

CHAPTER 15

FENESTRATION

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FENESTRATION is an architectural term that refers to the arrangement, proportion, and design of window, skylight, and door systems in a building. Fenestration can serve as a physical and/or visual connection to the outdoors, as well as a means to admit solar radiation for natural lighting (**daylighting**), and for heat gain to a space. Fenestration can be fixed or operable, and operable units can allow natural ventilation to a space and egress in low-rise buildings.

Fenestration affects building energy use through four basic mechanisms: thermal heat transfer, solar heat gain, air leakage, and daylighting. The energy effects of fenestration can be minimized by (1) using daylight to offset lighting requirements, (2) using glazings and shading strategies to control solar heat gain to supplement heating through passive solar gain and minimize cooling requirements, (3) using glazing to minimize conductive heat loss, (4) specifying low-air-leakage fenestration products, and (5) integrating fenestration into natural ventilation strategies that can reduce energy use for cooling and fresh air requirements.

Today’s designers, builders, energy codes, and energy-efficiency incentive programs [such as ENERGY STAR (www.energystar.gov) and the LEED Green Building Program (www.usgbc.org)] are asking more and more from fenestration systems. Window, skylight, and door manufacturers are responding with new and improved products to meet those demands. With the advent of computer simulation software, designing to improve thermal performance of fenestration products has become much easier. Through participation in rating and certification programs [such as those of the National Fenestration Rating Council (NFRC)] that require the use of this software, fenestration manufacturers can take credit for these improvements through certified ratings that are credible to designers, builders, and code officials. A designer should consider architectural requirements, thermal performance, economic criteria, and human comfort when selecting fenestration. Typically, a wide range of fenestration products are available that meet the specifications for a project. Refining the specifications to improve energy performance and enhance a living or work space can result in lower energy costs, increased productivity, and improved thermal and visual comfort. CEA (1995) provides guidance for carrying out these requirements.

FENESTRATION COMPONENTS

Fenestration components include glazing material, either glass or plastic; framing, mullions, muntin bars, dividers, and opaque

door slabs; and shading devices such as louvered blinds, drapes, roller shades, and awnings. In this chapter, **fenestration** and **fenestration systems** refer to the basic assemblies and components of exterior window, skylight, and door systems within the building envelope.

Glazing Units

A glazing unit may consist of a single glazing or multiple glazings. Units with multiple glazing layers, sometimes called **insulating glazing units (IGUs)**, are hermetically sealed, multiple-pane assemblies consisting of two or more glazing layers held and bonded at their perimeter by a spacer bar typically containing a desiccant material. The desiccated spacer is surrounded on at least two sides by a sealant that adheres the glass to the spacer. **Figure 1** shows the construction of a typical double-glazing unit.

Glazing. The most common glazing material is glass, although plastic is also used. Both may be clear, tinted, coated, laminated, patterned, or obscured. Clear glass transmits more than 75% of the incident solar radiation and more than 85% of the visible light. Tinted glass is available in many colors, all of which differ in the amount of solar radiation and visible light they transmit and absorb. Coatings on glass affect the transmission of solar radiation, and visible light may affect the absorptance of room-temperature radiation.

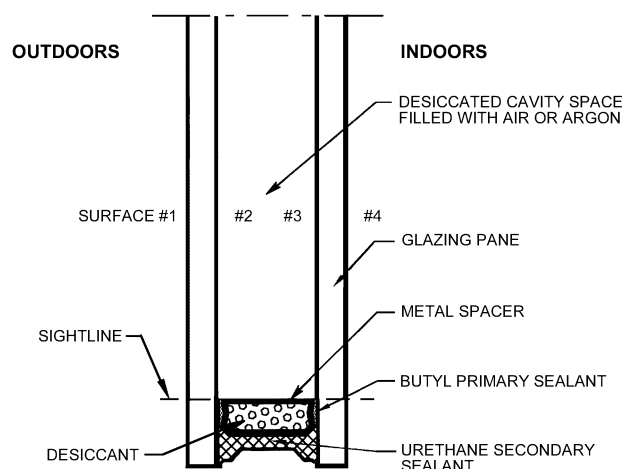


Fig. 1 Double-Glazing Unit Construction Detail

The preparation of this chapter is assigned to TC 4.5, Fenestration.

Some coatings are highly reflective (e.g., mirrors), whereas others have very low reflectance. Some coatings result in visible light transmittance as much as twice the solar heat gain coefficient (desirable for good daylighting while minimizing cooling loads). Laminated glass is made of two panes of glass adhered together. The interlayer between the two panes of glass is typically plastic and may be clear, tinted, or coated. Patterned glass is a durable ceramic frit applied to a glass surface in a decorative pattern. Obscured glass is translucent and is typically used in privacy applications.

Because of its energy efficiency, daylighting, and comfort benefits, low-emissivity (low-e) coated glass is now used in more than 50% of all fenestration products installed in the United States. Tinted and reflective glazing can also be used to reduce solar heat gain through fenestration products. Low-e coatings can also be applied to thin plastic films for use as one of the middle layers in glazing units with three or more layers. There are two types of low-e coating: **high-solar-gain** coatings primarily reduce heat conduction through the glazing system, and are intended for cold climates. **Low-solar-gain coatings**, for hot climates, reduce solar heat gain by blocking admission of the infrared portion of the solar spectrum. There are two ways of achieving low-solar-gain low-e performance: (1) with a special, multilayer solar-infrared-reflecting coating, and (2) with a solar-infrared-absorbing outer glass. To protect the inner glazing and building interior from the absorbed heat from this outer glass, a cold-climate-type low-e coating is also used to reduce conduction of heat from the outer pane to the inner one. In addition, argon and krypton gas are used in lieu of air in the gap between the panes in combination with low-e glazing to further reduce energy transfer. Some manufacturers construct glazing units with one or more suspended, low-e coated plastic films between glazing layers and with a spacer that has better insulating properties and a dual sealant that improves the seal around the gas spaces.

Spacer. The spacer separates the panes of glass and provides the surface for primary and secondary sealant adhesion. Several types of spacers are used today. Each type provides different heat transfer properties, depending on spacer material and geometry.

Heat transfer at the edge of the glazing unit is greater than at its center because of greater heat flow through the spacer system. To minimize this heat flow, **warm-edge spacers** have been developed that reduce edge heat transfer by using spacer materials that have lower thermal conductivity than the typical aluminum (e.g., stainless steel, galvanized steel, tin-plated steel, polymers, foamed silicone) from which spacers have often been made.

Fusing or bending the corners of the spacer minimizes moisture and hydrocarbon vapor transmission into the air space through the corners. Desiccants such as molecular sieve or silica gel are also used to absorb moisture initially trapped in the glazing unit during assembly or that gradually diffuses through the seals after construction.

Sealant(s). Several different sealant configurations are used successfully in modern glazing unit construction. In all sealant configurations, the primary seal minimizes moisture and hydrocarbon transmission. In dual-seal construction, the secondary seal provides structural integrity between the lites of the glazing unit. A secondary seal ensures long-term adhesion and greater resistance to solvents, oils, and short-term water immersion. In typical dual-seal construction, the primary seal is made of compressed polyisobutylene (PIB), and the secondary seal is made of silicone, polysulfide, or polyurethane. Single-seal construction depends on a single sealant to provide adhesion of the glass to the spacer as well as minimizing moisture and hydrocarbon transmission. Single-seal construction is generally more cost efficient than dual-seal systems. A third type of sealant takes advantage of advanced cross-linking polymers that provide both low moisture transmission and structural properties equivalent to dual-seal systems; therefore, these sealants are typically called **dual-seal-equivalent (DSE)** materials.

Desiccants. Typical desiccants include molecular sieve, silica gel, or a matrix of both materials. Desiccants are used to absorb

moisture initially trapped in the glazing unit during assembly or that gradually diffused through the seals after construction.

Gas Fill. The hermetically sealed space between glass panes is most often filled with air. In some cases, argon and krypton gas are used instead, to further reduce energy transfer.

Framing

The three main categories of window framing materials are wood, metal, and polymers. **Wood** has good structural integrity and insulating value but low resistance to weather, moisture, warpage, and organic degradation (from mold and insects). **Metal** is durable and has excellent structural characteristics, but it has very poor thermal performance. The metal of choice in windows is almost exclusively aluminum, because of its ease of manufacture, low cost, and low mass, but aluminum has a thermal conductivity roughly 1000 times that of wood or polymers. The poor thermal performance of metal-frame windows can be improved with a thermal break (a nonmetal component that separates the metal frame exposed to the outside from the surfaces exposed to the inside). **Polymer** frames are made of extruded vinyl or poltruded fiberglass (glass-reinforced polyester). Their thermal and structural performance is similar to that of wood, although vinyl frames for large windows must be reinforced.

Manufacturers sometimes combine these materials as clad units (e.g., vinyl-clad aluminum, aluminum-clad wood, vinyl-clad wood) to increase durability, improve thermal performance, or improve aesthetics. In addition, curtain wall systems for commercial buildings may be structurally glazed, and the outdoor “framing” is simply rubber gaskets or silicone.

Residential windows can be categorized by operator type, as shown by the traditional basic types in [Figure 2](#). The glazing system can be mounted either directly in the frame (a direct-glazed or direct-set window, which is not operable) or in a sash that moves in the frame (for an operating window). In operable windows, a weather-sealing system between the frame and sash reduces air and water leakage.

Shading

Shading can be located either outdoors or indoors, and in some cases, internal to the glazing system (between the glass). Materials used include metal, wood, plastic, and fabric. Shading devices are available in a wide range of products that differ greatly in their appearance and energy performance. They include indoor and outdoor blinds, integral blinds, indoor and outdoor screens, shutters, draperies, and roller shades. Shading devices on the outdoor side of the glazing reduce solar heat gain more effectively than indoor devices. However, indoor devices are easier to operate and adjust. Some products help insulate the indoors from the outdoors, whereas others redirect incoming solar radiation to minimize visual and thermal discomfort. Window reveals and side fins as well as awnings and overhangs can offer effective shading as well. Outdoor vegetative shading is particularly effective in reducing solar heat gain while enhancing the outdoor scene.

DETERMINING FENESTRATION ENERGY FLOW

Energy flows through fenestration via (1) conductive and convective heat transfer caused by the temperature difference between outdoor and indoor air, (2) net long-wave (above 2500 nm) radiative exchange between the fenestration and its surroundings and between glazing layers, and (3) short-wave (below 2500 nm) solar radiation incident on the fenestration product, either directly from the sun or reflected from the ground or adjacent objects. Simplified calculations are based on the observation that temperatures of the sky, ground, and surrounding objects (and hence their radiant emission) correlate with the outdoor air temperature. The radiative interchanges are then approximated by assuming that all the radiating surfaces (including the sky) are at the same temperature as the

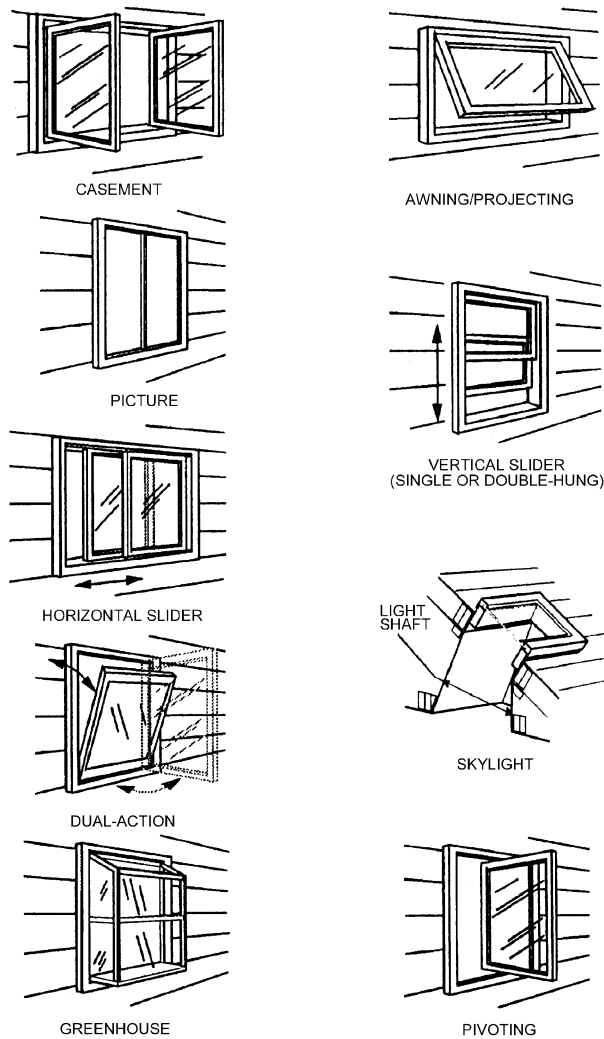


Fig. 2 Types of Residential Windows

outdoor air. With this assumption, the basic equation for the steady-state energy flow Q through a fenestration is

$$Q = UA_{pf}(t_{out} - t_{in}) + (SHGC)A_{pf}E_t \quad (1)$$

where

- Q = instantaneous energy flow, Btu/h
- U = overall coefficient of heat transfer (U-factor), Btu/h · ft² · °F
- A_{pf} = total projected area of fenestration (the product's rough opening in the wall or roof less installation clearances), ft²
- t_{in} = indoor air temperature, °F
- t_{out} = outdoor air temperature, °F
- SHGC = solar heat gain coefficient, dimensionless
- E_t = incident total irradiance, Btu/h · ft²

U and SHGC are steady-state performance indices. The main justification for Equation (1) is its simplicity, achieved by collecting all the linked radiative, conductive, and convective energy transfer processes into U and SHGC. These quantities vary because (1) convective heat transfer rates vary as fractional powers of temperature differences or free-stream speeds, (2) variations in temperature caused by weather or climate are small on the absolute temperature scale (°R) that controls radiative heat transfer rates, (3) fenestration systems always involve at least two thermal resistances in series, and (4) solar heat gain coefficients depend on solar incident angle and spectral distribution.

In this chapter, Q is divided into two parts:

$$Q = Q_{th} + Q_{sol} \quad (2)$$

where

Q_{th} = steady-state heat transfer caused by indoor/outdoor temperature difference, Btu/h

Q_{sol} = steady-state heat transfer caused by solar radiation, Btu/h

The section on U-Factor (Thermal Transmittance) deals with Q_{th} , and the section on Solar Heat Gain and Visible Transmittance discusses Q_{sol} . In the latter section, the effects of both direct solar radiation and solar radiation scattered by the sky or ground are included.

Equation (1) presents a fenestration as it might appear on a building plan: a featureless, planar object filling an opening in the building envelope. Real fenestrations, however, are composite three-dimensional objects that may consist of multiple complex assemblies. Heat transfer through such an assembly of elements is calculated by dividing the fenestration area into parts, each of which has an energy flow that is more simply calculated than the total:

$$Q = \sum_v A_v q_v \quad (3)$$

where

- q_v = energy flux (energy flow per unit area) of v th part, Btu/h
- A_v = area of v th part, ft²

This subdivision is applied to each term in Equation (2) separately; for example, heat transfer through glazings differs from that through frames, so it is useful to make the following separation:

$$Q_{th} = A_f q_f + A_g q_g \quad (4)$$

where the subscript f refers to the frame, and g refers to the glazing (both for thermal energy flow). Similarly, solar radiation has different effects on the frame and the glazed area of a fenestration (because the frame is generally opaque), so that

$$Q_{sol} = A_{op} q_{op} + A_s q_s \quad (5)$$

where the subscript op refers to the (opaque) frame (for solar energy flow), and s refers to the (solar-transmitting) glazing. This division into frame and glazing areas can be and usually is different for the solar and other thermal energy flows. Subdivisions of this sort, when Equation (3) is compared with Equation (1), effectively make the overall U-factor and solar heat gain coefficient area-averaged quantities. This area averaging is described explicitly in the appropriate sections of this chapter. Note that, in more complicated fenestrations, where the glazing portion may contain opaque shading elements, the opaque portion by definition can never under any conditions admit directly transmitted solar energy. A window with a closed, perfectly opaque blind would not be considered an opaque element because sometimes the blind may be open. A section of curtain wall consisting of wall or frame elements with an outdoor cover of glass (for uniform appearance) would be an opaque element despite its transparent covering.

A second type of subdivision occurs when, for a given part of the fenestration system, energy flow is driven by physical processes that are more complicated than those assumed in Equation (1). For example, heat transfer through a glazing consists of contact (i.e., glass-to-air) and radiative parts, and the latter (q_R) may depend on radiant temperatures that differ from the air temperatures in Equation (1):

$$q = q_C + q_R \quad (6)$$

U-FACTOR (THERMAL TRANSMITTANCE)

In the absence of sunlight, air infiltration, and moisture condensation, the first term in Equation (1) represents the heat transfer rate through a fenestration system. Most fenestration systems consist of transparent multipane glazing units and opaque elements comprising the sash and frame (hereafter called **frame**). The glazing unit's heat transfer paths are subdivided into center-of-glass, edge-of-glass, and frame contributions (denoted by subscripts *cg*, *eg*, and *f*, respectively). Consequently, the total rate of heat transfer through a fenestration system can be calculated knowing the separate contributions of these three paths. (When present, glazing dividers, such as decorative grilles and muntin bars, 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

$$U_o = \frac{U_{cg}A_{cg} + U_{eg}A_{eg} + U_fA_f}{A_{pf}} \quad (7)$$

When a fenestration product has glazed surfaces in only one direction, the sum of the areas equals the projected area A_{pf} . 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 a window with a similar glazing option and frame material; consequently, U-factors for such products are expected to be greater.

DETERMINING FENESTRATION U-FACTORS

Center-of-Glass U-Factor

For single glass, U-factors depend strongly on indoor and outdoor film coefficients. The U-factor for single glass is

$$U = \frac{1}{1/h_o + 1/h_i + L/k} \quad (8)$$

where

- h_o, h_i = outdoor and indoor respective glass surface heat transfer coefficients, $\text{Btu/h} \cdot \text{ft}^2 \cdot ^\circ\text{F}$
- L = glass thickness, ft
- k = thermal conductivity, $\text{Btu} \cdot \text{in/h} \cdot \text{ft}^2 \cdot ^\circ\text{F}$

For other fenestration, values for U_{cg} at standard indoor and outdoor conditions depend on glazing construction features such as the number of glazing lights, gas space dimensions, orientation relative to vertical, emissivity of each surface, and composition of fill gas. Several computer programs can be used to estimate glazing unit heat transfer for a wide range of glazing construction. The NFRC calls for WINDOW 5 (LBL 2001) as a standard calculation method for center glazing.

Heat flow across the central glazed portion of a multipane unit must consider both convective and radiative transfer in the gas space, and may be considered one-dimensional. Convective heat transfer is estimated based on high-aspect-ratio, natural convection correlations for vertical and inclined air layers (El Sherbiny et al. 1982; Shewen 1986; Wright 1996a). Radiative heat transfer (ignoring gas absorption) is quantified using a more fundamental approach. Computational methods solving the combined heat transfer problem have been devised (Hollands and Wright 1982; Rubin 1982a, 1982b).

Figure 3 shows the effect of gas space width on U_{cg} for vertical double- and triple-paned glazing units. U-factors are plotted for air, argon, and krypton fill gases and for high (uncoated) and low (coated) values of surface emissivity. The optimum gas space width is 0.5 in. for air and argon, and 5/16 in. for krypton. Greater widths

have no significant effect on U_{cg} . Greater glazing unit thicknesses decrease U_o because the length of the shortest heat flow path through the frame increases. A low-emissivity coating combined with krypton gas fill offers significant potential for reducing heat transfer in narrow-gap-width glazing units.

Edge-of-Glass U-Factor

Glazing 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. The edge-of-glass area is typically taken to be a band 2.5 in. wide around the sightline. The width of this area is determined from the extent of two-dimensional heat transfer effects in current computer models, which are based on conduction-only analysis. In reality, because of convective and radiative effects, this area may extend beyond 2.5 in. (Beck et al. 1995; Curcija and Goss 1994; Wright and Sullivan 1995b), and depends on the type of insulating glazing unit and its thickness.

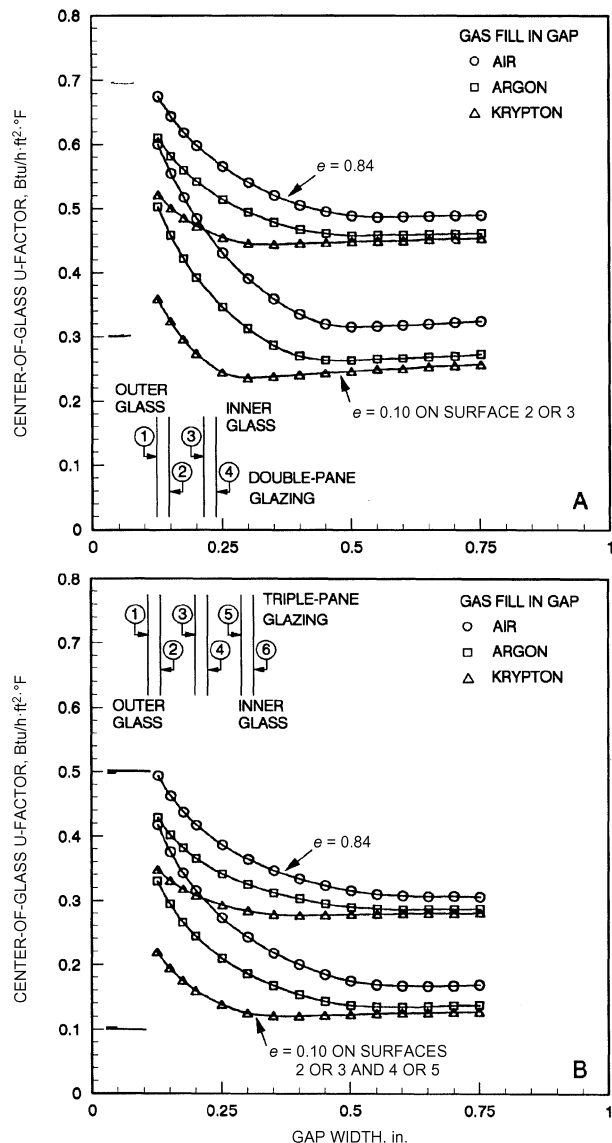


Fig. 3 Center-of-Glass U-Factor for Vertical Double- and Triple-Pane Glazing Units

Table 1 Representative Fenestration Frame U-Factors in Btu/h·ft²·°F, Vertical Orientation

Frame Material	Type of Spacer	Product Type/Number of Glazing Layers																
		Operable			Fixed			Garden Window		Plant-Assembled Skylight			Curtain Wall ^e			Sloped/Overhead Glazing ^e		
		1 ^b	2 ^c	3 ^d	1 ^b	2 ^c	3 ^d	1 ^b	2 ^c	1 ^b	2 ^c	3 ^d	1 ^f	2 ^g	3 ^h	1 ^f	2 ^g	3 ^h
Aluminum without thermal break	All	2.38	2.27	2.20	1.92	1.80	1.74	1.88	1.83	7.85	7.02	6.87	3.01	2.96	2.83	3.05	3.00	2.87
Aluminum with thermal break ^a	Metal	1.20	0.92	0.83	1.32	1.13	1.11			6.95	5.05	4.58	1.80	1.75	1.65	1.82	1.76	1.66
	Insulated	N/A	0.88	0.77	N/A	1.04	1.02			N/A	4.75	4.12	N/A	1.63	1.51	N/A	1.64	1.52
Aluminum-clad wood/reinforced vinyl	Metal	0.60	0.58	0.51	0.55	0.51	0.48			4.86	3.93	3.66						
	Insulated	N/A	0.55	0.48	N/A	0.48	0.44			N/A	3.75	3.43						
Wood/vinyl	Metal	0.55	0.51	0.48	0.55	0.48	0.42	0.90	0.85	2.50	2.08	1.78						
	Insulated	N/A	0.49	0.40	N/A	0.42	0.35	N/A	0.83	N/A	2.02	1.71						
Insulated fiber-glass/vinyl	Metal	0.37	0.33	0.32	0.37	0.33	0.32						1.80	1.27	1.04	1.82	1.28	1.05
	Insulated	N/A	0.32	0.26	N/A	0.32	0.26						N/A	1.02	0.75	N/A	1.02	0.75
Structural glazing	Metal																	
	Insulated																	

Note: This table should only be used as an estimating tool for early phases of design.
^aDepends strongly on width of thermal break. Value given is for 3/8 in.
^bSingle glazing corresponds to individual glazing unit thickness of 1/8 in. (nominal).
^cDouble glazing corresponds to individual glazing unit thickness of 3/4 in. (nominal).
^dTriple glazing corresponds to individual glazing unit thickness of 1 3/8 in. (nominal).

^eGlass thickness in curtainwall and sloped/overhead glazing is 1/4 in.
^fSingle glazing corresponds to individual glazing unit thickness of 1/4 in. (nominal).
^gDouble glazing corresponds to individual glazing unit thickness of 1 in. (nominal).
^hTriple glazing corresponds to individual glazing unit thickness of 1 3/4 in. (nominal).
 N/A: Not applicable

In low-conductivity frames, heat flow at the edge-of-glass and frame area is through the spacer, and so the type of spacer has a greater impact on the edge-of-glass and frame U-factor. In metal frames, the edge-of-glass and frame U-factor varies little with the type of spacer (metal or insulating) because there is a significant heat flow through the highly conductive frame near the edge-of-glass area.

Frame U-Factor

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

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 (EEL 1990). For example, the frame U-factor for thermally broken aluminum fenestration products 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 fenestration product types, sizes, and materials using computer modeling techniques. Table 1 lists frame U-factors for a variety of frame and spacer materials and glazing unit thicknesses. Frame and edge U-factors are normally determined by two-dimensional computer simulation.

Curtain Wall Construction

A curtain wall is an outdoor building wall that carries no roof or floor loads and consists entirely or principally of glass and other surfacing materials supported by a framework. A curtain wall typically has a metal frame. To improve the thermal performance of standard

metal frames, manufacturers provide both traditional thermal breaks as well as thermally improved products. The traditional thermal break is poured and debridged (i.e., urethane is poured into a metal U-channel in the frame and then the bottom of the channel is removed by machine). For this system to work well, there must be a thermal break between indoors and outdoors for all frame components, including those in any operable sash. Skip debridging (incomplete pour and debridging used for increased structural strength) can significantly degrade the U-factor. Bolts that penetrate the thermal break also degrade performance, but to a lesser degree. Griffith et al. (1998) showed that stainless steel bolts spaced 12 in. on center increased the frame U-factor by 18%. The paper also concluded that, in general, the isothermal planes method referenced in Chapter 27 provides a conservative approach to determining U-factors.

Thermally improved curtain wall products are a more recent development. In these products, most of the metal frame tends to be located on the indoor side with only a metal cap exposed on the outdoor side. Plastic spacers isolate the glazing assembly from both the outdoor metal cap and the indoor metal frame. These products can have significantly better thermal performance than standard metal frames, but it is important to minimize the number and area of the bolts that penetrate from outdoor to indoor.

SURFACE AND CAVITY HEAT TRANSFER COEFFICIENTS

Part of the overall thermal resistance of a fenestration system derives from convective and radiative heat transfer between the exposed surfaces and the environment, and in the cavity between panes of glass. Surface heat transfer coefficients h_o , h_i , and h_c at the outer and inner glazing surfaces, and in the cavity, respectively, combine the effects of radiation and convection.

Wind speed and building orientation 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 wind speeds by Klems (1989) differ significantly from 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 0.5 mph for calm weather, free convection conditions, to over 65 mph for storm conditions. A nominal

Table 2 Indoor Surface Heat Transfer Coefficient h_i in Btu/h · ft² · °F, Vertical Orientation (Still Air Conditions)

Glazing ID ^a	Glazing Type	Glazing Height, ft	Winter Conditions ^b			Summer Conditions ^c		
			Glass Temp., °F	Temp. Diff., °F	h_i , Btu/h · ft ² · °F	Glass Temp., °F	Temp. Diff., °F	h_i , Btu/h · ft ² · °F
1	Single glazing	2	17	53	1.41	89	14	1.41
		4	17	53	1.31	89	14	1.33
		6	17	53	1.25	89	14	1.29
5	Double glazing with 1/2 in. air space	2	45	25	1.36	89	14	1.41
		4	45	25	1.27	89	14	1.33
		6	45	25	1.22	89	14	1.29
23	Double glazing with $e = 0.1$ on surface 2 and 1/2 in. argon space	2	56	14	1.31	87	12	1.38
		4	56	14	1.23	87	12	1.31
		6	56	14	1.19	87	12	1.27
43	Triple glazing with $e = 0.1$ on surfaces 2 and 5 and 1/2 in. argon spaces	2	63	7	1.25	93	18	1.45
		4	63	7	1.18	93	18	1.36
		6	63	7	1.15	93	18	1.32

Notes:
^aGlazing ID refers to fenestration assemblies in Table 4.
^bWinter conditions: room air temperature $t_i = 70^\circ\text{F}$, outdoor air temperature $t_o = 0^\circ\text{F}$, no solar radiation
^cSummer conditions: room air temperature $t_i = 75^\circ\text{F}$, outdoor air temperature $t_o = 89^\circ\text{F}$, direct solar irradiance $E_D = 248 \text{ Btu/h} \cdot \text{ft}^2$
 $h_i = h_{ic} + h_{iR} = 1.46(\Delta T/L)^{0.25} + \epsilon\sigma(T_i^4 - T_g^4)/\Delta T$, where $\Delta T = T_i - T_g$, °R; L = glazing height, ft; T_g = glass temperature, °R; σ = Stefan-Boltzmann constant; and ϵ = surface emissivity.

value of 5.1 Btu/h · ft² · °F corresponding to a 15 mph wind is often used to represent winter design conditions. At low wind speeds, h_o varies with outside air and surface temperature, orientation to vertical, and air moisture content. The overall surface heat transfer coefficient can be as low as 1.2 Btu/h · ft² · °F (Yazdani and Klems 1993).

For natural convection and radiation at the indoor surface of a vertical fenestration product, surface coefficient h_i depends on the indoor air and glass surface temperatures and on the emissivity of the glass surface. Table 2 shows the variation of h_i for winter ($t_i = 70^\circ\text{F}$) and summer ($t_i = 75^\circ\text{F}$) design conditions, for a range of glass types and heights. Designers often use $h_i = 1.46 \text{ Btu/h} \cdot \text{ft}^2 \cdot \text{°F}$, which corresponds to $t_i = 70^\circ\text{F}$, glass temperature of 15°F , and uncoated glass with $e_g = 0.84$. For summer conditions, the same value [$h_i = 1.46 \text{ Btu/h} \cdot \text{ft}^2 \cdot \text{°F}$] is normally used, and it corresponds approximately to glass temperature of 95°F , $t_i = 75^\circ\text{F}$, and $e_g = 0.84$. For winter conditions, this most closely approximates single glazing with clear glass that is 2 ft tall, but it overestimates the value as the glazing unit conductance decreases and height increases. For summer conditions, this value approximates all types of glass that are 2 ft tall but, again, is less accurate as glass height increases. If the indoor surface of the glass has a low-e coating, h_i values are about halved at both winter and summer conditions.

Heat transfer between the glazing surface and its environment is driven not only by local air temperatures but also by 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. This is a safe assumption where a small fenestration is exposed to a large room with surface temperatures equal to the air temperature, but it is not valid in rooms where the fenestration is exposed to other large areas of glazing surfaces (e.g., greenhouse, atrium) or to other cooled or heated surfaces (Parmelee and Huebscher 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, because additional radiative heat loss occurs between a fenestration and the clear sky (Berdahl and Martin 1984). Therefore, for clear-sky conditions, some effective outdoor temperature $t_{o,e}$ should replace t_o in Equation (1). For methods of determining $t_{o,e}$, see, for example, work by AGSL (1992). Note that a fully cloudy sky is assumed in ASHRAE design conditions.

The air space in a window constructed using glass with no reflective coating on the air space surfaces has a coefficient h_s of 1.3 Btu/h · ft² · °F. When a reflective coating is applied to an air space surface, h_s can be selected from Table 3 by first calculating the effective air space emissivity $e_{s,e}$ by Equation (9):

$$e_{s,e} = \frac{1}{1/e_o + 1/e_i - 1} \tag{9}$$

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

Table 4 lists computed U-factors, using winter design conditions, for a variety of generic fenestration products, based on ASHRAE-sponsored research involving laboratory testing and computer simulations. In the past, test data were used to provide more accurate results for specific products (Hogan 1988). Computer simulations (with validation by testing) are now accepted as the standard method for accurate product-specific U-factor determination. The simulation methodologies are specified in the National Fenestration Rating Council's NFRC *Technical Document 100* (NFRC 2004a) and are based on algorithms published in ISO *Standard 15099* (ISO 2000). The *International Energy Conservation Code* and various state energy codes in the United States, the National Energy Code in Canada, and ASHRAE *Standards 90.1* and *90.2* all reference these standards. Fenestration must be rated in accordance with the NFRC standards for code compliance. Use of Table 4 should be limited to that of an estimating tool for the early phases of design.

Values in Table 4 are for vertical installation and for skylights and other sloped installations with glazing surfaces sloped 20° from the horizontal. Data are based on center-of-glass and edge-of-glass component U-factors and assume that there are no dividers. However, they apply only to the specific design conditions described in the table's footnotes, and are typically used only to determine peak load conditions for sizing heating equipment. Although these U-factors have been determined for winter conditions, they can also be used to estimate heat gain during peak cooling conditions, because 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.

Table 4 lists 48 glazing types, with multiple glazing categories appropriate for sealed glazing 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 garden window and sloped/pyramid/barrel vault skylight U-factors are approximately twice those of other similar products. Although this is partially due to the difference in slope in the case of sloped/pyramid/barrel vault skylights, it is largely because these products project out from the surface of the wall or roof. For instance, the skylight surface area,

Table 3 Air Space Coefficients for Horizontal Heat Flow

Air Space Thickness, in.	Air Space Temp., °F	Air Temp. Diff., °F	Air Space Coefficient h_s , Btu/h·ft ² ·°F Effective Emissivity $e_{s,e}$					
			0.82	0.72	0.40	0.20	0.10	0.05
0.5	5	10	0.88	0.82	0.60	0.46	0.39	0.35
		25	0.90	0.83	0.61	0.48	0.41	0.37
		55	1.00	0.93	0.71	0.57	0.50	0.47
		70	1.05	0.98	0.76	0.62	0.55	0.51
		90	1.10	1.03	0.81	0.67	0.60	0.57
	32	10	1.00	0.92	0.66	0.50	0.42	0.38
		25	1.01	0.93	0.67	0.51	0.43	0.39
		55	1.08	1.00	0.74	0.57	0.49	0.45
		70	1.12	1.04	0.78	0.62	0.53	0.49
		90	1.17	1.09	0.83	0.67	0.58	0.54
	50	10	1.09	1.00	0.71	0.53	0.44	0.39
		25	1.10	1.01	0.72	0.54	0.44	0.40
		55	1.14	1.05	0.76	0.58	0.49	0.44
		70	1.18	1.09	0.80	0.62	0.53	0.48
		90	1.23	1.14	0.85	0.67	0.57	0.53
	85	10	1.28	1.16	0.81	0.59	0.48	0.42
		25	1.28	1.17	0.81	0.59	0.48	0.43
		55	1.30	1.19	0.84	0.62	0.51	0.45
		70	1.33	1.21	0.86	0.64	0.53	0.47
		90	1.36	1.25	0.90	0.67	0.56	0.51
120	10	1.48	1.35	0.92	0.66	0.52	0.46	
	25	1.49	1.35	0.92	0.66	0.52	0.46	
	55	1.50	1.37	0.94	0.67	0.54	0.47	
	70	1.51	1.38	0.95	0.68	0.55	0.48	
	90	1.53	1.40	0.97	0.70	0.57	0.50	
0.4	5	10	0.96	0.89	0.67	0.54	0.47	0.43
		55	1.00	0.93	0.71	0.57	0.50	0.47
		90	1.07	1.01	0.78	0.64	0.58	0.54
	32	10	1.09	1.00	0.74	0.58	0.50	0.46
		55	1.11	1.03	0.76	0.60	0.52	0.48
		90	1.15	1.07	0.81	0.64	0.56	0.52
	50	10	1.18	1.09	0.79	0.61	0.52	0.48
		55	1.19	1.10	0.81	0.63	0.54	0.49
		90	1.22	1.13	0.84	0.66	0.57	0.52
	85	10	1.37	1.26	0.90	0.68	0.57	0.51
		55	1.38	1.26	0.91	0.69	0.58	0.52
		90	1.40	1.26	0.93	0.70	0.59	0.54
	120	10	1.58	1.45	1.02	0.75	0.62	0.55
		55	1.59	1.45	1.02	0.76	0.62	0.56
		90	1.60	1.46	1.03	0.77	0.63	0.57
0.3	5	<90	1.10	1.03	0.81	0.68	0.61	0.57
	32	<90	1.23	1.15	0.89	0.72	0.64	0.60
	50	<90	1.32	1.23	0.94	0.76	0.67	0.62
	85	<90	1.52	1.41	1.06	0.84	0.72	0.67
	120	<90	1.74	1.61	1.18	0.92	0.78	0.72
0.25	5	<90	1.20	1.13	0.91	0.77	0.70	0.67
	32	<90	1.34	1.26	0.99	0.83	0.75	0.71
	50	<90	1.43	1.34	1.05	0.87	0.78	0.74
	85	<90	1.64	1.53	1.18	0.96	0.84	0.79
	120	<90	1.87	1.74	1.31	1.04	0.91	0.84
0.2	5	<90	1.36	1.29	1.07	0.93	0.86	0.83
	32	<90	1.50	1.42	1.16	1.00	0.92	0.88
	50	<90	1.61	1.52	1.23	1.05	0.95	0.91
	85	<90	1.83	1.71	1.36	1.14	1.03	0.97
	120	<90	2.07	1.93	1.51	1.24	1.10	1.04

which includes the curb, can vary from 13 to 240% greater than the rough opening area, depending on the size and mounting method. Unless otherwise noted, all multiple-glazed units are filled with dry air. Argon units are assumed to be filled with 90% argon (Elmahdy and Yusuf 1995). U-factors for CO₂-filled units are similar to argon fills. For spaces up to 1/2 in., argon/SF₆ (sulfur hexafluoride) mixtures up to 70% SF₆ are generally the same as argon fills. Use of krypton gas can provide U-factors lower than those for argon for glazing spaces less than 1/2 in.

Table 4 provides data for six values of hemispherical emissivity and for 1/4 and 1/2 in. gas space widths. The emissivity of various low-e glasses varies considerably between manufacturers and processes. When the emissivity is between the listed values, interpolation may be used. When manufacturers' data are not available for low-e glass, assume that glass with a pyrolytic (hard) coating has a maximum emissivity of 0.20 and that glass with a sputtered (soft) coating has a maximum emissivity of 0.10. Tinted glass does not change the winter U-factor. Also, some reflective glass may have an emissivity less than 0.84. Values listed are for insulating glass units using aluminum edge spacers. If an insulated or nonmetallic spacer is used, the U-factors are approximately 0.03 Btu/h·ft²·°F lower.

Fenestration product types are subdivided first by vertical versus sloped installation and then into two general categories: manufactured and site-assembled. "Manufactured" represents products delivered as a complete unit to the site. These products are typically installed in low-rise residential and small commercial/institutional/industrial buildings. Use the operable category for vertical sliders, horizontal sliders, casement, awning, pivoted, and dual-action windows, and for sliding and swinging glass doors. For picture windows, use the fixed category. For products that project out from the surface of the wall, use the garden window category. For skylights, use the sloped skylight category.

