where

U_o = overall coefficient of heat transfer (U-factor)
t_{in} = interior air temperature
t_{out} = exterior air temperature
A_T = total area of fenestration
A_G = glazing (transparent) area
A_{Frm} = frame (opaque) area
F_G = glazing solar heat gain coefficient
F_{Frm} = frame solar heat gain coefficient
E_t = incident total irradiance

The quantities U_o, F_G, and F_{Frm} are frequently considered constants; however, they slowly vary as functions of the environmental variables, most importantly temperatures and wind speed. The solar heat gain coefficients also depend significantly on solar incident angle.

The principal justification for Equation (1) is its simplicity, achieved by collecting all the linked radiative, conductive, and convective energy transfer processes into U and F. These quantities vary slowly because (1) convective heat transfer rates vary as fractional powers of temperature differences or free-stream speeds, (2) variations in temperature due to the weather or climate are small on the absolute temperature scale (°R) that controls radiative heat transfer rates, and (3) fenestration systems always involve at least two thermal resistances in series.

OVERALL COEFFICIENT OF HEAT TRANSFER (U-FACTOR)

In the absence of sunlight, air infiltration, and moisture condensation, the first term in Equation (1) represents the rate of thermal heat transfer through a fenestration system. Most systems consist of transparent multipane glazing units and an opaque sash and frame (hereafter called frame). The glazing unit's heat transfer paths include a one-dimensional center-of-glass contribution and a two-dimensional edge contribution. The frame contribution is primarily two-dimensional.

Consequently, the total rate of heat transfer through a fenestration system can be calculated knowing the separate heat transfer contributions of the center glass, edge glass, and frame. (When present, glazing dividers, such as decorative grilles and muntins, also affect heat transfer, and their contribution must be considered). The overall U-factor is estimated using area-weighted U-factors for each contribution by:

$$U_o = (U_{cg}A_{cg} + U_{eg}A_{eg} + U_f A_f)/A_{pf} \qquad (2)$$

where the subscripts *cg*, *eg*, and *f* refer to the center-of-glass, edge-of-glass, and frame, respectively. A_{pf} is the area of the fenestration product's rough opening in the wall or roof less installation clearances. Where a fenestration product has glazed surfaces in only one direction (typical windows), the sum of the areas equals the projected area. Skylights, greenhouse/garden windows, bay/bow windows, etc., because they extend beyond the plane of the wall/roof, have greater surface area for heat loss than that of a window with a similar glazing option and frame material; consequently, U-factors for such products are greater.

Center-of-glass U-factor. Heat flow across the central glazed portion of a multipane unit must consider both convective and radiative transfer in the gas space. Convective heat transfer is estimated based on high aspect-ratio, natural convection correlations for vertical and inclined air layers (ElSherbiney *et al.* 1982, Shewen 1986, Wright 1991). Radiative heat transfer (ignoring gas absorption) is quantified using a more fundamental approach. Rubin (1982) and Hollands and Wright (1982) devised computational methods to solve the combined heat transfer problem.

Values for U_{cg} at standard indoor and outdoor conditions depend on such glazing construction features as the number of glazing panes, the gas-space dimensions, the orientation relative to vertical, the emittance of each surface, and the composition of the fill gas. Several computer programs can be used to estimate glazing unit heat transfer for a wide range of glazing construction (Arasteh *et al.* 1989, Sullivan and Wright 1987). The National Fenestration Rating Council calls for WINDOW 4.0 from Lawrence Berkeley Laboratory (1992) as a standard calculation method.

Figure 1 shows the effect of gas space width on U_{cg} for various glazing units. U-factors are plotted for air, argon, and krypton fill-gases and for high (uncoated) and low (coated) values of surface emittance. Gas space widths greater than 0.5 in. have no significant effect on U_{cg}, but greater glazing unit thicknesses decrease U_o since the length of the shortest heat flow path through the frame increases. A low-emittance coating combined with krypton gas fill significantly reduces heat transfer in narrow gap-width glazing units. The value of U_{cg} for sloped glazings (with heat flow

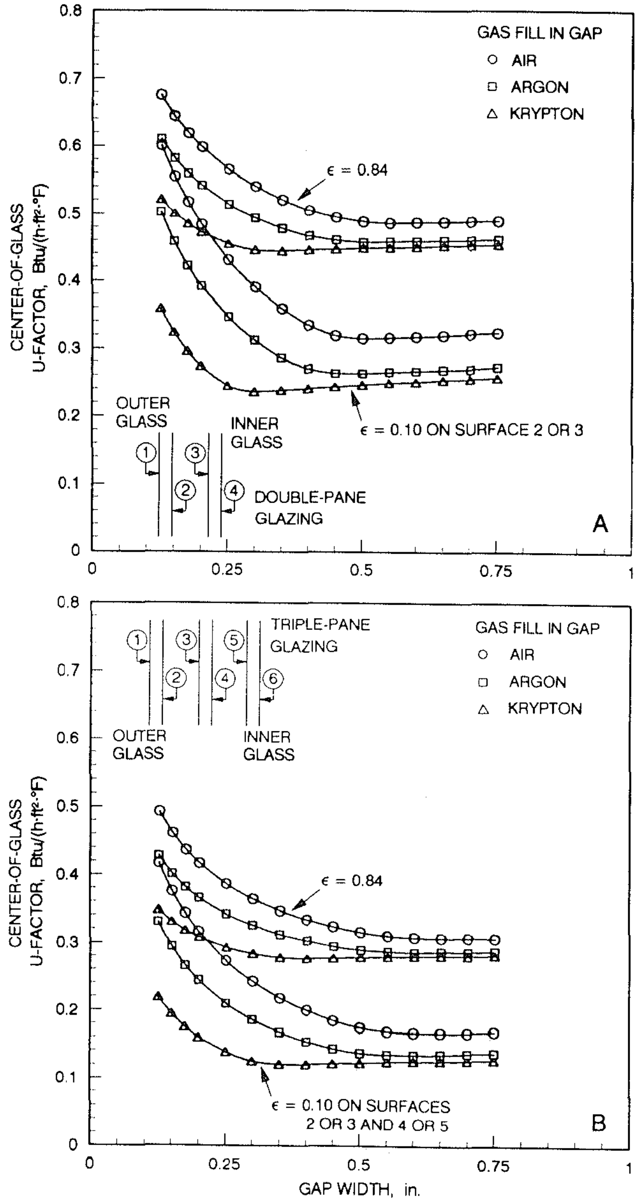


Fig. 1 Center of Glass U-Factor for Vertical Double- and Triple-Pane Glazing Units

up) is greater than that for vertical glazings because both the interior film coefficient and the air space coefficient is larger, particularly with the 0.5 in. gap spacing between glazings.

Edge-of-glass U-factor. Insulating glass units usually have continuous spacer members around the glass perimeter to separate the glazing and provide an edge seal. Aluminum spacers greatly increase conductive heat transfer between the contacted inner and outer glazing, thereby degrading the thermal performance of the glazing unit locally. Laboratory measurements reported by Peterson (1987) showed this conductive region to be limited to a 2.5 inch-wide band around the perimeter of the glazing unit.

Edge-of-glass heat transfer is two-dimensional and requires detailed modeling for accurate determination. Based on detailed two-dimensional modeling, Arasteh (1989) developed the following correlation to calculate the edge-of-glass U-factor as a function of spacer type and center-of-glass U-factor:

$$U_{eg} = A + BU_{cg} + CU_{cg}^2 \qquad (3)$$

where A, B, and C are correlation coefficients, which are listed in Table 1 for metal, insulating (including wood) and fused glass spacers, and a combination of insulating and metal spacers. The correlation constants for the combination of metal and insulated spacers were derived from computer simulations, which showed that 85% of the benefit in triple-glazing is attributable to the insulated spacer.

Approximate edge-of-glass U-factors as a function of the center-of-glass U-factor is shown in Figure 2. The spacer edge is assumed to be even with the line of sight of the glazing. Curves are for aluminum spacers with sealants (metallic) and nonmetal (insulating) spacers, including fiberglass, wood, and butyl. Values for glass edges and steel spacers fall between the metallic and insulating spacer curves. This edge effect does not occur with single glazing. For highly insulating glazing, edge heat transfer can significantly increase the overall U-factor. Thus, test data or design-specific computations should account for this effect.

