Thermal Performance of Window Framing Systems

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ABSTRACT

A comparison is made between the computer-simulated and hot-box test values for total window heat loss for 31 different windows. The same computer simulation technique was then used to analyze close to 200 commercially available products to determine representative frame U-factors. The frame U-factors cover the full range of window material types and operating styles. Equations are given to allow the user to determine total window heat loss for any window framing system.

INTRODUCTION

The wide range of window framing materials, operating types, and manufacturers' designs has made it difficult to characterize the thermal performance of windows. As a result, window U-factors are often quoted for the center glazing portion, ignoring any edge-of-glass and frame effects. This paper summarizes recent thermal testing and computer modeling used to develop a more robust technique for determining window frame heat loss.

This study uses the FRAME two-dimensional, finite-difference computer program to evaluate a wide range of window framing systems. In this study, close to 200 window framing systems are evaluated and the results analyzed. A procedure is then given to determine the total impact of the frame on the window U-factor.

ACCURACY OF COMPUTER SIMULATION

At more than $2,500 for a research-class test, it is simply too expensive to test all window framing designs. Recent research projects have shown that computer modeling using one-dimensional center-glazing models and two-dimensional finite-difference/finite-element modeling for the frame and edge can produce results of similar accuracy to those of research-caliber test chambers (Elmahdy 1990; Klems and Reilly 1990). The accuracy of the FRAME computer program (EE 1991) has been evaluated (EMR 1990) and it is currently the only acceptable computational method for rating the thermal performance of window frame systems in the U.S. and Canada.

Figure 1 presents the results of these studies plus the results of three additional research projects. Figure 1 contains 31 sets of computer-simulated and test total-window U-factors. The computer-simulated factors were generated using FRAME for the frame and edge-of-glass portions of the window and either WINDOW (LBL 1988) or VISION (UW 1989) for the center glazing. All but three of the simulations were performed "blind," i.e., the simulations were performed without knowledge of the test results. All U-factor tests were performed at the National Research Council of Canada. If there was perfect agreement, all the data points would fall on the diagonal line. The line on either side of the diagonal represents the uncertainty in the test value (based on a 6% uncertainty for a standard double-glazed window).

The mean of the ratio of simulated values to test values is 0.99 (i.e., simulated results are on average 1% lower than test results). Statistical analysis shows that test and simulated values are within 12% of each other 95.5% of the time. The only data point that was outside the 12% range was a window of very low heat loss with a solid foam frame in which the absolute difference was only 0.11 $W/m^2 \cdot °C$ (0.02 $Btu/h \cdot ft^2 \cdot °F$).

DETERMINATION OF FRAME U-FACTORS

When the exact window to be used is known, the building designer should be able to obtain U-factors from the manufacturer, preferably as produced in accordance with a recognized standard such as NFRC 100-91 (NFRC 1991) or CSA A440.2 (CSA 1991). When the manufacturer is not known or a generic study is being performed, the

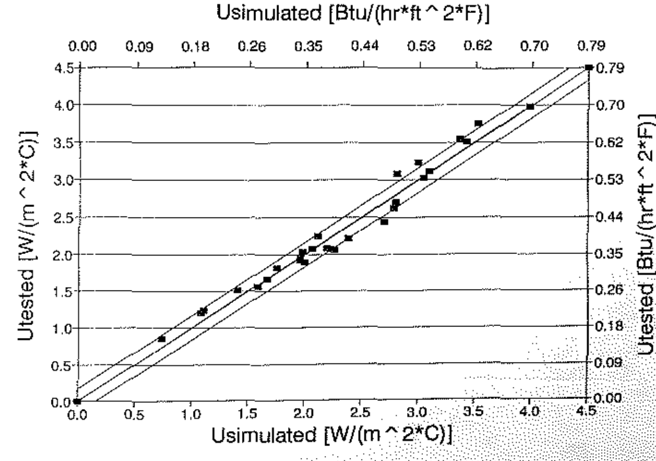

Figure 1 *Comparison of simulated and tested (total window U-values).*

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designer needs some method of estimating window performance. Chapter 27 of *ASHRAE Fundamentals* (ASHRAE 1989) recommends that the window be divided into three areas: center glazing, edge glazing, and frame. The total window U-factor is calculated as follows:

$$U_{total} = \frac{U_{cg} \cdot A_{cg} + U_{edge} \cdot A_{edge} + U_{frame} \cdot A_{frame}}{A_{total}} \qquad (1)$$

Table 13 in chapter 27 gives a wide range of values for center-glazing and edge-glazing window U-factor, but only four values are used to represent the wide range of window framing systems.