"Site-assembled" represents products where frame extrusions are assembled on site into a fenestration product and then glazing is added on site. These products are typically installed in high-rise residential and larger commercial/institutional/industrial buildings. Curtain walls are typically made up of vision (transparent) and spandrel (opaque) panels. Table 4 contains representative U-factors for the vision panel (including mullions) for these assemblies. The spandrel portion of curtain walls usually consists of a metal pan filled with insulation and covered with a sheet of glass or other weather-proof covering. Although the U-factor in the center of the spandrel panel can be quite low, the metal pan is a thermal bridge, significantly increasing the U-factor of the assembly. Two-dimensional simulation, validated by testing of a curtain wall having an aluminum frame with a thermal break, found that the U-factor for the edge of the spandrel panel (the 2 1/2 in. band around the perimeter adjacent to the frame) was 40% of the way toward the U-factor of the frame. The U-factor was 0.06 Btu/h·ft²·°F for the center of the spandrel, 0.45 for the edge of the spandrel, and 1.06 for the frame (Carpenter and Elmahdy 1994). Two-dimensional heat transfer analysis or physical testing is recommended to determine the U-factor of spandrel panels. Use the sloped/overhead glazing category for sloped glazing panels comparable to curtain walls.

Physical testing of double-glazed units showed U-factors of 1.0 Btu/h·ft²·°F for a thermally broken aluminum pyramidal skylight and 1.3 Btu/h·ft²·°F for an aluminum-frame half-round barrel vault (both normalized to a rough opening of 8 by 8 ft). Until more conclusive results are available, U-factors for these systems can be estimated by multiplying the site-assembled sloped/overhead glazing values in Table 4 by the ratio of total product surface area (including curbs) to rough opening area. These ratios range from 1.2 to 2.0 for low-slope skylights, 1.4 to 2.1 for pyramid assemblies sloped at 45°, and 1.7 to 2.9 for semicircular barrel vault assemblies.

U-factors in Table 4 are based on definitions of the six product types, frame sizes, and proportion of frame to glass area shown in Figure 4. Four of the products are manufactured type. Sizes are as

Table 4 U-Factors for Various Fenestration Products in Btu/h·ft²·°F

Product Type		Vertical Installation											
		Glass Only		Operable (including sliding and swinging glass doors)					Fixed				
Frame Type		Center of Glass	Edge of Glass	Aluminum		Aluminum Reinforced		Insulated Fiberglass/Vinyl	Aluminum		Aluminum Reinforced		Insulated Fiberglass/Vinyl
ID	Glazing Type			Without Thermal Break	With Thermal Break	Vinyl/Aluminum Clad	Wood/Vinyl		Without Thermal Break	With Thermal Break	Vinyl/Aluminum Clad	Wood/Vinyl	
Single Glazing													
1	1/8 in. glass	1.04	1.04	1.23	1.07	0.93	0.91	0.85	1.12	1.07	0.98	0.98	1.04
2	1/4 in. acrylic/polycarbonate	0.88	0.88	1.10	0.94	0.81	0.80	0.74	0.98	0.92	0.84	0.84	0.88
3	1/8 in. acrylic/polycarbonate	0.96	0.96	1.17	1.01	0.87	0.86	0.79	1.05	0.99	0.91	0.91	0.96
Double Glazing													
4	1/4 in. air space	0.55	0.64	0.81	0.64	0.57	0.55	0.50	0.68	0.62	0.56	0.56	0.55
5	1/2 in. air space	0.48	0.59	0.76	0.58	0.52	0.50	0.45	0.62	0.56	0.50	0.50	0.48
6	1/4 in. argon space	0.51	0.61	0.78	0.61	0.54	0.52	0.47	0.65	0.59	0.53	0.52	0.51
7	1/2 in. argon space	0.45	0.57	0.73	0.56	0.50	0.48	0.43	0.60	0.53	0.48	0.47	0.45
Double Glazing, e = 0.60 on surface 2 or 3													
8	1/4 in. air space	0.52	0.62	0.79	0.61	0.55	0.53	0.48	0.66	0.59	0.54	0.53	0.52
9	1/2 in. air space	0.44	0.56	0.72	0.55	0.49	0.48	0.43	0.59	0.53	0.47	0.47	0.44
10	1/4 in. argon space	0.47	0.58	0.75	0.57	0.51	0.50	0.45	0.61	0.55	0.49	0.49	0.47
11	1/2 in. argon space	0.41	0.54	0.70	0.53	0.47	0.45	0.41	0.56	0.50	0.44	0.44	0.41
Double Glazing, e = 0.40 on surface 2 or 3													
12	1/4 in. air space	0.49	0.60	0.76	0.59	0.53	0.51	0.46	0.63	0.57	0.51	0.51	0.49
13	1/2 in. air space	0.40	0.54	0.69	0.52	0.47	0.45	0.40	0.55	0.49	0.44	0.43	0.40
14	1/4 in. argon space	0.43	0.56	0.72	0.54	0.49	0.47	0.42	0.58	0.52	0.46	0.46	0.43
15	1/2 in. argon space	0.36	0.51	0.66	0.49	0.44	0.42	0.37	0.52	0.46	0.40	0.40	0.36
Double Glazing, e = 0.20 on surface 2 or 3													
16	1/4 in. air space	0.45	0.57	0.73	0.56	0.50	0.48	0.43	0.60	0.53	0.48	0.47	0.45
17	1/2 in. air space	0.35	0.50	0.65	0.48	0.43	0.41	0.37	0.51	0.45	0.39	0.39	0.35
18	1/4 in. argon space	0.38	0.52	0.68	0.51	0.45	0.43	0.39	0.54	0.47	0.42	0.42	0.38
19	1/2 in. argon space	0.30	0.46	0.61	0.45	0.39	0.38	0.33	0.47	0.41	0.35	0.35	0.30
Double Glazing, e = 0.10 on surface 2 or 3													
20	1/4 in. air space	0.42	0.55	0.71	0.54	0.48	0.46	0.41	0.57	0.51	0.45	0.45	0.42
21	1/2 in. air space	0.32	0.48	0.63	0.46	0.41	0.39	0.34	0.49	0.42	0.37	0.37	0.32
22	1/4 in. argon space	0.35	0.50	0.65	0.48	0.43	0.41	0.37	0.51	0.45	0.39	0.39	0.35
23	1/2 in. argon space	0.27	0.44	0.59	0.42	0.37	0.36	0.31	0.44	0.38	0.33	0.32	0.27
Double Glazing, e = 0.05 on surface 2 or 3													
24	1/4 in. air space	0.41	0.54	0.70	0.53	0.47	0.45	0.41	0.56	0.50	0.44	0.44	0.41
25	1/2 in. air space	0.30	0.46	0.61	0.45	0.39	0.38	0.33	0.47	0.41	0.35	0.35	0.30
26	1/4 in. argon space	0.33	0.48	0.64	0.47	0.42	0.40	0.35	0.49	0.43	0.38	0.37	0.33
27	1/2 in. argon space	0.25	0.42	0.57	0.41	0.36	0.34	0.30	0.43	0.36	0.31	0.31	0.25
Triple Glazing													
28	1/4 in. air spaces	0.38	0.52	0.67	0.49	0.43	0.43	0.38	0.53	0.47	0.42	0.42	0.38
29	1/2 in. air spaces	0.31	0.47	0.61	0.44	0.38	0.38	0.34	0.47	0.41	0.36	0.36	0.31
30	1/4 in. argon spaces	0.34	0.49	0.63	0.46	0.41	0.40	0.36	0.50	0.44	0.38	0.38	0.34
31	1/2 in. argon spaces	0.29	0.45	0.59	0.42	0.37	0.36	0.32	0.45	0.40	0.34	0.34	0.29
Triple Glazing, e = 0.20 on surface 2, 3, 4, or 5													
32	1/4 in. air spaces	0.33	0.48	0.62	0.45	0.40	0.39	0.35	0.49	0.43	0.37	0.37	0.33
33	1/2 in. air spaces	0.25	0.42	0.56	0.39	0.34	0.33	0.29	0.42	0.36	0.31	0.31	0.25
34	1/4 in. argon spaces	0.28	0.45	0.58	0.41	0.36	0.36	0.31	0.45	0.39	0.33	0.33	0.28
35	1/2 in. argon spaces	0.22	0.40	0.54	0.37	0.32	0.31	0.27	0.39	0.33	0.28	0.28	0.22
Triple Glazing, e = 0.20 on surfaces 2 or 3 and 4 or 5													
36	1/4 in. air spaces	0.29	0.45	0.59	0.42	0.37	0.36	0.32	0.45	0.40	0.34	0.34	0.29
37	1/2 in. air spaces	0.20	0.39	0.52	0.35	0.31	0.30	0.26	0.38	0.32	0.26	0.26	0.20
38	1/4 in. argon spaces	0.23	0.41	0.54	0.37	0.33	0.32	0.28	0.40	0.34	0.29	0.29	0.23
39	1/2 in. argon spaces	0.17	0.36	0.49	0.33	0.28	0.28	0.24	0.35	0.29	0.24	0.24	0.17
Triple Glazing, e = 0.10 on surfaces 2 or 3 and 4 or 5													
40	1/4 in. air spaces	0.27	0.44	0.58	0.40	0.36	0.35	0.31	0.44	0.38	0.32	0.32	0.27
41	1/2 in. air spaces	0.18	0.37	0.50	0.34	0.29	0.28	0.25	0.36	0.30	0.25	0.25	0.18
42	1/4 in. argon spaces	0.21	0.39	0.53	0.36	0.31	0.31	0.27	0.38	0.33	0.27	0.27	0.21
43	1/2 in. argon spaces	0.14	0.34	0.47	0.30	0.26	0.26	0.22	0.32	0.27	0.21	0.21	0.14
Quadruple Glazing, e = 0.10 on surfaces 2 or 3 and 4 or 5													
44	1/4 in. air spaces	0.22	0.40	0.54	0.37	0.32	0.31	0.27	0.39	0.33	0.28	0.28	0.22
45	1/2 in. air spaces	0.15	0.35	0.48	0.31	0.27	0.26	0.23	0.33	0.27	0.22	0.22	0.15
46	1/4 in. argon spaces	0.17	0.36	0.49	0.33	0.28	0.28	0.24	0.35	0.29	0.24	0.24	0.17
47	1/2 in. argon spaces	0.12	0.32	0.45	0.29	0.25	0.24	0.20	0.31	0.25	0.20	0.20	0.12
48	1/4 in. krypton spaces	0.12	0.32	0.45	0.29	0.25	0.24	0.20	0.31	0.25	0.20	0.20	0.12

Notes:
 1. All heat transmission coefficients in this table include film resistances and are based on winter conditions of 0°F outdoor air temperature 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 indoor and outdoor temperatures will not significantly affect overall U-factors. 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 outdoor to indoor. 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. Edge-of-glass effects are assumed to extend over the 2 1/2 in. band around perimeter of each glazing unit.

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Table 4 U-Factors for Various Fenestration Products in Btu/h·ft²·°F (Concluded)

Vertical Installation					Sloped Installation									
Garden Windows		Curtain Wall			Glass Only (Skylights)		Manufactured Skylight				Site-Assembled Sloped/Overhead Glazing			
Aluminum Without Thermal Break	Wood/Vinyl	Aluminum Without Thermal Break	Aluminum With Thermal Break	Structural Glazing	Center of Glass	Edge of Glass	Aluminum Without Thermal Break	Aluminum With Thermal Break	Reinforced Vinyl/Aluminum Clad Wood	Wood/Vinyl	Aluminum Without Thermal Break	Aluminum With Thermal Break	Structural Glazing	ID
2.50	2.10	1.21	1.10	1.10	1.19	1.19	1.77	1.70	1.61	1.42	1.35	1.34	1.25	1
2.24	1.84	1.06	0.96	0.96	1.03	1.03	1.60	1.54	1.45	1.31	1.20	1.20	1.10	2
2.37	1.97	1.13	1.03	1.03	1.11	1.11	1.68	1.62	1.53	1.39	1.27	1.27	1.18	3
1.72	1.32	0.77	0.67	0.63	0.58	0.66	1.10	0.96	0.92	0.84	0.80	0.83	0.66	4
1.62	1.22	0.71	0.61	0.57	0.57	0.65	1.09	0.95	0.91	0.84	0.79	0.82	0.65	5
1.66	1.26	0.74	0.63	0.59	0.53	0.63	1.05	0.91	0.87	0.80	0.76	0.80	0.62	6
1.57	1.17	0.68	0.58	0.54	0.53	0.63	1.05	0.91	0.87	0.80	0.76	0.80	0.62	7
1.68	1.28	0.74	0.64	0.60	0.54	0.63	1.06	0.92	0.88	0.81	0.77	0.80	0.63	8
1.56	1.16	0.68	0.57	0.53	0.53	0.63	1.05	0.91	0.87	0.80	0.76	0.80	0.62	9
1.60	1.20	0.70	0.60	0.56	0.49	0.60	1.01	0.87	0.83	0.76	0.72	0.77	0.58	10
1.51	1.11	0.65	0.55	0.51	0.49	0.60	1.01	0.87	0.83	0.76	0.72	0.77	0.58	11
1.63	1.23	0.72	0.62	0.58	0.51	0.61	1.03	0.89	0.85	0.78	0.74	0.78	0.60	12
1.50	1.10	0.64	0.54	0.50	0.50	0.61	1.02	0.88	0.84	0.77	0.73	0.78	0.59	13
1.54	1.14	0.67	0.56	0.52	0.44	0.56	0.96	0.83	0.78	0.72	0.68	0.74	0.54	14
1.44	1.04	0.61	0.50	0.46	0.46	0.58	0.98	0.85	0.80	0.74	0.70	0.75	0.56	15
1.57	1.17	0.68	0.58	0.54	0.46	0.58	0.98	0.85	0.80	0.74	0.70	0.75	0.56	16
1.43	1.03	0.60	0.50	0.45	0.46	0.58	0.98	0.85	0.80	0.74	0.70	0.75	0.56	17
1.47	1.07	0.62	0.52	0.48	0.39	0.53	0.91	0.78	0.74	0.68	0.64	0.70	0.50	18
1.35	0.95	0.55	0.45	0.41	0.40	0.54	0.92	0.79	0.75	0.68	0.64	0.71	0.51	19
1.53	1.13	0.66	0.56	0.51	0.44	0.56	0.96	0.83	0.78	0.72	0.68	0.74	0.54	20
1.38	0.98	0.57	0.47	0.43	0.44	0.56	0.96	0.83	0.78	0.72	0.68	0.74	0.54	21
1.43	1.03	0.60	0.50	0.45	0.36	0.51	0.88	0.75	0.71	0.65	0.61	0.68	0.47	22
1.30	0.90	0.53	0.43	0.38	0.38	0.52	0.90	0.77	0.73	0.67	0.63	0.69	0.49	23
1.51	1.11	0.65	0.55	0.51	0.42	0.55	0.94	0.81	0.76	0.70	0.66	0.72	0.52	24
1.35	0.95	0.55	0.45	0.41	0.43	0.56	0.95	0.82	0.77	0.71	0.67	0.73	0.53	25
1.40	1.00	0.58	0.48	0.44	0.34	0.49	0.86	0.73	0.69	0.63	0.59	0.66	0.45	26
1.27	0.87	0.51	0.41	0.37	0.36	0.51	0.88	0.75	0.71	0.65	0.61	0.68	0.47	27
see note 7	see note 7	0.61	0.51	0.46	0.39	0.53	0.90	0.75	0.71	0.64	0.62	0.69	0.48	28
		0.55	0.45	0.40	0.36	0.51	0.87	0.72	0.68	0.61	0.60	0.67	0.45	29
		0.58	0.48	0.43	0.35	0.50	0.86	0.71	0.67	0.60	0.59	0.66	0.44	30
		0.53	0.43	0.38	0.33	0.48	0.84	0.69	0.65	0.59	0.57	0.65	0.42	31
see note 7	see note 7	0.57	0.47	0.42	0.34	0.49	0.85	0.70	0.66	0.59	0.58	0.65	0.43	32
		0.50	0.40	0.35	0.31	0.47	0.82	0.67	0.63	0.57	0.56	0.63	0.41	33
		0.53	0.43	0.37	0.28	0.45	0.80	0.64	0.60	0.54	0.53	0.61	0.38	34
		0.47	0.37	0.32	0.27	0.44	0.79	0.63	0.59	0.53	0.52	0.60	0.37	35
see note 7	see note 7	0.53	0.43	0.38	0.29	0.45	0.81	0.65	0.61	0.55	0.54	0.62	0.39	36
		0.46	0.36	0.30	0.27	0.44	0.79	0.63	0.59	0.53	0.52	0.60	0.37	37
		0.48	0.38	0.33	0.24	0.42	0.76	0.60	0.57	0.50	0.49	0.58	0.35	38
		0.43	0.33	0.28	0.22	0.40	0.74	0.58	0.55	0.49	0.48	0.57	0.33	39
see note 7	see note 7	0.52	0.42	0.37	0.27	0.44	0.79	0.63	0.59	0.53	0.52	0.60	0.37	40
		0.44	0.34	0.29	0.25	0.42	0.77	0.61	0.57	0.51	0.50	0.59	0.36	41
		0.46	0.36	0.31	0.21	0.39	0.73	0.57	0.54	0.48	0.47	0.56	0.32	42
		0.40	0.30	0.25	0.20	0.39	0.72	0.56	0.53	0.47	0.46	0.55	0.31	43
see note 7	see note 7	0.47	0.37	0.32	0.22	0.40	0.74	0.58	0.55	0.49	0.48	0.57	0.33	44
		0.41	0.31	0.26	0.19	0.38	0.71	0.55	0.52	0.46	0.45	0.54	0.30	45
		0.43	0.33	0.28	0.18	0.37	0.70	0.54	0.51	0.45	0.44	0.54	0.29	46
		0.39	0.29	0.23	0.16	0.35	0.68	0.52	0.49	0.43	0.42	0.52	0.28	47
		0.39	0.29	0.23	0.13	0.33	0.65	0.49	0.46	0.40	0.40	0.50	0.25	48

4. Product sizes are described in Figure 4, and frame U-factors are from Table 1.

5. Use $U = 0.6$ Btu/(h·ft²·°F) for glass block with mortar but without reinforcing or framing.

6. Use of this table should be limited to that of an estimating tool for the early phases of design.

7. Values for triple- and quadruple-glazed garden windows are not listed, because these are not common products.

8. U-factors in this table were determined using NFRC 100-91. They have not been updated to the current rating methodology in NFRC 100-2004.

defined in NFRC *Technical Document 100*: operable and fixed (non-operable) glazing units are 20 ft² in area, and the overall size corresponds to a 4 by 5 ft fenestration product. The garden window category is 20 ft² in projected area (35 ft² in surface area) and 5 ft wide by 4 ft high by 15 in. deep. The manufactured skylight category is a nominal 16 ft² in area, corresponding to a 4 by 4 ft skylight. The nominal dimensions of a roof-mounted skylight correspond to centerline spacing of roof framing members; consequently, the rough opening dimensions are 3 ft 10.5 in. by 3 ft 10.5 in. The curtain wall and sloped/overhead glazing categories are a nominal 43 ft² in area, representing repeating 6 ft 8 in. by 6 ft 8 in. panels. The nominal dimensions correspond to centerline spacing of the head and sill and vertical mullions.

Six frame types are listed (although not all for any one category) in order of improving thermal performance. The most conservative assumption is to use the frame category of aluminum frame without a thermal break (although there are products on the market that have higher U-factors). The aluminum frame with a thermal break is for frames having at least a 3/8 in. thermal break between the inside and outside for all members including both the frame and the operable sash, if applicable. (Products are available with significantly wider thermal breaks, which achieve considerable improvement.) The aluminum-clad wood/reinforced vinyl category represents vinyl-frame products, such as sliding glass doors or large windows that have extensive metal reinforcing within the frame and wood products with extensive metal, usually on the outdoor surface of the frame. Both of these factors provide short circuits, which degrade the thermal performance of the frame material. The wood/vinyl frame category represents the improved thermal performance that is possible if the thermal short circuits from the previous frame category do not exist. Insulated fiberglass/vinyl represents fiberglass or vinyl frames that do not have metal reinforcing and whose frame cavities are filled with insulation. For several site-assembled product types, there is a structural glazing frame category that represents products where sheets of glass are butt-glazed to each other using a sealant only, and framing members are not exposed to the exterior. For glazing with a steel frame, use aluminum frame values. For aluminum window with wood trim or vinyl cladding, use the values for aluminum. Frame type refers to the primary unit; therefore, when storm sash is added over another fenestration product, use values given for the nonstorm product.

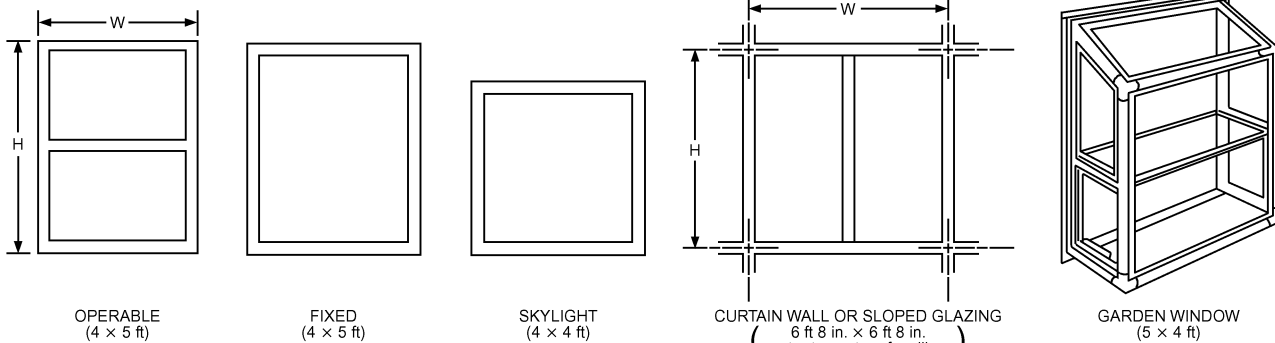
To estimate the overall U-factor of a fenestration product that differs significantly from the assumptions given in Table 4 and/or Figure 4, first determine the area that is frame/sash, center-of-glass, and edge-of-glass (based on a 2 1/2 in. band around the perimeter of each glazing unit). Next, determine the appropriate component U-factors. These can be taken either from the standard values listed in italics in Table 4 for glass, from the values in Table 1 for frames, or from some other source such as test data or computed factors. Finally, multiply the area and the component U-factors, sum these products, and then divide by the rough opening in the building envelope where this product will fit to obtain the overall U-factor U_o .

Table 5 provides approximate data to convert the overall U-factor at one wind condition to a U-factor at another.

Example 1. Estimate the design U-factor for a manufactured fixed fenestration product 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. The outdoor windspeed is 7.5 mph.

Table 5 Glazing U-Factors for Various Wind Speeds in Btu/h·ft²·°F

	Wind Speed, mph		
	15	7.5	0
0.10	0.10	0.10	0.10
0.20	0.20	0.20	0.19
0.30	0.29	0.29	0.28
0.40	0.38	0.38	0.37
0.50	0.47	0.47	0.45
0.60	0.56	0.56	0.53
0.70	0.65	0.65	0.61
0.80	0.74	0.74	0.69
0.90	0.83	0.83	0.78
1.00	0.92	0.92	0.86
1.10	1.01	1.01	0.94
1.20	1.10	1.10	1.02
1.30	1.19	1.19	1.10



Frame Material	Frame Width, in.					
	Operable	Fixed	Garden Window	Skylight	Curtainwall	Sloped/Overhead Glazing
Aluminum without thermal break	1.5	1.3	1.75	0.7	2.25	2.25
Aluminum with thermal break	2.1	1.3	N/A	0.7	2.25	2.25
Aluminum-clad wood/reinforcing vinyl	2.8	1.6	N/A	0.9	N/A	N/A
Wood/vinyl	2.8	1.6	1.75	0.9	N/A	N/A
Insulated fiberglass/vinyl	3.1	1.8	N/A	N/A	N/A	N/A
Structural glazing	N/A	N/A	N/A	N/A	2.25	2.5

Fig. 4 Frame Widths for Standard Fenestration Units

Solution: Locate the glazing system type in the first column of Table 4 (ID = 23), then find the appropriate product type (fixed) and frame type (reinforced vinyl). The U-factor listed (in the tenth column of U-factors) is 0.33 Btu/h·ft²·°F. This U-factor is for 15 mph outdoor windspeed.

From Table 5, interpolate 0.33 in the 15 mph column to the corresponding value in the 7.5 mph column.

$$\frac{0.33 - 0.30}{0.40 - 0.30} = \frac{U_{7.5 \text{ mph}} - 0.29}{0.38 - 0.29}$$

$$U_{7.5 \text{ mph}} = 0.32 \text{ Btu/h} \cdot \text{ft}^2 \cdot \text{°F}$$

Example 2. Estimate a representative U-factor for a wood-framed, 38 by 82 in. swinging French door with eight 11 by 16 in. panes (true divided panels), each consisting of clear double-glazing with a 0.25 in. air space and a metal spacer.

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 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 center-of-glass, edge-of-glass, and frame U-factors. These component U-factors are 0.55 and 0.64 (from Table 4, glazing ID = 4, U-factor columns 1 and 2) and 0.51 Btu/h·ft²·°F (from Table 4, wood frame, metal spacer, operable, double-glazing), respectively. From Equation (7),

$$U_o = \frac{(0.55 \times 528) + (0.64 \times 880) + (0.51 \times 1708)}{(38 \times 82)}$$

$$= 0.55 \text{ Btu/h} \cdot \text{ft}^2 \cdot \text{°F}$$

Example 3. Estimate the overall average U-factor for a multifloor curtain wall assembly that is part vision glass and part opaque spandrel. The typical floor-to-floor height is 12 ft, and the building module is 4 ft as reflected in the spacing of the mullions both horizontally and vertically. For a representative section 4 ft wide and 12 ft tall, one of the modules is glazed and the other two are opaque. The mullions are aluminum frame with a thermal break 3 in. wide and centered on the module. The IGU is double glazing with a pyrolytic low-e coating ($e = 0.40$) and has a 1/2 in. gap filled with air and a metal spacer. The spandrel panel has a metal pan backed by R-20 insulation and no intermediate reinforcing members.

Solution: It is necessary to calculate the U-factor for the glazed module and for the opaque spandrel modules, and then to do an area-weighted average to determine the average U-factor for the overall curtain wall assembly.

First, calculate the overall U-factor for the glazed module. Calculate center-of-glass, edge-of-glass, and frame areas. The glazed area is 45 by 45 in. (48 in. module, 1.5 in. of mullions on each edge).

$$A_{cg} = (45 - 5)(45 - 5) = 1600 \text{ in}^2$$

$$A_{eg} = (45 \times 45) - 1600 = 425 \text{ in}^2$$

$$A_f = (48 \times 48) - (45 \times 45) = 279 \text{ in}^2$$

Select center-of-glass, edge-of-glass, and frame U-factors. These component U-factors are 0.40 and 0.54 (from Table 4, ID = 13, columns 1 and 2) and 1.75 Btu/h·ft²·°F (from Table 4, aluminum frame with a thermal break, metal spacer, curtain wall, double glazing), respectively. From Equation (7),

$$U_{glazing \text{ module}} = \frac{(0.40 \times 1600) + (0.54 \times 425) + (1.75 \times 279)}{(48 \times 48)}$$

$$= 0.59 \text{ Btu/h} \cdot \text{ft}^2 \cdot \text{°F}$$

Then, calculate the overall U-factor for the two opaque spandrel modules. The center-of-spandrel, edge-of spandrel, and frame areas are the same as the glazed module. The frame U-factor is the same. Calculate the center-of-spandrel U-factor. In this particular case, the R-value of the insulation does not need to be rated, because there are no intermediate framing members penetrating it and providing thermal short circuits. When the resistance of the insulation is added to the exterior air film resistance of 0.17 and the interior air film resistance of 0.68 ft²·°F·h/Btu (from Table 1, Chapter 26), the total resistance is 20.85 ft²·°F·h/Btu, and the U-factor is 1/20.85 = 0.05 Btu/h·ft²·°F. The edge-of-spandrel U-factor is 40% of the way to the frame U-factor, which is 0.05 + [0.40 × (1.75 - 0.05)] = 0.73 Btu/h·ft²·°F.

$$U_{opaque \text{ spandrel module}} = \frac{(0.05 \times 1600) + (0.73 \times 425) + (1.75 \times 279)}{(48 \times 48)}$$

$$= 0.38 \text{ Btu/h} \cdot \text{ft}^2 \cdot \text{°F}$$

Finally, calculate the overall average U-factor for the curtain wall assembly, including the one module of vision glass and the two modules of opaque spandrel.

$$U_{curtain \text{ wall}} = \frac{[0.59 \times (48 \times 48)] + [0.38 \times 2 \times (48 \times 48)]}{3 \times (48 \times 48)}$$

$$= 0.45 \text{ Btu/h} \cdot \text{ft}^2 \cdot \text{°F}$$

Note that even with double glazing having a low-e coating and with R-20 in the opaque areas, this curtain wall with metal pans only has an overall R-value of approximately 2.

Example 4. Estimate the U-factor for a semicircular barrel vault that is 18 ft wide, 9 ft tall, and 30 ft long mounted on a 6 in. curb. The barrel vault has an aluminum frame without a thermal break. The glazing is double with a 1/2 in. gap width filled with air and a low-e coating ($e = 0.20$).

Solution: An approximation can be made by multiplying the U-factor for a site-assembled sloped/overhead glazing product having the same frame and glazing features by the ratio of the surface area (including the curb) of the barrel vault to the rough opening area in the roof that the barrel vault fits over. First, determine the surface area (including the curb) of the barrel vault:

$$\begin{aligned} \text{Area of the curved portion of the barrel vault} &= (\pi \times \text{diameter}/2) \times \text{length} \\ &= (3.14 \times 18/2) \times 30 = 848 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Area of the two ends of the barrel vault} &= 2 \times (\pi \times \text{radius}^2)/2 = \pi r^2 \\ &= 3.14 \times 9^2 = 254 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Area of the curb} &= \text{perimeter} \times \text{curb height} \\ &= (18 + 30 + 18 + 30) \times 6/12 = 48 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Total surface area of the barrel vault} &= 848 + 254 + 48 = 1150 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Second, determine the rough opening area in the roof that the barrel vault fits over:} &= \text{length} \times \text{width} \\ &= 18 \times 30 = 540 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Third, determine the ratio of the surface area to the rough opening area:} &= 1150/540 = 2.13 \end{aligned}$$

Fourth, determine the U-factor from Table 4 of a site-assembled sloped/overhead glazing product having the same frame and glazing features. The U-factor is 0.70 Btu/h·ft²·°F (ID = 17, 12th column on the second page of Table 4).

Fifth, determine the estimated U-factor of the barrel vault.

$$U_{barrel \text{ vault}} = U_{sloped \text{ overhead glazing}} \times \text{surface area/rough opening for the barrel vault}$$

$$= 0.70 \times 2.13 = 1.49 \text{ Btu/h} \cdot \text{ft}^2 \cdot \text{°F}$$

REPRESENTATIVE U-FACTORS FOR DOORS

Doors are often an overlooked component in the thermal integrity of the building envelope. Although swinging and revolving doors represent a small portion of the shell in residential, commercial, and institutional buildings, their U-factor is usually many times higher than that of the walls or ceilings. In some storage and industrial buildings, loading bay doors (overhead doors) represent a significant area of high heat loss. Table 6 contains representative U-factors for swinging doors determined through computer simulation (Carpenter and Hogan 1996). These are generic values, and product-specific values determined in accordance with standards should be used whenever available. NFRC *Technical Document* 100 (NFRC 2004a), and CSA *Standard* A440 give procedures for evaluating the performance of swinging doors. Tables 7 to 9 contain representative U-factors for revolving, emergency exit, garage, and aircraft hangar doors determined through testing (McGowan et al. 2006).

Swinging doors can be divided into two categories: slab and stile-and-rail. A stile-and-rail door is a swinging door with a full-glass insert supported by horizontal rails and vertical stiles. The stiles and rails are typically either solid wood members or extruded aluminum or vinyl, as shown in Figure 5. Most residential doors are slab type with solid wood, steel, or a fiberglass skin over foam insulation in a wood frame with aluminum sill. The edges of the steel skin door are normally wood to provide a thermal break. In commercial construction, doors are either steel skin over foam insulation in a steel frame (i.e., utility doors) or a full glass door made up of aluminum stiles, rails, and frame (i.e., entrance doors). The most important factors affecting door U-factor are material construction,

glass size, and glass type. Frame depth, slab width, and number of panels have a minor effect on door performance. Side lites and double doors have U-factors similar to a single door of the same construction. For wood slab doors in a wood frame, the glazing area has little effect on the U-factor. For an insulated steel slab in a wood frame, however, glazing area strongly affects U-factor. Typical commercial insulated slab doors have a U-factor approximately twice that of residential insulated doors, the prime reason being thermal bridging of the slab edge and the steel frame. Stile-and-rail doors, even if thermally broken, have U-factors 50% higher than a full-glass commercial steel slab door.

There are three generic types of overhead doors: roll-up, uninsulated sectional, and insulated sectional. Metal roll-up doors consist of small metal plates of approximately 2.5 in. in height that roll up around a metal rod to open. Sectional doors consist of a series of

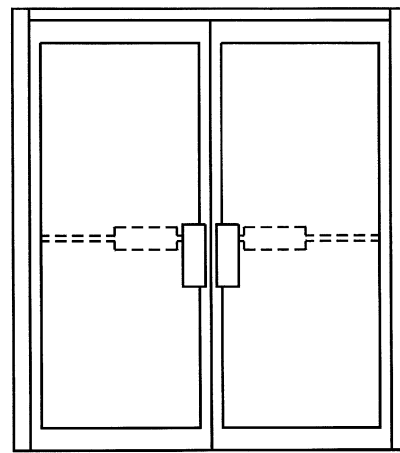


Fig. 5 Details of Stile-and-Rail Door

Table 6 Design U-Factors of Swinging Doors in Btu/h·ft²·°F

Door Type (Rough Opening = 38 × 82 in.)	Double Glazing with <i>e</i> = 0.10,			
	No Glazing	Single Glazing	1/2 in. Air Space	Double Glazing with 1/2 in. Argon
<i>Slab Doors</i>				
Wood slab in wood frame ^a	0.46			
6% glazing (22 × 8 in. lite)	—	0.48	0.46	0.44
25% glazing (22 × 36 in. lite)	—	0.58	0.46	0.42
45% glazing (22 × 64 in. lite)	—	0.69	0.46	0.39
More than 50% glazing	Use Table 4 (operable)			
Insulated steel slab with wood edge in wood frame ^b	0.16			
6% glazing (22 × 8 in. lite)	—	0.21	0.19	0.18
25% glazing (22 × 36 in. lite)	—	0.39	0.26	0.23
45% glazing (22 × 64 in. lite)	—	0.58	0.35	0.26
More than 50% glazing	Use Table 4 (operable)			
Foam-insulated steel slab with metal edge in steel frame ^c	0.37			
6% glazing (22 × 8 in. lite)	—	0.44	0.41	0.39
25% glazing (22 × 36 in. lite)	—	0.55	0.48	0.44
45% glazing (22 × 64 in. lite)	—	0.71	0.56	0.48
More than 50% glazing	Use Table 4 (operable)			
Cardboard honeycomb slab with metal edge in steel frame	0.61			
<i>Stile-and-Rail Doors</i>				
Sliding glass doors/French doors	Use Table 4 (operable)			
<i>Site-Assembled Stile-and-Rail Doors</i>				
Aluminum in aluminum frame	—	1.32	0.93	0.79
Aluminum in aluminum frame with thermal break	—	1.13	0.74	0.63

Notes:
^aThermally broken sill (add 0.03 Btu/h·ft²·°F for non-thermally broken sill)
^bNon-thermally broken sill
^cNominal U-factors are through center of insulated panel before consideration of thermal bridges around edges of door sections and because of frame.

Table 7 Design U-Factors for Revolving Doors in Btu/h·ft²·°F

Type	Size (Width × Height)	U-Factor
3-wing	8 × 7 ft	0.79
	10 × 8 ft	0.80
4-wing	7 × 6.5 ft	0.63
	7 × 7.5 ft	0.64
Open*	82 × 84 in.	1.32

*U-factor of Open door determined using NFRC *Technical Document* 100-91. It has not been updated to current rating methodology in NFRC *Technical Document* 100-2004.

Table 8 Design U-Factors for Double-Skin Steel Emergency Exit Doors in Btu/h·ft²·°F

Thickness, in.	Core Insulation Type	Rough Opening Size	
		3 ft × 6 ft 8 in.	6 ft × 6 ft 8 in.
1 3/8*	Honeycomb kraft paper	0.57	0.52
	Mineral wool, steel ribs	0.44	0.36
	Polyurethane foam	0.34	0.28
1 3/4*	Honeycomb kraft paper	0.57	0.54
	Mineral wool, steel ribs	0.41	0.33
	Polyurethane foam	0.31	0.26
1 3/8	Honeycomb kraft paper	0.60	0.55
	Mineral wool, steel ribs	0.47	0.39
	Polyurethane foam	0.37	0.31
1 3/4	Honeycomb kraft paper	0.60	0.57
	Mineral wool, steel ribs	0.44	0.37
	Polyurethane foam	0.34	0.30

*With thermal break

Table 9 Design U-Factors for Double-Skin Steel Garage and Aircraft Hangar Doors in Btu/h · ft² · °F

Insulation		One-Piece Tilt-Up ^a		Sectional Tilt-Up ^b	Aircraft Hangar	
Thickness, in.	Type	8 × 7 ft	16 × 7 ft	9 × 7 ft	72 × 12 ft ^c	240 × 50 ft ^d
1 3/8	EPS, steel ribs ^e	0.36	0.33	0.34 to 0.39		
	XPS, steel ribs ^f	0.33	0.31	0.31 to 0.36		
2	EPS, steel ribs ^e	0.31	0.28	0.29 to 0.33		
	XPS, steel ribs ^f	0.29	0.26	0.27 to 0.31		
3	EPS, steel ribs ^e	0.26	0.23	0.25 to 0.28		
	XPS, steel ribs ^f	0.24	0.21	0.24 to 0.27		
4	EPS, steel ribs ^e	0.23	0.20	0.23 to 0.25		
	XPS, steel ribs ^f	0.21	0.19	0.21 to 0.24		
6	EPS, steel ribs ^e	0.20	0.16	0.20 to 0.21		
	XPS, steel ribs ^f	0.19	0.15	0.19 to 0.21		
4	XPS				0.25	0.16
	Mineral wool, steel ribs				0.25	0.16
	EPS				0.23	0.15
6	XPS				0.21	0.13
	Mineral wool, steel ribs				0.23	0.13
	EPS				0.20	0.12
—	Uninsulated ^g				1.10	1.23
	All products ^f	1.15 ^g				

Notes:

^aValues are for thermally broken or thermally unbroken doors.

^bLower values are for thermally broken doors; upper values are for doors with no thermal break.

^cTypical size for a small private airplane (single- or twin-engine).

^dTypical hangar door for a midsized commercial jet airliner.

^eEPS = extruded polystyrene; XPS = expanded polystyrene.

^fU-factor determined using NFRC *Technical Document* 100-91. Not updated to current rating methodology in NFRC *Technical Document* 100-2004.

^gU-factor determined for 10 × 10 ft sectional door, but is representative of similar products of different size.