Table 1 Equation (3) Coefficients for Edge-of-Glass U-Factor

	A	B	C
Metal	0.223	0.842	−0.153
Insulating	0.120	0.682	0.244
Glass	0.158	0.774	0.057
Metal + insulation	0.135	0.706	0.187

Note: A, B, and C have units of $[\text{Btu}/(\text{h}\cdot\text{ft}^2\cdot{}^\circ\text{F})]^n$, where $n = 1, 0$, and -1, respectively.

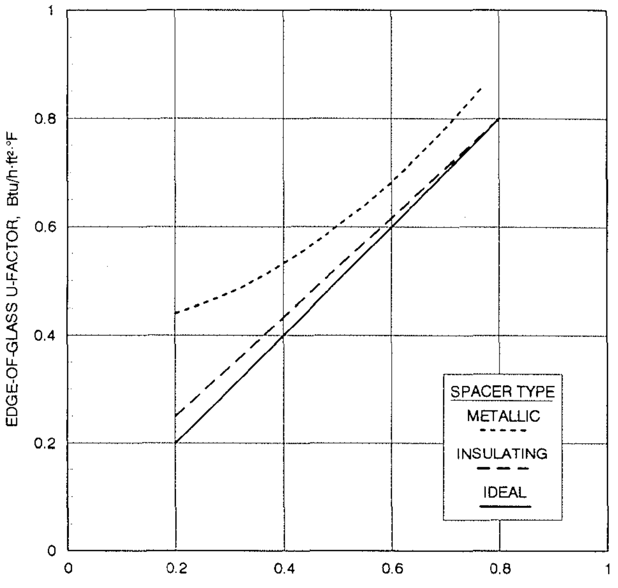


Fig. 2 Relationship between Edge-of-Glass U-Factor and Center-of-Glass U-Factor for Various Spacers

Frame U-factor. Fenestration frame elements consist of all structural members exclusive of the glazing units and include sash, jamb, head, and sill members; meeting rails; mullions; and other glazing dividers. Estimating the rate of heat transfer through the frame is complicated by (1) the variety of fenestration products and frame configurations, (2) the different combinations of materials used for frames, (3) the different sizes available in residential and commercial applications, and to a lesser extent, (4) the glazing unit width and spacer type. Internal dividers or grilles have little impact on the fenestration U-factor, provided there is at least a 1/8-in. gap between the divider and each panel of glass.

Fenestration product type (or operator type) refers to the design configuration (*e.g.*, casement, slider, or fixed window, patio door, skylight, etc.). Materials commonly used for framing members include wood, aluminum, and vinyl. Fiberglass-framed windows are also available. Manufacturers sometimes combine these materials as clad units, (*e.g.*, vinyl-clad aluminum, aluminum-clad wood) to increase durability or improve aesthetics. Aluminum units are available in both solid metal and in "thermally broken" units with plastic inserts that reduce the conductive heat transfer through framing members. Vinyl-framed units may also be structurally reinforced with steel rods and/or may have interior cavities filled with foam insulating materials.

Computer simulations found that frame heat loss in most fenestration is controlled by a single component or controlling resistance, and only changes in this component significantly affect frame heat loss (Enermodal Engineering 1990). For example, the frame U-factor for thermally broken aluminum windows is largely controlled by the depth of the thermal break material in the heat flow direction. For aluminum frames without a thermal break, the inside film coefficient provides most of the resistance to heat flow. For vinyl- and wood-framed fenestrations, the controlling resistance is the shortest distance between the inside and outside surfaces, which usually depends on the thickness of the sealed glazing unit.

Carpenter and McGowan (1993) experimentally validated frame U-factors for a variety of fixed and operable window types, sizes, and materials using computer modelling techniques. Table 2 lists frame U-factors for a variety of frame and spacer materials and glazing unit thicknesses.

Interior and exterior surface coefficients. Part of the overall thermal resistance of a fenestration system is due to the convective and radiative heat transfer between the exposed surfaces and the environment. Surface heat transfer coefficients at the outer and inner glazing surfaces, h_o and h_i, respectively, combine the effects of radiation and convection.

The wind speed and orientation of the building are important in determining h_o. This relationship has long been studied and many correlations have been proposed for h_o as a function of wind speed. However, no universal relationship has been accepted, and limited field measurements at low air speeds by Klems (1989) show significant difference with values used by others.

Convective heat transfer coefficients are usually determined at standard temperature and air velocity conditions on each side. Wind speed can vary from less than 50 fpm for calm weather, free convection conditions, to over 25 mph for storm conditions. A standard value of 5.1 Btu/h · ft² · °F corresponding to a 15 mph is often used to represent winter design conditions. At near-zero

Table 2 Representative Fenestration Frame U-Factors in Btu/(h · ft² · °F)—Vertical Orientation

		Operator Type / Glazing Thickness											
		Operable			Fixed			Double Door			Skylight		
Frame Material	Type of Spacer	Single[b]	Double[c]	Triple[d]	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
Thermal broken aluminum[a]	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
	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/ reinforced vinyl	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
	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	0.48	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 fiberglass/vinyl	Metal	0.37	0.33	0.30	0.37	0.33	0.30	0.37	0.33	0.30	n/a	n/a	n/a
	Insulated	n/a	0.28	0.25	n/a	0.28	0.25	n/a	0.28	0.25	n/a	n/a	n/a

[a] Depends strongly on width of thermal break. Value given is for 3/8 in.

[b] Single glazing corresponds to individual glazing unit thickness of 1/8 in (nominal).

[c] Double glazing corresponds to individual glazing unit thickness of 3/4 in (nominal).

[d] Triple glazing corresponds to individual glazing unit thickness of 1 3/8 in (nominal).

n/a Not applicable

Table 3 Indoor Radiation and Convection Coefficient h_i (Still Air Conditions)

Indoor Glass Surface Emittance, e_g						Temp. Diff., °F	Glass Temp., °F	Room Temp. °F
0.05	0.10	0.20	0.40	0.84	0.90			
Indoor Coefficient h_i, Btu/(h · ft² · °F)								
0.45	0.51	0.61	0.81	1.25	1.31	5	65	70 (winter design)
0.53	0.58	0.68	0.88	1.31	1.37	10	60	
0.62	0.67	0.76	0.96	1.38	1.44	20	50	
0.68	0.73	0.81	1.01	1.42	1.48	30	40	
0.73	0.77	0.86	1.04	1.44	1.50	40	30	
0.76	0.81	0.90	1.07	1.46	1.51	50	20	
0.79	0.84	0.92	1.10	1.47	1.52	60	10	
0.81	0.88	1.00	1.25	1.79	1.87	60	135	75 (summer design)
0.78	0.84	0.96	1.20	1.73	1.80	50	125	
0.74	0.80	0.91	1.15	1.66	1.73	40	115	
0.69	0.75	0.86	1.09	1.59	1.66	30	105	
0.63	0.68	0.79	1.02	1.50	1.57	20	95	
0.53	0.59	0.70	0.91	1.39	1.45	10	85	
0.46	0.51	0.62	0.83	1.30	1.36	5	80	

$h_i = h_c + h_r = A\,(\Delta t)^{0.25} + [e_g\,\sigma\,(T_g^{\,4} - T_i^{\,4})]/(T_g - T_i)$ where $A = 0.27$.

wind speed, h_o varies with outside air and surface temperature, orientation to vertical, and air moisture content.

For natural convection at the inner surface of a vertical window, the inner surface coefficient depends on the indoor air and glass surface temperatures and on the emittance of the glass inner surface. Table 3 shows the variation of h_i for winter (t_i = 70°F) and summer (t_i = 75°F) design conditions. Designers often use h_i = 1.46 Btu/h · ft² · °F, which corresponds to t_i = 70°F, glass temperature = 20°F, and uncoated glass with e_g = 0.84. For summer conditions, the conventional h_i = 1.46 Btu/h · ft² °F corresponds approximately to glass temperature = 90°F and t_i = 75°F.

