378 ± 2.5%	14.6
Cardboard Honeycomb	0.165 ± 2.6%	N/A

[1]all values are for a mean temperature of 10°C
[2]polyurethane blowing agent is HCFC 141b
[3]polystyrene blowing agent is pentane

Solar/Optical Properties

Many of the glazing inserts in doors have a decorative pattern. Three of the most popular treatments are stained glass, sandblasted glass, and glue-chip (or frosted). The solar/optical properties of these glasses are not well known. Stained glass is used in door inserts to produce a decorative item (e.g., a flower). The solar transmission of a stained glass insert can cover a wide range, depending on the size, extent, and color of the decorative item. Thus, it is difficult to characterize the solar/optical properties of this treatment.

Sandblasting and glue-chip, on the other hand, tend to be applied to the entire surface of one of the glass panes and are easier to characterize. The solar/optical properties of 3-mm glass with each of these treatments were evaluated using a spectrophotometer. The test results are listed in Table 3. For comparison purposes, published values for clear and bronze-tinted glass are also presented. Sandblasted or glue-chip panes have similar values—a 23% to 31% reduction in solar transmission over clear glass with a corresponding increase in solar absorbtivity. The solar/optical values for these two types of glass fall in the range of the various tinted glazings (e.g., green, gray, bronze), with the sandblasted glass having values close to the values for bronze-tinted glass.

TABLE 3 **Solar/Optical Properties for Various Glass Treatments**

Sample	Solar Transmission	Solar Reflectivity Side 1	Solar Reflectivity Side 2	Visible Transmission
Clear	0.837	0.075	0.075	0.898
Sandblasted	0.646	0.067	0.070	0.676
Glue-Chip	0.574	0.074	0.080	0.625
Bronze Tint	0.645	0.062	0.062	0.685

Thermal Performance of Door Systems

The final part of the research program compared total door system U-factors produced by computer simulation and guarded-hot-box testing. The purpose of this research was to see if the two techniques provided similar results so that both techniques could be used in the standard.

Three door systems were selected for evaluation: residential wood door, residential insulated steel door, and commercial steel door (see Figure 1). The systems were intended to cover the range of door products used in commercial and residential construction.

Residential Insulated Steel Door The insulated steel door consists of an 857-mm by 2006-mm (34-in. by 80-in.) door slab in a 116 mm (4.6 in.) deep wood frame. The threshold is thermally broken aluminum. The door slab has a wooden perimeter with an HCFC-141b polyurethane interior and inner and outer steel skins. The wood perimeter provides a thermal break between the two steel skins. The slab has six embossed panels with the upper four panels removed for a glazing insert. The glazing insert is double glazed with overall dimensions of 550 mm by 900 mm (22 in. by 36 in.). The overall product dimensions are 901 mm by 2090 mm (36 in. by 82.5 in.).

Residential Wood Door The wood door uses the same wooden door frame as the insulated steel door. The wood slab has nine panels, with the middle panel removed for a glazing insert. The glazing insert is triple glazed with a middle pane of stained glass and has overall dimensions of 300 mm by 600 mm (12 in. by 24 in.). The slab and overall product dimensions are the same as those of the insulated steel door.

Commercial Steel Door The commercial door consists of a flush steel slab in a steel frame with an aluminum threshold (no thermal breaks). The slab has an interior core of honeycomb cardboard. The steel skins cover all surfaces of the slab. Although polyurethane core doors usually are recommended for commercial applications, the honeycomb core provides a worst-case test and a more difficult heat transfer problem for the simulation program (because of possible convective motion within the honeycomb cells). The dimensions of the slab are 910 mm by 2010 mm (36 in. by 80 in.) and the overall product dimensions are 1015 mm by 2080 mm (40 in. by 82 in.).

The guarded-hot-box testing was performed in accordance with ASTM C1199 (ASTM 1991) and the procedures given in the standard. The specimens were taped shut to eliminate any air leakage. The tests were conducted at ASHRAE winter conditions: 21°C and natural convection air movement on the warm side, –18°C and 6.7 m/s perpendicular wind on the cold side. The measured U-factor was adjusted to standard inside and outside film coefficients of 8.3 and 30.0 W/m^2·K, respectively.

Computer simulations were performed using FRAME EE (1992); and VISION UW (1992) programs. The simulations were performed at the same conditions as those in the physical test. The thermal conductivities of the insulating materials were taken from Table 1. The nonaged thermal conductivity value for the polyurethane was used because the door was a new specimen.