2 ft high sections that travel in a track to open. There is a wide range in the design of insulated overhead doors. Factors affecting heat transfer include width of insulation, thermal break design (if any), and design of indoor skin. For uninsulated sectional doors, there is very little difference between the center value and the total value: essentially the value of single glazing. The center of an insulated door has low U-factors, but thermal bridging at the door and section edges significantly increases the total U-factor. For doors without thermally broken edges, the total value is 2.5 to 3.3 times greater than the center value. Adding a good thermal break design reduces this increase to a 1.6 multiplier.

Many commercial buildings use revolving entrance doors. Most of these doors are of similar design: single glazing in an aluminum frame without thermal break. The door, however, can be in two positions: closed (X-shaped as viewed from above) or open (+-shaped). At nighttime, these doors are locked in the X position, effectively creating a double-glazed system. During the daytime, the door revolves and is often left positioned so that there is only one glazing between the inside and outside (+ position). U-factors are given in [Table 7](#) for both positions.

SOLAR HEAT GAIN AND VISIBLE TRANSMITTANCE

Fenestration solar heat gain has two components. First is **directly transmitted solar radiation**. The quantity of radiation entering the fenestration directly is governed by the solar transmittance of the glazing system, and is determined by multiplying the incident irradiance by the glazing area and its solar transmittance. The second component is the inward flowing fraction of **absorbed solar radiation**, radiation that is absorbed in the glazing and framing materials of the window, some of which is subsequently conducted, convected, or radiated to the interior of the building.

Visible transmittance is the solar radiation transmitted through fenestration weighted with respect to the photopic response of the human eye. It physically represents the perceived clearness of the

fenestration, and is likely different from the solar transmittance of the same fenestration.

The underlying physics behind solar heat gain and visible transmittance can be very complex, but a rudimentary understanding is required if technologies such as low-e coatings are to be discussed. Accurately calculating the solar heat gain and visible transmittance of a fenestration system, including the effects of angular and spectral dependence, in the presence of multiple glass and shade layers, is very complex. The reader is referred to ISO *Standard* 15099 (ISO 2000) or the ASHRAE *Handbook* CD+ for complete details of how to do this calculation. Software such as WINDOW 5.0 (LBL 2001) incorporate these advanced calculations and can be used for more detailed window analysis.

SOLAR-OPTICAL PROPERTIES OF GLAZING

Optical Properties of Single Glazing Layers

Radiation passing from one medium into another is partly transmitted and partly reflected at the interface between the two media. Further, as this radiation passes through either medium, an additional fraction is absorbed because of the absorptivity of the material. Materials that do not absorb radiation completely, such as air or glass, are classified as being transparent or translucent. Translucent glazings exhibit sufficient light-diffusing properties that images of objects viewed through it are blurred. Opaque glazings transmit no perceptible light.

If solar radiation incident on glazing is considered, the **transmittance T**, **reflectance R**, and **absorptance A** of the glazing layer contain the effects of multiple reflections between the two interfaces of the layer as well as the effects of absorption during the passage through the layer of each interreflection ([Figure 6](#)). For radiation incident on the front side of the glazing, the reflectance is called the **front reflectance R^f**. The **back reflectance R^b** (not shown in [Figure 6](#)) is the reflectance of the layer for radiation incident on back side *b*.

The transmittance, reflectance, and absorptance of a layer are formally defined as the fractions of incident flux that transmit, reflect, and are absorbed by the layer, respectively, including the

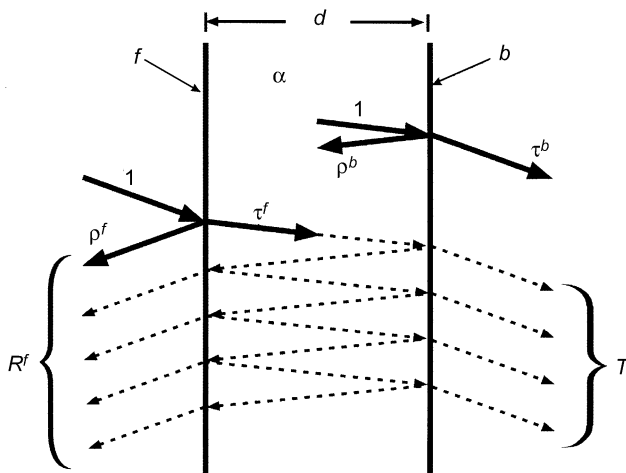


Fig. 6 Optical Properties of a Single Glazing Layer

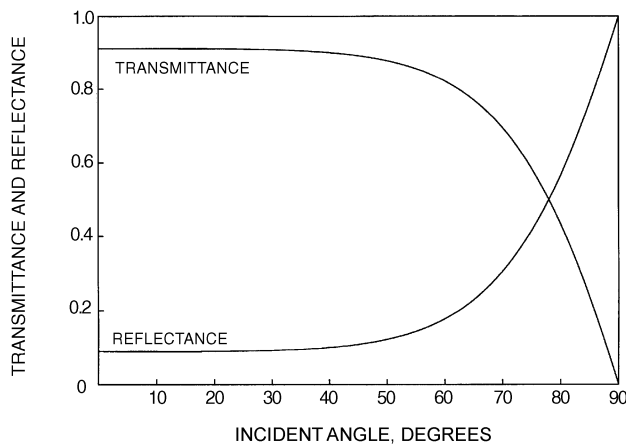


Fig. 7 Transmittance and Reflectance of Glass Plate
(Refractive index $n = 1.55$, thickness $t = 1/8$ in., absorptivity $\alpha = 0.0003$ in.)

effects of interreflection. Their sum equals unity, as shown in Equation (10).

$$T + R + \mathcal{A} = 1 \tag{10}$$

The layer has a thickness d and is characterized by **transmissivity** τ and **reflectivity** ρ of each of the two surfaces and by the **absorptivity** α of the glazing layer of thickness d . In general, τ and ρ are characteristics of the interface between the material and the adjacent medium; they may in principle be different for the two surfaces (e.g., for a coated surface, or where a material layer is adjacent to another material rather than air). Physical arguments, however, dictate that T^f and T^b for the layer be the same (and the f and b superscripts are therefore omitted). R^f and R^b will be different given similar variations in coatings or adjacent materials, and examination of Equation (10) shows that \mathcal{A}^f and \mathcal{A}^b may be different as well. Uncoated glass has the same front and back properties.

Angular Variations. The interfacial properties τ and ρ , and consequently layer properties T , R , and \mathcal{A} , also depend on the incident angle θ of the radiation incident on the layer. Figure 7 shows the optical properties of common window glass as a function of incidence angle. This variation of properties is small for incident angles below 40° but becomes significant at larger angles. Chapter 14 provides details on calculating the direction and magnitude of solar flux that is incident on a window.

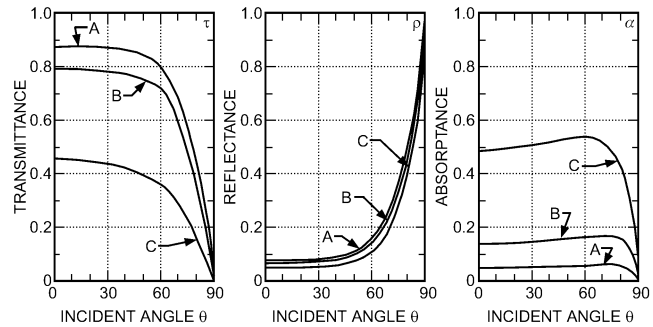


Fig. 8 Variations with Incident Angle of Solar-Optical Properties for (A) Double-Strength Sheet Glass, (B) Clear Plate Glass, and (C) Heat-Absorbing Plate Glass

Figure 8 compares the properties of glasses of different thickness and composition. As the incident angle increases from zero, transmittance decreases, reflectance increases, and absorbance first increases because of the lengthened optical path and then decreases as more incident radiation is reflected. Although the shapes of the property curves are superficially similar, note that both the magnitude of the transmittance at normal incidence and the angle at which the transmittance changes significantly vary with glass type and thickness. The three curves all have slightly different shapes. For coated glasses or for multiple-pane glazing systems, this difference is more pronounced. One cannot assume that all glazings or glazing systems have a universal angular dependence.

Angular performance is important when peak gains and annual energy performance are considered. In North America, peak summertime solar gains occur with east- and west-facing vertical windows at angles of incidence ranging from about 25° to 55° . The peak solar gain for horizontal glazings occurs typically at relatively small angles of incidence (midday sun high in sky in summer). For north- and south-facing vertical glazings, peak summertime solar gains occur at angles of incidence greater than about 40° . Angles of incidence important for annual energy performance calculations range from 5° to over 80° for east- and west-facing vertical and for horizontal windows. This range is only slightly diminished for south-facing windows. For north-facing windows, the direct beam solar gains are small and their angles of incidence range from 62° to 86° (McCluney 1994b).

Spectral Variations. Many glazing systems have optical properties that are *spectrally selective* (i.e., they vary across the electromagnetic spectrum with wavelength λ). Ordinary clear float glass possesses this property, but to a modest degree that is seldom of much concern in load calculations. Tinted and coated glass can exhibit strong spectral selectivity, a desirable property for certain applications, and this effect must be accounted for in solar heat gain determinations.

Figure 9 (McCluney 1993) shows the normal incidence spectral transmittances of several common commercially available glazings. Figure 10 (McCluney 1996) shows the normal incidence spectral transmittances and outdoor reflectances of a variety of additional coated and tinted glasses, indicating the strong spectral selectivity now available from some glass and window manufacturers. Actual transmittance varies with the amount of iron or other absorbers in the glass. Glass with low iron content has a relatively constant spectral transmittance over the entire solar spectrum.

Solar-Optical Property Data. Transmittance and reflectance are the basic measurable quantities for an isolated glazing layer in air. Measurements on glazing layers are typically made using a spectrophotometer at normal incidence, and the properties at other angles must be inferred from these measurements. A systematic

compilation of these measured properties (for most glazings manufactured in the United States) called the International Glazing Database (IGDB) is maintained by the National Fenestration Rating Council and is available on the Internet at <http://www.nfrc.org> or at <http://windows.lbl.gov/materials/IGDB/default.htm> (LBL 2001; NFRC 2004h). For uncoated glazings, layer properties can also be determined from first principles [e.g., McCluney (1994a)].

Obtaining the necessary basic information about the solar-optical properties of coated glass requires spectrophotometric measurements. Alternatively, an approximation procedure is described by Finlayson and Arasteh (1993). Coated glazing properties should vary from these estimates by no more than $\pm 20\%$ at 60° incidence (Rubin et al. 1999). It is currently not practical to determine the solar-optical properties of coated glazings from first principles.

Optical Properties of Glazing Systems

The optical properties of glazing systems (multiple glazing layers) are affected by interreflections between layers in addition to the

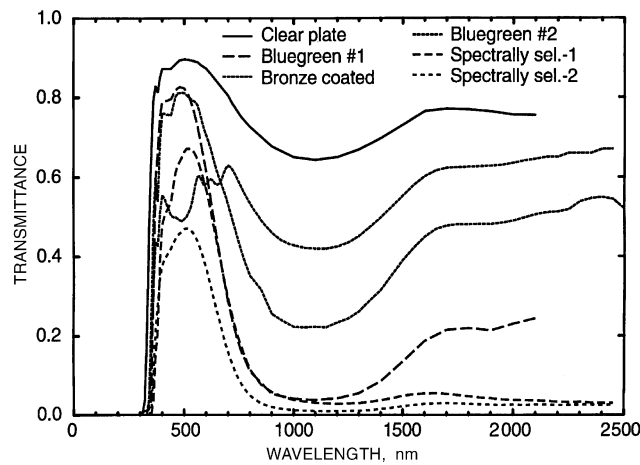


Fig. 9 Spectral Transmittances of Commercially Available Glazings (McCluney 1993)

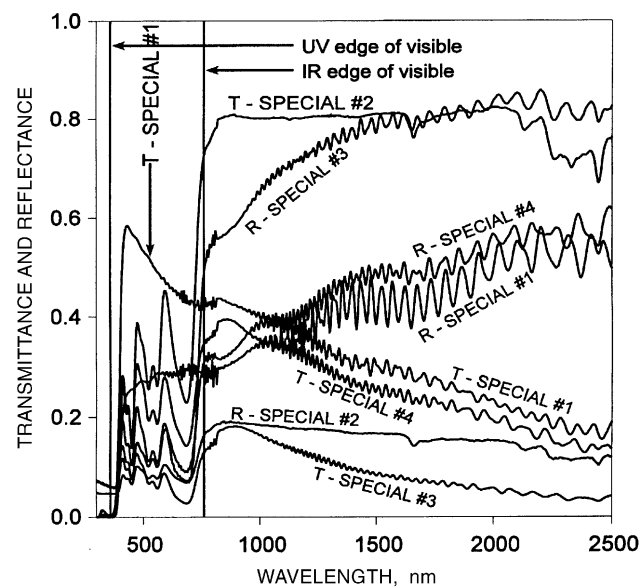


Fig. 10 Spectral Transmittances and Reflectances of Strongly Spectrally Selective Commercially Available Glazings (McCluney 1996)

specular and angular properties of the individual layers. Consequently, the effect of a particular layer on the overall properties may not only depend on its solar-optical properties, but also on its position within the assembly. It is therefore necessary to expand glazing layer considerations to apply to the overall properties of systems and subsystems of glazing layers. The properties of any subsystem can be calculated by use of recursion relations (LBL 2003).

Spectral Averaging of Glazing System Properties. The solar-optical properties of a glazing are the wavelength-integrated (or total) transmittance, reflectance, and absorbance of the glazing to incident solar radiation. If the spectral optical properties $T(\lambda)$, $R(\lambda)$, and $\mathcal{A}(\lambda)$ of the glazing and the spectral irradiance $E(\lambda)$ incident on the glazing are known, the solar optical properties can be calculated using ASTM Standards E903, E971, E972, and E1084, as well as NFRC Technical Document 300.

$$X = \frac{\int_{\lambda_{min}}^{\lambda_{max}} E_{STD}(\lambda)X(\lambda)d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} E_{STD}(\lambda)d\lambda} \quad (11)$$

where

- $X(\lambda) = T(\lambda), R(\lambda), \text{ or } \mathcal{A}(\lambda)$
- $E_{STD}(\lambda) =$ standard solar distribution
- $X =$ total $T, R, \text{ or } \mathcal{A}$ to standard solar distribution

For multiple-layer glazing systems, the spectral averaging should in general be applied to the system spectral properties at each angle. Because all glazing layer properties are to some extent both angle and wavelength dependent, and because these equations are nonlinear in the glazing properties, this is the only procedure that is valid in principle.

Many window glazings do not have strong spectral selectivity over the solar spectrum, so their spectral optical properties can be considered constant, even if the source spectrum changes substantially. In these cases, the transmitted spectral irradiance can be determined by multiplying the incident irradiance by the solar transmittance. For special combinations of climate and location, it may be desirable to use variant solar spectra as weighting functions. It is seldom either feasible or necessary to carry out heat transfer calculations using a detailed, time-dependent solar spectrum and the spectral glazing properties.

Angular Averaging of Glazing System Properties. It is relatively simple to account for angular dependence in beam solar radiation, because at a given time the radiation is incident from a single, easily determined direction. However, for diffuse solar and ground-reflected radiation, the situation is more complicated. In principle, energy flow through the glazing should equal the sum of individual energy flows caused by incident radiation from each direction.

Although such calculations can be done for specific sky conditions using detailed sky data or models, the labor involved is worthwhile only for very specific purposes. Usually, a drastically simplifying assumption is made. Both sky and ground radiation are assumed to be **ideally diffuse** (i.e., to have a sky radiance that is independent of direction). Diffuse properties are then determined by integrating over all directions. See the section on Diffuse Radiation under Solar Heat Gain Coefficient for more details. In addition, the spectral dependence is assumed to be the same as for beam solar radiation.

$$X_D = \frac{\iint_{hem} X(\theta)\cos\theta d\omega}{\iint_{hem} \cos\theta d\omega} = 2 \int_0^{\pi/2} X(\theta)\cos\theta d\theta \quad (12)$$

where

$$X(\theta) = T(\theta), R(\theta), \text{ or } \mathcal{A}(\theta)$$

ω = solid angle of integration

X_D = total T , R , or \mathcal{A} of standard solar distribution

More careful consideration must be given to these quantities for tilted glazings or for direction-dependent shading (e.g., overhangs, venetian blinds) greater accuracy is desired.

Spectrally Selective Glazing and Glazing Systems. Spectrally selective glazing shows strong changes in its optical properties with variations in wavelength over the spectrum. The spectral range from 0.3 to over 50 μm contains radiation from both the sun and sky incident on fenestration systems. The majority of this radiation is called **short-wave** or **solar** radiation. About 99% of the energy in the solar spectrum is between 0.3 to 3.5 μm . The spectral range from 3.5 to over 50 μm is called **long-wave, infrared, or thermal** radiation, which contains radiation from the sun and sky, but also from warm bodies both outside and inside the building. In Figure 11, the solar spectrum for an air mass $m = 1.5$ represents short-wave radiation, with thermal radiation represented by a blackbody source at 75°F. The latter has been scaled up to better compare it with the shape of the solar spectrum. The reflectance spectrum shown is an idealization of typical glazing reflectivity. Figure 11 clearly shows the separation of the solar spectrum from the long-wave spectrum characteristic of radiant emission from an indoor pane of a multiple-pane glazing system.

Figure 11 also shows the human eye spectral response (called the human photopic visibility function). To the human eye, the glazing represented in the figure does not appear very reflective. It is also strongly transmitting for solar radiation, including the visible portion. The glazing is, however, nearly opaque to long-wave radiation, demonstrating that visual perception of a material is a poor indicator of its overall spectral characteristics. The glazing system reflectance depicted in Figure 11 is good for admitting solar radiation while preventing the escape of long-wave radiation emitted by surfaces inside the room, a good design for cold sunny days.

Almost all window glass is opaque to the long-wave radiation emitted by surfaces at temperatures below about 2200°F. This characteristic produces the **greenhouse effect**, by which solar radiation passing through a window is partially retained inside by the following mechanism. Radiation absorbed by surfaces in the room is emitted as long-wavelength radiation, which cannot escape directly

through the glass because of its opacity to radiation beyond 4.5 μm . Instead, radiation from room surfaces is absorbed and reemitted to both sides as determined by several parameters, such as the inside and outside film heat transfer coefficients, the surface emissivities, and other glazing properties.

A good long-wave reflector can be a poor short-wave reflector and a good short-wave transmitter. Because of the conservation of energy ($T + R + \mathcal{A} = 1.0$), high long-wave reflectance means low transmittance and absorptance. Kirchhoff's law shows that low absorptance means low emissivity as well. This is the principle of operation of the high-solar-gain (or cold-climate) **low-e coating** on window glass. Such a coating has high transmittance over the entire solar spectrum, producing high solar heat gain while being highly reflective to long-wave infrared radiation emitted by the indoor surfaces, reflecting this radiation inward. The term *low-e* refers to a low emissivity over the long-wavelength portion of the spectrum.

Figure 12 shows hypothetical glazing systems with performance tuned to specific climates. In this case, the sharp **reflectance edge** that the ideal high solar gain cold-climate low-e coating exhibits just past the end of the solar spectrum in Figure 11 is shifted closer to the edge of the visible portion of the spectrum, thereby increasing the solar near-infrared (NIR) reflectance of the glazing. This results in a drop in the hot-climate transmittance to the right of the visible portion of the spectrum. The effect is to reflect the near-infrared portion of the solar spectrum outside, reducing solar gain, while still admitting visible light in the wavelength region below about 0.8 μm . This low-solar-gain, hot-climate coating also exhibits low emissivity over the long-wave spectrum, and is therefore also properly termed a low-e coating. To distinguish the cold- from the hot-climate version, a glazing with this type of spectral response is often termed **selective low-e**. This is something of a misnomer, because both hot- and cold-climate glazings are spectrally selective. Another term is **high-solar-gain, low-e** glazing system for cold climates, contrasted with **low-solar-gain, low-e** glazing system for hot climates.

The reduced infrared transmittance for the hot-climate glazing is ideally achieved by high reflectance and low absorptance (meaning also low emissivity). It can also be done with high infrared absorptance, if the flow of absorbed solar radiation to the interior of the building can be reduced, introducing a second approach to the construction of a hot-climate, low-solar-gain glazing system. In this case, the outer pane of a multiple-pane glazing system is made to have good visible transmittance but high absorptance over the solar infrared spectrum. To protect the interior of the building from the

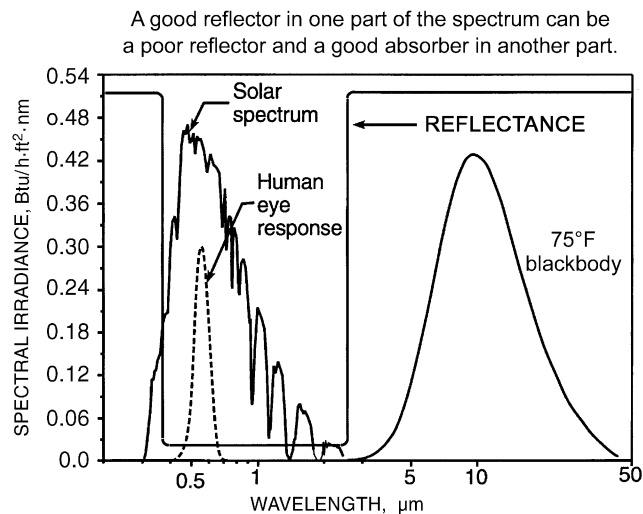


Fig. 11 Solar Spectrum, Human Eye Response Spectrum, Scaled Blackbody Radiation Spectrum, and Idealized Glazing Reflectance Spectrum

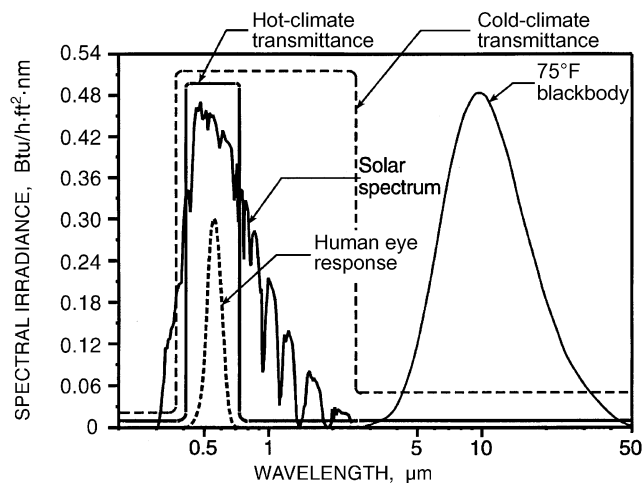


Fig. 12 Demonstration of Two Spectrally Selective Glazing Concepts, Showing Ideal Spectral Transmittances for Glazings Intended for Hot and Cold Climates

heat of this absorbed radiation, additional glazings, gas spaces, and cold-climate or low-solar-gain, low-e coatings are added.

By this means, radiation, conduction, and convection of heat from the hot outer pane to the interior ones and to the interior of the building are reduced because of the coating, the insulating gas space, and the additional panes. Such a glazing system for hot climates is insulated primarily *not* to protect the building from conductive heat losses in winter but to protect the interior from the solar radiant heat absorbed by the hot outer pane in summer. Several manufacturers offer this kind of nonreflecting, spectrally selective glazing system for commercial buildings having large cooling loads. Figure 12 shows that glazings intended for hot climates should have (1) high transmittance over the visible portion of the spectrum to let daylight in for both illumination and view and (2) low transmittance over all other portions of the spectrum to reduce solar heat gain. In contrast, glazings intended for very cold climates should have high transmittance over the whole solar spectrum, from 0.38 to over 3.5 μm , for maximum admission of solar radiant heat gain and light. In addition, glazings for cold climates should have low transmittance over the long-wavelength portion of the spectrum to block radiant heat emitted by the relatively warm indoor surfaces of buildings, preventing its escape to the outside.

Extreme spectral selectivity in glazing systems in the visible portion of the spectrum can produce an unwanted color shift in transmitted light. The color of transmitted light and its color-rendering properties should be considered in the design.

SOLAR HEAT GAIN COEFFICIENT

The concept of the solar heat gain coefficient is best illustrated for the case of a single glass pane in direct sunlight. If $E_D = E_{DN} \cos \theta$ is the direct solar irradiance incident on a single pane of glass, with T the solar transmittance, \mathcal{A} the solar absorptance, and N the **inward-flowing fraction** of the absorbed radiation, then the total solar gain (per unit area) q_b that enters the space because of incident solar radiation is

$$q_b = E_D(T + N\mathcal{A}) \quad (13)$$

in units of energy flux per unit area, $\text{Btu/h} \cdot \text{ft}^2$.

The inward-flowing fraction is thermal in origin; it depends on heat transfer properties of the assembly rather than on its optical properties. Absorbed solar radiation, including ultraviolet, visible, and infrared radiation from the sun and sky, is turned into heat inside the absorbing material. In a window, the glazing system temperature rises as a result to some approximately equilibrium value at which energy gains from absorbed radiation are balanced by equal losses. Absorbed solar radiation is dissipated through conduction, convection, and radiation. Some heat leaves the building, and the remainder goes inside, adding to the directly transmitted solar radiation. The magnitude of the inward-flowing fraction depends on the nature of the air boundary layers adjacent to both sides of the glazing, including any gas between the panes of a multiple-pane glazing system (N_i is often used to distinguish the inward-flowing fraction from the outward-flowing fraction, N_o). However, because only the inward-flowing fraction is used here, the subscript i is dropped for clarity).

The quantity in parenthesis in Equation (13) is called the **solar heat gain coefficient (SHGC)**. The total solar gain (from direct beam radiation) can therefore be computed using the following equation:

$$q_b = E_D \text{SHGC} \quad (14)$$

The SHGC is needed to determine the solar heat gain through a window's glazing system, and should be included along with U-factor and other instantaneous performance properties in any manufacturer's description of a window's energy performance.

Calculation of Solar Heat Gain Coefficient

Because the optical properties \mathcal{A} and T vary with the angle of incidence and wavelength, the solar heat gain coefficient is also a function of these variables. In the most general way, the solar heat gain $q(\theta)$ and the solar heat gain coefficient $\text{SHGC}(\theta, \lambda)$ are defined as

$$\begin{aligned} q(\theta) &= \int_{\lambda} E_D(\lambda) [T(\theta, \lambda) + N\mathcal{A}(\theta, \lambda)] d\lambda \\ &= \int_{\lambda} E_D(\lambda) \text{SHGC}(\theta, \lambda) d\lambda \end{aligned} \quad (15)$$

where

$E_D(\lambda)$ = incident solar spectral irradiance

$T(\theta, \lambda)$ = spectral transmittance of glazing system

$\mathcal{A}(\theta, \lambda)$ = total spectral absorptance of glazing system

Here, the angle- and wavelength-dependent solar heat gain coefficient is given by

$$\text{SHGC}(\theta, \lambda) = T(\theta, \lambda) + N\mathcal{A}(\theta, \lambda) \quad (16)$$

Combined with Equation (11), this becomes the wavelength-averaged solar heat gain coefficient:

$$\text{SHGC}(\theta) = \frac{\int_{\lambda_{\min}}^{\lambda_{\max}} E_D(\lambda) [T(\theta, \lambda) + N(\lambda)\mathcal{A}(\theta, \lambda)] d\lambda}{\int_{\lambda_{\min}}^{\lambda_{\max}} E_D(\lambda) d\lambda} \quad (17)$$

Equations (15) to (17) indicate the preferred way of determining the solar gain of glazing systems and calculating the solar heat gain coefficient. Computer programs such as WINDOW (LBL 2003) are available to assist in the calculation. In WINDOW, the overall system optical properties at a given incident angle are calculated for each wavelength and the results averaged following Equation (17). The ASTM *Standard* E891 spectrum is used in the averaging. The wavelength-averaged properties (at a given incident angle) can then be used in Equation (14). This approach has been adopted by the National Fenestration Rating Council in NFRC *Technical Documentation* 200 for rating, certifying, and labeling windows for energy performance and by the Canadian Standards Association (CSA *Standard* A440.2). The method is valid for strongly spectrally selective (as well as nonselective) glazing systems.

When a glazing system is not strongly spectrally selective, the solar-weighted spectral broadband values of the optical properties can be used, and the integral over wavelength shown in Equations (15) and (17) is not needed. In this case, each glazing layer has its own individual inward-flowing fraction of the absorbed radiation for that layer. With the glazings numbered from the outside inward, and k the glazing index, the SHGC is given by

$$\text{SHGC}(\theta) = T^f(\theta) + \sum_{k=1}^L N_k \mathcal{A}_k^f(\theta) \quad (18)$$

where

T^f = front transmittance of glazing system

L = number of glazing layers

\mathcal{A}_k^f = absorptance of layer k

N_k = inward-flowing fraction for layer k

The inward-flowing fractions can be calculated from simplified heat transfer models, using the following equation:

$$N_k = U \sum_{j=k}^1 R_{j-1,j} \quad (19)$$

This equation is essentially the U-factor of the fenestration times the thermal resistance from the k th layer to the outdoors. In more complicated multilayer glazing systems, it is advisable to perform a detailed heat transfer analysis of the system to determine the values of N_k , because the effective heat transfer coefficients and U depend (weakly) on the glazing layer temperatures and other environmental conditions [e.g., Finlayson and Arasteh (1993), LBL (2001), Wright (1995b)].

Diffuse Radiation

For incident diffuse radiation, the hemispherical average solar heat gain coefficient must be used. This may be calculated by combining Equation (17) with Equation (12) as follows:

$$\langle \text{SHGC}(\theta) \rangle_D = \frac{\int_{hem} \int_{hem} \text{SHGC}(\theta) \cos \theta d\omega}{\int_{hem} \int_{hem} \cos \theta d\omega} \quad (20)$$

$$= 2 \int_0^{\pi/2} \text{SHGC}(\theta) \cos \theta d\theta$$

Equivalently, T and \mathcal{A} in Equation (18) can be hemispherically averaged using Equation (12) so that

$$\langle \text{SHGC} \rangle_D = \langle T^f \rangle_D + \sum_{k=1}^L N_k \langle \mathcal{A}_k^f \rangle_D \quad (21)$$

In any case, N_k is unaffected in averaging, because it does not depend on incident angle or wavelength.

Solar Gain Through Frame and Other Opaque Elements

Figure 13 illustrates the mechanisms by which a window provides solar gain. It is assumed that all of the directly transmitted solar radiation is absorbed at indoor surfaces, where it is converted to heat. Solar gain also enters a building through opaque elements such as the frame and any mullion or dividers that are part of the fenestration system, because a portion of the solar energy absorbed at the surfaces of these elements is redirected to the indoor side by heat transfer.

The solar heat gain coefficient of the fenestration system can be calculated while accounting for solar gain through the opaque elements by area-weighting the solar heat gain coefficients of the glazing, frame, and M divider elements. Thus,

$$\text{SHGC} = \frac{\text{SHGC}_g A_g + \text{SHGC}_f A_f + \sum_{i=1}^M A_i \text{SHGC}_i}{A_g + A_f + \sum_{i=1}^M A_i} \quad (22)$$

where SHGC_g , SHGC_f , and SHGC_i are the solar heat gain coefficients of the glazed area, frame, and i th divider, respectively. A_g , A_f , and A_i are the corresponding projected areas.

In some cases, it is useful to have an overall SHGC for the opaque elements only, which is defined by

$$\text{SHGC}_{op} = \frac{\text{SHGC}_f A_f + \sum_{i=1}^M A_i \text{SHGC}_i}{A_{op}} \quad (23)$$

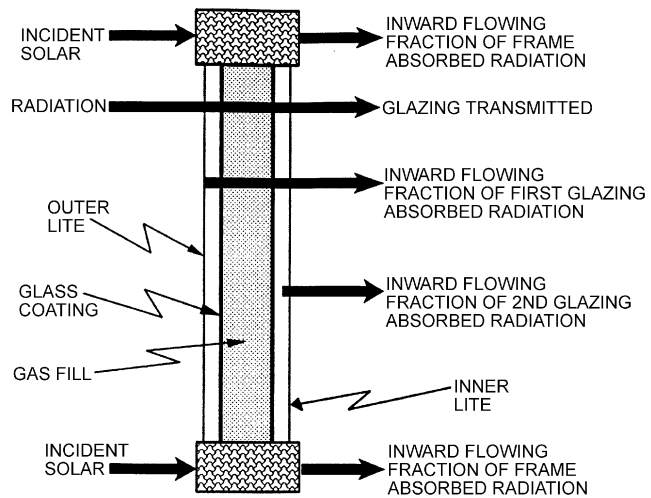


Fig. 13 Components of Solar Radiant Heat Gain with Double-Pane Window, Including Both Frame and Glazing Contributions

where

$$A_{op} = A_f + \sum_{i=1}^M A_i$$

SHGC_f can be estimated (Wright 1995a) using

$$\text{SHGC}_f = \alpha_f^s \left(\frac{U_f}{h_f} \right) \left(\frac{A_f}{A_{surf}} \right) \quad (24)$$

where α_f^s is the solar absorptivity of the outdoor surface of the frame, U_f is the frame U-factor, and h_f is the heat transfer coefficient (radiative plus convective) between the frame and the outdoor environment. The projected-to-surface area ratio (A_f/A_{surf}) corrects for the fact that U_f is based on projected area A_f and h_f is based on the exposed outdoor frame surface area A_{surf} . SHGC_i can be calculated in the same way:

$$\text{SHGC}_i = \alpha_i^s \left(\frac{U_i}{h_i} \right) \left(\frac{A_i}{A_{surf,i}} \right) \quad (25)$$

The outdoor-side heat transfer coefficients h_f and h_i can be estimated using ASHRAE (1996):

$$h_f \text{ or } h_i = h_{co} + 4\sigma e_f T_{out}^3 \quad (26)$$

where h_{co} is the convective heat transfer coefficient between the frame (or divider) surface and the outdoor environment, e_f is the emissivity (long-wave) of the outdoor frame (or divider) surface, T_{out} is the outdoor absolute temperature, and σ is the Stefan-Boltzmann constant.

Solar Heat Gain Coefficient, Visible Transmittance, and Spectrally Averaged Solar-Optical Property Values

Table 10 lists visible transmittance, solar transmittance, front and back reflectance, and solar heat gain coefficients for common glazing and window systems. The ID number for each entry in Table 10 refers to an ID number in Table 4, and the window systems therefore include windows with aluminum or metal frames and windows with other frames that have a lower conductivity (e.g., thermally broken

aluminum, wood, vinyl, and fiberglass). As can be seen in Table 10, the total window solar heat gain coefficient varies with the type of operator, size of the fenestration product, and type of frame.

The glazing T_v , T_{sol} , R^f , R^b , and SHGC values have been calculated using manufacturers' spectral data following methods described in Finlayson and Arasteh (1993) and Wright (1995a), and using the 1.5 air mass spectrum found in ASTM Standard E891. Glazing values are given for 1/8 and 1/4 in. glass and vary with glass thickness and glass manufacturer. Values shown are average values and may vary by ± 0.05 . It is recommended that actual values be determined using detailed spectral data from NFRC (2004h). The front reflectance is the reflectance of the unit to the outside, and the back reflectance is the reflectance to the room side.

Visible transmittances are center-glazing values at normal incidence. A rule of thumb is to select a glazing unit whose visible transmittance is greater than its solar heat gain coefficient, especially if daylighting strategies will be used in the building. For maximum light with minimum solar gain, there are fenestration products available having visible transmittance that is 1.4 times their SHGC. For energy calculations on a daylit building, visible transmittance for the entire window should be used. The visible transmittance of a window can be calculated by multiplying the fraction of glazing area by the center-glazing visible transmittance.

Solar heat gain coefficients are provided for center-glazing and total window values. Center-glazing solar heat gain coefficients are given at normal incidence (0°) and at 40° , 50° , 60° , 70° , and 80° incidence angles. For angles other than those listed, straight-line interpolation can be used between the two closest angles for which values are shown. Total window solar heat gain coefficients assume normal incidence. The operable and fixed window sizes in Table 4 were used. To calculate the frame area, frame heights shown in Figure 4 for aluminum and aluminum-clad wood/wood/vinyl were used. The frame area for aluminum windows is 11% for operable size, and 10% for fixed. The frame area for other frames is 20% for the operable size and 12% for fixed. The ratio of projected frame area to frame surface area is assumed to be 1.0, based on Wright (1995a).

Frame solar heat gain coefficients used to determine the total window solar heat gain coefficients are calculated according to the section on Solar Gain Through Frame and Other Opaque Elements. Frame U-factors are taken from Table 1. Frame absorptance is assumed to be 0.5. The outside film coefficient is $3.9 \text{ Btu/h}\cdot\text{ft}^2\cdot^\circ\text{F}$, corresponding to a wind speed of 7.5 mph. For the aluminum window, the frame solar heat gain coefficient is 0.14 for the operable window and 0.11 for the fixed. For the other frames, the frame solar heat gain coefficient varies between 0.02 and 0.07 for the various lower-conductivity frame types. A frame solar heat gain coefficient of 0.04 is used for the operable window, and 0.03 for the fixed. These values correspond directly to the aluminum-clad wood/reinforced vinyl frames.

Solar transmittances and front and back reflectances are also center-glazing values and are given at normal incidence (0°) and at 40° , 50° , 60° , 70° , and 80° incidence angles. The effective inward-flowing fraction of absorbed radiation for the entire system (not layer-specific values) can be determined from Equation (14) by inserting the solar transmittance and corresponding SHGC.

Example 5. Estimate the overall visible light transmittance for an operable wood casement window with clear, uncoated 1/4 in. double glazing. The operable window has 27% frame area with a wood frame.

Solution: The center-glazing visible light transmittance is 0.78 (see Table 10, glazing ID = 5b, first column). The overall visible light transmittance is

$$T_v = 0.27(0) + 0.73(0.78) = 0.57$$

Airflow Windows

If properly managed, airflow between panes of a double-glazed window can improve fenestration performance. In normal use, a venetian blind is located between the glazing layers. Ventilation air from the room enters the double-glazed cavity, flows over the blind, and can be exhausted from the building or returned through the ducts to the central HVAC system.

These systems can control window heat transfer under many different operating conditions. During sunny winter days, the blind acts as a solar air collector; heat removed by the moving air can be used elsewhere in the building. Further, the window acts as a heat exchanger when sunlit so that the indoor glass temperature nearly equals the room air temperature and improves thermal comfort. In the summer, the window can have a very low solar heat gain coefficient if the blinds are appropriately placed, because the majority of solar gains are removed from the window.

Brandle and Boehm (1982) and Sodergren and Bostrom (1971) give details on airflow windows.

Skylights

Skylight solar heat gain strongly depends on the configuration of the space below or adjacent to (i.e., in sloped applications) the skylight formed by the skylight curb and any associated light well.

Five aspects must be considered: (1) transmittance and absorptance of the skylight unit, (2) transmitted solar flux that reaches the aperture of the light well, (3) whether that aperture is covered by a diffuser, (4) transmitted solar flux that strikes the walls of the light well, and (5) reflectance of the walls of the light well. Data for flat skylights, which may be considered as sloped glazings, are found in Tables 4 and 11.

Domed Skylights. Solar and total heat gains for domed skylights can be determined by the same procedure used for windows. Table 11 gives SHGCs for plastic domed skylights at normal incidence (Shutrum and Ozisik 1961). Manufacturers' literature has further details. Given the poorly defined incident angle conditions for domed skylights, it is best to use these values without correction for incident angle, together with the correct (angle-dependent) value of incident solar irradiance. Results should be considered approximate. In the absence of other data, these values may also be used to make estimates for skylights on slanted roofs.