Heat transfer between the glazing surface and its environment is driven not only by the local air temperatures but also by the radiant temperatures to which the surface is exposed. The radiant temperature of the indoor environment is generally assumed to be equal to the indoor air temperature. While this is a safe assumption where a small window is exposed to a large room with surface temperatures equal to the air temperature, it is not valid in rooms where the window is exposed to other large areas of glazing surfaces (*e.g.*, greenhouse, atrium) or to other cooled or heated surfaces (Parmelee 1947).

The radiant temperature of the outdoor environment is frequently assumed to be equal to the outdoor air temperature. This assumption may be in error, since additional radiative heat loss occurs between a fenestration and the clear sky (Duffie and Beckman 1980). Therefore, for clear sky conditions, some effective outdoor temperature $t_{o,e}$ should replace t_o, in Equation (1). For methods for determining $t_{o,e}$ see, for example, work by the University of Waterloo (1987). Note that a fully cloudy sky is assumed in ASHRAE design conditions.

Especially for single glass, U-factors depend strongly on interior and exterior film coefficients. The U-factor for single glass (neglecting the glass resistance) is:

$$U_{cg} = h_o h_i/(h_o + h_i) \tag{4}$$

Values for h_i presented in Table 3 can result in values of U_{cg} for single glass to range from more than 1.4 Btu/h · ft² · °F in winter for an internally coated glass with a low-emittance film to approximately 1.0 Btu/h · ft² · °F in summer for an uncoated clear glass, and 1.2 Btu/h · ft² · °F with bright sunshine.

The air space in an insulating glass panel made up of glass with no reflective coating on the air space surface has a coefficient h_S is given in Table 4 for an effective emittance of 0.72. When a reflective coating is applied to the air space surface, h_S can be selected from Table 4 by first calculating the effective air space emittance E by Equation (5).

$$E = 1/(1/e_o + 1/e_i - 1) \tag{5}$$

where e_o and e_i are the hemispherical emittances of the two air space surfaces. Hemispherical emittance of ordinary uncoated glass is 0.84 over a wavelength range of 0.4 to 40 μm.

Representative U-factors for fenestration systems. Table 5 lists computed U-factors at winter design conditions for many currently available designs. The table is based on ASHRAE-sponsored research involving laboratory testing and computer simulation of various fenestration products. Values are listed for vertical installation and for skylights that are sloped 20° from the horizontal. When available, test data may provide more accurate results for specific products. However, a wide range of measured U-factors for similar products has been reported (Hogan 1988). Different test methods sometimes give different U-factors (McCabe *et al.* 1986), but the procedures presented in NFRC *Standard* 100-91 or CSA *Standard* A440.2 are generally accepted. Fenestration should be rated in accordance with these standards, while Table 5 can be used as an estimating tool in the early phases of design.

Data are based on center-of-glass and edge-of-glass component U-factors and assume that there are no dividers. If product-specific information is not available from the NFRC or CSA standards programs, the overall U-factors in Table 5 are appropriate

Table 4 Coefficients for Horizontal Heat Flow

Air Space Coefficient h_s, Btu/(h·ft²·°F) Effective Emittance E						Air Temp. Diff., °F	Air Space Temp., °F	Air Space Thickness, °F
0.05	**0.10**	**0.20**	**0.40**	**0.72**	**0.82**			
0.36	0.40	0.47	0.61	0.84	0.91	10	10	0.50
0.37	0.41	0.48	0.62	0.85	0.92	30		
0.40	0.43	0.50	0.65	0.87	0.95	50		
0.45	0.48	0.55	0.70	0.93	1.00	70		
0.48	0.52	0.59	0.73	0.96	1.04	90		
0.38	0.42	0.50	0.66	0.92	1.00	10	30	
0.39	0.43	0.51	0.67	0.93	1.01	30		
0.41	0.45	0.54	0.70	0.96	1.04	50		
0.45	0.50	0.58	0.74	1.00	1.08	70		
0.49	0.53	0.61	0.78	1.04	1.12	90		
0.40	0.44	0.53	0.71	1.00	1.10	10	50	
0.41	0.45	0.54	0.72	1.02	1.11	30		
0.43	0.48	0.57	0.75	1.04	1.13	50		
0.46	0.51	0.60	0.78	1.07	1.17	70		
0.50	0.55	0.64	0.82	1.11	1.21	90		
0.43	0.49	0.60	0.83	1.19	1.31	10	90	
0.44	0.50	0.61	0.84	1.21	1.32	30		
0.47	0.53	0.64	0.87	1.24	1.35	50		
0.48	0.54	0.65	0.88	1.25	1.36	70		
0.52	0.58	0.69	0.92	1.29	1.40	90		
0.45	0.51	0.64	0.89	1.30	1.43	10	110	
0.46	0.52	0.65	0.90	1.31	1.44	30		
0.49	0.55	0.68	0.93	1.34	1.47	50		
0.49	0.55	0.68	0.93	1.34	1.47	70		
0.53	0.59	0.72	0.97	1.38	1.51	90		
0.47	0.51	0.58	0.72	0.95	1.02	10	10	0.28–0.38
0.47	0.51	0.58	0.72	0.95	1.02	50		
0.50	0.53	0.60	0.75	0.98	1.05	90		
0.49	0.53	0.61	0.77	1.03	1.11	10	30	
0.49	0.53	0.61	0.77	1.03	1.11	50		
0.52	0.56	0.64	0.80	1.06	1.14	90		
0.51	0.56	0.65	0.83	1.12	1.21	10	50	
0.51	0.56	0.65	0.83	1.12	1.21	50		
0.54	0.58	0.68	0.86	1.15	1.24	90		
0.56	0.61	0.73	0.95	1.32	1.43	10	90	
0.56	0.61	0.73	0.95	1.32	1.43	50		
0.58	0.64	0.76	0.99	1.35	1.47	90		
0.58	0.64	0.77	1.02	1.43	1.55	10	110	
0.58	0.64	0.77	1.02	1.43	1.56	50		
0.61	0.67	0.80	1.05	1.46	1.59	90		
0.69	0.72	0.80	0.94	1.17	1.24	10	10	0.25
0.69	0.72	0.80	0.94	1.17	1.24	90		
0.72	0.76	0.84	1.00	1.26	1.34	10	30	
0.72	0.76	0.84	1.00	1.26	1.34	90		
0.75	0.79	0.88	1.06	1.35	1.45	10	50	
0.75	0.79	0.88	1.07	1.36	1.45	90		
0.81	0.86	0.98	1.20	1.57	1.68	10	90	
0.81	0.86	0.98	1.21	1.57	1.69	90		
0.84	0.90	1.03	1.28	1.69	1.81	10	110	
0.84	0.90	1.03	1.28	1.69	1.82	90		
0.91	0.94	1.01	1.15	1.38	1.45	10	10	0.19
0.91	0.94	1.01	1.16	1.39	1.46	90		
0.94	0.98	1.06	1.22	1.48	1.56	10	30	
0.94	0.98	1.06	1.23	1.49	1.57	90		
0.98	1.03	1.12	1.30	1.59	1.68	10	50	
0.98	1.03	1.12	1.30	1.59	1.68	90		
1.05	1.11	1.23	1.45	1.82	1.93	10	90	
1.05	1.11	1.23	1.46	1.82	1.94	90		
1.09	1.16	1.28	1.54	1.94	2.07	10	110	
1.09	1.16	1.28	1.54	1.95	2.08	90		

Adapted from Building Materials and Structures, Report 151, United States Dept. of Commerce.

for calculating compliance with the requirements of ASHRAE *Standard* 90. However, they apply only to the specific design conditions described in the footnotes in the table, and they are typically used only to determine peak load conditions for sizing heating equipment.

While these U-factors have been determined for winter conditions, they can also be used to estimate heat gain during peak cooling conditions, since conductive gain, which is one of several variables, is usually a small portion of the total heat gain for fenestration in direct sunlight. Glazing designs and framing materials may be compared in choosing a fenestration system that needs a specific winter design U-factor.