A typical window manufacturer will have hundreds of different products. These products vary in terms of six attributes: size, material construction (e.g., wood, aluminum-clad wood), operator type (e.g., casement, slider), design (e.g., narrow profile, wide profile), glazing type (e.g., double, double with low-emissivity coating), and sealed unit spacer type (e.g., aluminum, low-conductivity material). Theoretically, each of these products has a different frame U-factor. The issue becomes how to represent the thermal performance of these framing products with the fewest possible numbers.

Frame area effects can be handled quite easily by adjusting the proportion of the window that is frame. (There is a slight error in this procedure because the frame U-factor depends slightly on window shape, i.e., the proportion of the frame that is head, sill, and jamb.)

Clearly the frame U-factor is a function of material construction, design, and operator type, but how much does the glazing and spacer system affect the frame U-factor? Figures 2 and 3 show the effect of glazing system U-factor (for a fixed IG unit thickness) and glazing unit thickness (for a fixed glazing U-factor) for a typical wood-frame window with two spacer types. The figures show that the frame U-factor is a function of IG unit thickness and spacer type but is almost independent of glazing system U-factor.

If the window frame designs are chosen to be representative of typical products, then the window frame U-factors are a function of type of material, operator, and spacer and thickness of IG unit. This paper examines the most common material and operator types, specifically:

Material Type	Operator Type
Wood	Picture/fixed
Aluminum-clad wood	Casement/awning
Vinyl	Slider
Reinforced vinyl	Patio door
Aluminum	Skylight
Thermally broken aluminum	
Foam-filled fiberglass/vinyl	

Tables 1 and 2 present the frame U-factors for the above material and operator types for three IG unit thicknesses and two spacer types. The three IG unit thicknesses correspond to conventional single-, double-, and triple-glazed units; the frame cross sections were identical, other than the changes necessary to accommodate changes in IG unit thickness. The two spacers correspond to single-seal aluminum and an insulated spacer with a conductivity of 0.3 W/m·°C. The conductivity of commercially available nonmetallic spacer systems (including sealant) ranges from 0.20 to 0.78 W/m·°C. Because no spacer is used in single-glazed windows, only one frame value is listed for each frame material. These values have been proposed for inclusion in the *1993 ASHRAE Handbook—Fundamentals*.

Tables 3 and 4 give the average frame height for each of the framing systems. The reader is cautioned that the frame height and U-factor are interrelated and should not be used independently of each other. In general, increasing the frame height decreases the frame U-factor.

The window frame heat loss coefficient (*UA*) can be found by multiplying the frame U-factor by the frame height and average window perimeter. The equations for computing the frame *UA* for fixed, horizontally sliding, and vertically sliding windows are as follows:

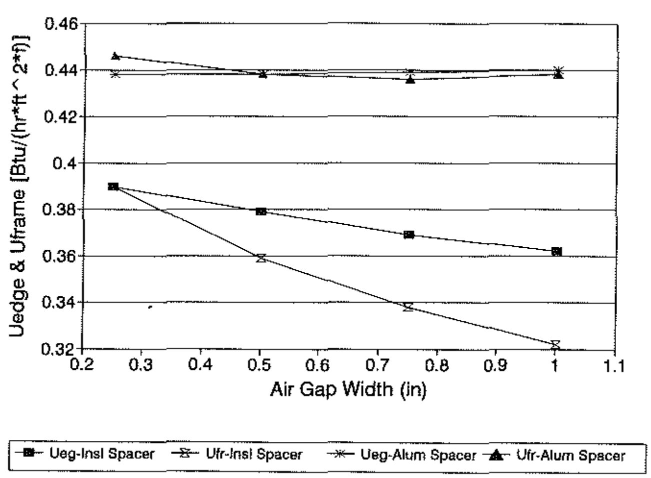

Figure 2 *U_{edge} and U_{frame} vs. air gap width.*

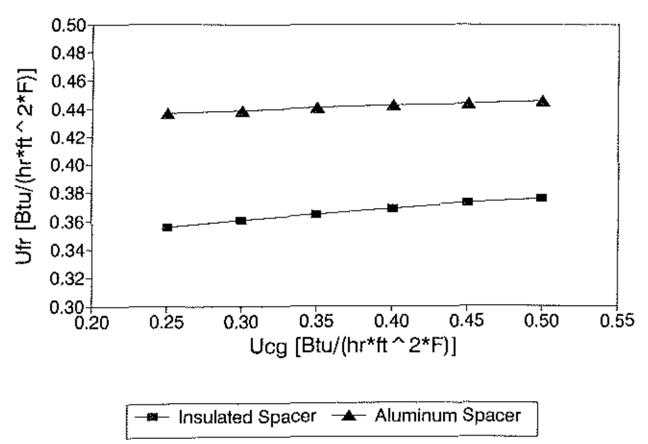

Figure 3 *Effect of U_{center} glass on frame heat loss (for a typical wood frame).*

TABLE 1
Representative Fenestration Frame U-Factors
($W/m^2 \cdot {}^\circ C$)

Frame Material	Spacer Type	Operator Type / Glazing Thickness											
		Operable			Fixed			Double Door			Skylight		
		Single(2)	Double(3)	Triple(4)	Single	Double	Triple	Single	Double	Triple	Single	Double	Triple
Aluminum	All	12.4	12.4	12.4	10.1	10.1	10.1	12.7	12.7	12.7	38.6	38.6	38.6
Therm. Broken	Metal	5.4	5.4	5.4	6.6	6.6	6.6	5.9	5.9	5.7	39.5	29.0	27.7
Aluminum (1)	Insulated	n/a	4.9	4.9	n/a	5.2	5.2	n/a	5.5	5.4	n/a	26.6	26.3
Al-Clad Wood/	Metal	3.9	3.6	3.3	3.2	3.0	2.8	3.3	3.1	2.9	13.8	13.1	12.9
Reinf. Vinyl	Insulated	n/a	3.2	2.7	n/a	2.6	2.3	n/a	2.8	2.5	n/a	12.8	12.6
Wood/Vinyl	Metal	3.1	2.9	2.7	2.9	2.8	2.7	2.9	2.8	2.7	12.3	11.5	11.3
	Insulated	n/a	2.6	2.2	n/a	2.4	2.1	n/a	2.5	2.3	n/a	11.0	10.6
Insulated	Metal	2.7	2.5	2.3	2.6	2.3	2.0	2.1	1.9	1.7	n/a	n/a	n/a
Fiberglass/Vinyl	Insulated	n/a	2.2	1.8	n/a	2.1	1.6	n/a	1.6	1.4	n/a	n/a	n/a

Notes:

(1) depends strongly on width of thermal break, value given for 10 mm
(2) single glazing corresponds to a IGU thickness of 3 mm
(3) double glazing corresponds to a IGU thickness of 18 mm
(4) triple glazing corresponds to a IGU thickness of 33 mm
n/a not applicable

TABLE 2
Representative Fenestration Frame U-Factors
($Btu/(h \cdot ft^2 \cdot {}^\circ F)$)

Frame Material	Spacer Type	Operator Type / Glazing Thickness											
		Operable			Fixed			Double Door			Skylight		
		Single(2)	Double(3)	Triple(4)	Single	Double	Triple	Single	Double	Triple	Single	Double	Triple
Aluminum	All	2.18	2.18	2.18	1.78	1.78	1.78	2.24	2.24	2.24	6.80	6.80	6.80
Therm. Broken	Metal	0.95	0.95	0.95	1.16	1.16	1.16	1.04	1.04	1.00	6.95	5.11	4.88
Aluminum (1)	Insulated	n/a	0.86	0.86	n/a	0.92	0.92	n/a	0.97	0.95	n/a	4.68	4.63
Al-Clad Wood/	Metal	0.69	0.63	0.58	0.56	0.53	0.49	0.58	0.55	0.51	2.43	2.31	2.27
Reinf. Vinyl	Insulated	n/a	0.56	0.48	n/a	0.46	0.40	n/a	0.49	0.44	n/a	2.25	2.22
Wood/Vinyl	Metal	0.55	0.51	0.48	0.51	0.49	0.48	0.51	0.49	0.46	2.17	2.02	1.99
	Insulated	n/a	0.46	0.39	n/a	0.42	0.37	n/a	0.44	0.40	n/a	1.94	1.87
Insulated	Metal	0.48	0.44	0.40	0.46	0.40	0.35	0.37	0.33	0.30	n/a	n/a	n/a
Fiberglass/Vinyl	Insulated	n/a	0.39	0.32	n/a	0.37	0.28	n/a	0.28	0.25	n/a	n/a	n/a