Glass Block Walls

Glass block can be used for light transmission through outdoor walls when optical clarity for view is unnecessary. Table 12 describes a variety of glass block patterns and gives solar heat gain coefficients to be applied to solar irradiances so that approximate instantaneous solar heat gains can be calculated (Smith and Pennington 1964).

Convection and low-temperature radiative heat gain for all hollow glass block panels fall within a narrow range. Differences in SHGCs are largely the result of differences in transmittance of glass blocks for solar radiation. Solar heat gain coefficients for any particular glass block pattern vary depending on orientation and time of day. The SHGC for western exposures in the morning (shaded) is depressed because of heat storage in the block, whereas the SHGC for eastern exposures in the afternoon (shaded) is elevated as stored heat is dissipated. Time lag effects from heat storage are estimated by using solar gains and air-to-air temperature differences for one hour earlier than the time for which the load calculation is made.

Calorimeter tests of Type 1A glass block showed little difference in solar heat gains between glass block with either black or white ceramic enamel on the exterior of the block. White and black ceramic enamel surfaces represent the two extremes for reflecting or absorbing solar energy; therefore, glass block with enamel surfaces of other colors should have solar heat gain coefficients between these values. Because glass blocks are good examples of strongly angularly selective fenestrations, appropriate caution must be taken.

Table 10 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (\mathcal{A}_l^f) for Glazing and Window Systems

ID	Glazing System			Center Glazing T_v		Center-of-Glazing Properties							Total Window SHGC at Normal Incidence		Total Window T_v at Normal Incidence					
						Incidence Angles							Aluminum		Other Frames		Aluminum		Other Frames	
						Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
<i>Uncoated Single Glazing</i>																				
1a	1/8	CLR	0.90	SHGC	0.86	0.84	0.82	0.78	0.67	0.42	0.78	0.78	0.79	0.70	0.76	0.80	0.81	0.72	0.79	
				T	0.83	0.82	0.80	0.75	0.64	0.39	0.75									
				R^f	0.08	0.08	0.10	0.14	0.25	0.51	0.14									
				R^b	0.08	0.08	0.10	0.14	0.25	0.51	0.14									
				\mathcal{A}_1^f	0.09	0.10	0.10	0.11	0.11	0.11	0.10									
1b	1/4	CLR	0.88	SHGC	0.81	0.80	0.78	0.73	0.62	0.39	0.73	0.74	0.74	0.66	0.72	0.78	0.79	0.70	0.77	
				T	0.77	0.75	0.73	0.68	0.58	0.35	0.69									
				R^f	0.07	0.08	0.09	0.13	0.24	0.48	0.13									
				R^b	0.07	0.08	0.09	0.13	0.24	0.48	0.13									
				\mathcal{A}_1^f	0.16	0.17	0.18	0.19	0.19	0.17	0.17									
1c	1/8	BRZ	0.68	SHGC	0.73	0.71	0.68	0.64	0.55	0.34	0.65	0.67	0.67	0.59	0.65	0.61	0.61	0.54	0.60	
				T	0.65	0.62	0.59	0.55	0.46	0.27	0.56									
				R^f	0.06	0.07	0.08	0.12	0.22	0.45	0.12									
				R^b	0.06	0.07	0.08	0.12	0.22	0.45	0.12									
				\mathcal{A}_1^f	0.29	0.31	0.32	0.33	0.33	0.29	0.31									
1d	1/4	BRZ	0.54	SHGC	0.62	0.59	0.57	0.53	0.45	0.29	0.54	0.57	0.57	0.50	0.55	0.48	0.49	0.43	0.48	
				T	0.49	0.45	0.43	0.39	0.32	0.18	0.41									
				R^f	0.05	0.06	0.07	0.11	0.19	0.42	0.10									
				R^b	0.05	0.06	0.07	0.11	0.19	0.42	0.10									
				\mathcal{A}_1^f	0.46	0.49	0.50	0.51	0.49	0.41	0.48									
1e	1/8	GRN	0.82	SHGC	0.70	0.68	0.66	0.62	0.53	0.33	0.63	0.64	0.64	0.57	0.62	0.73	0.74	0.66	0.72	
				T	0.61	0.58	0.56	0.52	0.43	0.25	0.53									
				R^f	0.06	0.07	0.08	0.12	0.21	0.45	0.11									
				R^b	0.06	0.07	0.08	0.12	0.21	0.45	0.11									
				\mathcal{A}_1^f	0.33	0.35	0.36	0.37	0.36	0.31	0.35									
1f	1/4	GRN	0.76	SHGC	0.60	0.58	0.56	0.52	0.45	0.29	0.54	0.55	0.55	0.49	0.53	0.68	0.68	0.61	0.67	
				T	0.47	0.44	0.42	0.38	0.32	0.18	0.40									
				R^f	0.05	0.06	0.07	0.11	0.20	0.42	0.10									
				R^b	0.05	0.06	0.07	0.11	0.20	0.42	0.10									
				\mathcal{A}_1^f	0.47	0.50	0.51	0.51	0.49	0.40	0.49									
1g	1/8	GRY	0.62	SHGC	0.70	0.68	0.66	0.61	0.53	0.33	0.63	0.64	0.64	0.57	0.62	0.55	0.56	0.50	0.55	
				T	0.61	0.58	0.56	0.51	0.42	0.24	0.53									
				R^f	0.06	0.07	0.08	0.12	0.21	0.44	0.11									
				R^b	0.06	0.07	0.08	0.12	0.21	0.44	0.11									
				\mathcal{A}_1^f	0.33	0.36	0.37	0.37	0.37	0.32	0.35									
1h	1/4	GRY	0.46	SHGC	0.59	0.57	0.55	0.51	0.44	0.28	0.52	0.54	0.54	0.48	0.52	0.41	0.41	0.37	0.40	
				T	0.46	0.42	0.40	0.36	0.29	0.16	0.38									
				R^f	0.05	0.06	0.07	0.10	0.19	0.41	0.10									
				R^b	0.05	0.06	0.07	0.10	0.19	0.41	0.10									
				\mathcal{A}_1^f	0.49	0.52	0.54	0.54	0.52	0.43	0.51									
1i	1/4	BLUGRN	0.75	SHGC	0.62	0.59	0.57	0.54	0.46	0.30	0.55	0.57	0.57	0.50	0.55	0.67	0.68	0.60	0.66	
				T	0.49	0.46	0.44	0.40	0.33	0.19	0.42									
				R^f	0.06	0.06	0.07	0.11	0.20	0.43	0.11									
				R^b	0.06	0.06	0.07	0.11	0.20	0.43	0.11									
				\mathcal{A}_1^f	0.45	0.48	0.49	0.49	0.47	0.38	0.48									
<i>Reflective Single Glazing</i>																				
1j	1/4	SS on CLR 8%	0.08	SHGC	0.19	0.19	0.19	0.18	0.16	0.10	0.18	0.18	0.18	0.16	0.17	0.07	0.07	0.06	0.07	
				T	0.06	0.06	0.06	0.05	0.04	0.03	0.05									
				R^f	0.33	0.34	0.35	0.37	0.44	0.61	0.36									
				R^b	0.50	0.50	0.51	0.53	0.58	0.71	0.52									
				\mathcal{A}_1^f	0.61	0.61	0.60	0.58	0.52	0.37	0.57									
1k	1/4	SS on CLR 14%	0.14	SHGC	0.25	0.25	0.24	0.23	0.20	0.13	0.23	0.24	0.24	0.21	0.22	0.12	0.13	0.11	0.12	
				T	0.11	0.10	0.10	0.09	0.07	0.04	0.09									
				R^f	0.26	0.27	0.28	0.31	0.38	0.57	0.30									
				R^b	0.44	0.44	0.45	0.47	0.52	0.67	0.46									
				\mathcal{A}_1^f	0.63	0.63	0.62	0.60	0.55	0.39	0.60									

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Table 10 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (\mathcal{A}_n^f) for Glazing and Window Systems (Continued)

Glazing System			Center-of-Glazing Properties										Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence					
			Center Glazing T_v	Incidence Angles									Aluminum		Other Frames		Aluminum		Other Frames			
				Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed				
ID	Glass Thick., in.		SHGC																			
1l	1/4	SS on CLR 20%	0.20	SHGC	0.31	0.30	0.30	0.28	0.24	0.16	0.28	0.29	0.29	0.26	0.28	0.18	0.18	0.16	0.18			
				T	0.15	0.15	0.14	0.13	0.11	0.06	0.13											
				R^f	0.21	0.22	0.23	0.26	0.34	0.54	0.25											
				R^b	0.38	0.38	0.39	0.41	0.48	0.64	0.41											
				\mathcal{A}_1^f	0.64	0.64	0.63	0.61	0.56	0.40	0.60											
1m	1/4	SS on GRN 14%	0.12	SHGC	0.25	0.25	0.24	0.23	0.21	0.14	0.23	0.24	0.24	0.21	0.22	0.11	0.11	0.10	0.11			
				T	0.06	0.06	0.06	0.06	0.04	0.03	0.06											
				R^f	0.14	0.14	0.16	0.19	0.27	0.49	0.18											
				R^b	0.44	0.44	0.45	0.47	0.52	0.67	0.46											
				\mathcal{A}_1^f	0.80	0.80	0.78	0.76	0.68	0.48	0.75											
1n	1/4	TI on CLR 20%	0.20	SHGC	0.29	0.29	0.28	0.27	0.23	0.15	0.27	0.27	0.27	0.24	0.26	0.18	0.18	0.16	0.18			
				T	0.14	0.13	0.13	0.12	0.09	0.06	0.12											
				R^f	0.22	0.22	0.24	0.26	0.34	0.54	0.26											
				R^b	0.40	0.40	0.42	0.44	0.50	0.65	0.43											
				\mathcal{A}_1^f	0.65	0.65	0.64	0.62	0.57	0.40	0.62											
1o	1/4	TI on CLR 30%	0.30	SHGC	0.39	0.38	0.37	0.35	0.30	0.20	0.35	0.36	0.36	0.32	0.35	0.27	0.27	0.24	0.26			
				T	0.23	0.22	0.21	0.19	0.16	0.09	0.20											
				R^f	0.15	0.15	0.17	0.20	0.28	0.50	0.19											
				R^b	0.32	0.33	0.34	0.36	0.43	0.60	0.36											
				\mathcal{A}_1^f	0.63	0.65	0.64	0.62	0.57	0.40	0.62											
Uncoated Double Glazing																						
5a	1/8	CLR CLR	0.81	SHGC	0.76	0.74	0.71	0.64	0.50	0.26	0.66	0.69	0.70	0.62	0.67	0.72	0.73	0.65	0.71			
				T	0.70	0.68	0.65	0.58	0.44	0.21	0.60											
				R^f	0.13	0.14	0.16	0.23	0.36	0.61	0.21											
				R^b	0.13	0.14	0.16	0.23	0.36	0.61	0.21											
				\mathcal{A}_1^f	0.10	0.11	0.11	0.12	0.13	0.13	0.11											
5b	1/4	CLR CLR	0.78	SHGC	0.70	0.67	0.64	0.58	0.45	0.23	0.60	0.64	0.64	0.57	0.62	0.69	0.70	0.62	0.69			
				T	0.61	0.58	0.55	0.48	0.36	0.17	0.51											
				R^f	0.11	0.12	0.15	0.20	0.33	0.57	0.18											
				R^b	0.11	0.12	0.15	0.20	0.33	0.57	0.18											
				\mathcal{A}_1^f	0.17	0.18	0.19	0.20	0.21	0.20	0.19											
5c	1/8	BRZ CLR	0.62	SHGC	0.62	0.60	0.57	0.51	0.39	0.20	0.53	0.57	0.57	0.50	0.55	0.55	0.56	0.50	0.55			
				T	0.55	0.51	0.48	0.42	0.31	0.14	0.45											
				R^f	0.09	0.10	0.12	0.16	0.27	0.49	0.15											
				R^b	0.12	0.13	0.15	0.21	0.35	0.59	0.19											
				\mathcal{A}_1^f	0.30	0.33	0.34	0.36	0.37	0.34	0.33											
5d	1/4	BRZ CLR	0.47	SHGC	0.49	0.46	0.44	0.39	0.31	0.17	0.41	0.45	0.45	0.40	0.43	0.42	0.42	0.38	0.41			
				T	0.38	0.35	0.32	0.27	0.20	0.08	0.30											
				R^f	0.07	0.08	0.09	0.13	0.22	0.44	0.12											
				R^b	0.10	0.11	0.13	0.19	0.31	0.55	0.17											
				\mathcal{A}_1^f	0.48	0.51	0.52	0.53	0.53	0.45	0.50											
5e	1/8	GRN CLR	0.75	SHGC	0.60	0.57	0.54	0.49	0.38	0.20	0.51	0.55	0.55	0.49	0.53	0.67	0.68	0.60	0.66			
				T	0.52	0.49	0.46	0.40	0.30	0.13	0.43											
				R^f	0.09	0.10	0.12	0.16	0.27	0.50	0.15											
				R^b	0.12	0.13	0.15	0.21	0.35	0.60	0.19											
				\mathcal{A}_1^f	0.34	0.37	0.38	0.39	0.39	0.35	0.37											
5f	1/4	GRN CLR	0.68	SHGC	0.49	0.46	0.44	0.39	0.31	0.17	0.41	0.45	0.45	0.40	0.43	0.61	0.61	0.54	0.60			
				T	0.39	0.36	0.33	0.29	0.21	0.09	0.31											
				R^f	0.08	0.08	0.10	0.14	0.23	0.45	0.13											
				R^b	0.10	0.11	0.13	0.19	0.31	0.55	0.17											
				\mathcal{A}_1^f	0.49	0.51	0.05	0.53	0.52	0.43	0.50											

Table 10 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (\mathcal{A}_n^f) for Glazing and Window Systems (Continued)

Glazing System			Center-of-Glazing Properties									Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence				
			Incidence Angles									Aluminum		Other Frames		Aluminum		Other Frames		
			Normal	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed			
ID	Glass Thick., in.	Center Glazing T_v																		
5g	1/8	GRY CLR	0.56	SHGC	0.60	0.57	0.54	0.48	0.37	0.20	0.51	0.55	0.55	0.49	0.53	0.50	0.50	0.45	0.49	
				T	0.51	0.48	0.45	0.39	0.29	0.12	0.42									
				R^f	0.09	0.09	0.11	0.16	0.26	0.48	0.14									
				R^b	0.12	0.13	0.15	0.21	0.34	0.59	0.19									
				\mathcal{A}_1^f	0.34	0.37	0.39	0.40	0.41	0.37	0.37									
5h	1/4	GRY CLR	0.41	SHGC	0.47	0.44	0.42	0.37	0.29	0.16	0.39	0.43	0.43	0.38	0.42	0.36	0.37	0.33	0.36	
				T	0.36	0.32	0.29	0.25	0.18	0.07	0.28									
				R^f	0.07	0.07	0.08	0.12	0.21	0.43	0.12									
				R^b	0.10	0.11	0.13	0.18	0.31	0.55	0.17									
				\mathcal{A}_1^f	0.51	0.54	0.56	0.57	0.56	0.47	0.53									
5i	1/4	BLUGRN CLR	0.67	SHGC	0.50	0.47	0.45	0.40	0.32	0.17	0.43	0.46	0.46	0.41	0.44	0.60	0.60	0.54	0.59	
				T	0.40	0.37	0.34	0.30	0.22	0.10	0.32									
				R^f	0.08	0.08	0.10	0.14	0.24	0.46	0.13									
				R^b	0.11	0.11	0.14	0.19	0.31	0.55	0.17									
				\mathcal{A}_1^f	0.47	0.49	0.50	0.51	0.50	0.42	0.48									
5j	1/4	HI-P GRN CLR	0.59	SHGC	0.39	0.37	0.35	0.31	0.25	0.14	0.33	0.36	0.36	0.32	0.35	0.53	0.53	0.47	0.52	
				T	0.28	0.26	0.24	0.20	0.15	0.06	0.22									
				R^f	0.06	0.07	0.08	0.12	0.21	0.43	0.11									
				R^b	0.10	0.11	0.13	0.19	0.31	0.55	0.17									
				\mathcal{A}_1^f	0.62	0.65	0.65	0.65	0.62	0.50	0.63									
Reflective Double Glazing																				
5k	1/4	SS on CLR 8%, CLR	0.07	SHGC	0.13	0.12	0.12	0.11	0.10	0.06	0.11	0.13	0.13	0.11	0.12	0.06	0.06	0.06	0.06	
				T	0.05	0.05	0.04	0.04	0.03	0.01	0.04									
				R^f	0.33	0.34	0.35	0.37	0.44	0.61	0.37									
				R^b	0.38	0.37	0.38	0.40	0.46	0.61	0.40									
				\mathcal{A}_1^f	0.61	0.61	0.60	0.58	0.53	0.37	0.56									
5l	1/4	SS on CLR 14%, CLR	0.13	SHGC	0.17	0.17	0.16	0.15	0.13	0.08	0.16	0.17	0.16	0.14	0.15	0.12	0.12	0.10	0.11	
				T	0.08	0.08	0.08	0.07	0.05	0.02	0.07									
				R^f	0.26	0.27	0.28	0.31	0.38	0.57	0.30									
				R^b	0.34	0.33	0.34	0.37	0.44	0.60	0.36									
				\mathcal{A}_1^f	0.63	0.64	0.64	0.63	0.61	0.56	0.60									
5m	1/4	SS on CLR 20%, CLR	0.18	SHGC	0.22	0.21	0.21	0.19	0.16	0.09	0.20	0.21	0.21	0.18	0.20	0.16	0.16	0.14	0.16	
				T	0.12	0.11	0.11	0.09	0.07	0.03	0.10									
				R^f	0.21	0.22	0.23	0.26	0.34	0.54	0.25									
				R^b	0.30	0.30	0.31	0.34	0.41	0.59	0.33									
				\mathcal{A}_1^f	0.64	0.64	0.63	0.62	0.57	0.41	0.61									
5n	1/4	SS on GRN 14%, CLR	0.11	SHGC	0.16	0.16	0.15	0.14	0.12	0.08	0.14	0.16	0.16	0.14	0.14	0.10	0.10	0.09	0.10	
				T	0.05	0.05	0.05	0.04	0.03	0.01	0.04									
				R^f	0.14	0.14	0.16	0.19	0.27	0.49	0.18									
				R^b	0.34	0.33	0.34	0.37	0.44	0.60	0.36									
				\mathcal{A}_1^f	0.80	0.80	0.79	0.76	0.69	0.49	0.76									
5o	1/4	TI on CLR 20%, CLR	0.18	SHGC	0.21	0.20	0.19	0.18	0.15	0.09	0.18	0.20	0.20	0.18	0.19	0.16	0.16	0.14	0.16	
				T	0.11	0.10	0.10	0.08	0.06	0.03	0.09									
				R^f	0.22	0.22	0.24	0.27	0.34	0.54	0.26									
				R^b	0.32	0.31	0.32	0.35	0.42	0.59	0.35									
				\mathcal{A}_1^f	0.65	0.66	0.65	0.63	0.58	0.41	0.62									
5p	1/4	TI on CLR 30%, CLR	0.27	SHGC	0.29	0.28	0.27	0.25	0.20	0.12	0.25	0.27	0.27	0.24	0.26	0.24	0.24	0.22	0.24	
				T	0.18	0.17	0.16	0.14	0.10	0.05	0.15									
				R^f	0.15	0.15	0.17	0.20	0.29	0.51	0.19									
				R^b	0.27	0.27	0.28	0.31	0.40	0.58	0.31									
				\mathcal{A}_1^f	0.64	0.64	0.63	0.62	0.58	0.43	0.61									

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Table 10 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (\mathcal{A}_n^f) for Glazing and Window Systems (Continued)

ID	Glazing System		Center Glazing T_v		Center-of-Glazing Properties								Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence			
					Incidence Angles								Aluminum		Other Frames		Aluminum		Other Frames	
					Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed	
<i>Low-e Double Glazing, e = 0.2 on surface 2</i>																				
17a	1/8	LE CLR	0.76	SHGC	0.65	0.64	0.61	0.56	0.43	0.23	0.57	0.59	0.60	0.53	0.58	0.68	0.68	0.61	0.67	
				T	0.59	0.56	0.54	0.48	0.36	0.18	0.50									
				R^f	0.15	0.16	0.18	0.24	0.37	0.61	0.22									
				R^b	0.17	0.18	0.20	0.26	0.38	0.61	0.24									
				\mathcal{A}_1^f	0.20	0.21	0.21	0.21	0.20	0.16	0.20									
				\mathcal{A}_2^f	0.07	0.07	0.08	0.08	0.07	0.05	0.07									
17b	1/4	LE CLR	0.73	SHGC	0.60	0.59	0.57	0.51	0.40	0.21	0.53	0.55	0.55	0.49	0.53	0.65	0.66	0.58	0.64	
				T	0.51	0.48	0.46	0.41	0.30	0.14	0.43									
				R^f	0.14	0.15	0.17	0.22	0.35	0.59	0.21									
				R^b	0.15	0.16	0.18	0.23	0.35	0.57	0.22									
				\mathcal{A}_1^f	0.26	0.26	0.26	0.26	0.25	0.19	0.25									
				\mathcal{A}_2^f	0.10	0.11	0.11	0.11	0.10	0.07	0.10									
<i>Low-e Double Glazing, e = 0.2 on surface 3</i>																				
17c	1/8	CLR LE	0.76	SHGC	0.70	0.68	0.65	0.59	0.46	0.24	0.61	0.64	0.64	0.57	0.62	0.68	0.68	0.1	0.67	
				T	0.59	0.56	0.54	0.48	0.36	0.18	0.50									
				R^f	0.17	0.18	0.20	0.26	0.38	0.61	0.24									
				R^b	0.15	0.16	0.18	0.24	0.37	0.61	0.22									
				\mathcal{A}_1^f	0.11	0.12	0.13	0.13	0.14	0.15	0.12									
				\mathcal{A}_2^f	0.14	0.14	0.14	0.13	0.11	0.07	0.13									
17d	1/4	CLR LE	0.73	SHGC	0.65	0.63	0.60	0.54	0.42	0.21	0.56	0.59	0.60	0.53	0.58	0.65	0.66	0.58	0.64	
				T	0.51	0.48	0.46	0.41	0.30	0.14	0.43									
				R^f	0.15	0.16	0.18	0.23	0.35	0.57	0.22									
				R^b	0.14	0.15	0.17	0.22	0.35	0.59	0.21									
				\mathcal{A}_1^f	0.17	0.19	0.20	0.21	0.22	0.22	0.19									
				\mathcal{A}_2^f	0.17	0.17	0.17	0.15	0.13	0.07	0.16									
17e	1/8	BRZ LE	0.58	SHGC	0.57	0.54	0.51	0.46	0.35	0.18	0.48	0.52	0.52	0.46	0.51	0.52	0.52	0.46	0.51	
				T	0.46	0.43	0.41	0.36	0.26	0.12	0.38									
				R^f	0.12	0.12	0.14	0.18	0.28	0.50	0.17									
				R^b	0.14	0.15	0.17	0.23	0.35	0.60	0.21									
				\mathcal{A}_1^f	0.31	0.34	0.35	0.37	0.38	0.35	0.34									
				\mathcal{A}_2^f	0.11	0.11	0.10	0.10	0.08	0.04	0.10									
17f	1/4	BRZ LE	0.45	SHGC	0.45	0.42	0.40	0.35	0.27	0.14	0.38	0.42	0.42	0.37	0.40	0.40	0.41	0.36	0.40	
				T	0.33	0.30	0.28	0.24	0.17	0.07	0.26									
				R^f	0.09	0.09	0.10	0.14	0.23	0.44	0.13									
				R^b	0.13	0.14	0.16	0.21	0.34	0.58	0.20									
				\mathcal{A}_1^f	0.48	0.51	0.52	0.54	0.53	0.45	0.50									
				\mathcal{A}_2^f	0.11	0.11	0.10	0.09	0.07	0.04	0.09									
17g	1/8	GRN LE	0.70	SHGC	0.55	0.52	0.50	0.44	0.34	0.17	0.46	0.50	0.51	0.45	0.49	0.62	0.63	0.56	0.62	
				T	0.44	0.41	0.38	0.33	0.24	0.11	0.36									
				R^f	0.11	0.11	0.13	0.17	0.27	0.48	0.16									
				R^b	0.14	0.15	0.17	0.23	0.35	0.60	0.21									
				\mathcal{A}_1^f	0.35	0.38	0.39	0.41	0.42	0.37	0.38									
				\mathcal{A}_2^f	0.11	0.10	0.10	0.09	0.07	0.04	0.09									
17h	1/4	GRN LE	0.61	SHGC	0.41	0.39	0.36	0.32	0.25	0.13	0.34	0.38	0.38	0.34	0.36	0.54	0.55	0.49	0.54	
				T	0.29	0.26	0.24	0.21	0.15	0.06	0.23									
				R^f	0.08	0.08	0.09	0.13	0.22	0.43	0.13									
				R^b	0.13	0.14	0.16	0.21	0.34	0.58	0.20									
				\mathcal{A}_1^f	0.53	0.57	0.58	0.59	0.58	0.48	0.56									
				\mathcal{A}_2^f	0.10	0.09	0.09	0.08	0.06	0.03	0.08									
17i	1/8	GRY LE	0.53	SHGC	0.54	0.51	0.49	0.44	0.33	0.17	0.46	0.50	0.50	0.44	0.48	0.47	0.48	0.42	0.47	
				T	0.43	0.40	0.38	0.33	0.24	0.11	0.35									
				R^f	0.11	0.11	0.13	0.17	0.27	0.48	0.16									
				R^b	0.14	0.15	0.17	0.22	0.35	0.60	0.21									
				\mathcal{A}_1^f	0.36	0.39	0.40	0.42	0.42	0.38	0.39									
				\mathcal{A}_2^f	0.10	0.10	0.10	0.09	0.07	0.04	0.09									

Table 10 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (\mathcal{A}_n^f) for Glazing and Window Systems (Continued)

Glazing System			Center-of-Glazing Properties									Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence				
			Center Glazing T_v	Incidence Angles								Aluminum		Other Frames		Aluminum		Other Frames		
				Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed		
ID	Glass Thick., in.		SHGC	T	R^f	R^b	\mathcal{A}_1^f	\mathcal{A}_2^f												
17j	1/4	GRY LE	0.37	SHGC	0.39	0.37	0.35	0.31	0.24	0.13	0.33	0.36	0.36	0.32	0.35	0.33	0.33	0.30	0.33	
			T	0.27	0.25	0.23	0.20	0.14	0.06	0.21										
			R^f	0.09	0.09	0.11	0.14	0.23	0.44	0.14										
			R^b	0.13	0.14	0.16	0.22	0.34	0.58	0.20										
			\mathcal{A}_1^f	0.55	0.58	0.59	0.59	0.58	0.48	0.56										
			\mathcal{A}_2^f	0.09	0.09	0.08	0.07	0.06	0.03	0.08										
17k	1/4	BLUGRN LE	0.62	SHGC	0.45	0.42	0.40	0.35	0.27	0.14	0.37	0.42	0.42	0.37	0.40	0.55	0.56	0.50	0.55	
			T	0.32	0.29	0.27	0.23	0.17	0.07	0.26										
			R^f	0.09	0.09	0.10	0.14	0.23	0.44	0.13										
			R^b	0.13	0.14	0.16	0.21	0.34	0.58	0.20										
			\mathcal{A}_1^f	0.48	0.51	0.53	0.54	0.54	0.45	0.51										
			\mathcal{A}_2^f	0.11	0.10	0.10	0.09	0.07	0.03	0.09										
17l	1/4	HI-P GRN LE	0.55	0.241	0.34	0.31	0.30	0.26	0.20	0.11	0.28	0.32	0.32	0.28	0.30	0.49	0.50	0.44	0.48	
			T	0.22	0.19	0.18	0.15	0.10	0.04	0.17										
			R^f	0.07	0.07	0.08	0.11	0.20	0.41	0.11										
			R^b	0.13	0.14	0.16	0.21	0.33	0.58	0.20										
			\mathcal{A}_1^f	0.64	0.67	0.68	0.68	0.66	0.53	0.65										
			\mathcal{A}_2^f	0.08	0.07	0.06	0.06	0.04	0.02	0.06										
Low-e Double Glazing, e = 0.1 on surface 2																				
21a	1/8	LE CLR	0.76	SHGC	0.65	0.64	0.62	0.56	0.43	0.23	0.57	0.59	0.60	0.53	0.58	0.68	0.68	0.61	0.67	
			T	0.59	0.56	0.54	0.48	0.36	0.18	0.50										
			R^f	0.15	0.16	0.18	0.24	0.37	0.61	0.22										
			R^b	0.17	0.18	0.20	0.26	0.38	0.61	0.24										
			\mathcal{A}_1^f	0.20	0.21	0.21	0.21	0.20	0.16	0.20										
			\mathcal{A}_2^f	0.07	0.07	0.08	0.08	0.07	0.05	0.07										
21b	1/4	LE CLR	0.72	SHGC	0.60	0.59	0.57	0.51	0.40	0.21	0.53	0.55	0.55	0.49	0.53	0.64	0.65	0.58	0.63	
			T	0.51	0.48	0.46	0.41	0.30	0.14	0.43										
			R^f	0.14	0.15	0.17	0.22	0.35	0.59	0.21										
			R^b	0.15	0.16	0.18	0.23	0.35	0.57	0.22										
			\mathcal{A}_1^f	0.26	0.26	0.26	0.26	0.25	0.19	0.25										
			\mathcal{A}_2^f	0.10	0.11	0.11	0.11	0.10	0.07	0.10										
Low-e Double Glazing, e = 0.1 on surface 3																				
21c	1/8	CLR LE	0.75	SHGC	0.60	0.58	0.56	0.51	0.40	0.22	0.52	0.55	0.55	0.49	0.53	0.67	0.68	0.60	0.66	
			T	0.48	0.45	0.43	0.37	0.27	0.13	0.40										
			R^f	0.26	0.27	0.28	0.32	0.42	0.62	0.31										
			R^b	0.24	0.24	0.26	0.29	0.38	0.58	0.28										
			\mathcal{A}_1^f	0.12	0.13	0.14	0.14	0.15	0.15	0.13										
			\mathcal{A}_2^f	0.14	0.15	0.15	0.16	0.16	0.10	0.15										
21d	1/4	CLR LE	0.72	SHGC	0.56	0.55	0.52	0.48	0.38	0.20	0.49	0.51	0.52	0.46	0.50	0.64	0.65	0.58	0.63	
			T	0.42	0.40	0.37	0.32	0.24	0.11	0.35										
			R^f	0.24	0.24	0.25	0.29	0.38	0.58	0.28										
			R^b	0.20	0.20	0.22	0.26	0.34	0.55	0.25										
			\mathcal{A}_1^f	0.19	0.20	0.21	0.22	0.23	0.22	0.21										
			\mathcal{A}_2^f	0.16	0.17	0.17	0.17	0.16	0.10	0.16										
21e	1/8	BRZ LE	0.57	SHGC	0.48	0.46	0.44	0.40	0.31	0.17	0.42	0.44	0.44	0.39	0.43	0.51	0.51	0.46	0.50	
			T	0.37	0.34	0.32	0.27	0.20	0.08	0.30										
			R^f	0.18	0.17	0.19	0.22	0.30	0.50	0.21										
			R^b	0.23	0.23	0.25	0.29	0.37	0.57	0.28										
			\mathcal{A}_1^f	0.34	0.37	0.38	0.39	0.39	0.35	0.37										
			\mathcal{A}_2^f	0.11	0.12	0.12	0.12	0.11	0.07	0.11										
21f	1/4	BRZ LE	0.45	SHGC	0.39	0.37	0.35	0.31	0.24	0.13	0.33	0.36	0.36	0.32	0.35	0.40	0.41	0.36	0.40	
			T	0.27	0.24	0.22	0.19	0.13	0.05	0.21										
			R^f	0.12	0.12	0.13	0.16	0.24	0.44	0.16										
			R^b	0.19	0.20	0.22	0.25	0.34	0.55	0.24										
			\mathcal{A}_1^f	0.51	0.54	0.55	0.56	0.55	0.46	0.53										
			\mathcal{A}_2^f	0.10	0.10	0.10	0.10	0.09	0.05	0.10										

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Table 10 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (\mathcal{A}_n^f) for Glazing and Window Systems (Continued)

ID	Glazing System			Center Glazing T_v	Center-of-Glazing Properties								Total Window SHGC at Normal Incidence		Total Window T_v at Normal Incidence				
					Incidence Angles								Aluminum		Other Frames		Aluminum		Other Frames
	Glass Thick., in.				Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
21g	1/8	GRN LE	0.68	SHGC	0.46	0.44	0.42	0.38	0.30	0.16	0.40	0.42	0.43	0.38	0.41	0.61	0.61	0.54	0.60
				T	0.36	0.32	0.30	0.26	0.18	0.08	0.28								
				R^f	0.17	0.16	0.17	0.20	0.29	0.48	0.20								
				R^b	0.23	0.23	0.25	0.29	0.37	0.57	0.27								
				\mathcal{A}_1^f	0.38	0.41	0.42	0.43	0.43	0.38	0.40								
21h	1/4	GRN LE	0.61	SHGC	0.36	0.33	0.31	0.28	0.22	0.12	0.30	0.34	0.34	0.30	0.32	0.54	0.55	0.49	0.54
				T	0.24	0.21	0.19	0.16	0.11	0.05	0.18								
				R^f	0.11	0.10	0.11	0.14	0.22	0.43	0.14								
				R^b	0.19	0.20	0.22	0.25	0.34	0.55	0.24								
				\mathcal{A}_1^f	0.56	0.59	0.61	0.61	0.59	0.48	0.58								
21i	1/8	GRY LE	0.52	SHGC	0.46	0.44	0.42	0.38	0.30	0.16	0.39	0.42	0.43	0.38	0.41	0.46	0.47	0.42	0.46
				T	0.35	0.32	0.30	0.25	0.18	0.08	0.28								
				R^f	0.16	0.16	0.17	0.20	0.28	0.48	0.20								
				R^b	0.23	0.23	0.25	0.29	0.37	0.57	0.27								
				\mathcal{A}_1^f	0.39	0.42	0.43	0.44	0.44	0.38	0.41								
21j	1/4	GRY LE	0.37	SHGC	0.34	0.32	0.30	0.27	0.21	0.12	0.28	0.32	0.32	0.28	0.30	0.33	0.33	0.30	0.33
				T	0.23	0.20	0.18	0.15	0.11	0.04	0.17								
				R^f	0.11	0.11	0.12	0.15	0.23	0.44	0.15								
				R^b	0.20	0.20	0.22	0.25	0.34	0.55	0.24								
				\mathcal{A}_1^f	0.58	0.60	0.61	0.61	0.59	0.48	0.59								
21k	1/4	BLUGRN LE	0.62	SHGC	0.39	0.37	0.34	0.31	0.24	0.13	0.33	0.36	0.36	0.32	0.35	0.55	0.56	0.50	0.55
				T	0.28	0.25	0.23	0.20	0.14	0.06	0.22								
				R^f	0.12	0.12	0.13	0.16	0.24	0.44	0.16								
				R^b	0.23	0.23	0.25	0.28	0.37	0.57	0.27								
				\mathcal{A}_1^f	0.51	0.54	0.56	0.56	0.55	0.46	0.53								
21l	1/4	HI-P GRN W/LE CLR	0.57	SHGC	0.31	0.30	0.29	0.26	0.21	0.12	0.27	0.29	0.29	0.26	0.28	0.51	0.51	0.46	0.50
				T	0.22	0.21	0.19	0.17	0.12	0.06	0.18								
				R^f	0.07	0.07	0.09	0.13	0.22	0.46	0.12								
				R^b	0.23	0.23	0.24	0.28	0.37	0.57	0.27								
				\mathcal{A}_1^f	0.67	0.68	0.67	0.66	0.62	0.46	0.65								
Low-e Double Glazing, $e = 0.05$ on surface 2																			
25a	1/8	LE CLR	0.72	SHGC	0.41	0.40	0.38	0.34	0.27	0.14	0.36	0.38	0.38	0.34	0.36	0.64	0.65	0.58	0.63
				T	0.37	0.35	0.33	0.29	0.22	0.11	0.31								
				R^f	0.35	0.36	0.37	0.40	0.47	0.64	0.39								
				R^b	0.39	0.39	0.40	0.43	0.50	0.66	0.42								
				\mathcal{A}_1^f	0.24	0.26	0.26	0.27	0.28	0.23	0.26								
25b	1/4	LE CLR	0.70	SHGC	0.37	0.36	0.34	0.31	0.24	0.13	0.32	0.34	0.34	0.30	0.33	0.62	0.63	0.56	0.62
				T	0.30	0.28	0.27	0.23	0.17	0.08	0.25								
				R^f	0.30	0.30	0.32	0.35	0.42	0.60	0.34								
				R^b	0.35	0.35	0.35	0.38	0.44	0.60	0.37								
				\mathcal{A}_1^f	0.34	0.35	0.35	0.36	0.35	0.28	0.34								
25c	1/4	BRZ W/LE CLR	0.42	SHGC	0.26	0.25	0.24	0.22	0.18	0.10	0.23	0.25	0.25	0.22	0.23	0.37	0.38	0.34	0.37
				T	0.18	0.17	0.16	0.14	0.10	0.05	0.15								
				R^f	0.15	0.16	0.17	0.21	0.29	0.51	0.20								
				R^b	0.34	0.34	0.35	0.37	0.44	0.60	0.37								
				\mathcal{A}_1^f	0.63	0.63	0.63	0.61	0.57	0.42	0.60								
				\mathcal{A}_2^f	0.04	0.04	0.04	0.04	0.03	0.03	0.04								

Table 10 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (\mathcal{A}_n^f) for Glazing and Window Systems (Continued)