The multiple glazing categories are appropriate for sealed glass units and the addition of storm sash to other glazing units. No distinction is made between flat and domed units such as skylights. For acrylic domes, use an average gas-space width to determine the U-factor. Note that skylight U-factors are greater than those of other similar products. While this is partially due to the difference in slope, it is largely because the skylight surface area, which includes the curb, can vary from 13 to 240% greater than the rough opening area depending on the size and mounting method. Unless noted, all multiple-glazed units are filled with dry air. Argon units are filled with 100% argon. U-factors for CO_2 filled units are similar to argon fills. For spaces up to 0.5 in., argon/SF_6 mixtures with up to 70% SF_6 are generally the same as argon fills. Krypton gas can provide U-factors lower than those for argon for glazing spaces less than 0.5 in.

Table 5 provides data for four values of hemispherical emittance and for 0.25 and 0.5 in. gas space width. The emittance of various low-emittance glasses varies considerably between manufacturers and processes. When the emittance is between the listed values, interpolation may be used. When manufacturers' data are not available, assume that glass with a pyrolytic (hard) coating has an emittance of 0.40, and that glass with a sputtered (soft) coating has an emittance of 0.10. Some coated glazings have lower emittance values. Tinted glass does not change the winter U-factor. Also, some reflective glass may have an emittance less than 0.84. Nonlinear interpolation for gas space width should be based on the equation in footnote 5.

Frame type refers to the primary unit. Thus, when storm sash is added over another glazing, use the values for a nonstorm frame. For glazing with a steel frame, use aluminum frame values. For vertical sliders, horizontal sliders, casement, awning, and pivoted and dual-action windows, use the operable category. Fixed windows can also represent glazed wall systems. Double-door U-factors can also represent single glass doors.

The U-factors in Table 5 are based on the definitions of the four product types, nominal frame sizes, and proportion of frame to glass area as shown in Figure 3. The nominal dimensions for skylights (NFRC size AA) correspond to centerline spacings of roof framing members; consequently, the rough opening dimensions are 22.5 in. by 46.5 in. The skylight coefficients assume the presence of an uninsulated 4 in. curb (either integral to the skylight or field installed). Skylights with smaller curbs, insulated curbs, or no curbs would have lower U-factors.

To estimate the overall U-factor of a fenestration product that differs significantly from the assumptions given in Table 5 and/or Figure 3, first determine the percentage area that is frame/sash, center-of-glass, and edge-of-glass (based on a 2.5 in. band around the perimeter of each glazing unit). Next, determine the appropriate component U-factors. These can be taken either from the standard values listed in italics in Table 5 for glass, the values in Table 2 for frames, or from some other source such as test data or computed factors. Finally, multiply the percent area and the component U-factors, and sum these products to obtain the overall U-factor U_o.

Table 5 Overall Coefficients of Heat Transmission of Various Fenestration Products (Btu/h · ft^2 · °F)