Notes:

(1) depends strongly on width of thermal break, value given for 3/8"
(2) single glazing corresponds to a IGU thickness of 1/8" (nom.)
(3) double glazing corresponds to a IGU thickness of 3/4" (nom.)
(4) triple glazing corresponds to a IGU thickness of 1 3/8" (nom.)
n/a not applicable

TABLE 3
Representative Fenestration Frame Heights
(mm)

Frame Material	Operator Type			
	Operable	Fixed	Double Door	Skylight
Aluminum	39	32	53	19
Therm. Broken Aluminum	53	32	66	19
Al-Clad Wood/ Reinf. Vinyl	71	41	96	23
Wood/Vinyl	71	41	88	23
Fiberglass	79	46	102	n/a

TABLE 4
Representative Fenestration Frame Heights
(in.)

Frame Material	Operator Type			
	Operable	Fixed	Double Door	Skylight
Aluminum	1.5	1.3	2.1	0.7
Therm. Broken Aluminum	2.1	1.3	2.6	0.7
Al-Clad Wood/ Reinf. Vinyl	2.8	1.6	3.8	0.9
Wood/Vinyl	2.8	1.6	3.5	0.9
Fiberglass	3.1	1.8	4.0	n/a

For fixed and hinged windows,

$$UA_{frame} = U_{frame} \cdot [W \cdot H - (W - 2H_{fr}) \cdot (H - 2H_{fr})];$$

for vertically sliding windows,

$$UA_{frame} = U_{frame} \cdot [W \cdot H - (W - 2H_{fr}) \cdot (H - 3H_{fr})];$$

for horizontally sliding windows and patio doors,

$$UA_{frame} = U_{frame} \cdot [W \cdot H - (W - 3H_{fr}) \cdot (H - 2H_{fr})];$$

where

W = width of the rough opening for the window,
H = height of the rough opening for the window,
H_{fr} = height of the frame as given in Tables 3 and 4, and
U_{frame} = frame U-factor as given in Tables 1 and 2.

Several trends can be identified from the results presented in Tables 1 and 2. Material type is the most important factor in assessing frame heat loss. In order of decreasing frame heat loss, the frames are aluminum, thermally broken aluminum, aluminum-clad wood, reinforced vinyl, wood, vinyl, and foam-filled fiberglass. The second most important factor is operator type. Skylights have the highest frame heat loss because of the increased surface area of the mounting curb. Sliding windows have the second highest value because of the high heat loss through the meeting rail.

Use of an insulated spacer reduces the frame U-factor by 15% to 25%. This benefit is in addition to reduced edge-of-glass heat loss identified in ASHRAE (1989) and Arasteh (1990). For wood and vinyl windows, widening the IG unit from 18 mm to 33 mm reduces the frame U-factor by 10%.

CONCLUSIONS

This paper presents a method of determining the heat loss through the opaque portions of windows. Window frame U-factors and heights are given for seven frame material types and five operator types. The main conclusions from this study are:

- for 95% of the time, computer simulation and research-class laboratory testing can produce total window U-factors within 12%;
- window frame U-factors depend on IG unit thickness and spacer type but not on glazing system U-factor;
- aluminum and thermally broken aluminum frames have the highest heat loss, fiberglass frames with interior insulation the lowest; and
- skylights and sliding windows have the highest heat loss, fixed the lowest heat loss.

ACKNOWLEDGMENTS

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