ID	Glazing System		Center Glazing T_v		Center-of-Glazing Properties								Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence				
					Incidence Angles								Aluminum		Other Frames		Aluminum		Other Frames		
					Normal	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed		
25d	1/4	GRN W/LE CLR	0.60	SHGC	0.31	0.30	0.28	0.26	0.21	0.12	0.27	0.29	0.29	0.26	0.28	0.53	0.54	0.48	0.53		
				T	0.22	0.21	0.20	0.17	0.13	0.06	0.18										
				R^f	0.10	0.10	0.12	0.16	0.25	0.48	0.15										
				R^b	0.35	0.34	0.35	0.37	0.44	0.60	0.37										
				\mathcal{A}_1^f	0.64	0.64	0.64	0.63	0.59	0.43	0.62										
				\mathcal{A}_2^f	0.05	0.05	0.05	0.05	0.04	0.03	0.05										
25e	1/4	GRY W/LE CLR	0.35	SHGC	0.24	0.23	0.22	0.20	0.16	0.09	0.21	0.23	0.23	0.20	0.21	0.31	0.32	0.28	0.31		
				T	0.16	0.15	0.14	0.12	0.09	0.04	0.13										
				R^f	0.12	0.13	0.15	0.18	0.26	0.49	0.17										
				R^b	0.34	0.34	0.35	0.37	0.44	0.60	0.37										
				\mathcal{A}_1^f	0.69	0.69	0.68	0.67	0.62	0.45	0.66										
				\mathcal{A}_2^f	0.03	0.03	0.03	0.03	0.03	0.02	0.03										
25f	1/4	BLUE W/LE CLR	0.45	SHGC	0.27	0.26	0.25	0.23	0.18	0.11	0.24	0.26	0.25	0.22	0.24	0.40	0.41	0.36	0.40		
				T	0.19	0.18	0.17	0.15	0.11	0.05	0.16										
				R^f	0.12	0.12	0.14	0.17	0.26	0.49	0.16										
				R^b	0.34	0.34	0.35	0.37	0.44	0.60	0.37										
				\mathcal{A}_1^f	0.66	0.66	0.65	0.64	0.60	0.44	0.63										
				\mathcal{A}_2^f	0.04	0.04	0.04	0.04	0.04	0.03	0.04										
25g	1/4	HI-P GRN W/LE CLR	0.53	SHGC	0.27	0.26	0.25	0.23	0.18	0.11	0.23	0.26	0.25	0.22	0.24	0.47	0.48	0.42	0.47		
				T	0.18	0.17	0.16	0.14	0.10	0.05	0.15										
				R^f	0.07	0.07	0.09	0.13	0.22	0.46	0.12										
				R^b	0.35	0.34	0.35	0.38	0.44	0.60	0.37										
				\mathcal{A}_1^f	0.71	0.72	0.71	0.69	0.64	0.47	0.68										
				\mathcal{A}_2^f	0.04	0.04	0.04	0.04	0.03	0.02	0.04										
Triple Glazing																					
29a	1/8	CLR CLR CLR	0.74	SHGC	0.68	0.65	0.62	0.54	0.39	0.18	0.57	0.62	0.62	0.55	0.60	0.66	0.67	0.59	0.65		
				T	0.60	0.57	0.53	0.45	0.31	0.12	0.49										
				R^f	0.17	0.18	0.21	0.28	0.42	0.65	0.25										
				R^b	0.17	0.18	0.21	0.28	0.42	0.65	0.25										
				\mathcal{A}_1^f	0.10	0.11	0.12	0.13	0.14	0.14	0.12										
				\mathcal{A}_2^f	0.08	0.08	0.09	0.09	0.08	0.07	0.08										
				\mathcal{A}_3^f	0.06	0.06	0.06	0.06	0.05	0.03	0.06										
29b	1/4	CLR CLR CLR	0.70	SHGC	0.61	0.58	0.55	0.48	0.35	0.16	0.51	0.56	0.56	0.50	0.54	0.62	0.63	0.56	0.62		
				T	0.49	0.45	0.42	0.35	0.24	0.09	0.39										
				R^f	0.14	0.15	0.18	0.24	0.37	0.59	0.22										
				R^b	0.14	0.15	0.18	0.24	0.37	0.59	0.22										
				\mathcal{A}_1^f	0.17	0.19	0.20	0.21	0.22	0.21	0.19										
				\mathcal{A}_2^f	0.12	0.13	0.13	0.13	0.12	0.08	0.12										
				\mathcal{A}_3^f	0.08	0.08	0.08	0.08	0.06	0.03	0.08										
29c	1/4	HI-P GRN CLR CLR	0.53	SHGC	0.32	0.29	0.27	0.24	0.18	0.10	0.26	0.30	0.30	0.26	0.29	0.47	0.48	0.42	0.47		
				T	0.20	0.17	0.15	0.12	0.07	0.02	0.15										
				R^f	0.06	0.07	0.08	0.11	0.20	0.41	0.11										
				R^b	0.13	0.14	0.16	0.22	0.35	0.57	0.20										
				\mathcal{A}_1^f	0.64	0.67	0.68	0.68	0.66	0.53	0.65										
				\mathcal{A}_2^f	0.06	0.06	0.05	0.05	0.05	0.03	0.05										
				\mathcal{A}_3^f	0.04	0.04	0.04	0.03	0.02	0.01	0.04										
Triple Glazing, $e = 0.2$ on surface 2																					
32a	1/8	LE CLR CLR	0.68	SHGC	0.60	0.58	0.55	0.48	0.35	0.17	0.51	0.55	0.55	0.49	0.53	0.61	0.61	0.54	0.60		
				T	0.50	0.47	0.44	0.38	0.26	0.10	0.41										
				R^f	0.17	0.19	0.21	0.27	0.41	0.64	0.25										
				R^b	0.19	0.20	0.22	0.29	0.42	0.63	0.26										
				\mathcal{A}_1^f	0.20	0.20	0.20	0.21	0.21	0.17	0.20										
				\mathcal{A}_2^f	0.08	0.08	0.08	0.09	0.08	0.07	0.08										
				\mathcal{A}_3^f	0.06	0.06	0.06	0.06	0.05	0.03	0.06										

Table 10 Visible Transmittance (T_v), Solar Heat Gain Coefficient (SHGC), Solar Transmittance (T), Front Reflectance (R^f), Back Reflectance (R^b), and Layer Absorptances (\mathcal{A}_n^f) for Glazing and Window Systems (Continued)

Glazing System			Center-of-Glazing Properties										Total Window SHGC at Normal Incidence				Total Window T_v at Normal Incidence			
			Center Glazing T_v	Incidence Angles									Aluminum		Other Frames		Aluminum		Other Frames	
				Normal 0.00	40.00	50.00	60.00	70.00	80.00	Hemis., Diffuse	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed		
ID	Glass Thick., in.		SHGC	T	R^f	R^b	\mathcal{A}_1^f	\mathcal{A}_2^f	\mathcal{A}_3^f											
<i>Triple Glazing, e = 0.2 on surface 5</i>																				
32b	1/4	LE CLR CLR	0.64	SHGC	0.53	0.50	0.47	0.41	0.29	0.14	0.44	0.49	0.49	0.43	0.47	0.57	0.58	0.51	0.56	
				T	0.39	0.36	0.33	0.27	0.17	0.06	0.30									
				R^f	0.14	0.15	0.17	0.21	0.31	0.53	0.20									
				R^b	0.16	0.16	0.19	0.24	0.36	0.57	0.22									
				\mathcal{A}_1^f	0.28	0.31	0.31	0.34	0.37	0.31	0.31									
				\mathcal{A}_2^f	0.11	0.11	0.11	0.11	0.10	0.08	0.11									
				\mathcal{A}_3^f	0.08	0.08	0.08	0.07	0.05	0.03	0.07									
32c	1/8	CLR CLR LE	0.68	SHGC	0.62	0.60	0.57	0.49	0.36	0.16	0.52	0.57	0.57	0.50	0.55	0.61	0.61	0.54	0.60	
				T	0.50	0.47	0.44	0.38	0.26	0.10	0.41									
				R^f	0.19	0.20	0.22	0.29	0.42	0.63	0.26									
				R^b	0.18	0.19	0.21	0.27	0.41	0.64	0.25									
				\mathcal{A}_1^f	0.11	0.12	0.13	0.14	0.15	0.15	0.13									
				\mathcal{A}_2^f	0.09	0.10	0.10	0.10	0.10	0.08	0.10									
				\mathcal{A}_3^f	0.11	0.11	0.11	0.10	0.08	0.04	0.10									
32d	1/4	CLR CLR LE	0.64	SHGC	0.56	0.53	0.50	0.44	0.32	0.15	0.47	0.51	0.52	0.46	0.50	0.57	0.58	0.1	0.56	
				T	0.39	0.36	0.33	0.27	0.17	0.06	0.30									
				R^f	0.16	0.16	0.19	0.24	0.36	0.57	0.22									
				R^b	0.14	0.15	0.17	0.21	0.31	0.53	0.20									
				\mathcal{A}_1^f	0.17	0.19	0.20	0.21	0.22	0.22	0.19									
				\mathcal{A}_2^f	0.13	0.14	0.14	0.14	0.13	0.10	0.13									
				\mathcal{A}_3^f	0.15	0.16	0.15	0.14	0.12	0.05	0.14									
<i>Triple Glazing, e = 0.1 on surface 2 and 5</i>																				
40a	1/8	LE CLR LE	0.62	SHGC	0.41	0.39	0.37	0.32	0.24	0.12	0.34	0.38	0.38	0.34	0.36	0.55	0.56	0.50	0.55	
				T	0.29	0.26	0.24	0.20	0.13	0.05	0.23									
				R^f	0.30	0.30	0.31	0.34	0.41	0.59	0.33									
				R^b	0.30	0.30	0.31	0.34	0.41	0.59	0.33									
				\mathcal{A}_1^f	0.25	0.27	0.28	0.30	0.32	0.27	0.28									
				\mathcal{A}_2^f	0.07	0.08	0.08	0.08	0.07	0.06	0.07									
				\mathcal{A}_3^f	0.08	0.09	0.09	0.09	0.07	0.04	0.08									
40b	1/4	LE CLR LE	0.59	SHGC	0.36	0.34	0.32	0.28	0.21	0.10	0.30	0.34	0.34	0.30	0.32	0.53	0.53	0.47	0.52	
				T	0.24	0.21	0.19	0.16	0.10	0.03	0.18									
				R^f	0.34	0.34	0.35	0.38	0.44	0.61	0.37									
				R^b	0.23	0.23	0.25	0.28	0.36	0.56	0.27									
				\mathcal{A}_1^f	0.24	0.25	0.26	0.28	0.30	0.25	0.26									
				\mathcal{A}_2^f	0.10	0.11	0.11	0.11	0.10	0.07	0.10									
				\mathcal{A}_3^f	0.09	0.09	0.09	0.08	0.07	0.03	0.08									
<i>Triple Glazing, e = 0.05 on surface 2 and 4</i>																				
49	1/8	LE LE CLR	0.58	SHGC	0.27	0.25	0.24	0.21	0.16	0.08	0.23	0.26	0.25	0.22	0.25	0.52	0.52	0.46	0.51	
				T	0.18	0.17	0.16	0.13	0.08	0.03	0.14									
				R^f	0.41	0.41	0.42	0.44	0.50	0.65	0.44									
				R^b	0.46	0.45	0.46	0.48	0.53	0.68	0.47									
				\mathcal{A}_1^f	0.27	0.28	0.28	0.29	0.30	0.24	0.28									
				\mathcal{A}_2^f	0.12	0.12	0.12	0.12	0.11	0.07	0.12									
				\mathcal{A}_3^f	0.02	0.02	0.02	0.02	0.01	0.01	0.02									
50	1/4	LE LE CLR	0.55	SHGC	0.26	0.25	0.23	0.21	0.16	0.08	0.22	0.25	0.25	0.21	0.24	0.49	0.0	0.44	0.48	
				T	0.15	0.14	0.12	0.10	0.07	0.02	0.12									
				R^f	0.33	0.33	0.34	0.37	0.43	0.60	0.36									
				R^b	0.39	0.38	0.38	0.40	0.46	0.61	0.40									
				\mathcal{A}_1^f	0.34	0.36	0.36	0.37	0.36	0.28	0.35									
				\mathcal{A}_2^f	0.15	0.15	0.15	0.14	0.12	0.08	0.14									
				\mathcal{A}_3^f	0.03	0.03	0.03	0.03	0.02	0.01	0.03									

KEY:

CLR = clear, BRZ = bronze, GRN = green, GRY = gray, BLUGRN = blue-green, SS = stainless steel reflective coating, TI = titanium reflective coating
 Reflective coating descriptors include percent visible transmittance as x%.
 HI-P GRN = high-performance green tinted glass, LE = low-emissivity coating

T_v = visible transmittance, T = solar transmittance, SHGC = solar heat gain coefficient, and H. = hemispherical SHGC
 ID #s refer to U-factors in Table 4, except for products 49 and 50.

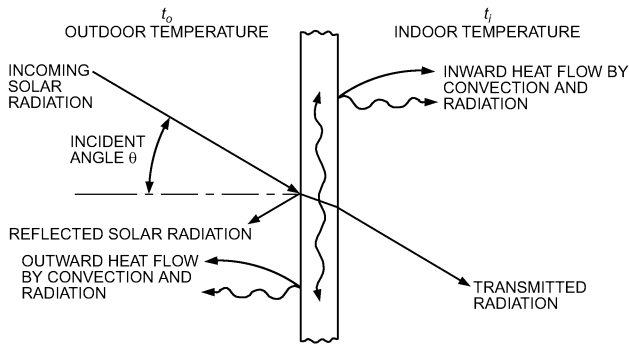


Fig. 14 Instantaneous Heat Balance for Sunlit Glazing Material

Plastic Materials for Glazing

Generally, factors outlined for glass apply also to glazing materials such as acrylic, polycarbonate, polystyrene, or other plastic panels. If solar transmittance, absorptance, and reflectance are known, an SHGC and a shading coefficient can be calculated in the same way as for glass. These properties can be obtained from the manufacturer or be determined by simple laboratory tests. The National Fenestration Rating Council has developed standards for testing the optical properties of glazing (NFRC 2004d, 2004e).

In selecting plastic panels for glazing, concerns include possible deterioration from the sun, expansion and contraction because of temperature extremes, and possible damage from abrasion.

CALCULATION OF SOLAR HEAT GAIN

To calculate solar energy fluxes, first calculate the incident angle θ from the local standard time and the longitude. The direct normal solar irradiance E_{DN} , diffuse sky irradiance E_d , ground-reflected radiation E_r , and total incident irradiance E_t can then be determined. Note that the latter two are assumed to be ideally diffuse radiation. Calculation methods for these parameters are described in Chapter 14.

Solar energy flow through a fenestration may be divided into two parts, opaque and glazing portions, q_{op} and q_s , respectively, as given in Equation (5). The glazing solar energy flux q_s can be split into that from incident beam radiation (q_b) and incident diffuse radiation (q_d), which includes both diffuse sky radiation and radiation scattered (reflected) from the ground:

$$q_s = q_b + q_d \tag{27}$$

The net heat balance that would occur for a sunlit glazing if there were no diffuse radiation is shown in Figure 14. This net heat balance does not include any of the heat flows contained in Q_{th} in Equation (1) (i.e., those resulting from inside/outside temperature differences). The heat balance is pictured as superimposed on the thermal effect. This superposition picture should not be carried too far, however, because the heat flows indicated in Figure 14 as resulting from convection and radiation depend in part on processes that are nonlinear with respect to temperature, so that in reality the two effects cannot be separated. To calculate them, the actual glazing (and other) temperatures are needed, not simply the incremental temperature rise caused by sunlight.

Figure 14 shows that the glazing solar energy flow from beam radiation consists of two parts:

$$q_b = q_{bt} + q_{ba} \tag{28}$$

where

- q_{bt} = glazing solar energy flux caused by transmitted incident beam radiation
- q_{ba} = glazing solar energy flux caused by inward heat flow of absorbed beam radiation

Table 11 Solar Heat Gain Coefficients for Domed Horizontal Skylights

Dome	Light Diffuser (Translucent)	Curb		Solar Heat Gain Coefficient	Visible Transmittance
		Height, in.	Width-to-Height Ratio		
Clear $\tau = 0.86$	Yes $\tau = 0.58$	0	∞	0.53	0.56
		9	5	0.50	0.58
		12	2.5	0.44	0.59
Clear $\tau = 0.86$	None	0	∞	0.86	0.91
		9	5	0.77	0.91
		12	2.5	0.70	0.91
Translucent $\tau = 0.52$	None	0	∞	0.50	0.46
		12	2.5	0.40	0.32
Translucent $\tau = 0.27$	None	0	∞	0.30	0.25
		9	5	0.26	0.21
		12	2.5	0.24	0.18

Sources: Laouadi et al. (2003), Schutrum and Ozisik (1961).

The glazing solar energy flux caused by incident beam radiation is calculated from

$$q_b = E_{DN} \cos\theta \text{SHGC}(\theta) \tag{29}$$

where the beam solar heat gain coefficient is given by Equation (17) or (18). If, instead, the solar radiant and heat fluxes are needed separately, calculate the glazing transmitted solar flux (solar radiation traveling in the incident direction) from

$$q_{bt} = E_{DN} \cos\theta T(\theta) \tag{30}$$

and the inward-flowing absorbed solar flux (heat) from

$$q_{ba} = E_{DN} \cos\theta \sum_{k=1}^L N_k \mathcal{A}_k^f(\theta) \tag{31}$$

Values of $T(\theta)$ and $\mathcal{A}^f(\theta)$ in these equations can be found in Table 10, and determination of N_k is discussed in the section on Calculation of Solar Heat Gain Coefficient.

For diffuse radiation,

$$q_d = q_{dt} + q_{da} \tag{32}$$

where

- q_{dt} = glazing solar energy flux caused by transmitted incident diffuse radiation
- q_{da} = glazing solar energy flux caused by inward heat flow of absorbed diffuse radiation

Glazing solar energy flux caused by diffuse incident radiation is calculated from

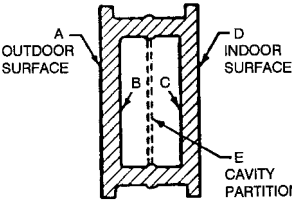
$$q_d = (E_d + E_r) \langle \text{SHGC} \rangle_D \tag{33}$$

where the hemispherically averaged solar heat gain coefficient is calculated from Equation (20). Solar radiant and heat fluxes can be separately calculated from

$$q_{dt} = (E_d + E_r) \langle T \rangle_D \tag{34}$$

which is diffusely distributed solar radiation (note that effects of finite glazing size and thickness are neglected), and

Table 12 Solar Heat Gain Coefficients and U-Factors for Standard Hollow Glass Block Wall Panels

	Type of Glass Block ^a	Description of Glass Block	Solar Heat Gain Coefficient		U-Factor, ^c Btu/h·ft ² ·°F
			In Sun	In Shade ^b	
	Type I	Glass colorless or aqua A, D: Smooth B, C: Smooth or wide ribs, or flutes horizontal or vertical, or shallow configuration E: None	0.57	0.35	0.51
	Type IA	Same as type I except ceramic enamel on A	0.23	0.17	0.51
	Type II	Same as type I except glass fiber screen partition E	0.38	0.30	0.48
	Type III	Glass colorless or aqua A, D: Narrow vertical ribs or flutes. B, C: Horizontal light-diffusing prisms, or horizontal light-directing prisms E: Glass fiber screen	0.29	0.23	0.48
	Type IIIA	Same as type III except E: Glass fiber screen with green ceramic spray coating or glass fiber screen and gray glass or glass fiber screen with light-selecting prisms	0.22	0.16	0.48
Type IV	Same as type I except reflective oxide coating on A	0.14	0.10	0.51	

^aAll values are for 7 3/4 by 7 3/4 by 3 7/8 in. block, set in light colored mortar. For 11 3/4 by 11 3/4 by 3 7/8 in. block, increase coefficients by 15%, and for 5 3/4 by 5 3/4 by 3 7/8 in. block, reduce coefficients by 15%.

^bFor NE, E, and SE panels in shade, add 50% to values listed for panels in shade.

^cValues shown are identical for all size block.

$$q_{da} = (E_d + E_r) \sum_{k=1}^L N_k \langle \mathcal{A}_k^f \rangle_D \quad (35)$$

the solar heat gain of the fenestration can be approximated by modifying Equation (27):

$$q_s = F_u q_b + q_{d,shaded} \quad (37)$$

Opaque Fenestration Elements

The opaque portion solar energy flux is calculated from

$$q_{op} = (E_{DN} \cos \theta + E_d + E_r) SHGC_{op} \quad (36)$$

where SHGC_{op} is obtained from Equation (23).

Example 6. Calculate the solar energy flux through the glazing system ID 25a given $\theta = 60^\circ$, $E_{DN} = 190$ Btu/h·ft², and $E_d = 50$ Btu/h·ft².

Solution: The solar heat gain coefficients are SHGC(60°) = 0.34, and SHGC_D = 0.36 (see Table 10, glazing ID 25a, 5th and 8th columns).

$$\begin{aligned} q_s &= q_t + q_a \\ &= E_{DN} \cos(60) SHGC(60) + (E_d + E_r) \langle SHGC \rangle_D \\ &= (190.0) \cos(60)(0.34) + (50)(0.36) = 50.3 \text{ Btu/h} \cdot \text{ft}^2 \end{aligned}$$

SHADING AND FENESTRATION ATTACHMENTS

SHADING

The most effective way to reduce the solar load on fenestration is to intercept direct radiation from the sun before it reaches the glass. Fenestration products fully shaded from the outside reduce solar heat gain by as much as 80%. Fenestration can be shaded by roof overhangs, vertical and horizontal architectural projections, awnings, heavily proportioned outdoor louvers, or a variety of vegetative shades, including trees, hedges, and trellis vines. In all outdoor shading structures, it is necessary to consider the structures' geometry relative to changing sun position to determine the times and quantities of direct sunlight penetration. A detailed discussion of the effectiveness of outside shading is given in Ewing and Yellott (1976).

The general effect of shading is to attenuate solar radiation. Some of the beam radiation may reach the fenestration unaffected by the shade, and this is accounted for by the unshaded fraction F_u . Assuming that the shade does not transmit or diffuse solar radiation,

Here, the term $q_{d,shaded}$ indicates that a new SHGC must be determined to account for the fact that the shading device restricts the amount of sky-diffuse radiation on the fenestration system. More complex models are required for situations where the shade is partially transmitting and diffusing in nature.

Roof Overhangs: Horizontal and Vertical Projections

In the northern hemisphere, horizontal projections can considerably reduce solar heat gain on south, southeast, and southwest exposures during late spring, summer, and early fall. On east and west exposures during the entire year, and on south exposures in winter, the solar altitude is generally so low that, to be effective, horizontal projections must be excessively long.

The ability of horizontal projections to intercept the direct component of solar radiation depends on their geometry and the profile or shadow-line angle Ω (Figure 15), defined as the angular difference between a horizontal plane and a plane tilted about a horizontal axis in the plane of the fenestration until it includes the sun. The vertical profile angle Ω can be calculated by

$$\tan \Omega = \tan \beta / \cos \gamma \quad (38)$$

where

- β = solar altitude angle
- γ = solar azimuth

The shadow width S_W and shadow height S_H (Figure 16) produced by the vertical and horizontal projections (P_V and P_H), respectively, can be calculated using the surface solar azimuth γ and the vertical profile angle Ω determined by Equation (38).

$$S_W = P_V |\tan \gamma| \quad (39)$$

$$S_H = P_H \tan \Omega \quad (40)$$

When the surface solar azimuth γ is greater than 90° and less than 270°, the fenestration product is completely in the shade; thus, $S_W = W + R_w$ and sunlit area $A_{SL} = 0$.

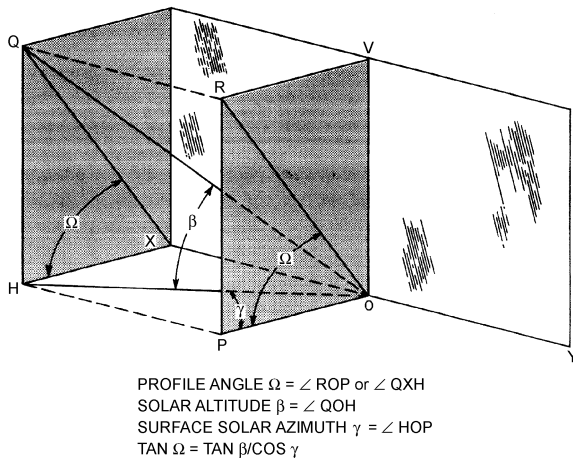


Fig. 15 Profile Angle for South-Facing Horizontal Projections

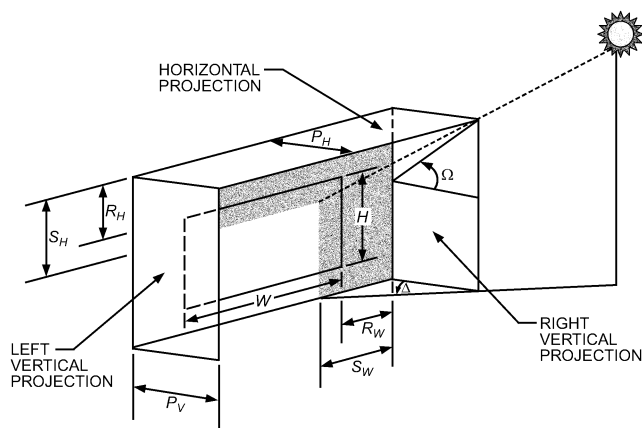


Fig. 16 Vertical and Horizontal Projections and Related Profile Angles for Vertical Surface Containing Fenestration

The sunlit (A_{SL}) and shaded (A_{SH}) areas of the fenestration product are variable during the day and can be calculated for each moment using the following relations:

$$A_{SL} = [W - (S_W - R_W)][H - (S_H - R_H)] \quad (41)$$

$$A_{SH} = A - A_{SL} \quad (42)$$

where A is total fenestration product area.

For software-based or multiple calculations, McCluney (1990) describes an algorithm that can be used to calculate the unshaded fraction of a window equipped with overhangs, awnings, or side fins.

Example 7. A window facing 30° south of west (wall azimuth $\psi = +60^\circ$) in a building at $33.65^\circ N$ latitude, and $84.42^\circ W$ longitude is 72.5 in. wide and 247.5 in. high. The depth of the horizontal projection is 96 in. At 3:00 PM on July 21, it is calculated that the hour angle $H = 15 \times (13.27 - 12) = 19.03^\circ$; and the declination $\delta = 20.60^\circ$.

The solar altitude β is calculated to be:

$$\sin \beta = \cos(33.65) \cos(20.60) \cos(19.03) + \sin(33.65) \sin(20.60)$$

$$\beta = 68.7^\circ$$

The solar azimuth ϕ is

$$\cos \phi = [\sin(68.7) \sin(33.65) - \sin(20.60)] / [\cos(68.7) \cos(33.65)]$$

$$\phi = 57.1^\circ$$

Thus, the wall solar azimuth is $\gamma = 57.1 - 60 = -2.9^\circ$.

- (a) Find the sunlit and shaded area of the window.
 (b) Find the depth of the projections necessary to fully shade the window.

Solution:

- (a) Using Equation (39), the width of the vertical projection shadow is

$$S_W = 0 |\tan(-2.9)| = 0 \text{ in.}$$

- Using Equation (38), the profile angle for the horizontal projection is

$$\tan \Omega = \tan(68.7) / \cos(2.9)$$

$$\Omega = 68.7^\circ$$

- Using Equation (40), the height of the horizontal projection shadow is

$$S_H = 96 \tan(68.7) = 246 \text{ in.}$$

- Using Equations (41) and (42), the sunlit and shaded areas of the window are now

$$A_{SL} = [72.5 - (0 - 0)][247.5 - (246 - 0)] / 144 = 0.76 \text{ ft}^2$$

$$A_{SH} = (72.5 \times 247.5) / 144 - 0.76 = 123.8 \text{ ft}^2$$

- (b) The shadow length necessary to fully shade the given window $S_{H(fs)}$ and $S_{W(fs)}$ from the horizontal and vertical projection are given by (see Figure 16)

$$S_{H(fs)} = 247.5 + 0 = 247.5 \text{ in.}$$

$$S_{W(fs)} = 72.5 + 0 = 72.5 \text{ in.}$$

- Thus, using Equations (39) and (40),

$$P_{H(fs)} = 247.5 \cot(68.7) = 96.6 \text{ in.}$$

$$P_{W(fs)} = 72.5 |\cot(-2.9)| = 1431 \text{ in.}$$

For this example, because both horizontal and vertical projections do not need to fully shade the window, a horizontal projection of 96.6 in. is satisfactory. Also, to accurately analyze the influence of external projections, an hour-by-hour calculation must be performed over the periods of the year for which shading is desired.

FENESTRATION ATTACHMENTS

Fenestration attachments generally consist of items that can be used as part of a system to provide solar and daylighting control, as well as privacy, aesthetics, and comfort for building occupants. Attachments also include other devices that, though not intended for solar control, affect the solar and visual performance of the fenestration system. Attachments to the indoor side of a window can include horizontal louvers (venetian blinds), vertical louvers, roller shades, insect screens, and drapery. Between glazings of multi-glazed windows, horizontal louvers and roller shades may be incorporated. On the outdoor side, insect screens can be added, as well as horizontal louvers in the plane of the window.

Fenestrations with shading devices have a degree of thermal and optical complexity far greater than that of unshaded fenestrations, and are referred to as **complex fenestration**.

In unshaded fenestration, individual glazing layers can only communicate thermally with adjacent layers. This is not the case for complex fenestration. A fenestration layer such as a screen or louvered blind is not sealed, and allows convective heat transfer between nonadjacent layers. Similarly, shading layers are inherently diathermanous (i.e., they transmit both long- and short-wave radiation). Radiative heat transfer, therefore, can also occur between nonadjacent layers. For example, for a window with indoor venetian blinds, heat transfer occurs between the indoor glass and the blind, the indoor glass and the room, and between the blind and the room. Therefore, methods described previously for determining the U-factor and inward-flowing fractions of fenestration systems cannot be applied to complex fenestration (Collins and Wright 2006; Wright 2008).

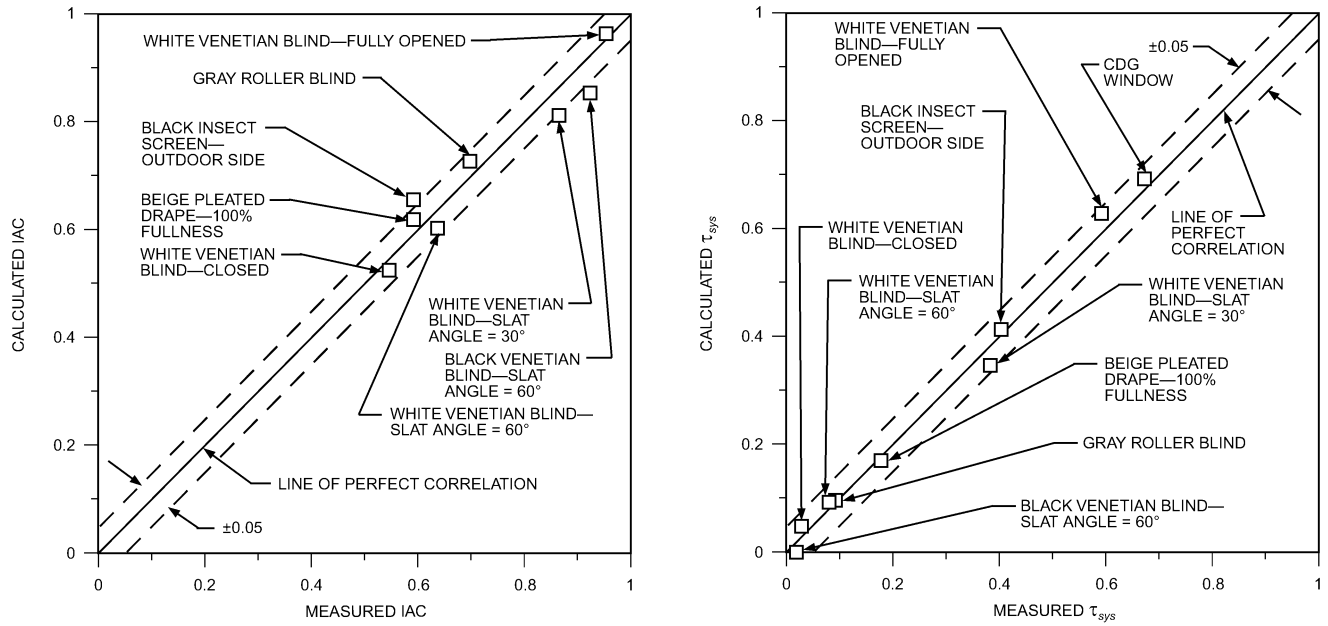


Fig. 17 Comparison of IAC and Solar Transmission Values from ASHWAT Model Versus Measurements
 (Normal incidence; various shading layers attached to conventional double-glazed window)
 (Wright et al. 2009)

Also, complex fenestration can have a **nonspecular optical element**. This is an element for which light (or short-wave infrared radiation) incident on the element from a single spatial direction does not emerge traveling in a single transmitted direction and/or a single reflected direction. Examples of nonspecular elements are shades, drapes, blinds, honeycombs, figured glass, ground glass, and other diffusers, lenses, prisms, and holographic glazings.

Two methods have been developed that allow the analysis of complex fenestration. The first method was proposed by Klems (1994a, 1994b, 2001), and relies on measurement of the bidirectional transmittance and reflectance of each glazing layer, and on calorimetrically determined values of inward flowing fraction, as input to a matrix calculation. It is a physically based and highly accurate approach that is also computationally and experimentally intensive. For details of this approach, see Chapter 31 of the 2005 *ASHRAE Handbook—Fundamentals*. The second method, developed through ASHRAE-sponsored research (Wright et al. 2008b), is an empirically based approach that uses readily available information about the system geometry and material properties, and is designed to fit into established window analysis methodology. The methodology has been shown to accurately predict complex fenestration performance from easily obtained data regarding shade geometry and material.

In contrast to these two methods, a simplified approach is presented in the following section for calculating the approximate SHGC for a selection of the more common shading elements and glazing systems.

Simplified Methodology

Considering only the approximate total heat flux through the fenestration, measurements made on a fenestration under one set of conditions can often be extrapolated to other fenestrations and conditions to give an adequate answer. In this case, the heat flux through the center-glass region is represented by

$$q = E_{DN} \cos(\theta)SHGC(\theta)IAC(\theta, \Omega) + (E_d + E_r)\langle SHGC \rangle_D IAC_D \tag{43}$$

where the solar heat gain coefficients in Equation (43) are for the center-glass region of an unshaded glazing, and may be calculated using methods described previously, or obtained from Table 10. The **indoor solar attenuation coefficient (IAC)** represents the fraction of heat flow that enters the room, some energy having been excluded by the shading. Depending on the type of shade, it may vary angularly and with shade type and geometry. The IAC is defined as

$$IAC(\theta, \Omega) = \frac{SHGC(\theta, \Omega)_{cg, shaded}}{SHGC(\theta)_{cg}} \tag{44}$$

$$IAC_D = \frac{\langle SHGC \rangle_{D, cg, shaded}}{\langle SHGC \rangle_{D, cg}}$$

where Ω is either the horizontal or vertical profile angle.

IAC values presented in the following sections have been determined using the ASHWAT models (Wright et al. 2008b), which have been validated, with calorimetric results showing prediction of fenestration performance to within 5% (Figure 17).

Because shading layers generally have a small effect on the U-value of complex fenestration systems (Wright et al. 2008b), in this simplified analysis, the effects of shading devices on U-factor are ignored. System U-value is assumed to be similar to that of the same glazing (minus the shade) and can be determined from Table 4.

Note that this simplified approach applies only to the SHGC of the center-glass region of the fenestration product. Results from this analysis must be combined with the methods provided in the Solar Heat Gain Coefficient and Solar Heat Gain sections.

Slat-Type Sunshades

Slat-type sunshades consist of horizontal or vertically oriented louvers in located in the plane of the window. They can be installed on the outdoor and indoor side of the fenestration, or between glazings in a multilayered glazing system. The transmitted solar radiation may consist of straight-through, transmitted diffuse, and reflected through components.

The geometry considered is shown in Figure 18, with slat width w , slat crown c , slat spacing s , and slat angle ϕ . The ratios of w/s and

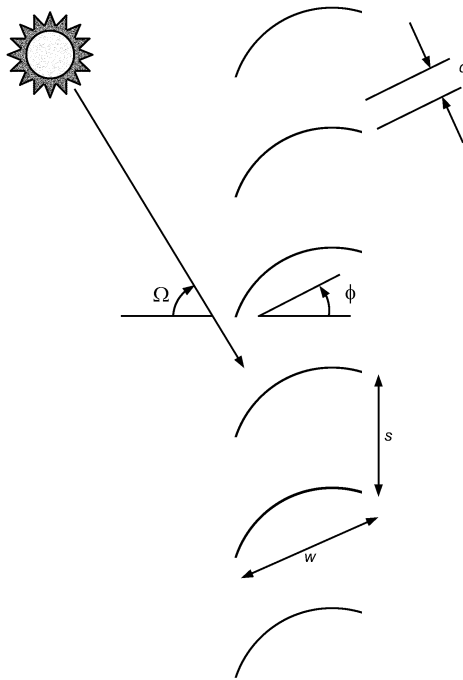


Fig. 18 Geometry of Slat-Type Sunshades

w/c are assumed constant at 1.2 and 16 respectively, which are representative of many commercially available products. The profile angle Ω can represent either the vertical profile Ω_V or the horizontal profile Ω_H . The vertical profile angle is used for horizontal louvered shades, and is calculated using Equation (38). The horizontal profile angle is used for vertical louvered shades and is equal to the wall solar azimuth γ .

Tables 13A to G presents IAC values at profile angles of 0 and 60° for various glazing and shade combinations. IAC varies with profile angle where the profile angle can be the vertical profile (for horizontal louvers) or horizontal profile (for vertical louvers). The variation of IAC with profile angle can be determined from

$$IAC(\theta, \Omega) = IAC_0 + IAC_x \times \min(1, 0.02 \times \Omega) \quad (45)$$

Collins et al. (2008), Huang et al. (2006), Kotey et al. (2009e), and Wright et al. (2008) contain more comprehensive discussions of models used to determine IACs of louvered sunshades.

Example 8. Calculate the SHGC of glazing system ID 25a if a horizontally louvered shade is added (a) on the indoor side, (b) between the glazings, and (c) on the outdoor side. The shade material has a reflectivity of 0.60 and the shades are installed in the open position (0°). $\theta = 60^\circ$ and $\Omega_V = 40^\circ$. Also consider (d) vertical louvers located on the indoor side of the glazing with $\Omega_H = 40^\circ$.

Solution: Use Equations (44) and (45) and values from Table 13E. From Example 6, $SHGC(60^\circ) = 0.34$, and $SHGC_D = 0.36$.

(a) Indoor shade

$$\begin{aligned} IAC(60, 40) &= IAC_0 + (IAC_{60} - IAC_0) \times \frac{\min(\Omega, 60)}{60} \\ &= 0.99 + (0.87 - 0.99) \times \frac{40}{60} \\ &= 0.91 \end{aligned}$$

$$\begin{aligned} SHGC(\theta, \Omega)_{cg, shaded} &= IAC(60, 40) \times SHGC(\theta)_{cg} \\ &= 0.91 \times 0.34 \\ &= 0.31 \end{aligned}$$

$$\begin{aligned} SHGC_{D, cg, shaded} &= IAC_D \times SHGC_{D, cg} \\ &= 0.93 \times 0.36 \\ &= 0.33 \end{aligned}$$

(b) Louvers between glazings

$$\begin{aligned} IAC(60, 40) &= IAC_0 + (IAC_{60} - IAC_0) \times \frac{\min(\Omega, 60)}{60} \\ &= 0.97 + (0.68 - 0.97) \times \frac{40}{60} \\ &= 0.78 \end{aligned}$$

$$\begin{aligned} SHGC(\theta, \Omega)_{cg, shaded} &= IAC(60, 40) \times SHGC(\theta)_{cg} \\ &= 0.78 \times 0.34 \\ &= 0.27 \end{aligned}$$

$$\begin{aligned} SHGC_{D, cg, shaded} &= IAC_D \times SHGC_{D, cg} \\ &= 0.82 \times 0.36 \\ &= 0.30 \end{aligned}$$

(c) Outdoor louvers

$$\begin{aligned} IAC(60, 40) &= IAC_0 + (IAC_{60} - IAC_0) \times \frac{\min(\Omega, 60)}{60} \\ &= 0.94 + (0.15 - 0.94) \times \frac{40}{60} \\ &= 0.41 \end{aligned}$$

$$\begin{aligned} SHGC(\theta, \Omega)_{cg, shaded} &= IAC(60, 40) \times SHGC(\theta)_{cg} \\ &= 0.41 \times 0.34 \\ &= 0.14 \end{aligned}$$

$$\begin{aligned} SHGC_{D, cg, shaded} &= IAC_D \times SHGC_{D, cg} \\ &= 0.51 \times 0.36 \\ &= 0.18 \end{aligned}$$

(d) Vertical louvers

For the given conditions, results are the same as for part (a).