	Glass Only			Aluminum w/o Thermal Break				Aluminum with Thermal Break							
Operator Type	**Center Glass**	**Edge of Glass**		**Operable**	**Fixed**	**Double Door**	**Sloped Skylight**	**Operable**		**Fixed**		**Double Door**		**Sloped Skylight**	
Spacer Type		**Metal**	**Insul.**	**All**	**All**	**All**	**All**	**Metal**	**Insul.**	**Metal**	**Insul.**	**Metal**	**Insul.**	**Metal**	**Insul.**
Glazing ID and Type															
Single Glazing															
1 1/8 in. glass	*1.11*	*1.11*	—	1.30	1.17	1.26	1.92	1.07	—	1.11	—	1.10	—	1.93	—
2 1/4 in. acrylic/polycarbonate	*0.93*	*0.93*	—	1.15	1.00	1.10	1.72	0.93	—	0.95	—	0.95	—	1.73	—
3 1/8 in. acrylic/polycarbonate	*1.02*	*1.02*	—	1.22	1.08	1.18	1.93	1.00	—	1.03	—	1.02	—	1.94	—
4 glass block	*0.60*														
Double Glazing															
5 1/4 in. air space	*0.57*	*0.65*	*0.59*	0.87	0.69	0.80	1.30	0.67	0.64	0.63	0.60	0.66	0.64	1.13	1.07
6 1/2 in. air space	*0.49*	*0.60*	*0.51*	0.81	0.62	0.74	1.29	0.62	0.58	0.56	0.53	0.59	0.57	1.12	1.06
7 1/4 in. argon space	*0.52*	*0.62*	*0.54*	0.83	0.64	0.76	1.25	0.64	0.60	0.59	0.56	0.62	0.60	1.08	1.02
8 1/2 in. argon space	*0.46*	*0.58*	*0.49*	0.78	0.59	0.71	1.25	0.59	0.56	0.54	0.50	0.57	0.55	1.08	1.02
Double Glazing, E = 0.40 on surface 2 or 3															
9 1/4 in. air space	*0.50*	*0.61*	*0.52*	0.81	0.63	0.74	1.24	0.62	0.59	0.57	0.54	0.60	0.58	1.06	1.00
10 1/2 in. air space	*0.40*	*0.54*	*0.43*	0.74	0.54	0.66	1.23	0.55	0.51	0.49	0.45	0.52	0.50	1.06	0.99
10 1/4 in. argon space	*0.43*	*0.56*	*0.46*	0.76	0.57	0.69	1.17	0.57	0.54	0.51	0.48	0.54	0.52	1.00	0.93
12 1/2 in. argon space	*0.36*	*0.51*	*0.40*	0.71	0.50	0.63	1.18	0.52	0.48	0.45	0.41	0.49	0.46	1.01	0.94
Double Glazing, E = 0.20 on surface 2 or 3															
13 1/4 in. air space	*0.46*	*0.58*	*0.49*	0.78	0.59	0.71	1.20	0.59	0.56	0.54	0.50	0.57	0.55	1.03	0.96
14 1/2 in. air space	*0.35*	*0.50*	*0.39*	0.70	0.50	0.62	1.19	0.52	0.48	0.44	0.40	0.48	0.46	1.02	0.95
15 1/4 in. argon space	*0.38*	*0.52*	*0.41*	0.72	0.52	0.64	1.12	0.54	0.50	0.47	0.43	0.50	0.48	0.95	0.87
16 1/2 in. argon space	*0.30*	*0.46*	*0.35*	0.66	0.45	0.58	1.14	0.48	0.44	0.40	0.36	0.44	0.42	0.97	0.89
Double Glazing, E = 0.10 on surface 2 or 3															
17 1/4 in. air space	*0.43*	*0.56*	*0.46*	0.76	0.57	0.69	1.17	0.57	0.54	0.51	0.48	0.54	0.52	1.00	0.93
18 1/2 in. air space	*0.32*	*0.48*	*0.36*	0.67	0.47	0.59	1.17	0.49	0.45	0.42	0.38	0.46	0.43	1.00	0.93
19 1/4 in. argon space	*0.35*	*0.50*	*0.39*	0.70	0.50	0.62	1.09	0.52	0.48	0.44	0.40	0.48	0.46	0.92	0.84
20 1/2 in. argon space	*0.27*	*0.44*	*0.32*	0.64	0.43	0.55	1.11	0.46	0.42	0.37	0.33	0.42	0.39	0.94	0.86
Triple Glazing															
21 1/4 in. air spaces	*0.38*	*0.52*	*0.41*	0.72	0.52	0.64	1.13	0.54	0.50	0.47	0.43	0.50	0.48	0.93	0.88
22 1/2 in. air spaces	*0.31*	*0.47*	*0.35*	0.67	0.46	0.59	1.10	0.49	0.45	0.41	0.37	0.44	0.42	0.91	0.85
23 1/4 in. argon spaces	*0.34*	*0.49*	*0.38*	0.69	0.49	0.61	1.08	0.51	0.47	0.43	0.40	0.47	0.45	0.89	0.83
24 1/2 in. argon spaces	*0.29*	*0.45*	*0.34*	0.65	0.44	0.57	1.07	0.47	0.43	0.39	0.35	0.43	0.40	0.88	0.82
Triple Glazing, E = 0.40 on surface 2, 3, 4, or 5															
25 1/4 in. air spaces	*0.35*	*0.50*	*0.39*	0.70	0.50	0.62	1.09	0.52	0.48	0.44	0.40	0.47	0.45	0.90	0.84
26 1/2 in. air spaces	*0.27*	*0.44*	*0.32*	0.64	0.43	0.55	1.06	0.46	0.42	0.37	0.33	0.41	0.39	0.87	0.81
27 1/4 in. argon spaces	*0.30*	*0.46*	*0.35*	0.66	0.45	0.58	1.04	0.48	0.44	0.40	0.36	0.43	0.41	0.85	0.79
28 1/2 in. argon spaces	*0.24*	*0.42*	*0.30*	0.61	0.40	0.53	1.03	0.44	0.40	0.35	0.31	0.39	0.36	0.84	0.78
Triple Glazing, E = 0.20 on surface 2, 3 ,4, or 5															
29 1/4 in. air spaces	*0.33*	*0.48*	*0.37*	0.68	0.48	0.60	1.07	0.50	0.46	0.43	0.39	0.46	0.44	0.88	0.82
30 1/2 in. air spaces	*0.24*	*0.42*	*0.30*	0.61	0.40	0.53	1.04	0.44	0.40	0.35	0.31	0.39	0.36	0.85	0.79
31 1/4 in. argon spaces	*0.27*	*0.44*	*0.32*	0.64	0.43	0.55	1.02	0.46	0.42	0.37	0.33	0.41	0.39	0.82	0.76
32 1/2 in. argon spaces	*0.21*	*0.39*	*0.27*	0.59	0.37	0.50	1.01	0.41	0.37	0.32	0.28	0.36	0.34	0.81	0.75
Triple Glazing, E = 0.10 on surface 2, 3, 4, or 5															
33 1/4 in. air spaces	*0.32*	*0.48*	*0.36*	0.67	0.47	0.59	1.05	0.49	0.45	0.42	0.38	0.45	0.43	0.86	0.80
34 1/2 in. air spaces	*0.22*	*0.40*	*0.28*	0.60	0.38	0.51	1.03	0.42	0.38	0.33	0.29	0.37	0.35	0.84	0.78
35 1/4 in. argon spaces	*0.26*	*0.43*	*0.31*	0.63	0.42	0.54	1.00	0.45	0.41	0.36	0.32	0.40	0.38	0.80	0.74
36 1/2 in. argon spaces	*0.19*	*0.38*	*0.26*	0.57	0.36	0.48	0.99	0.40	0.36	0.30	0.26	0.35	0.32	0.79	0.73
Triple Glazing, E = 0.40 on surfaces 3 and 5															
37 1/4 in. air spaces	*0.33*	*0.48*	*0.37*	0.68	0.48	0.60	1.06	0.50	0.46	0.43	0.39	0.46	0.44	0.87	0.81
38 1/2 in. air spaces	*0.24*	*0.42*	*0.30*	0.61	0.40	0.53	1.04	0.44	0.40	0.35	0.31	0.39	0.36	0.85	0.79
39 1/4 in. argon spaces	*0.27*	*0.44*	*0.32*	0.64	0.43	0.55	1.02	0.46	0.42	0.37	0.33	0.41	0.39	0.82	0.76
40 1/2 in. argon spaces	*0.21*	*0.39*	*0.27*	0.59	0.37	0.50	1.00	0.41	0.37	0.32	0.28	0.36	0.34	0.80	0.74
Triple Glazing, E = 0.20 on surfaces 3 and 5															
41 1/4 in. air spaces	*0.29*	*0.45*	*0.34*	0.65	0.44	0.57	1.03	0.47	0.43	0.39	0.35	0.43	0.40	0.84	0.78
42 1/2 in. air spaces	*0.20*	*0.39*	*0.27*	0.58	0.36	0.49	1.01	0.41	0.37	0.31	0.27	0.35	0.33	0.81	0.75
43 1/4 in. argon spaces	*0.23*	*0.41*	*0.29*	0.60	0.39	0.52	0.98	0.43	0.39	0.34	0.30	0.38	0.36	0.79	0.72
44 1/2 in. argon spaces	*0.16*	*0.35*	*0.24*	0.55	0.33	0.46	0.96	0.38	0.34	0.28	0.24	0.32	0.30	0.77	0.71
Triple Glazing, E = 0.10 on surfaces 3 and 5															
45 1/4 in. air spaces	*0.27*	*0.44*	*0.32*	0.64	0.43	0.55	1.02	0.46	0.42	0.37	0.33	0.41	0.39	0.82	0.76
46 1/2 in. air spaces	*0.17*	*0.36*	*0.24*	0.56	0.34	0.47	0.99	0.39	0.34	0.29	0.25	0.33	0.31	0.79	0.73
47 1/4 in. argon spaces	*0.21*	*0.39*	*0.27*	0.59	0.37	0.50	0.95	0.41	0.37	0.32	0.28	0.36	0.34	0.76	0.70
48 1/2 in. argon spaces	*0.14*	*0.34*	*0.22*	0.53	0.31	0.44	0.94	0.36	0.32	0.26	0.22	0.31	0.28	0.75	0.69
Quadruple Glazing, E = 0.10 on surfaces 3 and 5															
49 1/4 in. air spaces	*0.23*	*0.41*	*0.29*	0.60	0.39	0.52	0.97	0.43	0.39	0.34	0.30	0.38	0.36	0.78	0.71
50 1/2 in. air spaces	*0.15*	*0.35*	*0.23*	0.54	0.32	0.45	0.93	0.37	0.33	0.27	0.23	0.31	0.29	0.74	0.68
51 1/4 in. argon spaces	*0.17*	*0.36*	*0.24*	0.56	0.34	0.47	0.92	0.39	0.34	0.29	0.25	0.33	0.31	0.73	0.67
52 1/2 in. argon spaces	*0.12*	*0.32*	*0.21*	0.52	0.29	0.43	0.90	0.35	0.31	0.24	0.20	0.29	0.27	0.71	0.65
53 1/4 in. krypton spaces	*0.12*	*0.32*	*0.21*	0.52	0.29	0.43	0.89	0.35	0.31	0.24	0.20	0.29	0.27	0.69	0.63
54 1/2 in. krypton spaces	*0.11*	*0.31*	*0.20*	0.51	0.29	0.42	0.89	0.34	0.30	0.23	0.19	0.28	0.26	0.69	0.63

Table 5 Overall Coefficients of Heat Transmission of Various Fenestration Products (Btu/h·ft²·°F) (*Concluded*)