The simulation and test results are summarized in Table 4. There is good agreement between the simulated

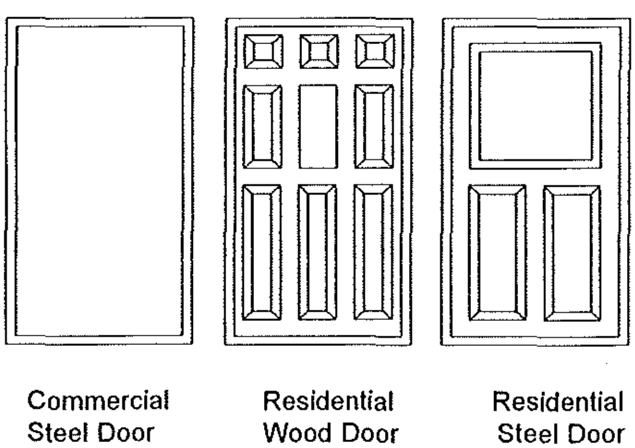

Figure 1 *Door Systems Evaluated*

TABLE 4 **Simulated and Tested Door U-Factors, W/m^2·K (Btu/h·ft^2·°F)**

Sample	Tested U-factor	Simulated U-factor	% Difference
Residential Ins. Steel Door	1.52 (0.27)	1.46 (0.26)	–3.9%
Residential Wood Door	2.44 (0.43)	2.55 (0.45)	4.5%
Commercial Steel Door	3.57 (0.63)	3.49 (0.61)	–2.2%

and tested U-factors: the largest difference for the three door systems is 4.5%.

APPLICATION OF THE STANDARD

The thermal performance of typical residential and commercial door systems has been determined in accordance with the standard. These values are summarized in Tables 5 and 6. Energy rating values are not given for the commercial door because they are applicable to residential products only.

The 1995 National Energy Code is being developed for adoption by the provinces in 1996 and 1997. This standard will require that doors be rated in accordance with CSA A453. Commercial doors will have to have U-factors below those listed in Table 5 for double glazing with low-e argon. One residential door per house will be allowed to have a U-factor as high as 2.6 $W/m^2 \cdot °C$ (0.46 $Btu/h \cdot ft^2 \cdot °F$) to permit the installation of a single decorative wood door. The remaining residential doors will be required to have either a U-factor below 1.2 $W/m^2 \cdot °C$ (0.21 $Btu/h \cdot ft^2 \cdot °F$) or an energy rating above –20. This, in effect, will require unglazed, minimal glazed, and half-glazed doors to meet the U-factor requirement and fully glazed doors to meet the ER requirement. Therefore, most residential doors will have to contain foam insulation and low-e argon-filled glazing inserts.

CONCLUSIONS

A standard was developed that provides performance ratings for most door systems. By careful selection of the procedures and products to be evaluated, the standard covers the important aspects of door performance at a reasonable cost of compliance.

A research program was performed in support of the development of a standard for rating the energy performance of doors. The conclusions from this study are as follows:

- the thermal conductivity of door core insulating materials varies widely, from 0.019 for polyurethane to 0.16 $W/m^2 \cdot °C$ for cardboard honeycomb;
- the thermal conductivity of refrigerant-blown polyurethane in a door slab increases significantly as the foam ages (approximately 15% over 5 years);
- the solar transmissions of sandblasted and glue-chip glass are 23% and 31% below that of clear glass, with a corresponding increase in solar absorbtivity; and
- computer simulation and guarded-hot-box testing provide similar results (within 5%) for total door U-factors.

The standard will be referenced in the new Canadian National Energy Code and doors will be required to meet minimum performance levels.

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TABLE 5 **Typical U-Factors of Swinging Doors in $W/m^2 \cdot K$ ($Btu/h \cdot ft^2 \cdot °F$)**

	Solid Wood Doors		Insulated Residential Doors[1]		Insulated Commercial Doors[2]	
Category	Double Glazing	Double Glazing with Low-E and Argon	Double Glazing	Double Glazing with Low-E and Argon	Double glazing	Double Glazing with Low-E and Argon
No Glazing	2.6 (0.46)	2.6 (0.46)	0.9 (0.16)	0.9 (0.16)	2.1 (0.37)	2.1 (0.37)
Minimal Glazing	2.6 (0.46)	2.5 (0.44)	1.1 (0.19)	1.0 (0.18)	2.2 (0.39)	2.2 (0.39)
1/2 Glazing	2.6 (0.46)	2.4 (0.42)	1.5 (0.26)	1.3 (0.23)	2.7 (0.48)	2.4 (0.42)
Maximum Glazing	2.6 (0.46)	2.2 (0.39)	2.0 (0.35)	1.5 (0.26)	3.1 (0.55)	2.7 (0.48)

[1]based on steel-skin with polyurethane foam insulation in a wood frame
[2]based on a steel skin with polyurethane insulation in a thermally unbroken metal frame

TABLE 6 **Typical ER Values of Swinging Doors in W/m^2**

	Solid Wood Doors		Insulated Residential Doors[1]		Insulated Commercial Doors[2]	
Category	Double Glazing	Double Glazing with Low-E and Argon	Double Glazing	Double Glazing with Low-E and Argon	Double glazing	Double Glazing with Low-E and Argon
No Glazing	–57	–57	–22	–22	NA	NA
Minimal Glazing	–57	–55	–24	–22	NA	NA
1/2 Glazing	–45	–43	–21	–19	NA	NA
Maximum Glazing	–36	–31	–23	–16	NA	NA

[1]based on steel-skin with polyurethane foam insulation in a wood frame
[2]based on a steel skin with polyurethane insulation in a thermally unbroken metal frame

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