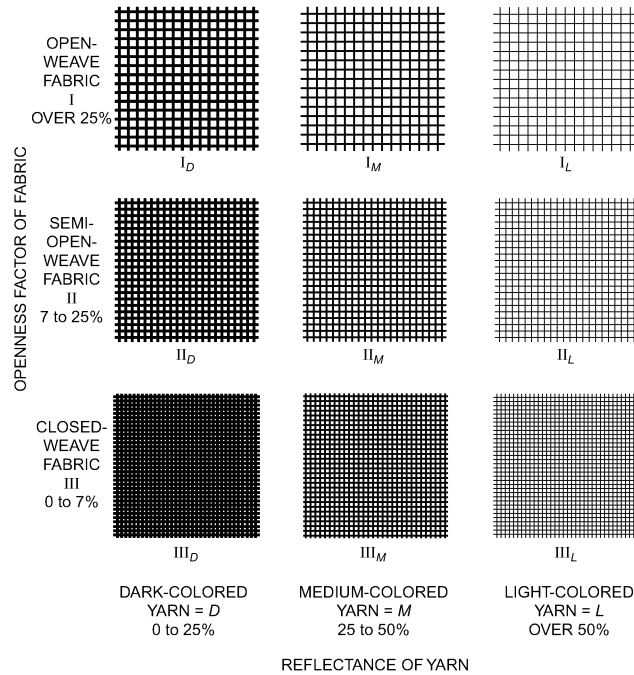
Drapery

Drapery fabrics can be classified in terms of their solar-optical properties as having specific values of fabric transmittance and reflectance. Fabric reflectance is the major factor in determining the ability of a fabric to reduce solar heat gain. Based on their appearance, draperies can also be classified by yarn color as dark, medium, and light and by weave as closed, semiopen, and open. The apparent color of a fabric is determined by the reflectance of the yarn itself. Drapery fabrics are classified into nine types, rated by openness and yarn reflectances (Figures 19 and 20).

The solar-optical properties of drapery fabrics can be determined accurately by laboratory tests (Kotey et al. 2009b; Yellott 1963), and manufacturers can usually supply solar transmittance and reflectance values for their products. In addition to these properties, the openness factor (ratio of the open area between the fibers to the total area of the fabric) is a useful property that can be measured exactly (Keyes 1967; Pennington and Moore 1967). Visual estimations of openness and yarn reflectance, interpreted through Figures 19 and 20, are valuable in judging the effectiveness of drapes for (1) protection from excessive radiant energy from either sunlight or sun-heated glass, (2) brightness control, (3) providing either outward view or privacy, and (4) sound control.

To understand drapery layer solar-optical properties, the **fullness** of the drapery is needed. As simplified in Figure 21, the pleating of the drape is assumed to be square, with pleat depth w and width s . For 100% fullness, the width of fabric used is twice the width of the fenestration. If the drapery is hung flat, like a fenestration product shade, the fullness is 0%.

Table 13G presents IAC and F_R values for typical glazing and shade combinations. For these types of shades, the IAC value is not strongly influenced by the incident angle of irradiation; therefore, a constant value of IAC can be used.



NOTE: Classes may be approximated by eye. With closed fabrics, no objects are visible through the material, but large light or dark areas may show. Semiopen fabrics do not allow details to be seen, and large objects are clearly defined. Open fabrics allow details to be seen, and the general view is relatively clear with no confusion of vision. The yarn color or shade of light or dark may be observed to determine whether the fabric is light, medium, or dark.

Fig. 19 Designation of Drapery Fabrics

Kotey et al. (2009a, 2009b) and Wright et al. (2009) contain more comprehensive discussions of models used to determine IACs of draperies.

Example 9. Calculate the SHGC of glazing system ID 25a if a drapery is added on the indoor side. The fabric has an openness factor of 0.05 and a yarn reflectance of 0.60, and the drapery has 100% fullness.

Solution: In Figure 20, these lines intersect in the area of designator III_L. Fabric is closed and light in color, with probable fabric reflectance of 0.52 and fabric transmittance of 0.30.

From Table 13G, both IAC and IAC_D = 0.68.

$$\begin{aligned} SHGC(\theta, \Omega)_{cg, shaded} &= IAC(60, 40) \times SHGC(\theta)_{cg} \\ &= 0.68 \times 0.34 \\ &= 0.23 \\ SHGC_{D, cg, shaded} &= IAC_D \times SHGC_{D, cg} \\ &= 0.68 \times 0.36 \\ &= 0.25 \end{aligned}$$

Roller Shades and Insect Screens

In general, both roller shades and insect screens are equivalent to drapery of 0% fullness. Appropriately, much of the methodology applied to drapery fabrics applies for these devices as well.

Table 13G presents IAC for typical glazing and shade combinations. For these types of shades, the IAC value is not strongly influenced by the incident angle of irradiation; therefore, a constant value of IAC can be used.

For a more comprehensive discussion of models used to determine IACs, see Kotey et al. (2008, 2009c) for roller shades and Kotey et al. (2009d) for insect screens.

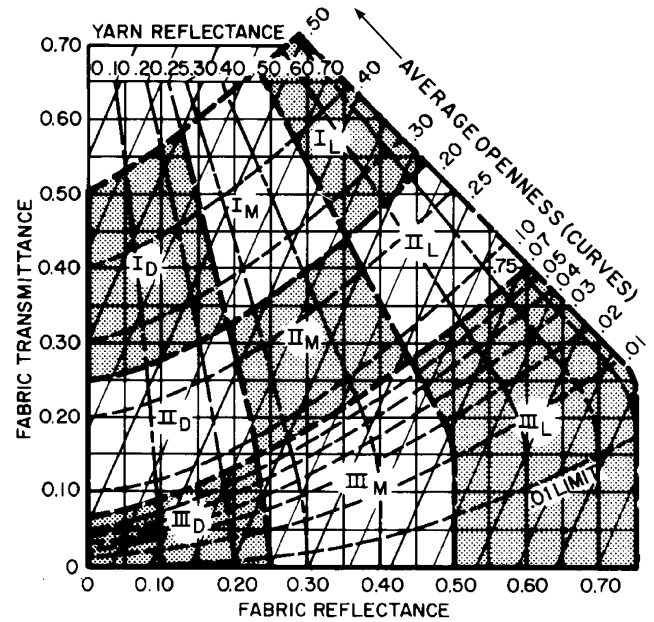


Fig. 20 Drapery Fabric Properties

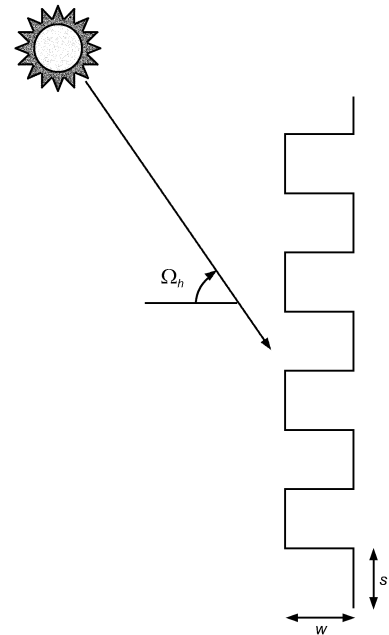


Fig. 21 Geometry of Drapery Fabrics

Example 10. Calculate the SHGC of glazing system ID 25a if a roller shade is added on the indoor side. The shade has an openness factor of 0.0 and a yarn reflectance of 0.65.

Solution: From Table 13G, both IAC and IAC_D = 0.60.

$$\begin{aligned} SHGC(\theta, \Omega)_{cg, shaded} &= IAC(60, 40) \times SHGC(\theta)_{cg} \\ &= 0.60 \times 0.34 \\ &= 0.20 \\ SHGC_{D, cg, shaded} &= IAC_D \times SHGC_{D, cg} \\ &= 0.60 \times 0.36 \\ &= 0.22 \end{aligned}$$

Table 13A IAC Values for Louvered Shades: Uncoated Single Glazings

Glazing ID:	1a	1b	1c	1d	1e	1f	1g	1h	1i	
Louver Location	Louver Reflection									
	$IAC_0(IAC_{60})/IAC_{diff} \cdot F_R$									
Indoor Side	0.15	Worst ^a	0.98 (0.97)/0.86 0.92	0.98 (0.96)/0.86 0.88	0.97 (0.95)/0.87 0.82	0.98 (0.96)/0.87 0.87	0.97 (0.95)/0.87 0.82	0.98 (0.96)/0.87 0.87	0.97 (0.95)/0.87 0.81	0.97 (0.95)/0.87 0.83
	0°		0.98 (0.78)/0.87 0.69	0.98 (0.79)/0.87 0.68	0.98 (0.80)/0.88 0.66	0.98 (0.80)/0.88 0.66	0.97 (0.82)/0.89 0.63	0.98 (0.80)/0.88 0.66	0.97 (0.82)/0.89 0.63	0.97 (0.82)/0.88 0.64
	Excluded Beam ^b		0.73 (0.78)/0.87 0.43	0.74 (0.79)/0.87 0.43	0.75 (0.80)/0.88 0.42	0.76 (0.80)/0.88 0.42	0.77 (0.82)/0.88 0.41	0.76 (0.80)/0.88 0.42	0.78 (0.82)/0.88 0.41	0.77 (0.82)/0.88 0.41
	45°		0.80 (0.74)/0.83 0.47	0.80 (0.75)/0.83 0.46	0.81 (0.76)/0.84 0.45	0.81 (0.77)/0.84 0.45	0.83 (0.79)/0.85 0.43	0.81 (0.77)/0.84 0.45	0.83 (0.79)/0.85 0.43	0.82 (0.78)/0.85 0.44
	Closed		0.70 (0.70)/0.73 0.44	0.70 (0.70)/0.74 0.44	0.72 (0.72)/0.75 0.42	0.72 (0.72)/0.75 0.42	0.74 (0.74)/0.77 0.4	0.72 (0.72)/0.75 0.42	0.74 (0.74)/0.77 0.4	0.74 (0.74)/0.76 0.4
Indoor Side	0.50	Worst ^a	0.98 (0.96)/0.80 0.94	0.97 (0.96)/0.80 0.93	0.97 (0.96)/0.81 0.89	0.97 (0.95)/0.83 0.88	0.97 (0.95)/0.83 0.88	0.97 (0.96)/0.82 0.88	0.97 (0.95)/0.83 0.82	0.97 (0.95)/0.83 0.84
	0°		0.98 (0.70)/0.83 0.74	0.97 (0.70)/0.84 0.73	0.97 (0.72)/0.84 0.71	0.97 (0.75)/0.86 0.7	0.97 (0.76)/0.86 0.67	0.97 (0.73)/0.85 0.7	0.97 (0.76)/0.86 0.66	0.97 (0.75)/0.86 0.67
	Excluded Beam ^b		0.59 (0.70)/0.82 0.5	0.60 (0.70)/0.83 0.5	0.63 (0.72)/0.84 0.48	0.64 (0.73)/0.85 0.48	0.67 (0.76)/0.85 0.46	0.64 (0.73)/0.84 0.48	0.67 (0.76)/0.85 0.46	0.67 (0.75)/0.85 0.46
	45°		0.69 (0.58)/0.74 0.53	0.70 (0.59)/0.75 0.52	0.72 (0.62)/0.76 0.5	0.73 (0.63)/0.77 0.5	0.75 (0.67)/0.79 0.47	0.73 (0.63)/0.77 0.5	0.75 (0.67)/0.79 0.47	0.75 (0.66)/0.79 0.48
	Closed		0.51 (0.49)/0.58 0.46	0.52 (0.50)/0.58 0.45	0.55 (0.53)/0.61 0.43	0.56 (0.54)/0.62 0.42	0.60 (0.59)/0.65 0.4	0.56 (0.54)/0.62 0.42	0.61 (0.59)/0.66 0.39	0.60 (0.58)/0.65 0.4
Indoor Side	0.80	Worst ^a	0.97 (0.96)/0.73 0.95	0.97 (0.96)/0.74 0.94	0.97 (0.95)/0.76 0.9	0.97 (0.95)/0.78 0.85	0.96 (0.95)/0.79 0.84	0.97 (0.95)/0.76 0.89	0.96 (0.95)/0.79 0.83	0.96 (0.95)/0.78 0.85
	0°		0.97 (0.60)/0.78 0.82	0.97 (0.61)/0.79 0.81	0.97 (0.64)/0.80 0.78	0.97 (0.65)/0.81 0.77	0.96 (0.69)/0.83 0.72	0.97 (0.65)/0.81 0.77	0.96 (0.69)/0.83 0.72	0.96 (0.68)/0.82 0.73
	Excluded Beam ^b		0.45 (0.60)/0.77 0.66	0.47 (0.61)/0.77 0.65	0.51 (0.64)/0.79 0.61	0.52 (0.65)/0.79 0.59	0.57 (0.69)/0.81 0.55	0.52 (0.65)/0.79 0.59	0.58 (0.69)/0.82 0.55	0.57 (0.68)/0.81 0.56
	45°		0.59 (0.42)/0.66 0.66	0.60 (0.43)/0.67 0.65	0.63 (0.48)/0.69 0.61	0.64 (0.49)/0.73 0.56	0.68 (0.55)/0.73 0.55	0.64 (0.49)/0.70 0.59	0.68 (0.56)/0.73 0.55	0.68 (0.54)/0.73 0.56
	Closed		0.33 (0.29)/0.43 0.52	0.35 (0.31)/0.44 0.51	0.40 (0.37)/0.49 0.46	0.42 (0.38)/0.50 0.45	0.48 (0.45)/0.55 0.41	0.42 (0.38)/0.50 0.45	0.49 (0.46)/0.55 0.41	0.47 (0.44)/0.54 0.42
Between Glazings ^c	0.15	Worst ^a	0.93 (0.89)/0.36 0.98	0.93 (0.89)/0.36 0.97	0.93 (0.89)/0.36 0.95	0.93 (0.89)/0.37 0.94	0.93 (0.89)/0.37 0.91	0.93 (0.89)/0.36 0.94	0.93 (0.89)/0.37 0.91	0.93 (0.89)/0.37 0.92
	0°		0.93 (0.05)/0.41 0.9	0.93 (0.06)/0.41 0.89	0.93 (0.06)/0.42 0.87	0.93 (0.06)/0.42 0.87	0.93 (0.06)/0.42 0.84	0.93 (0.06)/0.42 0.84	0.93 (0.07)/0.42 0.83	0.93 (0.06)/0.42 0.84
	Excluded Beam ^b		0.04 (0.05)/0.39 0.77	0.04 (0.06)/0.40 0.76	0.04 (0.06)/0.40 0.74	0.04 (0.06)/0.40 0.74	0.05 (0.06)/0.40 0.72	0.04 (0.06)/0.40 0.74	0.05 (0.07)/0.40 0.72	0.05 (0.06)/0.40 0.72
	45°		0.20 (0.04)/0.29 0.83	0.20 (0.04)/0.30 0.82	0.21 (0.04)/0.30 0.81	0.21 (0.05)/0.30 0.8	0.21 (0.05)/0.30 0.78	0.21 (0.04)/0.30 0.8	0.21 (0.05)/0.30 0.77	0.21 (0.05)/0.30 0.78
	Closed		0.03 (0.03)/0.11 0.65	0.03 (0.04)/0.11 0.65	0.04 (0.04)/0.11 0.65	0.04 (0.05)/0.12 0.64	0.05 (0.05)/0.12 0.64	0.04 (0.04)/0.11 0.64	0.05 (0.05)/0.12 0.64	0.04 (0.05)/0.12 0.64
Between Glazings ^c	0.50	Worst ^a	0.94 (0.95)/0.44 0.98	0.94 (0.95)/0.44 0.97	0.94 (0.95)/0.44 0.95	0.94 (0.95)/0.44 0.94	0.94 (0.95)/0.44 0.91	0.94 (0.95)/0.44 0.94	0.94 (0.95)/0.44 0.91	0.94 (0.95)/0.44 0.92
	0°		0.94 (0.15)/0.50 0.96	0.94 (0.15)/0.50 0.96	0.94 (0.15)/0.50 0.93	0.94 (0.15)/0.50 0.92	0.94 (0.15)/0.50 0.89	0.94 (0.15)/0.50 0.92	0.94 (0.15)/0.50 0.89	0.94 (0.15)/0.50 0.9
	Excluded Beam ^b		0.08 (0.15)/0.48 0.92	0.08 (0.15)/0.48 0.91	0.09 (0.15)/0.48 0.89	0.09 (0.15)/0.48 0.88	0.09 (0.15)/0.48 0.85	0.09 (0.15)/0.48 0.88	0.09 (0.15)/0.48 0.84	0.09 (0.15)/0.48 0.85

Table 13A IAC Values for Louvered Shades: Uncoated Single Glazings (Continued)

Glazing ID:	1a	1b	1c	1d	1e	1f	1g	1h	1i
45°	0.26 (0.07)/0.36 0.93	0.26 (0.07)/0.36 0.92	0.26 (0.07)/0.36 0.89	0.26 (0.07)/0.37 0.86	0.26 (0.07)/0.36 0.89	0.26 (0.07)/0.37 0.85	0.26 (0.07)/0.36 0.89	0.26 (0.07)/0.37 0.85	0.26 (0.07)/0.37 0.86
Closed	0.05 (0.03)/0.14 0.8	0.05 (0.03)/0.14 0.8	0.05 (0.03)/0.14 0.77	0.05 (0.04)/0.15 0.75	0.05 (0.04)/0.14 0.77	0.06 (0.04)/0.15 0.74	0.05 (0.04)/0.14 0.77	0.06 (0.04)/0.15 0.74	0.05 (0.04)/0.15 0.75
Worst ^a	0.95 (1.02)/0.54 0.98	0.95 (1.02)/0.54 0.98	0.95 (1.01)/0.54 0.95	0.95 (1.00)/0.54 0.92	0.95 (1.01)/0.54 0.95	0.95 (1.00)/0.54 0.91	0.95 (1.01)/0.54 0.95	0.95 (1.00)/0.54 0.91	0.95 (1.01)/0.54 0.92
Between Glazings ^c	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
0°	0.95 (0.28)/0.61 0.98	0.95 (0.28)/0.61 0.97	0.95 (0.28)/0.61 0.95	0.95 (0.28)/0.61 0.91	0.95 (0.28)/0.61 0.94	0.95 (0.28)/0.61 0.91	0.95 (0.28)/0.61 0.94	0.95 (0.28)/0.61 0.91	0.95 (0.28)/0.61 0.91
Excluded Beam ^b	0.17 (0.28)/0.59 0.97	0.17 (0.28)/0.59 0.96	0.17 (0.28)/0.58 0.94	0.17 (0.28)/0.58 0.9	0.17 (0.28)/0.58 0.93	0.17 (0.28)/0.58 0.89	0.17 (0.28)/0.58 0.93	0.17 (0.28)/0.58 0.89	0.17 (0.28)/0.59 0.9
45°	0.34 (0.12)/0.46 0.97	0.34 (0.12)/0.46 0.96	0.34 (0.12)/0.46 0.94	0.34 (0.12)/0.46 0.9	0.34 (0.12)/0.46 0.93	0.34 (0.12)/0.46 0.9	0.34 (0.12)/0.46 0.93	0.34 (0.12)/0.46 0.89	0.35 (0.12)/0.46 0.9
Closed	0.08 (0.04)/0.21 0.93	0.08 (0.04)/0.21 0.92	0.09 (0.04)/0.20 0.89	0.09 (0.04)/0.21 0.86	0.09 (0.04)/0.20 0.89	0.09 (0.04)/0.21 0.85	0.09 (0.04)/0.20 0.89	0.09 (0.04)/0.21 0.85	0.09 (0.04)/0.21 0.86
Outdoor Side	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Worst ^a	0.93 (0.89)/0.36 0.98	0.93 (0.89)/0.36 0.97	0.93 (0.89)/0.36 0.95	0.93 (0.89)/0.37 0.92	0.93 (0.89)/0.36 0.94	0.93 (0.89)/0.37 0.91	0.93 (0.89)/0.36 0.94	0.93 (0.89)/0.37 0.91	0.93 (0.89)/0.37 0.92
0°	0.93 (0.05)/0.41 0.9	0.93 (0.06)/0.41 0.89	0.93 (0.06)/0.42 0.87	0.93 (0.06)/0.42 0.84	0.93 (0.06)/0.42 0.87	0.93 (0.06)/0.42 0.84	0.93 (0.06)/0.42 0.87	0.93 (0.07)/0.42 0.83	0.93 (0.06)/0.42 0.84
Excluded Beam ^b	0.04 (0.05)/0.39 0.77	0.04 (0.06)/0.40 0.76	0.04 (0.06)/0.40 0.74	0.05 (0.06)/0.40 0.72	0.04 (0.06)/0.40 0.74	0.05 (0.06)/0.40 0.72	0.04 (0.06)/0.40 0.74	0.05 (0.07)/0.40 0.72	0.05 (0.06)/0.40 0.72
45°	0.20 (0.04)/0.29 0.83	0.20 (0.04)/0.30 0.82	0.21 (0.04)/0.30 0.81	0.21 (0.04)/0.30 0.78	0.21 (0.04)/0.30 0.8	0.21 (0.05)/0.30 0.78	0.21 (0.04)/0.30 0.8	0.21 (0.05)/0.30 0.77	0.21 (0.05)/0.30 0.78
Closed	0.03 (0.03)/0.11 0.65	0.03 (0.04)/0.11 0.65	0.04 (0.04)/0.11 0.65	0.04 (0.05)/0.12 0.64	0.04 (0.04)/0.11 0.64	0.05 (0.05)/0.12 0.64	0.04 (0.04)/0.11 0.64	0.05 (0.05)/0.12 0.64	0.04 (0.05)/0.12 0.64
Outdoor Side	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Worst ^a	0.94 (0.95)/0.44 0.98	0.94 (0.95)/0.44 0.97	0.94 (0.95)/0.44 0.95	0.94 (0.95)/0.44 0.92	0.94 (0.95)/0.44 0.94	0.94 (0.95)/0.44 0.91	0.94 (0.95)/0.44 0.94	0.94 (0.95)/0.44 0.91	0.94 (0.95)/0.44 0.92
0°	0.94 (0.15)/0.50 0.96	0.94 (0.15)/0.50 0.96	0.94 (0.15)/0.50 0.93	0.94 (0.15)/0.50 0.9	0.94 (0.15)/0.50 0.92	0.94 (0.15)/0.50 0.89	0.94 (0.15)/0.50 0.92	0.94 (0.15)/0.50 0.89	0.94 (0.15)/0.50 0.9
Excluded Beam ^b	0.08 (0.15)/0.48 0.92	0.08 (0.15)/0.48 0.91	0.09 (0.15)/0.48 0.89	0.09 (0.15)/0.48 0.85	0.09 (0.15)/0.48 0.88	0.09 (0.15)/0.48 0.85	0.09 (0.15)/0.48 0.88	0.09 (0.15)/0.48 0.84	0.09 (0.15)/0.48 0.85
45°	0.26 (0.07)/0.36 0.93	0.26 (0.07)/0.36 0.92	0.26 (0.07)/0.36 0.89	0.26 (0.07)/0.37 0.86	0.26 (0.07)/0.36 0.89	0.26 (0.07)/0.37 0.85	0.26 (0.07)/0.36 0.89	0.26 (0.07)/0.37 0.85	0.26 (0.07)/0.37 0.86
Closed	0.05 (0.03)/0.14 0.8	0.05 (0.03)/0.14 0.8	0.05 (0.03)/0.14 0.77	0.05 (0.04)/0.15 0.75	0.05 (0.04)/0.14 0.77	0.06 (0.04)/0.15 0.74	0.05 (0.04)/0.14 0.77	0.06 (0.04)/0.15 0.74	0.05 (0.04)/0.15 0.75
Outdoor Side	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Worst ^a	0.95 (1.02)/0.54 0.98	0.95 (1.02)/0.54 0.98	0.95 (1.01)/0.54 0.95	0.95 (1.00)/0.54 0.92	0.95 (1.01)/0.54 0.95	0.95 (1.00)/0.54 0.91	0.95 (1.01)/0.54 0.95	0.95 (1.00)/0.54 0.91	0.95 (1.01)/0.54 0.92
0°	0.95 (0.28)/0.61 0.98	0.95 (0.28)/0.61 0.97	0.95 (0.28)/0.61 0.95	0.95 (0.28)/0.61 0.91	0.95 (0.28)/0.61 0.94	0.95 (0.28)/0.61 0.91	0.95 (0.28)/0.61 0.94	0.95 (0.28)/0.61 0.91	0.95 (0.28)/0.61 0.91
Excluded Beam ^b	0.17 (0.28)/0.59 0.97	0.17 (0.28)/0.59 0.96	0.17 (0.28)/0.58 0.94	0.17 (0.28)/0.58 0.9	0.17 (0.28)/0.58 0.93	0.17 (0.28)/0.58 0.89	0.17 (0.28)/0.58 0.93	0.17 (0.28)/0.58 0.89	0.17 (0.28)/0.59 0.9
45°	0.34 (0.12)/0.46 0.97	0.34 (0.12)/0.46 0.96	0.34 (0.12)/0.46 0.94	0.34 (0.12)/0.46 0.9	0.34 (0.12)/0.46 0.93	0.34 (0.12)/0.46 0.9	0.34 (0.12)/0.46 0.93	0.34 (0.12)/0.46 0.89	0.35 (0.12)/0.46 0.9
Closed	0.08 (0.04)/0.21 0.93	0.08 (0.04)/0.21 0.92	0.09 (0.04)/0.20 0.89	0.09 (0.04)/0.21 0.86	0.09 (0.04)/0.20 0.89	0.09 (0.04)/0.21 0.85	0.09 (0.04)/0.20 0.89	0.09 (0.04)/0.21 0.85	0.09 (0.04)/0.21 0.86
Outdoor Side	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Worst ^a	0.7	0.71	0.72	0.74	0.72	0.74	0.72	0.74	0.74
100%	0.5	0.49	0.47	0.45	0.47	0.44	0.47	0.44	0.45

^b Louvers track to block direct beam radiation. When negative slit angles result, slit defaults to 0°.
^c Glazing cavity width equals original cavity width plus slit width.

Table 13B IAC Values for Louvered Shades: Uncoated Double Glazings

Glazing ID:	5a	5b	5c	5d	5e	5f	5g	5h	5i	
Louver Location	IAC ₀ (IAC ₆₀)/IAC _{diff} , F _R									
Louver Reflection										
Indoor Side	0.15	Worst ^d	0.99 (0.98)/0.92	0.99 (0.97)/0.92	0.99 (0.97)/0.93	0.99 (0.97)/0.92	0.98 (0.97)/0.93	0.99 (0.97)/0.92	0.98 (0.97)/0.93	0.98 (0.97)/0.93
Indoor Side	0.50	Worst ^d	0.99 (0.88)/0.93	0.99 (0.89)/0.93	0.99 (0.90)/0.93	0.99 (0.89)/0.93	0.98 (0.90)/0.94	0.99 (0.89)/0.93	0.98 (0.90)/0.93	0.98 (0.90)/0.93
Indoor Side	0.80	Worst ^d	0.84 (0.88)/0.93	0.84 (0.89)/0.93	0.86 (0.90)/0.93	0.85 (0.89)/0.93	0.86 (0.90)/0.93	0.85 (0.89)/0.93	0.86 (0.90)/0.93	0.86 (0.90)/0.93
Indoor Side	0.15	Worst ^d	0.88 (0.85)/0.90	0.88 (0.85)/0.90	0.88 (0.87)/0.91	0.88 (0.86)/0.90	0.89 (0.87)/0.91	0.88 (0.86)/0.90	0.89 (0.87)/0.91	0.89 (0.87)/0.91
Indoor Side	0.50	Worst ^d	0.81 (0.81)/0.83	0.82 (0.82)/0.84	0.83 (0.84)/0.85	0.82 (0.82)/0.84	0.83 (0.84)/0.85	0.82 (0.82)/0.84	0.83 (0.84)/0.85	0.83 (0.84)/0.85
Indoor Side	0.80	Worst ^d	0.98 (0.97)/0.86	0.98 (0.97)/0.87	0.98 (0.97)/0.88	0.98 (0.97)/0.87	0.98 (0.97)/0.89	0.98 (0.97)/0.87	0.98 (0.97)/0.87	0.98 (0.97)/0.87
Indoor Side	0.15	Worst ^d	0.98 (0.80)/0.89	0.98 (0.82)/0.90	0.98 (0.84)/0.91	0.98 (0.82)/0.90	0.98 (0.84)/0.91	0.98 (0.82)/0.90	0.98 (0.84)/0.91	0.98 (0.84)/0.91
Indoor Side	0.50	Worst ^d	0.70 (0.80)/0.88	0.72 (0.82)/0.89	0.75 (0.84)/0.90	0.73 (0.82)/0.89	0.76 (0.84)/0.90	0.73 (0.82)/0.89	0.76 (0.84)/0.90	0.75 (0.84)/0.90
Indoor Side	0.15	Worst ^d	0.78 (0.70)/0.82	0.80 (0.72)/0.83	0.82 (0.76)/0.85	0.80 (0.76)/0.85	0.82 (0.76)/0.85	0.80 (0.73)/0.84	0.82 (0.76)/0.85	0.82 (0.76)/0.85
Indoor Side	0.80	Worst ^d	0.63 (0.63)/0.69	0.66 (0.65)/0.71	0.65 (0.65)/0.71	0.66 (0.66)/0.71	0.70 (0.70)/0.75	0.66 (0.66)/0.71	0.70 (0.70)/0.75	0.70 (0.70)/0.75
Indoor Side	0.15	Worst ^d	0.97 (0.96)/0.80	0.97 (0.96)/0.81	0.97 (0.96)/0.84	0.97 (0.96)/0.82	0.97 (0.96)/0.84	0.97 (0.96)/0.82	0.97 (0.96)/0.84	0.97 (0.96)/0.84
Indoor Side	0.50	Worst ^d	0.97 (0.71)/0.84	0.97 (0.73)/0.85	0.97 (0.73)/0.85	0.97 (0.73)/0.85	0.97 (0.77)/0.87	0.97 (0.73)/0.85	0.97 (0.77)/0.87	0.97 (0.77)/0.87
Indoor Side	0.15	Worst ^d	0.57 (0.71)/0.83	0.60 (0.73)/0.84	0.65 (0.77)/0.86	0.61 (0.73)/0.84	0.66 (0.77)/0.86	0.61 (0.73)/0.84	0.66 (0.77)/0.86	0.65 (0.77)/0.86
Indoor Side	0.50	Worst ^d	0.68 (0.56)/0.74	0.71 (0.60)/0.76	0.74 (0.65)/0.79	0.71 (0.60)/0.76	0.75 (0.66)/0.79	0.71 (0.60)/0.76	0.75 (0.66)/0.79	0.74 (0.65)/0.79
Indoor Side	0.15	Worst ^d	0.47 (0.45)/0.55	0.51 (0.50)/0.59	0.50 (0.49)/0.58	0.51 (0.50)/0.59	0.57 (0.57)/0.64	0.51 (0.50)/0.59	0.57 (0.57)/0.64	0.57 (0.56)/0.64
Indoor Side	0.50	Worst ^d	0.97 (0.98)/0.66	0.97 (0.99)/0.67	0.96 (0.97)/0.67	0.95 (0.96)/0.69	0.95 (0.95)/0.69	0.95 (0.97)/0.67	0.95 (0.95)/0.69	0.95 (0.96)/0.69
Indoor Side	0.15	Worst ^d	0.97 (0.50)/0.70	0.97 (0.51)/0.71	0.96 (0.52)/0.70	0.95 (0.55)/0.72	0.95 (0.52)/0.70	0.95 (0.52)/0.70	0.95 (0.55)/0.72	0.95 (0.55)/0.72
Indoor Side	0.50	Worst ^d	0.43 (0.50)/0.69	0.45 (0.51)/0.69	0.46 (0.52)/0.69	0.49 (0.55)/0.71	0.46 (0.52)/0.69	0.49 (0.55)/0.71	0.46 (0.52)/0.69	0.49 (0.55)/0.71
Indoor Side	0.15	Worst ^d	0.54 (0.47)/0.62	0.55 (0.48)/0.63	0.56 (0.49)/0.63	0.58 (0.52)/0.65	0.56 (0.49)/0.63	0.58 (0.52)/0.65	0.56 (0.49)/0.63	0.58 (0.52)/0.65
Indoor Side	0.50	Worst ^d	0.42 (0.45)/0.50	0.44 (0.47)/0.51	0.44 (0.47)/0.52	0.47 (0.50)/0.54	0.45 (0.48)/0.52	0.48 (0.51)/0.54	0.45 (0.48)/0.52	0.48 (0.51)/0.54
Indoor Side	0.15	Worst ^d	0.97 (1.01)/0.67	0.97 (1.02)/0.67	0.96 (1.00)/0.67	0.95 (0.98)/0.69	0.95 (0.99)/0.68	0.95 (0.98)/0.69	0.95 (0.99)/0.68	0.95 (0.98)/0.69
Indoor Side	0.50	Worst ^d	0.97 (0.49)/0.71	0.97 (0.50)/0.72	0.96 (0.51)/0.72	0.95 (0.54)/0.73	0.95 (0.52)/0.72	0.95 (0.55)/0.73	0.95 (0.52)/0.72	0.95 (0.54)/0.73
Indoor Side	0.15	Worst ^d	0.38 (0.49)/0.70	0.39 (0.50)/0.70	0.40 (0.51)/0.70	0.44 (0.54)/0.72	0.41 (0.52)/0.71	0.45 (0.55)/0.72	0.41 (0.52)/0.71	0.45 (0.55)/0.72

Table 13B IAC Values for Louvered Shades: Uncoated Double Glazings (Continued)

Glazing ID:	5a	5b	5c	5d	5e	5f	5g	5h	5i	
45°	0.51 (0.38)/0.61 0.75	0.52 (0.40)/0.62 0.74	0.53 (0.41)/0.62 0.73	0.56 (0.45)/0.64 0.72	0.53 (0.42)/0.62 0.73	0.56 (0.46)/0.64 0.71	0.53 (0.42)/0.62 0.73	0.56 (0.46)/0.64 0.71	0.56 (0.45)/0.64 0.72	
Closed	0.32 (0.32)/0.42 0.67	0.33 (0.33)/0.43 0.66	0.35 (0.35)/0.44 0.66	0.39 (0.39)/0.47 0.65	0.36 (0.36)/0.45 0.66	0.39 (0.40)/0.48 0.65	0.36 (0.36)/0.45 0.66	0.40 (0.40)/0.48 0.65	0.39 (0.39)/0.47 0.66	
Worst ^a	0.97 (1.04)/0.68 0.94	0.97 (1.04)/0.68 0.93	0.96 (1.02)/0.69 0.93	0.95 (1.01)/0.70 0.9	0.96 (1.02)/0.69 0.93	0.95 (1.00)/0.70 0.9	0.96 (1.02)/0.69 0.93	0.95 (1.00)/0.70 0.9	0.95 (1.01)/0.70 0.9	
Between Glazings ^c	0.97 (0.49)/0.73 0.89	0.97 (0.50)/0.74 0.88	0.96 (0.51)/0.74 0.87	0.95 (0.55)/0.75 0.84	0.96 (0.52)/0.74 0.87	0.95 (0.55)/0.75 0.84	0.96 (0.52)/0.74 0.87	0.95 (0.55)/0.75 0.84	0.95 (0.55)/0.75 0.84	
0°	0.35 (0.49)/0.72 0.82	0.36 (0.50)/0.72 0.81	0.37 (0.51)/0.72 0.8	0.42 (0.55)/0.74 0.76	0.38 (0.52)/0.72 0.79	0.42 (0.55)/0.74 0.76	0.38 (0.52)/0.72 0.79	0.42 (0.55)/0.74 0.76	0.42 (0.55)/0.74 0.77	
Excluded Beam ^b	0.50 (0.32)/0.60 0.83	0.51 (0.33)/0.61 0.81	0.52 (0.35)/0.62 0.8	0.55 (0.40)/0.64 0.77	0.53 (0.36)/0.62 0.8	0.55 (0.41)/0.64 0.77	0.53 (0.36)/0.62 0.8	0.56 (0.41)/0.64 0.77	0.55 (0.40)/0.64 0.77	
45°	0.24 (0.20)/0.36 0.74	0.25 (0.22)/0.37 0.73	0.27 (0.25)/0.39 0.71	0.32 (0.30)/0.43 0.69	0.28 (0.26)/0.40 0.71	0.33 (0.31)/0.43 0.69	0.28 (0.26)/0.40 0.71	0.33 (0.31)/0.43 0.69	0.32 (0.30)/0.43 0.69	
Closed	0.93 (0.89)/0.35 0.95	0.93 (0.89)/0.36 0.94	0.93 (0.89)/0.36 0.93	0.93 (0.89)/0.36 0.9	0.93 (0.89)/0.36 0.93	0.93 (0.89)/0.36 0.89	0.93 (0.89)/0.36 0.93	0.93 (0.89)/0.36 0.89	0.93 (0.89)/0.36 0.9	
Worst ^a	0.93 (0.05)/0.41 0.9	0.93 (0.05)/0.41 0.88	0.93 (0.05)/0.41 0.88	0.93 (0.05)/0.41 0.84	0.93 (0.05)/0.41 0.87	0.93 (0.06)/0.41 0.84	0.93 (0.05)/0.41 0.87	0.93 (0.06)/0.41 0.84	0.93 (0.05)/0.41 0.84	
0°	0.03 (0.05)/0.39 0.78	0.03 (0.05)/0.39 0.77	0.03 (0.05)/0.39 0.76	0.03 (0.05)/0.39 0.73	0.03 (0.05)/0.39 0.76	0.03 (0.06)/0.39 0.73	0.03 (0.05)/0.39 0.76	0.04 (0.06)/0.40 0.73	0.03 (0.05)/0.39 0.73	
Excluded Beam ^b	0.19 (0.03)/0.29 0.84	0.19 (0.03)/0.29 0.82	0.20 (0.03)/0.29 0.82	0.20 (0.04)/0.29 0.79	0.20 (0.03)/0.29 0.81	0.20 (0.04)/0.29 0.78	0.20 (0.03)/0.29 0.81	0.20 (0.04)/0.30 0.78	0.20 (0.04)/0.29 0.79	
45°	0.02 (0.02)/0.10 0.66	0.02 (0.02)/0.10 0.66	0.02 (0.03)/0.10 0.65	0.03 (0.03)/0.11 0.64	0.03 (0.03)/0.10 0.65	0.03 (0.03)/0.10 0.64	0.03 (0.03)/0.10 0.65	0.03 (0.03)/0.11 0.64	0.03 (0.03)/0.11 0.64	
Closed	0.94 (0.98)/0.44 0.95	0.94 (0.98)/0.44 0.94	0.94 (0.97)/0.44 0.93	0.94 (0.96)/0.44 0.9	0.94 (0.96)/0.44 0.93	0.94 (0.95)/0.44 0.9	0.94 (0.96)/0.44 0.93	0.94 (0.95)/0.44 0.89	0.94 (0.96)/0.44 0.9	
Worst ^a	0.94 (0.14)/0.50 0.94	0.94 (0.14)/0.50 0.93	0.94 (0.15)/0.50 0.92	0.94 (0.15)/0.50 0.89	0.94 (0.15)/0.50 0.92	0.94 (0.15)/0.50 0.88	0.94 (0.15)/0.50 0.92	0.94 (0.15)/0.50 0.88	0.94 (0.15)/0.50 0.89	
0°	0.07 (0.14)/0.48 0.91	0.07 (0.14)/0.48 0.9	0.08 (0.15)/0.48 0.89	0.08 (0.15)/0.48 0.85	0.08 (0.15)/0.48 0.88	0.08 (0.15)/0.48 0.85	0.08 (0.15)/0.48 0.88	0.08 (0.15)/0.48 0.84	0.08 (0.15)/0.48 0.85	
Excluded Beam ^b	0.25 (0.06)/0.36 0.92	0.25 (0.06)/0.36 0.9	0.25 (0.06)/0.36 0.9	0.25 (0.07)/0.36 0.86	0.25 (0.06)/0.36 0.89	0.25 (0.07)/0.36 0.85	0.25 (0.06)/0.36 0.89	0.25 (0.07)/0.36 0.85	0.25 (0.07)/0.36 0.86	
45°	0.04 (0.02)/0.14 0.82	0.04 (0.03)/0.14 0.81	0.04 (0.03)/0.14 0.8	0.04 (0.03)/0.14 0.76	0.04 (0.03)/0.14 0.79	0.05 (0.03)/0.14 0.76	0.04 (0.03)/0.14 0.79	0.05 (0.03)/0.14 0.76	0.04 (0.03)/0.14 0.76	
Closed	0.95 (1.08)/0.55 0.95	0.95 (1.07)/0.55 0.94	0.95 (1.04)/0.55 0.93	0.95 (1.02)/0.54 0.9	0.95 (1.04)/0.55 0.93	0.95 (1.02)/0.54 0.9	0.95 (1.04)/0.55 0.93	0.95 (1.02)/0.54 0.89	0.95 (1.03)/0.54 0.9	
Worst ^a	0.95 (0.29)/0.62 0.95	0.95 (0.29)/0.61 0.94	0.95 (0.28)/0.61 0.94	0.95 (0.28)/0.61 0.9	0.95 (0.28)/0.61 0.93	0.95 (0.28)/0.61 0.9	0.95 (0.28)/0.61 0.93	0.95 (0.28)/0.61 0.89	0.95 (0.28)/0.61 0.9	
0°	0.16 (0.29)/0.59 0.94	0.16 (0.29)/0.59 0.93	0.16 (0.28)/0.59 0.92	0.16 (0.28)/0.59 0.89	0.16 (0.28)/0.59 0.92	0.16 (0.28)/0.59 0.88	0.16 (0.28)/0.59 0.92	0.16 (0.28)/0.59 0.88	0.16 (0.28)/0.59 0.89	
Excluded Beam ^b	0.34 (0.12)/0.47 0.95	0.34 (0.12)/0.47 0.93	0.33 (0.12)/0.47 0.93	0.33 (0.12)/0.46 0.89	0.33 (0.12)/0.46 0.92	0.33 (0.12)/0.46 0.88	0.33 (0.12)/0.46 0.92	0.33 (0.12)/0.46 0.88	0.34 (0.12)/0.46 0.89	
45°	0.08 (0.04)/0.21 0.92	0.08 (0.04)/0.21 0.9	0.08 (0.04)/0.21 0.89	0.08 (0.04)/0.21 0.86	0.08 (0.04)/0.21 0.89	0.08 (0.04)/0.21 0.85	0.08 (0.04)/0.21 0.89	0.08 (0.04)/0.21 0.85	0.08 (0.04)/0.21 0.86	
Closed	<p>^a Louvers track so that profile angle equals negative slat angle and maximum direct beam is admitted.</p> <p>^b Louvers track to block direct beam radiation. When negative slat angles result, slat defaults to 0°.</p> <p>^c Glazing cavity width equals original cavity width plus slat width.</p>									

Notes:
^a Louvers track so that profile angle equals negative slat angle and maximum direct beam is admitted.
^b Louvers track to block direct beam radiation. When negative slat angles result, slat defaults to 0°.
^c Glazing cavity width equals original cavity width plus slat width.