Reinforced Vinyl/Aluminum-Clad Wood								Wood Vinyl								Insulated Fiberglass/Vinyl						
Operable		Fixed		Double Door		Sloped Skylight		Operable		Fixed		Double Door		Sloped Skylight		Operable		Fixed		Double Door		
Metal	Insul.	Metal	Insul.	Metal	Insul.	Metal	Insul.	Metal	Insul.	Metal	Insul.	Metal	Insul.	Metal	Insul.	Metal	Insul.	Metal	Insul.	Metal	Insul.	ID
0.98	—	1.05	—	0.99	—	1.50	—	0.94	—	1.04	—	0.98	—	1.47	—	0.86	—	1.02	—	0.93	—	1
0.85	—	0.89	—	0.85	—	1.31	—	0.81	—	0.88	—	0.84	—	1.27	—	0.74	—	0.86	—	0.79	—	2
0.92	—	0.97	—	0.92	—	1.51	—	0.87	—	0.96	—	0.91	—	1.48	—	0.80	—	0.94	—	0.86	—	3
																						4
0.60	0.57	0.58	0.56	0.57	0.55	0.88	0.86	0.56	0.54	0.57	0.56	0.56	0.54	0.85	0.82	0.50	0.47	0.55	0.54	0.52	0.50	5
0.55	0.52	0.51	0.49	0.52	0.49	0.87	0.85	0.51	0.48	0.51	0.49	0.50	0.48	0.84	0.81	0.45	0.42	0.49	0.47	0.46	0.44	6
0.57	0.54	0.54	0.52	0.54	0.52	0.84	0.81	0.53	0.50	0.53	0.51	0.53	0.51	0.80	0.77	0.47	0.44	0.51	0.49	0.48	0.46	7
0.53	0.50	0.49	0.46	0.49	0.47	0.84	0.81	0.49	0.46	0.48	0.46	0.48	0.46	0.80	0.77	0.43	0.40	0.46	0.44	0.44	0.42	8
0.56	0.52	0.52	0.50	0.52	0.50	0.82	0.79	0.52	0.49	0.52	0.50	0.51	0.49	0.79	0.75	0.46	0.43	0.50	0.48	0.47	0.45	9
0.49	0.46	0.44	0.41	0.45	0.43	0.81	0.78	0.45	0.42	0.43	0.41	0.44	0.41	0.78	0.74	0.40	0.36	0.41	0.39	0.40	0.37	10
0.51	0.48	0.46	0.44	0.47	0.45	0.76	0.72	0.47	0.44	0.46	0.43	0.46	0.44	0.72	0.68	0.42	0.38	0.44	0.42	0.42	0.40	11
0.47	0.43	0.40	0.38	0.42	0.40	0.77	0.73	0.43	0.40	0.40	0.37	0.41	0.38	0.73	0.69	0.37	0.34	0.38	0.36	0.37	0.34	12
0.53	0.50	0.49	0.46	0.49	0.47	0.78	0.75	0.49	0.46	0.48	0.46	0.48	0.46	0.75	0.71	0.43	0.40	0.46	0.44	0.44	0.42	13
0.46	0.42	0.39	0.37	0.41	0.39	0.78	0.74	0.42	0.39	0.39	0.36	0.40	0.37	0.74	0.70	0.37	0.33	0.37	0.35	0.36	0.34	14
0.48	0.44	0.42	0.39	0.43	0.41	0.70	0.67	0.44	0.41	0.41	0.39	0.42	0.40	0.67	0.63	0.38	0.35	0.40	0.37	0.38	0.36	15
0.43	0.39	0.35	0.32	0.38	0.35	0.72	0.68	0.39	0.36	0.35	0.32	0.36	0.34	0.69	0.65	0.33	0.30	0.33	0.31	0.33	0.30	16
0.51	0.48	0.46	0.44	0.47	0.45	0.76	0.72	0.47	0.44	0.46	0.43	0.46	0.44	0.72	0.68	0.42	0.38	0.44	0.42	0.42	0.40	17
0.44	0.40	0.37	0.34	0.39	0.37	0.76	0.72	0.40	0.37	0.36	0.34	0.37	0.35	0.72	0.68	0.35	0.31	0.35	0.32	0.34	0.32	18
0.46	0.42	0.39	0.37	0.41	0.39	0.68	0.64	0.42	0.39	0.39	0.36	0.40	0.37	0.64	0.60	0.37	0.33	0.37	0.35	0.36	0.34	19
0.41	0.37	0.32	0.30	0.35	0.33	0.69	0.66	0.37	0.34	0.32	0.29	0.34	0.31	0.66	0.62	0.32	0.28	0.30	0.28	0.30	0.28	20
0.46	0.41	0.41	0.39	0.43	0.40	0.71	0.67	0.43	0.39	0.41	0.38	0.42	0.39	0.67	0.63	0.37	0.34	0.39	0.37	0.38	0.35	21
0.42	0.37	0.35	0.33	0.37	0.35	0.68	0.64	0.38	0.34	0.35	0.32	0.36	0.34	0.65	0.60	0.33	0.29	0.33	0.31	0.32	0.30	22
0.44	0.39	0.38	0.35	0.40	0.37	0.66	0.62	0.40	0.36	0.38	0.35	0.39	0.36	0.63	0.58	0.35	0.31	0.36	0.33	0.35	0.32	23
0.40	0.35	0.34	0.31	0.36	0.33	0.65	0.61	0.37	0.33	0.34	0.31	0.35	0.32	0.62	0.57	0.32	0.28	0.32	0.29	0.31	0.28	24
0.44	0.39	0.39	0.36	0.40	0.38	0.67	0.63	0.41	0.37	0.39	0.36	0.39	0.37	0.64	0.59	0.35	0.32	0.37	0.34	0.35	0.33	25
0.39	0.34	0.32	0.29	0.35	0.32	0.65	0.61	0.36	0.31	0.32	0.29	0.33	0.31	0.61	0.56	0.30	0.27	0.30	0.28	0.30	0.27	26
0.41	0.36	0.35	0.32	0.37	0.34	0.63	0.59	0.38	0.33	0.34	0.31	0.36	0.33	0.59	0.54	0.32	0.29	0.33	0.30	0.32	0.29	27
0.37	0.32	0.30	0.27	0.32	0.29	0.62	0.58	0.34	0.29	0.29	0.26	0.31	0.28	0.58	0.53	0.29	0.25	0.27	0.25	0.27	0.25	28
0.43	0.38	0.37	0.34	0.39	0.36	0.65	0.61	0.40	0.35	0.37	0.34	0.38	0.35	0.62	0.57	0.34	0.31	0.35	0.33	0.34	0.31	29
0.37	0.32	0.30	0.27	0.32	0.29	0.63	0.59	0.34	0.29	0.29	0.26	0.31	0.28	0.59	0.54	0.29	0.25	0.27	0.25	0.27	0.25	30
0.39	0.34	0.32	0.29	0.35	0.32	0.60	0.56	0.36	0.31	0.32	0.29	0.33	0.31	0.57	0.52	0.30	0.27	0.30	0.28	0.30	0.27	31
0.35	0.30	0.27	0.24	0.30	0.27	0.59	0.55	0.32	0.27	0.27	0.24	0.29	0.26	0.56	0.51	0.27	0.23	0.25	0.22	0.25	0.23	32
0.42	0.37	0.36	0.34	0.38	0.35	0.64	0.60	0.39	0.35	0.36	0.33	0.37	0.34	0.60	0.55	0.34	0.30	0.34	0.32	0.33	0.31	33
0.36	0.31	0.28	0.25	0.31	0.28	0.62	0.58	0.33	0.28	0.28	0.25	0.30	0.27	0.58	0.53	0.27	0.24	0.26	0.23	0.26	0.23	34
0.38	0.33	0.31	0.28	0.34	0.31	0.58	0.54	0.35	0.31	0.31	0.28	0.33	0.30	0.55	0.50	0.30	0.26	0.29	0.27	0.29	0.26	35
0.34	0.29	0.25	0.22	0.29	0.26	0.57	0.53	0.31	0.26	0.25	0.22	0.27	0.24	0.54	0.49	0.25	0.22	0.23	0.21	0.24	0.21	36
0.43	0.38	0.37	0.34	0.39	0.36	0.65	0.61	0.40	0.35	0.37	0.34	0.38	0.35	0.61	0.56	0.34	0.31	0.35	0.33	0.34	0.31	37
0.37	0.32	0.30	0.27	0.32	0.29	0.63	0.59	0.34	0.29	0.29	0.26	0.31	0.28	0.59	0.54	0.29	0.25	0.27	0.25	0.27	0.25	38
0.39	0.34	0.32	0.29	0.35	0.32	0.60	0.56	0.36	0.31	0.32	0.29	0.33	0.31	0.57	0.52	0.30	0.27	0.30	0.28	0.30	0.27	39
0.35	0.30	0.27	0.24	0.30	0.27	0.58	0.54	0.32	0.27	0.27	0.24	0.29	0.26	0.55	0.50	0.27	0.23	0.25	0.22	0.25	0.23	40
0.40	0.35	0.34	0.31	0.36	0.33	0.62	0.58	0.37	0.33	0.34	0.31	0.35	0.32	0.58	0.53	0.32	0.28	0.32	0.29	0.31	0.28	41
0.35	0.29	0.26	0.23	0.29	0.26	0.59	0.55	0.31	0.27	0.26	0.23	0.28	0.25	0.56	0.51	0.26	0.23	0.24	0.22	0.24	0.22	42
0.37	0.31	0.29	0.26	0.32	0.29	0.56	0.52	0.33	0.29	0.28	0.25	0.30	0.27	0.53	0.48	0.28	0.24	0.27	0.24	0.27	0.24	43
0.32	0.27	0.23	0.20	0.26	0.23	0.55	0.50	0.29	0.24	0.22	0.19	0.25	0.22	0.51	0.46	0.23	0.20	0.21	0.18	0.22	0.19	44
0.39	0.34	0.32	0.29	0.35	0.32	0.60	0.56	0.36	0.31	0.32	0.29	0.33	0.31	0.57	0.52	0.30	0.27	0.30	0.28	0.30	0.27	45
0.33	0.28	0.24	0.21	0.27	0.24	0.57	0.53	0.29	0.25	0.23	0.20	0.26	0.23	0.54	0.49	0.24	0.21	0.22	0.19	0.22	0.20	46
0.35	0.30	0.27	0.24	0.30	0.27	0.54	0.49	0.32	0.27	0.27	0.24	0.29	0.26	0.50	0.45	0.27	0.23	0.25	0.22	0.25	0.23	47
0.31	0.26	0.21	0.18	0.25	0.22	0.53	0.49	0.27	0.23	0.21	0.18	0.23	0.21	0.49	0.44	0.22	0.19	0.19	0.17	0.20	0.18	48
0.37	0.31	0.29	0.26	0.32	0.29	0.56	0.51	0.33	0.29	0.28	0.25	0.30	0.27	0.52	0.47	0.28	0.24	0.27	0.24	0.27	0.24	49
0.31	0.26	0.22	0.19	0.26	0.23	0.52	0.48	0.28	0.23	0.22	0.19	0.24	0.21	0.48	0.43	0.23	0.19	0.20	0.17	0.21	0.18	50
0.33	0.28	0.24	0.21	0.27	0.24	0.51	0.47	0.29	0.25	0.23	0.20	0.26	0.23	0.48	0.42	0.24	0.21	0.22	0.19	0.22	0.20	51
0.29	0.24	0.19	0.16	0.23	0.20	0.49	0.45	0.26	0.22	0.19	0.16	0.22	0.19	0.46	0.41	0.21	0.18	0.17	0.15	0.19	0.16	52
0.29	0.24	0.19	0.16	0.23	0.20	0.47	0.43	0.26	0.22	0.19	0.16	0.22	0.19	0.44	0.39	0.21	0.18	0.17	0.15	0.19	0.16	53
0.29	0.24	0.18	0.16	0.23	0.20	0.47	0.43	0.25	0.21	0.18	0.15	0.21	0.18	0.44	0.39	0.20	0.17	0.16	0.14	0.18	0.15	54