Table 13C IAC Values for Louvered Shades: Coated Double Glazings with 0.2 Low-e

Glazing ID:		17a	17b	17c	17d	17e	17f	17g	17h	17i	17j	17k	
Louver Location	Louver Reflection	IAC ₀ (IAC ₆₀)/IAC _{diff} , F _k											
Indoor Side	0.15	Worst ^a											
		0.99 (0.98)/0.94	0.99 (0.98)/0.94	0.99 (0.98)/0.94	0.99 (0.98)/0.94	0.99 (0.98)/0.94	0.99 (0.98)/0.94	0.99 (0.98)/0.94	0.99 (0.98)/0.94	0.99 (0.98)/0.94	0.99 (0.98)/0.94	0.99 (0.98)/0.94	0.99 (0.98)/0.95
Indoor Side	0°	0.86	0.83	0.83	0.79	0.81	0.76	0.8	0.75	0.8	0.8	0.75	0.76
		0.99 (0.91)/0.95	0.99 (0.91)/0.95	0.99 (0.91)/0.95	0.99 (0.92)/0.95	0.99 (0.92)/0.95	0.99 (0.93)/0.95	0.99 (0.93)/0.95	0.99 (0.93)/0.95	0.99 (0.93)/0.95	0.99 (0.92)/0.95	0.99 (0.93)/0.95	0.99 (0.93)/0.95
Indoor Side	Excluded Beam ^b	0.66	0.64	0.65	0.63	0.63	0.61	0.63	0.63	0.6	0.63	0.6	0.61
		0.87 (0.91)/0.94	0.88 (0.91)/0.95	0.88 (0.91)/0.95	0.89 (0.92)/0.95	0.88 (0.92)/0.95	0.90 (0.93)/0.95	0.88 (0.92)/0.95	0.90 (0.93)/0.95	0.88 (0.92)/0.95	0.90 (0.93)/0.95	0.90 (0.93)/0.95	0.90 (0.93)/0.95
Indoor Side	45°	0.90 (0.88)/0.92	0.91 (0.89)/0.93	0.91 (0.89)/0.93	0.92 (0.89)/0.93	0.91 (0.89)/0.93	0.92 (0.90)/0.93	0.91 (0.89)/0.93	0.92 (0.90)/0.93	0.92 (0.90)/0.93	0.91 (0.89)/0.93	0.92 (0.90)/0.93	0.92 (0.90)/0.93
		0.44	0.43	0.44	0.43	0.43	0.42	0.43	0.43	0.42	0.43	0.42	0.42
Indoor Side	Closed	0.85 (0.85)/0.87	0.86 (0.86)/0.88	0.85 (0.86)/0.88	0.86 (0.87)/0.88	0.86 (0.86)/0.88	0.87 (0.88)/0.89	0.86 (0.86)/0.88	0.87 (0.88)/0.89	0.86 (0.86)/0.88	0.87 (0.88)/0.89	0.87 (0.88)/0.89	0.87 (0.88)/0.89
		0.4	0.39	0.4	0.39	0.39	0.37	0.39	0.39	0.37	0.39	0.37	0.37
Indoor Side	Worst ^a	0.98 (0.98)/0.88	0.98 (0.98)/0.89	0.98 (0.98)/0.89	0.98 (0.98)/0.90	0.98 (0.98)/0.90	0.98 (0.98)/0.91	0.98 (0.98)/0.90	0.98 (0.98)/0.90	0.98 (0.98)/0.90	0.98 (0.98)/0.90	0.98 (0.98)/0.91	0.98 (0.98)/0.91
		0.87	0.84	0.84	0.8	0.82	0.76	0.81	0.76	0.81	0.81	0.76	0.77
Indoor Side	0°	0.98 (0.83)/0.91	0.98 (0.85)/0.91	0.98 (0.85)/0.91	0.98 (0.86)/0.92	0.98 (0.85)/0.92	0.98 (0.87)/0.93	0.98 (0.85)/0.92	0.98 (0.87)/0.93	0.98 (0.85)/0.92	0.98 (0.87)/0.93	0.98 (0.87)/0.93	0.98 (0.87)/0.93
		0.7	0.68	0.68	0.66	0.67	0.63	0.66	0.63	0.66	0.66	0.63	0.64
Indoor Side	Excluded Beam ^b	0.74 (0.83)/0.90	0.76 (0.85)/0.91	0.76 (0.85)/0.91	0.79 (0.86)/0.92	0.77 (0.85)/0.91	0.80 (0.87)/0.92	0.77 (0.85)/0.91	0.80 (0.87)/0.92	0.77 (0.85)/0.91	0.81 (0.87)/0.92	0.80 (0.87)/0.92	0.80 (0.87)/0.92
		0.47	0.46	0.46	0.45	0.45	0.44	0.45	0.44	0.45	0.44	0.44	0.44
Indoor Side	45°	0.81 (0.74)/0.85	0.83 (0.76)/0.86	0.83 (0.76)/0.86	0.84 (0.79)/0.87	0.83 (0.77)/0.86	0.86 (0.81)/0.88	0.83 (0.77)/0.87	0.86 (0.81)/0.88	0.83 (0.77)/0.87	0.86 (0.81)/0.88	0.86 (0.81)/0.88	0.86 (0.81)/0.88
		0.49	0.48	0.48	0.47	0.47	0.45	0.47	0.45	0.47	0.45	0.45	0.45
Indoor Side	Closed	0.67 (0.67)/0.73	0.70 (0.70)/0.75	0.70 (0.70)/0.75	0.73 (0.73)/0.78	0.71 (0.71)/0.76	0.75 (0.75)/0.79	0.72 (0.71)/0.76	0.76 (0.76)/0.80	0.72 (0.71)/0.76	0.76 (0.76)/0.80	0.75 (0.75)/0.79	0.75 (0.75)/0.79
		0.41	0.39	0.4	0.38	0.39	0.37	0.38	0.37	0.38	0.37	0.37	0.37
Indoor Side	Worst ^a	0.98 (0.97)/0.82	0.98 (0.97)/0.83	0.98 (0.97)/0.83	0.98 (0.97)/0.85	0.98 (0.97)/0.84	0.98 (0.97)/0.86	0.98 (0.97)/0.86	0.98 (0.97)/0.84	0.98 (0.97)/0.87	0.98 (0.97)/0.84	0.98 (0.97)/0.87	0.98 (0.97)/0.87
		0.88	0.85	0.85	0.82	0.83	0.78	0.83	0.77	0.83	0.77	0.83	0.78
Indoor Side	0°	0.98 (0.74)/0.86	0.98 (0.76)/0.87	0.98 (0.76)/0.87	0.98 (0.79)/0.88	0.98 (0.77)/0.88	0.98 (0.81)/0.89	0.98 (0.77)/0.88	0.98 (0.81)/0.89	0.98 (0.77)/0.88	0.98 (0.81)/0.89	0.98 (0.81)/0.89	0.98 (0.81)/0.89
		0.76	0.74	0.74	0.71	0.72	0.68	0.72	0.68	0.72	0.68	0.68	0.68
Indoor Side	Excluded Beam ^b	0.61 (0.74)/0.84	0.64 (0.76)/0.86	0.64 (0.76)/0.86	0.68 (0.79)/0.87	0.66 (0.77)/0.86	0.71 (0.81)/0.88	0.66 (0.77)/0.87	0.71 (0.81)/0.89	0.66 (0.77)/0.87	0.72 (0.81)/0.89	0.71 (0.81)/0.89	0.71 (0.81)/0.88
		0.59	0.56	0.56	0.54	0.55	0.51	0.54	0.51	0.54	0.51	0.51	0.51
Indoor Side	45°	0.71 (0.60)/0.77	0.74 (0.64)/0.79	0.74 (0.64)/0.79	0.77 (0.68)/0.81	0.75 (0.66)/0.80	0.79 (0.71)/0.83	0.75 (0.66)/0.80	0.79 (0.71)/0.83	0.75 (0.66)/0.80	0.79 (0.71)/0.83	0.79 (0.71)/0.83	0.79 (0.71)/0.83
		0.59	0.56	0.56	0.54	0.55	0.51	0.54	0.51	0.54	0.51	0.51	0.51
Indoor Side	Closed	0.51 (0.50)/0.59	0.55 (0.54)/0.63	0.55 (0.55)/0.63	0.60 (0.60)/0.67	0.57 (0.57)/0.65	0.64 (0.64)/0.70	0.58 (0.57)/0.65	0.64 (0.64)/0.70	0.58 (0.57)/0.65	0.64 (0.64)/0.70	0.64 (0.64)/0.70	0.64 (0.64)/0.70
		0.44	0.42	0.42	0.4	0.41	0.38	0.4	0.38	0.4	0.38	0.38	0.38
Indoor Side	Worst ^a	0.92	0.9	0.91	0.89	0.9	0.87	0.9	0.87	0.9	0.87	0.87	0.87
		0.97 (0.66)/0.80	0.98 (0.67)/0.81	0.96 (0.39)/0.63	0.96 (0.40)/0.64	0.95 (0.41)/0.64	0.95 (0.44)/0.65	0.95 (0.41)/0.64	0.95 (0.44)/0.65	0.95 (0.41)/0.64	0.95 (0.44)/0.65	0.95 (0.44)/0.65	0.95 (0.44)/0.65
Indoor Side	0°	0.8	0.79	0.79	0.78	0.79	0.77	0.79	0.77	0.79	0.77	0.77	0.77
		0.59 (0.66)/0.79	0.60 (0.67)/0.80	0.33 (0.39)/0.62	0.34 (0.40)/0.62	0.35 (0.41)/0.62	0.38 (0.44)/0.64	0.36 (0.41)/0.63	0.39 (0.44)/0.64	0.36 (0.41)/0.63	0.39 (0.44)/0.64	0.38 (0.44)/0.64	0.38 (0.44)/0.64
Indoor Side	Excluded Beam ^b	0.66	0.66	0.66	0.66	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
		0.67 (0.62)/0.74	0.68 (0.63)/0.75	0.46 (0.36)/0.54	0.46 (0.37)/0.55	0.47 (0.38)/0.55	0.50 (0.41)/0.57	0.47 (0.38)/0.56	0.50 (0.41)/0.57	0.47 (0.38)/0.56	0.50 (0.41)/0.57	0.49 (0.41)/0.57	0.49 (0.41)/0.57
Indoor Side	45°	0.69	0.69	0.7	0.7	0.7	0.69	0.7	0.69	0.7	0.69	0.69	0.69
		0.57 (0.60)/0.64	0.58 (0.61)/0.65	0.32 (0.34)/0.40	0.33 (0.35)/0.41	0.34 (0.36)/0.42	0.37 (0.40)/0.44	0.35 (0.37)/0.42	0.38 (0.40)/0.45	0.35 (0.37)/0.42	0.38 (0.40)/0.45	0.37 (0.39)/0.44	0.37 (0.39)/0.44
Indoor Side	Closed	0.65	0.65	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
		0.97 (1.03)/0.75	0.97 (1.03)/0.75	0.96 (1.01)/0.61	0.96 (1.01)/0.62	0.96 (1.00)/0.62	0.95 (0.99)/0.64	0.95 (0.99)/0.62	0.95 (0.98)/0.64	0.95 (0.99)/0.62	0.95 (0.99)/0.62	0.95 (0.98)/0.64	0.95 (0.99)/0.64
Indoor Side	Worst ^a	0.92	0.91	0.91	0.89	0.91	0.87	0.9	0.87	0.9	0.87	0.87	0.88
		0.97 (0.61)/0.79	0.97 (0.62)/0.79	0.96 (0.41)/0.66	0.96 (0.42)/0.67	0.96 (0.43)/0.67	0.95 (0.45)/0.68	0.95 (0.43)/0.67	0.95 (0.46)/0.68	0.95 (0.43)/0.67	0.95 (0.46)/0.69	0.95 (0.45)/0.68	0.95 (0.45)/0.68
Indoor Side	0°	0.83	0.82	0.83	0.82	0.82	0.8	0.82	0.8	0.82	0.8	0.8	0.8
		0.49 (0.61)/0.77	0.50 (0.62)/0.78	0.31 (0.41)/0.65	0.32 (0.42)/0.65	0.33 (0.43)/0.65	0.36 (0.45)/0.67	0.33 (0.43)/0.66	0.37 (0.46)/0.67	0.33 (0.43)/0.66	0.37 (0.46)/0.67	0.36 (0.45)/0.67	0.36 (0.45)/0.67
Indoor Side	Excluded Beam ^b	0.7	0.7	0.72	0.72	0.71	0.7	0.71	0.7	0.71	0.7	0.7	0.7

Table 13C IAC Values for Louvered Shades: Coated Double Glazings with 0.2 Low-e (Continued)

Glazing ID:	17a	17b	17c	17d	17e	17f	17g	17h	17i	17j	17k
45°	0.61 (0.49)/0.69	0.62 (0.50)/0.70	0.45 (0.31)/0.55	0.46 (0.32)/0.56	0.47 (0.33)/0.56	0.49 (0.37)/0.58	0.47 (0.34)/0.56	0.50 (0.37)/0.58	0.47 (0.34)/0.56	0.50 (0.37)/0.58	0.49 (0.37)/0.58
	0.73	0.72	0.75	0.74	0.74	0.72	0.74	0.72	0.74	0.72	0.72
Closed	0.42 (0.42)/0.52	0.43 (0.43)/0.53	0.25 (0.25)/0.35	0.26 (0.26)/0.36	0.28 (0.27)/0.37	0.31 (0.31)/0.40	0.28 (0.28)/0.38	0.32 (0.32)/0.41	0.28 (0.28)/0.38	0.32 (0.32)/0.41	0.31 (0.31)/0.40
	0.66	0.66	0.67	0.66	0.66	0.66	0.66	0.65	0.66	0.65	0.66
Worst ^a	0.97 (1.05)/0.72	0.97 (1.05)/0.72	0.97 (1.05)/0.65	0.97 (1.05)/0.66	0.96 (1.04)/0.66	0.96 (1.02)/0.67	0.96 (1.02)/0.66	0.95 (1.02)/0.67	0.96 (1.03)/0.66	0.95 (1.02)/0.68	0.96 (1.02)/0.67
Between Glazings ^c	0.94	0.92	0.92	0.9	0.91	0.88	0.91	0.88	0.91	0.88	0.88
0°	0.97 (0.55)/0.77	0.97 (0.56)/0.78	0.97 (0.45)/0.71	0.97 (0.46)/0.72	0.96 (0.46)/0.72	0.96 (0.49)/0.73	0.96 (0.47)/0.72	0.95 (0.49)/0.73	0.96 (0.47)/0.72	0.95 (0.50)/0.73	0.96 (0.49)/0.73
	0.88	0.86	0.88	0.86	0.87	0.84	0.86	0.83	0.86	0.83	0.84
Excluded Beam ^b	0.40 (0.55)/0.75	0.41 (0.56)/0.76	0.31 (0.45)/0.69	0.32 (0.46)/0.70	0.33 (0.46)/0.70	0.37 (0.49)/0.71	0.34 (0.47)/0.70	0.37 (0.49)/0.71	0.34 (0.47)/0.70	0.37 (0.50)/0.71	0.37 (0.49)/0.71
	0.8	0.78	0.82	0.81	0.8	0.77	0.8	0.77	0.8	0.77	0.77
45°	0.55 (0.37)/0.65	0.56 (0.39)/0.65	0.47 (0.28)/0.58	0.48 (0.29)/0.58	0.49 (0.31)/0.59	0.51 (0.34)/0.61	0.49 (0.31)/0.59	0.51 (0.35)/0.61	0.49 (0.31)/0.59	0.52 (0.35)/0.61	0.51 (0.34)/0.61
	0.81	0.79	0.83	0.81	0.81	0.77	0.8	0.77	0.8	0.77	0.78
Closed	0.29 (0.25)/0.41	0.30 (0.27)/0.42	0.21 (0.17)/0.33	0.22 (0.18)/0.34	0.24 (0.20)/0.35	0.27 (0.25)/0.38	0.24 (0.21)/0.36	0.28 (0.25)/0.39	0.24 (0.21)/0.36	0.28 (0.26)/0.39	0.27 (0.25)/0.38
	0.72	0.71	0.75	0.73	0.72	0.7	0.72	0.7	0.72	0.69	0.7
Outdoor Side	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35
Worst ^a	0.95	0.93	0.93	0.91	0.92	0.88	0.91	0.88	0.91	0.88	0.88
0°	0.93 (0.04)/0.41	0.93 (0.04)/0.41	0.93 (0.04)/0.41	0.93 (0.04)/0.41	0.93 (0.04)/0.41	0.93 (0.05)/0.41	0.93 (0.04)/0.41	0.93 (0.05)/0.41	0.93 (0.04)/0.41	0.93 (0.05)/0.41	0.93 (0.05)/0.41
	0.9	0.88	0.89	0.87	0.87	0.84	0.87	0.83	0.87	0.83	0.84
Excluded Beam ^b	0.02 (0.04)/0.39	0.02 (0.04)/0.39	0.02 (0.04)/0.39	0.02 (0.04)/0.39	0.02 (0.04)/0.39	0.03 (0.05)/0.39	0.02 (0.04)/0.39	0.03 (0.05)/0.39	0.02 (0.04)/0.39	0.03 (0.05)/0.39	0.03 (0.05)/0.39
	0.8	0.79	0.8	0.78	0.77	0.74	0.77	0.74	0.77	0.74	0.74
45°	0.19 (0.02)/0.28	0.19 (0.02)/0.29	0.19 (0.02)/0.28	0.19 (0.02)/0.29	0.19 (0.02)/0.29	0.19 (0.03)/0.29	0.19 (0.03)/0.29	0.20 (0.03)/0.29	0.19 (0.03)/0.29	0.20 (0.03)/0.29	0.19 (0.03)/0.29
	0.84	0.83	0.84	0.82	0.82	0.79	0.81	0.78	0.81	0.78	0.79
Closed	0.02 (0.02)/0.09	0.02 (0.02)/0.09	0.02 (0.02)/0.09	0.02 (0.02)/0.09	0.02 (0.02)/0.09	0.02 (0.02)/0.10	0.02 (0.02)/0.09	0.02 (0.03)/0.10	0.02 (0.02)/0.09	0.02 (0.03)/0.10	0.02 (0.02)/0.10
	0.67	0.66	0.67	0.66	0.66	0.65	0.66	0.65	0.66	0.65	0.65
Outdoor Side	0.94 (0.98)/0.43	0.94 (0.98)/0.43	0.94 (0.99)/0.44	0.94 (0.98)/0.44	0.94 (0.97)/0.43	0.94 (0.95)/0.43	0.94 (0.96)/0.43	0.94 (0.95)/0.43	0.94 (0.96)/0.43	0.94 (0.95)/0.43	0.94 (0.96)/0.43
	0.95	0.93	0.93	0.91	0.92	0.88	0.91	0.88	0.91	0.88	0.88
0°	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.49	0.94 (0.14)/0.49	0.94 (0.14)/0.49	0.94 (0.14)/0.49	0.94 (0.14)/0.49	0.94 (0.14)/0.49
	0.94	0.92	0.92	0.9	0.91	0.87	0.91	0.87	0.91	0.87	0.88
Excluded Beam ^b	0.07 (0.14)/0.47	0.07 (0.14)/0.47	0.07 (0.14)/0.48	0.07 (0.14)/0.48	0.07 (0.14)/0.47	0.07 (0.14)/0.47	0.07 (0.14)/0.47	0.07 (0.14)/0.47	0.07 (0.14)/0.47	0.08 (0.14)/0.47	0.07 (0.14)/0.47
	0.91	0.9	0.9	0.88	0.88	0.85	0.88	0.84	0.88	0.84	0.85
45°	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36
	0.92	0.9	0.91	0.88	0.89	0.85	0.88	0.85	0.88	0.85	0.85
Closed	0.04 (0.02)/0.13	0.04 (0.02)/0.13	0.04 (0.02)/0.13	0.04 (0.02)/0.13	0.04 (0.02)/0.13	0.04 (0.03)/0.13	0.04 (0.02)/0.13	0.04 (0.03)/0.14	0.04 (0.02)/0.13	0.04 (0.03)/0.14	0.04 (0.03)/0.14
	0.84	0.82	0.83	0.81	0.81	0.77	0.8	0.77	0.8	0.77	0.77
Outdoor Side	0.95 (1.07)/0.55	0.95 (1.07)/0.55	0.95 (1.08)/0.55	0.95 (1.08)/0.55	0.95 (1.04)/0.55	0.95 (1.02)/0.54	0.95 (1.04)/0.54	0.95 (1.02)/0.54	0.95 (1.04)/0.54	0.95 (1.02)/0.54	0.95 (1.03)/0.54
	0.95	0.93	0.93	0.91	0.92	0.88	0.91	0.88	0.91	0.88	0.88
0°	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.29)/0.62	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61
	0.95	0.93	0.93	0.91	0.92	0.88	0.91	0.88	0.91	0.88	0.88
Excluded Beam ^b	0.16 (0.28)/0.59	0.16 (0.28)/0.59	0.16 (0.29)/0.59	0.16 (0.28)/0.59	0.16 (0.28)/0.59	0.16 (0.28)/0.58	0.16 (0.28)/0.59	0.16 (0.28)/0.58	0.16 (0.28)/0.59	0.16 (0.28)/0.58	0.16 (0.28)/0.59
	0.94	0.92	0.92	0.9	0.91	0.87	0.9	0.87	0.9	0.87	0.87
45°	0.34 (0.12)/0.47	0.34 (0.12)/0.47	0.34 (0.12)/0.47	0.34 (0.12)/0.47	0.33 (0.12)/0.46	0.33 (0.12)/0.46	0.33 (0.12)/0.46	0.33 (0.12)/0.46	0.33 (0.12)/0.46	0.33 (0.12)/0.46	0.33 (0.12)/0.46
	0.94	0.92	0.92	0.9	0.91	0.88	0.91	0.87	0.91	0.87	0.88
Closed	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21
	0.92	0.9	0.91	0.88	0.89	0.85	0.88	0.85	0.88	0.85	0.85

Notes:
^aLouvers track so that profile angle equals negative slat angle and maximum direct beam is admitted.
^bLouvers track to block direct beam radiation. When negative slat angles result, slat defaults to 0°.
^cGlazing cavity width equals original cavity width plus slat width.

Table 13D IAC Values for Louvered Shades: Coated Double Glazings with 0.1 Low-e

Glazing ID:	21a	21b	21c	21d	21e	21f	21g	21h	21i	21j	21k
Louver Location	IAC₀ (IAC₆₀)/IAC_{diff} · F_R										
Louver Reflection											
Indoor Side	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Worst ^a	0.99 (0.98)/0.94	0.99 (0.98)/0.95	0.99 (0.98)/0.95	0.99 (0.98)/0.95	0.99 (0.98)/0.95	0.99 (0.98)/0.95	0.99 (0.98)/0.95	0.99 (0.98)/0.95	0.99 (0.98)/0.95	0.99 (0.98)/0.95	0.99 (0.98)/0.95
	0.85	0.82	0.82	0.8	0.8	0.75	0.79	0.75	0.79	0.75	0.76
0°	0.99 (0.92)/0.95	0.99 (0.92)/0.95	0.99 (0.93)/0.96	0.99 (0.93)/0.96	0.99 (0.93)/0.96	0.99 (0.93)/0.96	0.99 (0.93)/0.96	0.99 (0.94)/0.96	0.99 (0.93)/0.96	0.99 (0.94)/0.96	0.99 (0.93)/0.96
Excluded Beam ^b	0.66	0.64	0.64	0.63	0.63	0.61	0.63	0.6	0.63	0.6	0.61
45°	0.89 (0.92)/0.95	0.89 (0.92)/0.95	0.90 (0.93)/0.96	0.90 (0.93)/0.96	0.91 (0.93)/0.96	0.91 (0.93)/0.96	0.90 (0.93)/0.96	0.91 (0.94)/0.96	0.90 (0.93)/0.96	0.91 (0.94)/0.96	0.91 (0.93)/0.96
	0.41	0.41	0.41	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
45°	0.92 (0.89)/0.93	0.92 (0.90)/0.93	0.92 (0.90)/0.93	0.93 (0.91)/0.94	0.92 (0.91)/0.94	0.93 (0.91)/0.94	0.93 (0.91)/0.94	0.93 (0.91)/0.94	0.93 (0.91)/0.94	0.93 (0.91)/0.94	0.93 (0.91)/0.94
	0.44	0.43	0.43	0.43	0.43	0.42	0.42	0.41	0.42	0.41	0.42
Closed	0.86 (0.87)/0.88	0.87 (0.87)/0.89	0.87 (0.88)/0.89	0.88 (0.88)/0.90	0.88 (0.88)/0.90	0.89 (0.89)/0.90	0.88 (0.88)/0.90	0.89 (0.89)/0.90	0.88 (0.88)/0.90	0.89 (0.89)/0.90	0.89 (0.89)/0.90
	0.4	0.39	0.39	0.38	0.38	0.37	0.38	0.37	0.38	0.37	0.37
Worst ^a	0.99 (0.98)/0.89	0.99 (0.98)/0.90	0.99 (0.98)/0.91	0.99 (0.98)/0.92	0.99 (0.98)/0.91	0.99 (0.98)/0.92	0.99 (0.98)/0.91	0.99 (0.98)/0.92	0.99 (0.98)/0.91	0.99 (0.98)/0.92	0.99 (0.98)/0.92
	0.86	0.84	0.83	0.81	0.81	0.76	0.8	0.76	0.8	0.76	0.76
0°	0.99 (0.85)/0.92	0.99 (0.86)/0.92	0.99 (0.87)/0.93	0.99 (0.87)/0.93	0.99 (0.87)/0.93	0.99 (0.87)/0.93	0.99 (0.87)/0.93	0.99 (0.87)/0.93	0.99 (0.87)/0.93	0.99 (0.87)/0.93	0.99 (0.89)/0.94
Excluded Beam ^b	0.7	0.68	0.67	0.66	0.66	0.63	0.66	0.63	0.66	0.63	0.64
45°	0.77 (0.85)/0.91	0.79 (0.86)/0.92	0.79 (0.87)/0.92	0.81 (0.87)/0.92	0.80 (0.87)/0.93	0.82 (0.89)/0.93	0.80 (0.87)/0.92	0.82 (0.89)/0.93	0.80 (0.87)/0.92	0.82 (0.89)/0.93	0.82 (0.89)/0.93
	0.47	0.46	0.46	0.45	0.45	0.44	0.45	0.44	0.45	0.44	0.44
45°	0.83 (0.77)/0.86	0.84 (0.79)/0.87	0.85 (0.79)/0.88	0.86 (0.81)/0.88	0.85 (0.80)/0.88	0.87 (0.82)/0.89	0.86 (0.80)/0.88	0.87 (0.83)/0.89	0.86 (0.80)/0.88	0.87 (0.83)/0.89	0.87 (0.82)/0.89
	0.49	0.48	0.48	0.47	0.47	0.45	0.47	0.45	0.47	0.45	0.45
Closed	0.71 (0.70)/0.75	0.73 (0.73)/0.77	0.74 (0.73)/0.78	0.75 (0.75)/0.79	0.75 (0.75)/0.79	0.77 (0.77)/0.81	0.75 (0.75)/0.79	0.78 (0.78)/0.81	0.75 (0.75)/0.79	0.78 (0.78)/0.81	0.77 (0.77)/0.81
	0.41	0.39	0.39	0.38	0.39	0.37	0.38	0.37	0.38	0.37	0.37
Worst ^a	0.98 (0.97)/0.84	0.98 (0.97)/0.85	0.98 (0.97)/0.86	0.98 (0.97)/0.87	0.98 (0.97)/0.88	0.98 (0.97)/0.88	0.98 (0.97)/0.88	0.98 (0.97)/0.86	0.98 (0.97)/0.88	0.98 (0.97)/0.88	0.98 (0.97)/0.88
	0.88	0.85	0.84	0.82	0.82	0.77	0.81	0.77	0.81	0.77	0.78
0°	0.98 (0.76)/0.87	0.98 (0.78)/0.88	0.98 (0.79)/0.89	0.98 (0.81)/0.89	0.98 (0.83)/0.90	0.98 (0.83)/0.90	0.98 (0.83)/0.90	0.98 (0.83)/0.90	0.98 (0.83)/0.90	0.98 (0.83)/0.90	0.98 (0.83)/0.90
	0.76	0.74	0.73	0.71	0.72	0.68	0.71	0.68	0.71	0.68	0.68
Excluded Beam ^b	0.64 (0.76)/0.86	0.67 (0.78)/0.87	0.69 (0.79)/0.88	0.71 (0.81)/0.89	0.70 (0.80)/0.88	0.73 (0.83)/0.90	0.70 (0.81)/0.88	0.74 (0.83)/0.90	0.70 (0.81)/0.88	0.74 (0.83)/0.90	0.73 (0.83)/0.90
	0.59	0.56	0.56	0.54	0.55	0.52	0.54	0.52	0.54	0.52	0.52
45°	0.74 (0.64)/0.79	0.76 (0.67)/0.81	0.77 (0.68)/0.81	0.79 (0.71)/0.83	0.78 (0.70)/0.82	0.80 (0.74)/0.84	0.78 (0.70)/0.82	0.81 (0.74)/0.84	0.78 (0.70)/0.82	0.81 (0.74)/0.84	0.81 (0.74)/0.84
	0.59	0.57	0.56	0.54	0.55	0.52	0.55	0.52	0.55	0.51	0.52
Closed	0.54 (0.53)/0.62	0.59 (0.58)/0.66	0.60 (0.59)/0.67	0.63 (0.62)/0.69	0.62 (0.61)/0.68	0.66 (0.66)/0.72	0.62 (0.62)/0.69	0.67 (0.66)/0.72	0.62 (0.62)/0.69	0.67 (0.67)/0.72	0.66 (0.66)/0.72
	0.45	0.42	0.42	0.4	0.41	0.38	0.41	0.38	0.41	0.38	0.38
Worst ^a	0.98 (1.01)/0.80	0.98 (1.01)/0.80	0.96 (0.99)/0.60	0.96 (0.99)/0.61	0.96 (0.98)/0.61	0.95 (0.97)/0.63	0.95 (0.98)/0.61	0.95 (0.97)/0.63	0.95 (0.98)/0.61	0.95 (0.97)/0.63	0.95 (0.97)/0.62
	0.91	0.9	0.9	0.89	0.89	0.87	0.89	0.86	0.89	0.86	0.87
0°	0.98 (0.69)/0.82	0.98 (0.70)/0.83	0.96 (0.40)/0.64	0.96 (0.40)/0.65	0.96 (0.42)/0.65	0.95 (0.44)/0.66	0.95 (0.42)/0.65	0.95 (0.45)/0.66	0.95 (0.42)/0.65	0.95 (0.45)/0.66	0.95 (0.44)/0.66
	0.8	0.79	0.79	0.78	0.78	0.77	0.78	0.77	0.78	0.77	0.77
Excluded Beam ^b	0.63 (0.69)/0.81	0.64 (0.70)/0.82	0.34 (0.40)/0.63	0.35 (0.40)/0.63	0.36 (0.42)/0.64	0.39 (0.44)/0.65	0.37 (0.42)/0.64	0.39 (0.45)/0.65	0.37 (0.42)/0.64	0.40 (0.45)/0.65	0.39 (0.44)/0.65
	0.66	0.66	0.66	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
45°	0.71 (0.66)/0.77	0.71 (0.67)/0.78	0.47 (0.36)/0.55	0.47 (0.37)/0.56	0.48 (0.38)/0.56	0.50 (0.41)/0.58	0.49 (0.39)/0.57	0.51 (0.42)/0.58	0.49 (0.39)/0.57	0.51 (0.42)/0.58	0.50 (0.41)/0.58
	0.69	0.69	0.7	0.7	0.69	0.69	0.69	0.68	0.69	0.68	0.69
Closed	0.61 (0.64)/0.68	0.63 (0.65)/0.69	0.33 (0.35)/0.41	0.34 (0.36)/0.41	0.35 (0.37)/0.42	0.38 (0.40)/0.45	0.35 (0.37)/0.43	0.38 (0.40)/0.45	0.35 (0.37)/0.43	0.38 (0.40)/0.45	0.38 (0.40)/0.45
	0.65	0.65	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Worst ^a	0.97 (1.03)/0.77	0.97 (1.03)/0.78	0.97 (1.06)/0.63	0.96 (1.05)/0.63	0.96 (1.03)/0.65	0.95 (1.03)/0.65	0.96 (1.04)/0.64	0.95 (1.03)/0.65	0.96 (1.04)/0.64	0.95 (1.03)/0.65	0.95 (1.03)/0.65
	0.92	0.9	0.91	0.89	0.9	0.87	0.89	0.87	0.89	0.87	0.87
0°	0.97 (0.65)/0.81	0.97 (0.66)/0.81	0.97 (0.42)/0.68	0.97 (0.42)/0.68	0.96 (0.44)/0.69	0.95 (0.46)/0.69	0.96 (0.44)/0.69	0.95 (0.46)/0.69	0.96 (0.44)/0.69	0.95 (0.47)/0.70	0.95 (0.46)/0.69
	0.83	0.82	0.83	0.82	0.82	0.8	0.81	0.8	0.81	0.79	0.8
Excluded Beam ^b	0.54 (0.65)/0.80	0.55 (0.66)/0.80	0.32 (0.42)/0.66	0.32 (0.42)/0.67	0.34 (0.44)/0.68	0.37 (0.46)/0.67	0.34 (0.44)/0.67	0.37 (0.46)/0.68	0.34 (0.44)/0.67	0.38 (0.47)/0.68	0.37 (0.46)/0.68
	0.7	0.7	0.72	0.71	0.71	0.7	0.71	0.7	0.71	0.7	0.7

Table 13D IAC Values for Louvered Shades: Coated Double Glazings with 0.1 Low-e (Continued)