Notes for Table 5

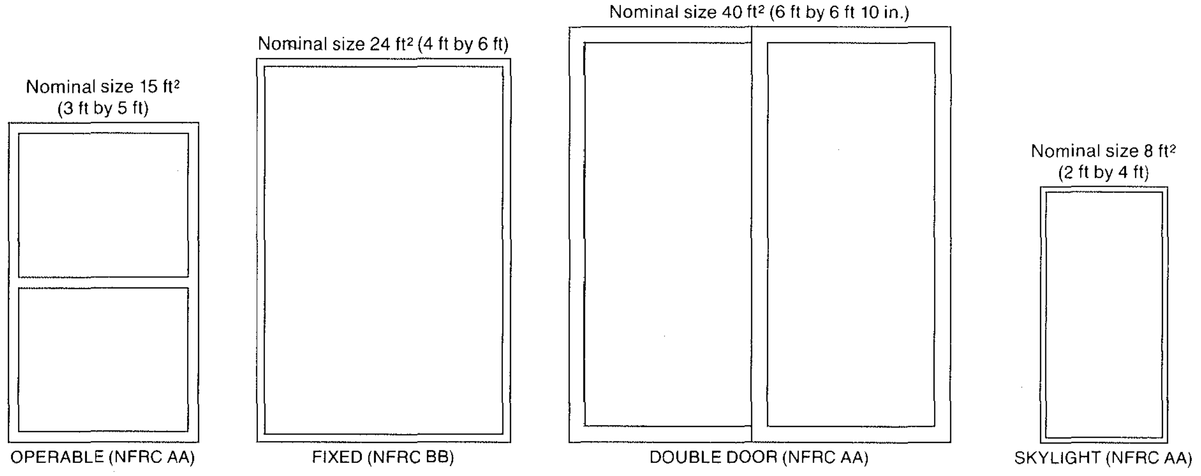
1. All heat transmission coefficients in this table include film resistances and are based on winter conditions of 0°F outdoor air and 70°F indoor air temperature, with 15 mph outdoor air velocity and zero solar flux. With the exception of single glazing, small changes in the interior and exterior temperatures will not significantly affect overall U-factors. The coefficients are for vertical position except skylight values, which are for 20° from horizontal with heat flow up.
2. Glazing layer surfaces are numbered from the outside to the inside. Double, triple, and quadruple refer to the number of glazing panels. All data are based on 1/8 in. glass, unless otherwise noted. Thermal conductivities are: 0.53 Btu/(h · ft · °F) for glass, and 0.11 Btu/(h · ft · °F) for acrylic and polycarbonate .
3. Standard spacers are metal. Insulation means wood, fiberglass, or butyl. Edge-of-glass effects assumed to extend over the 2-1/2 in. band around perimeter of each glazing unit as seen in Figure 3.
4. Product sizes are described in Figure 3 and frame U-factors are from Table 2.
5. Interpolation procedure for estimating U_{cg} for vertically oriented gas space widths between 0.25 and 0.5 in. The most general equation is:

$$U_t = \left[\frac{1}{U_{1/4}} - \frac{n_g}{h + 48\,k_g} + \frac{n_g}{h + (12\,k_g/t)}\right]^{-1}$$

$$h = -\,36\,k_g + \left[\frac{24\,n_g\,k_g\,U_{1/4}\,U_{1/2}}{U_{1/4} - U_{1/2}} + 144\,k_g{}^2\right]^{0.5}$$

where

n_g = number of gaps (*e.g.*, double-pane windows have one gap)
k_g = gas conductivity Btu/(h · ft · °F)
t = gas space width of window, in.
$U_{1/4}$ = U-factor for identical glazing with 1/4 in. gas spaces
$U_{1/2}$ = U-factor for identical glazing with 1/2 in. gas spaces



	Frame Width, in.			
Frame Material	**Operable**	**Fixed**	**Double Door**	**Skylight**
Aluminum without thermal break	1.5	1.3	2.1	0.7
Aluminum with thermal break	2.8	1.3	2.6	0.7
Aluminum clad wood/reinforcing 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

Fig. 3 Standard Fenestration Units

Example 1. Estimate the U-factor for a fixed window (NFRC Size BB) with a reinforced vinyl frame and double-glazing with a sputter-type low-e coating (e = 0.10). The gap is 0.5 in. wide and argon-filled and the spacer is metal.

Solution: Locate the glazing system type in the first column of Table 5 (ID = 20). Then, find the appropriate frame type (reinforced vinyl), operator type (fixed), and spacer type (metal). The U-factor listed (in the third column on the facing page) is 0.32.

Example 2. Estimate a representative U-factor for a wood-framed, 38 in. by 82 in. swinging French door with eight 11-in. by 16-in. panes (true divided panels), each consisting of clear double-glazing with a 0.5 in. air space.

Solution: Without more detailed information, assume that the dividers have the same U-factor as the frame, and that the divider edge has the same U-factor as the edge-of-glass. Calculate the center-of-glass, edge-of-glass, and frame areas.

$$A_{cg} = 8\,[(11 - 5)(16 - 5)] = 528\text{ in}^2$$

$$A_{eg} = 8\,(11 \times 16) - 528 = 880\text{ in}^2$$

$$A_f = (38 \times 82) - 8\,(11 \times 16) = 1708\text{ in}^2$$

Select the center-of-glass, edge-of-glass, and frame U-factors. These component U-factors are 0.49 and 0.60 (from Table 5, glazing ID = 6, columns 1 and 2) and 0.49 (from Table 2, wood frame double door, double-glazing) Btu/h · ft² · °F, respectively.

$$U_o = [(0.49 \times 528) + (0.60 \times 880) + (0.49 \times 1708)]/(38 \times 82) = 0.52\text{ Btu/h}\cdot\text{ft}^2\cdot{}^\circ\text{F.}$$

Example 3. Estimate the U-factor for a 60 in. by 36 in. aluminum framed garden window (NFRC Size AA) that projects out 12 in. from the wall surface. The glazing is double-glass with a 0.25 in. air space and a metal spacer. All of the glazing is fixed (*i.e.*, nonoperable) and the frame is 1 in. wide. The base is 0.75 in. plywood.

Solution: The U-factor is determined by calculating the heat flow through all five surfaces (front, two sides, top, and bottom) and then dividing by the projected area of the window (*i.e.*, the 60 in. by 36 in. opening in the insulated wall).

The U-factors are 0.57 Btu/h · ft² · °F for the center-of-glass and 0.65 Btu/h · ft² · °F for the edge-of-glass (from Table 5, glazing ID = 5, columns 1 and 2) and 1.78 Btu/h · ft² · °F (from Table 2, aluminum frame, fixed window, double-glazing), respectively.

From Table 4 in Chapter 22, the resistance of 0.75 in. plywood is 0.93 h · ft² · °F/Btu. When the exterior film resistance of 0.17 and interior downward flow film resistance of 0.92 h · ft² · °F/Btu (from Table 1, Chapter 22) are added, the total resistance is 2.02 h · ft² · °F/Btu and the

U-factor is 1/2.02 = 0.50 Btu/h · ft² · °F. (The glazing U-factors in Table 5 already include the film resistances.) Now calculate the areas.

For the front surface:

$$A_{cg} = 53 \times 29 = 1537 \text{ in}^2$$

$$A_{eg} = (58 \times 34) - (53 \times 29) = 435 \text{ in}^2$$

$$A_f = (60 \times 36) - (58 \times 34) = 188 \text{ in}^2$$

For the two sides:

$$A_{cg} = 2(5 \times 29) = 290 \text{ in}^2$$

$$A_{eg} = 2[(10 \times 34) - (5 \times 29)] = 390 \text{ in}^2$$

$$A_f = 2[(12 \times 36) - (10 \times 34)] = 184 \text{ in}^2$$

For the top surface:

$$A_{cg} = 53 \times 5 = 265 \text{ in}^2$$

$$A_{eg} = (58 \times 10) - (53 \times 5) = 315 \text{ in}^2$$

$$A_f = (60 \times 12) - (58 \times 10) = 140 \text{ in}^2$$

For the bottom surface,

$$A_{plywood} = 58 \times 10 = 580 \text{ in}^2$$

$$A_f = (60 \times 12) - (58 \times 10) = 140 \text{ in}^2$$

Then calculate the U-factor as follows:

$$\begin{aligned} U_o &= [0.57(1537 + 290 + 265) + 0.65(435 + 390 + 315) \\ &\quad + 1.78(188 + 184 + 140 + 140) + (0.50 \times 580)]/(60 \times 36) \\ &= 1.57 \text{ Btu/h} \cdot \text{ft}^2 \cdot {}^\circ\text{F} \end{aligned}$$

Note that the U-factor for this garden window is even greater than that for a skylight with the same type of glazing. While both have a surface area that is approximately twice the rough opening area, the skylight curbs are often wood, but the garden window side and top panels are glazed.

Example 4. Find the center-of-glass U-factor for a triple-pane window with 0.375 in. air-filled gaps and a low-e coating ($e = 0.2$) on the fifth surface.

Solution: From Table 5, for 0.25 in. spacing, $U_{1/4} = 0.33$ and for 0.5 in. spacing, $U_{1/2} = 0.24$. The thermal conductivity of air is 0.014 Btu/h · ft · °F. Using the equation in footnote 5,

$$\begin{aligned} h &= -36 \times 0.014 \\ &\quad + \left[\frac{24 \times 2 \times 0.014 \times 0.33 \times 0.24}{(0.33 - 0.24)} + 144 \times 0.014^2\right]^{0.5} = 0.283 \end{aligned}$$

$$\begin{aligned} U_{3/8} &= \left[\frac{1}{0.33} - \frac{2}{0.283 + 48 \times 0.014} + \frac{2}{0.283 + (12 \times 0.014/0.375)}\right]^{-1} \\ &= 0.27 \text{ Btu/h} \cdot \text{ft}^2 \cdot {}^\circ\text{F} \end{aligned}$$

Table 6 Glazing U-Factor for Various Wind Speeds

Wind speed, mph		
15	7.5	0
U-Factor, Btu/h · ft² · °F		
0.10	0.10	0.10
0.20	0.20	0.19
0.30	0.29	0.28
0.40	0.38	0.37
0.50	0.47	0.45
0.60	0.56	0.53
0.70	0.65	0.61
0.80	0.74	0.69
0.90	0.83	0.78
1.00	0.92	0.86
1.10	1.01	0.94
1.20	1.10	1.02
1.30	1.19	1.10

Because of the combined effects of solar gain, wind, ambient temperature and cloud cover, fenestration performance is likely to be different from the data in Table 5 when products are installed in buildings. Since these factors influence the rate of heat transfer through fenestration, seasonal or annual energy flows cannot be accurately determined solely on the basis of the design-day U-factors. Where U-factors are to be compared at different wind speeds, Table 6 provides approximate data to convert the overall U-factor data at one specific wind condition to a U-factor at another. Performance data in Table 5 are based on the assumption of an overcast sky, which implies that the effective sky temperature for radiative heat transfer is equal to the outdoor air temperature. This assumption gives reasonable results with 7.5- and 15-mph wind speeds; however, with a clear sky and nearly still wind conditions, significant heat transfer occurs by radiation, and the data in Table 6 may underestimate the actual U-factor.

DETERMINING INCIDENT SOLAR FLUX

Solar Radiation

The flux of solar radiation on a surface normal to the sun's rays beyond the earth's atmosphere at the mean earth-sun distance (92.9 × 10⁶ miles) is defined as the solar constant E_{sc}. The currently accepted value is 433.34 Btu/h · ft² (CIMO 1982). Because the earth's orbit is slightly elliptical, the extraterrestrial radiant flux E_o varies from a maximum of 448.2 Btu/h · ft² on January 3, when the earth is closest to the sun, to a minimum of 419.2 Btu/h · ft² on July 4, when the earth-sun distance reaches its maximum.

The earth's orbital velocity also varies throughout the year, so *apparent solar time*, as determined by a sundial, varies slightly from the *mean time* kept by a clock running at a uniform rate. This variation, called the *equation of time*, is given in Table 7. The sun's position in the sky is determined by *local solar time*, found by adding the equation of time to the local civil time. *Local civil time* is found by adding to or subtracting from *local standard time* (LST) the longitude correction of 4 minutes per degree difference between the local longitude and the longitude of the standard time meridian for that locality. In the United States and Canada, these values are 60° for Atlantic Standard Time (ST); 75° for Eastern ST; 90° for Central ST; 105° for Mountain ST; 120° for Pacific ST, 135° for Yukon ST; 150° for Alaska-Hawaii ST.

Table 7 Extraterrestrial Solar Radiation Intensity and Related Data

	I_o Btu/(h · ft²)	Equation of Time, min.	Declination, degrees	A $\frac{\text{Btu}}{(\text{h} \cdot \text{ft}^2)}$	B (Dimensionless Ratios)	C (Dimensionless Ratios)
Jan	448.8	−11.2	−20.0	390	0.142	0.058
Feb	444.2	−13.9	−10.8	385	0.144	0.060
Mar	437.7	−7.5	0.0	376	0.156	0.071
Apr	429.9	1.1	11.6	360	0.180	0.097
May	423.6	3.3	20.0	350	0.196	0.121
June	420.2	−1.4	23.45	345	0.205	0.134
July	420.3	−6.2	20.6	344	0.207	0.136
Aug	424.1	−2.4	12.3	351	0.201	0.122
Sep	430.7	7.5	0.0	365	0.177	0.092
Oct	437.3	15.4	−10.5	378	0.160	0.073
Nov	445.3	13.8	−19.8	387	0.149	0.063
Dec	449.1	1.6	−23.45	391	0.142	0.057

Note: Data are for 21st day of each month during the base year of 1964.