Glazing ID:	21a	21b	21c	21d	21e	21f	21g	21h	21i	21j	21k
45°	0.64 (0.54)/0.72	0.65 (0.55)/0.73	0.47 (0.31)/0.56	0.47 (0.32)/0.57	0.48 (0.34)/0.58	0.50 (0.37)/0.59	0.49 (0.34)/0.58	0.51 (0.37)/0.59	0.49 (0.34)/0.58	0.51 (0.38)/0.59	0.50 (0.37)/0.59
	0.73	0.72	0.75	0.74	0.74	0.72	0.73	0.72	0.73	0.72	0.72
Closed	0.47 (0.47)/0.56	0.48 (0.48)/0.57	0.26 (0.25)/0.36	0.27 (0.26)/0.37	0.28 (0.28)/0.38	0.32 (0.32)/0.41	0.29 (0.29)/0.39	0.32 (0.32)/0.41	0.29 (0.29)/0.39	0.33 (0.32)/0.42	0.32 (0.32)/0.41
	0.66	0.66	0.67	0.66	0.66	0.65	0.66	0.65	0.66	0.65	0.66
Worst ^a	0.97 (1.04)/0.74	0.97 (1.04)/0.75	0.97 (1.12)/0.67	0.97 (1.12)/0.68	0.96 (1.11)/0.68	0.96 (1.09)/0.69	0.96 (1.11)/0.68	0.96 (1.09)/0.69	0.96 (1.11)/0.68	0.95 (1.09)/0.69	0.96 (1.09)/0.69
Between Glazings ^c	0.93	0.92	0.91	0.92	0.91	0.88	0.91	0.88	0.91	0.88	0.88
0°	0.97 (0.60)/0.79	0.97 (0.60)/0.80	0.97 (0.46)/0.73	0.97 (0.46)/0.73	0.96 (0.47)/0.73	0.96 (0.50)/0.74	0.96 (0.48)/0.73	0.96 (0.50)/0.74	0.96 (0.48)/0.73	0.95 (0.50)/0.74	0.96 (0.50)/0.74
	0.88	0.86	0.87	0.86	0.86	0.84	0.86	0.83	0.86	0.83	0.84
Excluded Beam ^b	0.45 (0.60)/0.78	0.46 (0.60)/0.78	0.33 (0.46)/0.71	0.33 (0.46)/0.71	0.35 (0.47)/0.71	0.38 (0.50)/0.72	0.35 (0.48)/0.72	0.38 (0.50)/0.72	0.35 (0.48)/0.72	0.39 (0.50)/0.72	0.38 (0.50)/0.72
	0.8	0.79	0.82	0.81	0.8	0.77	0.79	0.77	0.79	0.77	0.77
45°	0.59 (0.43)/0.68	0.59 (0.44)/0.68	0.49 (0.29)/0.60	0.50 (0.30)/0.60	0.51 (0.31)/0.61	0.53 (0.35)/0.62	0.51 (0.32)/0.61	0.53 (0.35)/0.63	0.51 (0.32)/0.61	0.53 (0.36)/0.63	0.53 (0.35)/0.62
	0.81	0.8	0.82	0.81	0.8	0.78	0.8	0.77	0.8	0.77	0.78
Closed	0.33 (0.30)/0.44	0.34 (0.31)/0.45	0.22 (0.17)/0.34	0.23 (0.18)/0.35	0.25 (0.21)/0.37	0.28 (0.25)/0.40	0.25 (0.22)/0.37	0.29 (0.26)/0.40	0.25 (0.22)/0.37	0.29 (0.26)/0.41	0.28 (0.25)/0.40
	0.73	0.72	0.75	0.74	0.72	0.7	0.72	0.7	0.72	0.7	0.7
Outdoor Side	0.93 (0.90)/0.35	0.93 (0.90)/0.35	0.93 (0.90)/0.35	0.93 (0.90)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.35	0.93 (0.89)/0.36	0.93 (0.89)/0.35
	0.94	0.93	0.92	0.91	0.91	0.88	0.9	0.88	0.9	0.88	0.88
0°	0.93 (0.04)/0.41	0.93 (0.04)/0.41	0.93 (0.04)/0.41	0.93 (0.04)/0.41	0.93 (0.04)/0.41	0.93 (0.05)/0.41	0.93 (0.04)/0.41	0.93 (0.05)/0.41	0.93 (0.04)/0.41	0.93 (0.05)/0.41	0.93 (0.05)/0.41
	0.9	0.88	0.88	0.87	0.87	0.84	0.86	0.84	0.86	0.83	0.84
Excluded Beam ^b	0.02 (0.04)/0.39	0.02 (0.04)/0.39	0.02 (0.04)/0.39	0.02 (0.04)/0.39	0.02 (0.04)/0.39	0.03 (0.05)/0.39	0.02 (0.04)/0.39	0.03 (0.05)/0.39	0.02 (0.04)/0.39	0.03 (0.05)/0.39	0.03 (0.05)/0.39
	0.8	0.79	0.79	0.78	0.77	0.74	0.77	0.74	0.77	0.74	0.74
45°	0.19 (0.02)/0.29	0.19 (0.02)/0.29	0.19 (0.02)/0.29	0.19 (0.02)/0.29	0.19 (0.02)/0.29	0.20 (0.03)/0.29	0.19 (0.03)/0.29	0.20 (0.03)/0.29	0.19 (0.03)/0.29	0.20 (0.03)/0.29	0.20 (0.03)/0.29
	0.84	0.83	0.83	0.82	0.81	0.79	0.81	0.78	0.81	0.78	0.79
Closed	0.02 (0.02)/0.09	0.02 (0.02)/0.09	0.02 (0.02)/0.09	0.02 (0.02)/0.09	0.02 (0.02)/0.09	0.02 (0.02)/0.10	0.02 (0.02)/0.09	0.02 (0.02)/0.10	0.02 (0.02)/0.09	0.02 (0.02)/0.10	0.02 (0.02)/0.10
	0.67	0.66	0.67	0.66	0.66	0.65	0.66	0.65	0.66	0.65	0.65
Worst ^a	0.94 (1.02)/0.44	0.94 (1.01)/0.44	0.94 (1.01)/0.44	0.94 (1.01)/0.44	0.94 (0.98)/0.44	0.94 (0.96)/0.44	0.94 (0.98)/0.44	0.94 (0.96)/0.44	0.94 (0.98)/0.44	0.94 (0.96)/0.44	0.94 (0.97)/0.44
	0.94	0.93	0.92	0.91	0.91	0.88	0.91	0.88	0.91	0.88	0.88
Outdoor Side	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50	0.94 (0.14)/0.50
	0.94	0.92	0.92	0.9	0.9	0.87	0.9	0.87	0.9	0.87	0.88
0°	0.07 (0.14)/0.48	0.07 (0.14)/0.48	0.07 (0.14)/0.48	0.07 (0.14)/0.48	0.07 (0.14)/0.48	0.08 (0.14)/0.48	0.07 (0.14)/0.48	0.08 (0.14)/0.48	0.07 (0.14)/0.48	0.08 (0.14)/0.48	0.08 (0.14)/0.48
	0.91	0.9	0.89	0.88	0.88	0.85	0.87	0.84	0.87	0.84	0.85
Excluded Beam ^b	0.25 (0.06)/0.37	0.25 (0.06)/0.37	0.25 (0.06)/0.37	0.25 (0.06)/0.37	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36	0.25 (0.06)/0.36
	0.92	0.9	0.9	0.89	0.88	0.85	0.88	0.85	0.88	0.85	0.85
45°	0.04 (0.02)/0.14	0.04 (0.02)/0.14	0.04 (0.02)/0.14	0.04 (0.02)/0.14	0.04 (0.02)/0.14	0.04 (0.03)/0.14	0.04 (0.02)/0.14	0.04 (0.03)/0.14	0.04 (0.02)/0.14	0.04 (0.03)/0.14	0.04 (0.03)/0.14
	0.84	0.82	0.83	0.81	0.8	0.77	0.8	0.77	0.8	0.77	0.77
Closed	0.95 (1.14)/0.56	0.95 (1.12)/0.56	0.95 (1.13)/0.56	0.95 (1.07)/0.56	0.95 (1.07)/0.55	0.95 (1.04)/0.55	0.95 (1.07)/0.55	0.95 (1.03)/0.54	0.95 (1.03)/0.54	0.95 (1.03)/0.54	0.95 (1.03)/0.55
	0.94	0.93	0.92	0.91	0.91	0.88	0.91	0.88	0.91	0.88	0.88
Worst ^a	0.95 (0.29)/0.62	0.95 (0.29)/0.62	0.95 (0.29)/0.62	0.95 (0.28)/0.62	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61	0.95 (0.28)/0.61
	0.95	0.93	0.92	0.91	0.91	0.88	0.91	0.88	0.91	0.88	0.88
0°	0.17 (0.29)/0.60	0.17 (0.29)/0.60	0.17 (0.29)/0.60	0.17 (0.29)/0.60	0.16 (0.28)/0.59	0.16 (0.28)/0.59	0.16 (0.28)/0.59	0.16 (0.28)/0.59	0.16 (0.28)/0.59	0.16 (0.28)/0.59	0.16 (0.28)/0.59
	0.94	0.92	0.91	0.9	0.9	0.87	0.9	0.87	0.9	0.87	0.87
Excluded Beam ^b	0.35 (0.13)/0.49	0.35 (0.13)/0.48	0.35 (0.13)/0.48	0.34 (0.12)/0.47	0.34 (0.12)/0.46	0.34 (0.12)/0.46	0.34 (0.12)/0.46	0.34 (0.12)/0.46	0.34 (0.12)/0.46	0.34 (0.12)/0.46	0.34 (0.12)/0.46
	0.94	0.92	0.92	0.9	0.9	0.88	0.9	0.87	0.9	0.87	0.88
45°	0.08 (0.04)/0.22	0.08 (0.04)/0.22	0.08 (0.04)/0.22	0.08 (0.04)/0.22	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21	0.08 (0.04)/0.21
	0.92	0.9	0.9	0.89	0.88	0.85	0.88	0.85	0.88	0.85	0.85

Notes:
^a Louvers track so that profile angle equals negative slit angle and maximum direct beam is admitted.
^b Louvers track to block direct beam radiation. When negative slit angles result, slit defaults to 0°.
^c Glazing cavity width equals original cavity width plus slit width.

Table 13E IAC Values for Louvered Shades: Double Glazings with 0.05 Low-e

Glazing ID:		25a	25b	25c	26d	25e	25f	
Louver Location	Louver Reflection	IAC ₀ (IAC ₆₀)/IAC _{diff} , F _R						
Indoor Side	0.15	Worst ^a	0.99 (0.99)/0.95	0.99 (0.98)/0.95	0.99 (0.98)/0.96	0.99 (0.98)/0.96	0.99 (0.98)/0.96	0.99 (0.98)/0.96
		0°	0.84	0.81	0.74	0.76	0.72	0.76
Excluded Beam ^b	0°	0.99 (0.93)/0.96	0.99 (0.93)/0.96	0.99 (0.94)/0.96	0.99 (0.94)/0.96	0.99 (0.95)/0.96	0.99 (0.94)/0.96	0.99 (0.94)/0.96
		0.65	0.64	0.6	0.61	0.59	0.61	0.61
45°	Closed	0.90 (0.93)/0.96	0.91 (0.93)/0.96	0.92 (0.94)/0.96	0.92 (0.94)/0.96	0.92 (0.95)/0.96	0.92 (0.94)/0.96	0.92 (0.94)/0.96
		0.41	0.4	0.39	0.4	0.39	0.4	0.4
Indoor Side	0.50	Worst ^a	0.93 (0.91)/0.94	0.93 (0.91)/0.94	0.94 (0.93)/0.95	0.94 (0.92)/0.95	0.94 (0.93)/0.95	0.94 (0.92)/0.95
		0.43	0.43	0.41	0.42	0.41	0.42	0.42
Excluded Beam ^b	0°	0.88 (0.88)/0.90	0.89 (0.89)/0.90	0.90 (0.90)/0.91	0.90 (0.90)/0.91	0.90 (0.91)/0.92	0.90 (0.91)/0.92	0.90 (0.90)/0.91
		0.39	0.39	0.36	0.37	0.36	0.37	0.37
Indoor Side	0.50	Worst ^a	0.99 (0.98)/0.91	0.99 (0.98)/0.92	0.99 (0.98)/0.93	0.99 (0.98)/0.93	0.99 (0.98)/0.93	0.99 (0.98)/0.93
		0.86	0.82	0.75	0.77	0.73	0.77	0.77
Excluded Beam ^b	0°	0.99 (0.87)/0.93	0.99 (0.89)/0.94	0.99 (0.91)/0.95	0.99 (0.90)/0.94	0.99 (0.91)/0.95	0.99 (0.91)/0.95	0.99 (0.90)/0.94
		0.69	0.67	0.63	0.64	0.62	0.64	0.64
45°	Closed	0.80 (0.87)/0.92	0.82 (0.89)/0.93	0.85 (0.91)/0.94	0.85 (0.90)/0.94	0.86 (0.91)/0.94	0.84 (0.90)/0.94	0.84 (0.90)/0.94
		0.47	0.46	0.44	0.44	0.43	0.45	0.45
Indoor Side	0.80	Worst ^a	0.85 (0.80)/0.88	0.87 (0.83)/0.90	0.89 (0.85)/0.91	0.89 (0.85)/0.91	0.89 (0.86)/0.91	0.89 (0.85)/0.91
		0.49	0.48	0.45	0.46	0.45	0.46	0.46
Excluded Beam ^b	0°	0.74 (0.74)/0.79	0.77 (0.77)/0.81	0.81 (0.81)/0.84	0.80 (0.80)/0.83	0.82 (0.82)/0.85	0.80 (0.80)/0.83	0.80 (0.80)/0.83
		0.4	0.39	0.37	0.37	0.36	0.38	0.38
Indoor Side	0.80	Worst ^a	0.98 (0.98)/0.86	0.98 (0.98)/0.88	0.98 (0.97)/0.90	0.98 (0.98)/0.90	0.98 (0.97)/0.90	0.98 (0.98)/0.89
		0.87	0.84	0.76	0.78	0.74	0.78	0.78
Excluded Beam ^b	0°	0.98 (0.80)/0.89	0.98 (0.83)/0.91	0.98 (0.86)/0.92	0.98 (0.85)/0.92	0.98 (0.86)/0.92	0.98 (0.85)/0.92	0.98 (0.86)/0.92
		0.76	0.73	0.68	0.69	0.66	0.69	0.69
45°	Closed	0.69 (0.80)/0.88	0.73 (0.83)/0.90	0.78 (0.86)/0.91	0.77 (0.85)/0.91	0.78 (0.86)/0.92	0.77 (0.85)/0.91	0.77 (0.85)/0.91
		0.59	0.56	0.52	0.53	0.51	0.53	0.53
Indoor Side	0.15	Worst ^a	0.78 (0.69)/0.82	0.81 (0.73)/0.84	0.84 (0.78)/0.87	0.83 (0.77)/0.86	0.84 (0.79)/0.87	0.83 (0.77)/0.86
		0.59	0.57	0.52	0.53	0.51	0.54	0.54
Excluded Beam ^b	0°	0.60 (0.59)/0.67	0.65 (0.65)/0.71	0.71 (0.71)/0.76	0.70 (0.70)/0.75	0.72 (0.72)/0.77	0.70 (0.69)/0.75	0.70 (0.69)/0.75
		0.45	0.42	0.39	0.4	0.38	0.4	0.4
Between Glazings ^c	0.15	Worst ^a	0.97 (1.00)/0.80	0.97 (0.99)/0.81	0.95 (0.96)/0.80	0.95 (0.96)/0.80	0.94 (0.95)/0.80	0.96 (0.96)/0.80
		0.91	0.89	0.86	0.86	0.85	0.86	0.86
Excluded Beam ^b	0°	0.97 (0.71)/0.82	0.97 (0.72)/0.82	0.95 (0.73)/0.82	0.95 (0.73)/0.82	0.94 (0.73)/0.82	0.96 (0.73)/0.82	0.96 (0.73)/0.82
		0.79	0.78	0.76	0.77	0.76	0.77	0.77
45°	Closed	0.66 (0.71)/0.82	0.67 (0.72)/0.82	0.69 (0.73)/0.81	0.69 (0.73)/0.81	0.70 (0.73)/0.81	0.69 (0.73)/0.81	0.69 (0.73)/0.81
		0.65	0.65	0.65	0.65	0.64	0.65	0.65
Between Glazings ^c	0.50	Worst ^a	0.97 (1.01)/0.79	0.97 (1.00)/0.79	0.95 (0.97)/0.80	0.95 (0.98)/0.80	0.94 (0.96)/0.80	0.95 (0.98)/0.80
		0.92	0.9	0.86	0.87	0.85	0.87	0.87
Excluded Beam ^b	0°	0.97 (0.68)/0.82	0.97 (0.69)/0.82	0.95 (0.71)/0.82	0.95 (0.71)/0.82	0.94 (0.72)/0.82	0.95 (0.71)/0.82	0.95 (0.71)/0.82
		0.82	0.81	0.79	0.79	0.78	0.79	0.79

Table 13E IAC Values for Louvered Shades: Double Glazings with 0.05 Low-e (Continued)

Glazing ID:	25a	25b	25c	26d	25e	25f
Excluded Beam ^b	0.58 (0.68)/0.81 0.7	0.60 (0.69)/0.81 0.7	0.64 (0.71)/0.81 0.68	0.63 (0.71)/0.81 0.69	0.65 (0.72)/0.81 0.68	0.63 (0.71)/0.81 0.69
45°	0.68 (0.59)/0.74 0.73	0.69 (0.61)/0.75 0.72	0.71 (0.65)/0.76 0.7	0.71 (0.64)/0.76 0.71	0.72 (0.66)/0.77 0.7	0.71 (0.64)/0.76 0.71
Closed	0.52 (0.52)/0.60 0.66	0.54 (0.54)/0.61 0.66	0.59 (0.59)/0.65 0.65	0.58 (0.58)/0.64 0.66	0.60 (0.60)/0.65 0.65	0.58 (0.58)/0.64 0.66
Between Glazings ^c	0.97 (1.02)/0.77 0.93	0.97 (1.01)/0.78 0.91	0.95 (0.98)/0.79 0.87	0.95 (0.98)/0.79 0.88	0.94 (0.97)/0.79 0.86	0.95 (0.99)/0.79 0.88
0°	0.97 (0.65)/0.81 0.87	0.97 (0.67)/0.82 0.86	0.95 (0.70)/0.82 0.83	0.95 (0.69)/0.82 0.83	0.94 (0.71)/0.82 0.82	0.95 (0.69)/0.82 0.84
Excluded Beam ^b	0.51 (0.65)/0.80 0.8	0.53 (0.67)/0.81 0.79	0.59 (0.70)/0.81 0.76	0.58 (0.69)/0.81 0.76	0.60 (0.71)/0.81 0.75	0.58 (0.69)/0.81 0.76
45°	0.64 (0.50)/0.71 0.81	0.65 (0.53)/0.73 0.8	0.69 (0.59)/0.74 0.76	0.68 (0.58)/0.74 0.77	0.69 (0.60)/0.75 0.76	0.68 (0.58)/0.74 0.77
Closed	0.39 (0.36)/0.49 0.73	0.42 (0.39)/0.51 0.73	0.49 (0.47)/0.57 0.7	0.48 (0.46)/0.56 0.71	0.51 (0.49)/0.58 0.7	0.48 (0.46)/0.56 0.71
Outdoor Side	0.93 (0.92)/0.36 0.94	0.93 (0.92)/0.36 0.92	0.93 (0.90)/0.36 0.87	0.93 (0.89)/0.36 0.88	0.93 (0.90)/0.36 0.86	0.93 (0.89)/0.36 0.89
0°	0.93 (0.05)/0.41 0.89	0.93 (0.05)/0.41 0.87	0.93 (0.06)/0.41 0.82	0.93 (0.05)/0.41 0.83	0.93 (0.06)/0.42 0.81	0.93 (0.05)/0.41 0.84
Excluded Beam ^b	0.03 (0.05)/0.39 0.78	0.03 (0.05)/0.39 0.77	0.04 (0.06)/0.40 0.72	0.03 (0.05)/0.39 0.73	0.04 (0.06)/0.40 0.71	0.03 (0.05)/0.39 0.74
45°	0.20 (0.03)/0.29 0.83	0.20 (0.03)/0.29 0.82	0.20 (0.03)/0.29 0.77	0.20 (0.03)/0.29 0.78	0.20 (0.04)/0.30 0.76	0.20 (0.03)/0.29 0.78
Closed	0.02 (0.02)/0.10 0.66	0.02 (0.02)/0.10 0.66	0.03 (0.03)/0.11 0.64	0.03 (0.03)/0.10 0.65	0.03 (0.04)/0.11 0.64	0.03 (0.03)/0.10 0.65
Outdoor Side	0.94 (1.08)/0.45 0.94	0.94 (1.06)/0.45 0.92	0.94 (0.99)/0.44 0.87	0.94 (0.96)/0.44 0.88	0.94 (0.98)/0.44 0.86	0.94 (0.97)/0.44 0.89
0°	0.94 (0.15)/0.51 0.93	0.94 (0.15)/0.51 0.91	0.94 (0.15)/0.50 0.86	0.94 (0.15)/0.50 0.87	0.94 (0.15)/0.50 0.85	0.94 (0.15)/0.50 0.88
Excluded Beam ^b	0.08 (0.15)/0.49 0.9	0.08 (0.15)/0.49 0.88	0.08 (0.15)/0.48 0.83	0.08 (0.15)/0.48 0.84	0.08 (0.15)/0.48 0.82	0.08 (0.15)/0.48 0.85
45°	0.26 (0.06)/0.38 0.91	0.26 (0.06)/0.38 0.89	0.26 (0.07)/0.37 0.84	0.25 (0.06)/0.36 0.85	0.26 (0.07)/0.37 0.82	0.25 (0.06)/0.36 0.85
Closed	0.04 (0.03)/0.15 0.82	0.04 (0.03)/0.15 0.81	0.05 (0.03)/0.14 0.75	0.04 (0.03)/0.14 0.76	0.05 (0.03)/0.14 0.74	0.04 (0.03)/0.14 0.76
Outdoor Side	0.95 (1.25)/0.59 0.94	0.95 (1.21)/0.58 0.92	0.95 (1.08)/0.56 0.87	0.95 (1.04)/0.55 0.88	0.95 (1.06)/0.55 0.86	0.95 (1.05)/0.55 0.89
0°	0.95 (0.30)/0.64 0.94	0.95 (0.30)/0.64 0.92	0.95 (0.29)/0.62 0.88	0.95 (0.28)/0.61 0.88	0.95 (0.29)/0.61 0.86	0.95 (0.28)/0.61 0.89
Excluded Beam ^b	0.18 (0.30)/0.62 0.93	0.18 (0.30)/0.62 0.91	0.17 (0.29)/0.60 0.86	0.16 (0.28)/0.59 0.87	0.17 (0.29)/0.59 0.85	0.17 (0.28)/0.59 0.88
45°	0.37 (0.13)/0.51 0.93	0.37 (0.13)/0.50 0.91	0.35 (0.13)/0.48 0.86	0.34 (0.12)/0.47 0.87	0.35 (0.13)/0.47 0.85	0.34 (0.12)/0.47 0.88
Closed	0.09 (0.04)/0.24 0.91	0.09 (0.04)/0.24 0.89	0.09 (0.04)/0.22 0.83	0.08 (0.04)/0.21 0.85	0.09 (0.04)/0.21 0.82	0.08 (0.04)/0.21 0.85

Notes:
^a Louvers track so that profile angle equals negative slat angle and maximum direct beam is admitted.
^b Louvers track to block direct beam radiation. When negative slat angles result, slat defaults to 0°.
^c Glazing cavity width equals original cavity width plus slat width.

Table 13F IAC Values for Louvered Shades: Triple Glazings

Glazing ID:		29a	29b	32a	32b	32c	32d	40a	40b	40c	40d	
Louver Location	Louver Reflection	IAC ₀ (IAC ₆₀)/IAC _{diff} , F _R										
Indoor Side	0.15	Worst ^d	0.99 (0.98)/0.94	0.99 (0.98)/0.95	0.99 (0.98)/0.96	1.00 (1.00)/0.97	1.00 (1.00)/0.97	1.00 (1.00)/0.97	1.00 (1.00)/0.98	1.00 (1.00)/0.98	0.99 (0.99)/0.96	0.99 (0.99)/0.96
		0°	0.82	0.78	0.8	0.75	0.76	0.71	0.73	0.67	0.78	0.73
Indoor Side	0.50	Worst ^d	0.99 (0.92)/0.95	0.99 (0.93)/0.95	0.99 (0.94)/0.96	1.00 (0.96)/0.98	1.00 (0.96)/0.98	1.00 (0.96)/0.98	1.00 (0.96)/0.98	1.00 (0.97)/0.99	0.99 (0.95)/0.97	0.99 (0.95)/0.97
		0°	0.65	0.62	0.64	0.61	0.6	0.56	0.58	0.54	0.63	0.6
Indoor Side	0.80	Worst ^d	0.88 (0.92)/0.95	0.89 (0.93)/0.95	0.90 (0.94)/0.96	0.93 (0.96)/0.97	0.93 (0.96)/0.98	0.93 (0.96)/0.98	0.94 (0.96)/0.98	0.95 (0.97)/0.98	0.92 (0.95)/0.97	0.93 (0.95)/0.97
		45°	0.41	0.4	0.41	0.4	0.39	0.36	0.37	0.35	0.4	0.4
Indoor Side	0.15	Worst ^d	0.91 (0.89)/0.93	0.92 (0.90)/0.93	0.93 (0.92)/0.95	0.95 (0.93)/0.96	0.95 (0.94)/0.97	0.95 (0.94)/0.97	0.95 (0.94)/0.97	0.96 (0.95)/0.97	0.94 (0.92)/0.95	0.94 (0.92)/0.95
		0°	0.43	0.43	0.43	0.42	0.41	0.38	0.39	0.37	0.42	0.41
Indoor Side	0.50	Worst ^d	0.86 (0.87)/0.88	0.87 (0.88)/0.89	0.88 (0.89)/0.90	0.89 (0.90)/0.91	0.91 (0.91)/0.93	0.92 (0.92)/0.94	0.92 (0.93)/0.94	0.93 (0.94)/0.95	0.90 (0.90)/0.92	0.91 (0.91)/0.92
		45°	0.39	0.38	0.39	0.37	0.37	0.35	0.36	0.33	0.38	0.37
Indoor Side	0.80	Worst ^d	0.98 (0.98)/0.90	0.98 (0.98)/0.91	0.99 (0.98)/0.92	0.99 (0.99)/0.92	1.00 (1.00)/0.93	1.00 (1.00)/0.93	0.99 (1.00)/0.93	1.00 (1.00)/0.95	0.99 (0.98)/0.92	0.99 (0.98)/0.93
		0°	0.83	0.79	0.81	0.76	0.77	0.72	0.74	0.68	0.79	0.74
Indoor Side	0.15	Worst ^d	0.98 (0.86)/0.92	0.98 (0.87)/0.93	0.99 (0.90)/0.94	0.99 (0.89)/0.94	1.00 (0.91)/0.95	1.00 (0.91)/0.95	0.99 (0.91)/0.95	1.00 (0.92)/0.96	0.99 (0.89)/0.94	0.99 (0.91)/0.95
		45°	0.68	0.65	0.67	0.64	0.62	0.58	0.6	0.56	0.66	0.63
Indoor Side	0.50	Worst ^d	0.77 (0.86)/0.91	0.80 (0.87)/0.92	0.80 (0.89)/0.94	0.81 (0.89)/0.94	0.83 (0.91)/0.95	0.83 (0.91)/0.95	0.83 (0.91)/0.95	0.86 (0.92)/0.96	0.82 (0.89)/0.93	0.84 (0.91)/0.94
		0°	0.46	0.45	0.45	0.44	0.42	0.39	0.4	0.37	0.45	0.44
Indoor Side	0.80	Worst ^d	0.83 (0.78)/0.87	0.85 (0.81)/0.88	0.85 (0.84)/0.90	0.86 (0.82)/0.90	0.88 (0.84)/0.91	0.88 (0.84)/0.91	0.88 (0.84)/0.91	0.90 (0.87)/0.93	0.87 (0.83)/0.90	0.89 (0.85)/0.91
		45°	0.48	0.46	0.47	0.45	0.43	0.4	0.41	0.38	0.46	0.45
Indoor Side	0.15	Worst ^d	0.71 (0.72)/0.77	0.74 (0.75)/0.79	0.75 (0.76)/0.80	0.78 (0.79)/0.82	0.76 (0.76)/0.81	0.79 (0.80)/0.83	0.78 (0.80)/0.83	0.82 (0.83)/0.86	0.77 (0.78)/0.81	0.80 (0.81)/0.84
		0°	0.39	0.38	0.39	0.37	0.35	0.33	0.34	0.31	0.38	0.36
Indoor Side	0.50	Worst ^d	0.98 (0.97)/0.85	0.98 (0.97)/0.87	0.98 (0.97)/0.86	0.98 (0.97)/0.88	0.99 (0.99)/0.87	0.99 (0.99)/0.89	0.99 (0.99)/0.88	0.99 (0.99)/0.90	0.98 (0.98)/0.87	0.98 (0.98)/0.89
		0°	0.84	0.8	0.82	0.77	0.79	0.73	0.75	0.69	0.8	0.75
Indoor Side	0.80	Worst ^d	0.98 (0.78)/0.88	0.98 (0.81)/0.89	0.98 (0.84)/0.91	0.99 (0.81)/0.90	0.99 (0.83)/0.91	0.99 (0.83)/0.91	0.99 (0.83)/0.91	0.99 (0.86)/0.93	0.98 (0.82)/0.90	0.98 (0.85)/0.92
		45°	0.74	0.7	0.72	0.68	0.67	0.62	0.64	0.59	0.71	0.67
Indoor Side	0.15	Worst ^d	0.66 (0.78)/0.87	0.70 (0.81)/0.89	0.69 (0.81)/0.88	0.74 (0.84)/0.90	0.69 (0.81)/0.89	0.73 (0.83)/0.90	0.72 (0.83)/0.90	0.77 (0.86)/0.92	0.71 (0.82)/0.89	0.76 (0.85)/0.91
		45°	0.56	0.53	0.55	0.52	0.49	0.45	0.46	0.42	0.54	0.51
Indoor Side	0.50	Worst ^d	0.75 (0.67)/0.80	0.78 (0.71)/0.83	0.77 (0.71)/0.82	0.81 (0.75)/0.85	0.77 (0.70)/0.83	0.80 (0.74)/0.85	0.80 (0.74)/0.85	0.83 (0.78)/0.87	0.79 (0.73)/0.84	0.82 (0.77)/0.86
		0°	0.56	0.53	0.55	0.52	0.49	0.44	0.46	0.42	0.54	0.51
Indoor Side	0.80	Worst ^d	0.57 (0.58)/0.65	0.62 (0.64)/0.70	0.61 (0.63)/0.69	0.67 (0.68)/0.74	0.60 (0.62)/0.69	0.66 (0.67)/0.73	0.65 (0.66)/0.72	0.71 (0.72)/0.77	0.64 (0.65)/0.71	0.69 (0.71)/0.76
		45°	0.42	0.4	0.41	0.38	0.35	0.31	0.33	0.29	0.4	0.38
Indoor Side	0.15	Worst ^d	0.97 (1.01)/0.63	0.97 (1.02)/0.64	0.98 (1.05)/0.76	0.98 (1.05)/0.77	0.97 (1.01)/0.60	0.98 (1.02)/0.62	0.98 (1.05)/0.73	0.99 (1.05)/0.75	0.98 (1.04)/0.71	0.99 (1.04)/0.73
		0°	0.9	0.87	0.88	0.85	0.79	0.74	0.75	0.7	0.87	0.84
Indoor Side	0.50	Worst ^d	0.97 (0.44)/0.66	0.97 (0.46)/0.68	0.98 (0.62)/0.78	0.98 (0.63)/0.80	0.97 (0.40)/0.64	0.98 (0.42)/0.66	0.98 (0.57)/0.76	0.99 (0.60)/0.78	0.98 (0.55)/0.74	0.99 (0.58)/0.76
		45°	0.79	0.78	0.78	0.77	0.59	0.56	0.57	0.54	0.78	0.76
Indoor Side	0.15	Worst ^d	0.36 (0.44)/0.65	0.38 (0.46)/0.67	0.52 (0.62)/0.77	0.54 (0.63)/0.79	0.32 (0.40)/0.63	0.35 (0.42)/0.65	0.48 (0.57)/0.75	0.50 (0.60)/0.77	0.46 (0.55)/0.73	0.49 (0.58)/0.75
		45°	0.66	0.65	0.66	0.65	0.34	0.33	0.33	0.33	0.65	0.65
Indoor Side	0.50	Worst ^d	0.48 (0.41)/0.59	0.50 (0.43)/0.60	0.62 (0.58)/0.72	0.64 (0.60)/0.73	0.45 (0.37)/0.56	0.47 (0.40)/0.58	0.58 (0.54)/0.69	0.60 (0.57)/0.71	0.57 (0.52)/0.68	0.59 (0.55)/0.69
		45°	0.7	0.69	0.69	0.68	0.43	0.41	0.4	0.39	0.69	0.68
Indoor Side	0.15	Worst ^d	0.36 (0.41)/0.46	0.38 (0.43)/0.48	0.51 (0.57)/0.61	0.53 (0.58)/0.63	0.32 (0.37)/0.43	0.34 (0.40)/0.45	0.46 (0.53)/0.57	0.49 (0.55)/0.60	0.45 (0.51)/0.56	0.48 (0.53)/0.58
		45°	0.64	0.64	0.65	0.65	0.31	0.31	0.32	0.32	0.64	0.64
Indoor Side	0.50	Worst ^d	0.97 (1.06)/0.65	0.98 (1.06)/0.66	0.98 (1.08)/0.74	0.98 (1.08)/0.75	0.97 (1.07)/0.63	0.98 (1.07)/0.65	0.98 (1.09)/0.72	0.99 (1.09)/0.74	0.98 (1.08)/0.71	0.99 (1.08)/0.72
		0°	0.9	0.88	0.89	0.86	0.8	0.75	0.77	0.71	0.88	0.85
Indoor Side	0.15	Worst ^d	0.97 (0.45)/0.69	0.98 (0.47)/0.71	0.98 (0.58)/0.78	0.98 (0.60)/0.79	0.97 (0.42)/0.68	0.98 (0.44)/0.69	0.98 (0.55)/0.77	0.99 (0.57)/0.78	0.98 (0.54)/0.75	0.99 (0.56)/0.77
		45°	0.83	0.81	0.81	0.79	0.66	0.62	0.62	0.59	0.81	0.79

Table 13F IAC Values for Louvered Shades: Triple Glazings (Continued)

Glazing ID:	29a	29b	32a	32b	32c	32d	40a	40b	40c	40d
Excluded Beam ^b	0.33 (0.45)/0.68 0.71	0.34 (0.47)/0.69 0.7	0.44 (0.58)/0.77 0.7	0.46 (0.60)/0.78 0.69	0.30 (0.42)/0.66 0.46	0.32 (0.44)/0.68 0.43	0.41 (0.55)/0.75 0.42	0.43 (0.57)/0.77 0.4	0.40 (0.54)/0.74 0.7	0.42 (0.56)/0.75 0.69
45°	0.47 (0.35)/0.59 0.74	0.49 (0.37)/0.60 0.73	0.57 (0.47)/0.68 0.72	0.59 (0.48)/0.69 0.71	0.45 (0.32)/0.57 0.51	0.47 (0.35)/0.59 0.48	0.55 (0.44)/0.66 0.47	0.56 (0.46)/0.68 0.44	0.54 (0.43)/0.65 0.72	0.56 (0.45)/0.67 0.71
Closed	0.28 (0.29)/0.39 0.66	0.29 (0.31)/0.41 0.66	0.38 (0.40)/0.50 0.66	0.40 (0.41)/0.51 0.66	0.25 (0.27)/0.37 0.36	0.27 (0.29)/0.39 0.35	0.35 (0.37)/0.48 0.35	0.37 (0.39)/0.49 0.34	0.34 (0.36)/0.46 0.66	0.36 (0.38)/0.48 0.65
Between Glazings ^c	0.80	0.80	0.97 (1.11)/0.68 0.91	0.98 (1.11)/0.73 0.87	0.98 (1.12)/0.67 0.81	0.98 (1.12)/0.69 0.76	0.98 (1.12)/0.72 0.79	0.99 (1.12)/0.73 0.73	0.98 (1.11)/0.71 0.89	0.99 (1.11)/0.72 0.86
0°	0.97 (0.48)/0.74 0.87	0.98 (0.49)/0.75 0.85	0.97 (0.55)/0.78 0.85	0.98 (0.56)/0.79 0.83	0.98 (0.47)/0.73 0.75	0.98 (0.48)/0.74 0.7	0.98 (0.54)/0.78 0.71	0.99 (0.55)/0.79 0.66	0.98 (0.53)/0.77 0.85	0.99 (0.54)/0.78 0.82
Excluded Beam ^b	0.32 (0.48)/0.72 0.81	0.33 (0.49)/0.73 0.79	0.38 (0.55)/0.76 0.78	0.39 (0.56)/0.77 0.76	0.31 (0.47)/0.71 0.63	0.32 (0.48)/0.72 0.59	0.37 (0.54)/0.76 0.58	0.38 (0.55)/0.77 0.54	0.36 (0.53)/0.75 0.78	0.38 (0.54)/0.76 0.76
45°	0.48 (0.31)/0.61 0.82	0.49 (0.32)/0.62 0.79	0.54 (0.37)/0.65 0.79	0.55 (0.38)/0.66 0.77	0.47 (0.30)/0.60 0.65	0.49 (0.32)/0.62 0.6	0.52 (0.36)/0.65 0.59	0.54 (0.37)/0.66 0.55	0.52 (0.35)/0.64 0.79	0.53 (0.36)/0.65 0.77
Closed	0.22 (0.19)/0.36 0.73	0.23 (0.21)/0.37 0.72	0.27 (0.24)/0.41 0.71	0.29 (0.26)/0.42 0.7	0.21 (0.18)/0.35 0.49	0.22 (0.20)/0.37 0.46	0.26 (0.23)/0.40 0.45	0.28 (0.25)/0.41 0.43	0.25 (0.23)/0.39 0.72	0.27 (0.24)/0.40 0.7
Outdoor Side	0.15	0.15	0.93 (0.90)/0.35 0.92	0.93 (0.89)/0.35 0.88	0.93 (0.90)/0.35 0.83	0.93 (0.90)/0.35 0.78	0.93 (0.90)/0.35 0.81	0.93 (0.89)/0.35 0.75	0.93 (0.89)/0.35 0.9	0.93 (0.89)/0.35 0.87
0°	0.93 (0.04)/0.41 0.88	0.93 (0.05)/0.41 0.86	0.93 (0.04)/0.40 0.88	0.93 (0.04)/0.41 0.85	0.93 (0.04)/0.41 0.77	0.93 (0.04)/0.41 0.72	0.93 (0.04)/0.40 0.76	0.93 (0.04)/0.40 0.7	0.93 (0.04)/0.40 0.87	0.93 (0.04)/0.40 0.84
Excluded Beam ^b	0.02 (0.04)/0.39 0.78	0.02 (0.05)/0.39 0.76	0.02 (0.04)/0.39 0.79	0.02 (0.04)/0.39 0.77	0.02 (0.04)/0.39 0.59	0.02 (0.04)/0.39 0.55	0.02 (0.04)/0.39 0.59	0.02 (0.04)/0.39 0.55	0.02 (0.04)/0.39 0.79	0.02 (0.04)/0.39 0.77
45°	0.19 (0.02)/0.29 0.83	0.19 (0.03)/0.29 0.81	0.19 (0.02)/0.28 0.83	0.19 (0.02)/0.28 0.81	0.19 (0.02)/0.29 0.67	0.19 (0.02)/0.29 0.63	0.19 (0.02)/0.28 0.66	0.19 (0.02)/0.28 0.62	0.19 (0.02)/0.28 0.83	0.19 (0.02)/0.28 0.8
Closed	0.02 (0.02)/0.09 0.66	0.02 (0.02)/0.09 0.66	0.01 (0.02)/0.09 0.67	0.02 (0.02)/0.09 0.66	0.02 (0.02)/0.09 0.36	0.02 (0.02)/0.09 0.35	0.01 (0.01)/0.09 0.37	0.01 (0.02)/0.09 0.35	0.01 (0.01)/0.09 0.67	0.01 (0.02)/0.09 0.66
Outdoor Side	0.50	0.50	0.94 (1.00)/0.44 0.92	0.94 (0.99)/0.44 0.88	0.94 (1.00)/0.44 0.84	0.94 (1.00)/0.44 0.79	0.94 (1.00)/0.44 0.81	0.94 (0.99)/0.44 0.75	0.94 (0.99)/0.44 0.9	0.94 (0.99)/0.44 0.87
0°	0.94 (0.14)/0.50 0.92	0.94 (0.14)/0.50 0.89	0.94 (0.14)/0.50 0.91	0.94 (0.14)/0.50 0.88	0.94 (0.14)/0.50 0.83	0.94 (0.14)/0.50 0.78	0.94 (0.14)/0.50 0.81	0.94 (0.14)/0.50 0.75	0.94 (0.14)/0.50 0.9	0.94 (0.14)/0.50 0.87
Excluded Beam ^b	0.07 (0.14)/0.48 0.89	0.07 (0.14)/0.48 0.86	0.07 (0.14)/0.48 0.88	0.07 (0.14)/0.48 0.85	0.07 (0.14)/0.48 0.78	0.07 (0.14)/0.48 0.73	0.07 (0.14)/0.48 0.76	0.07 (0.14)/0.48 0.7	0.07 (0.14)/0.48 0.88	0.07 (0.14)/0.48 0.85
45°	0.24 (0.06)/0.36 0.9	0.25 (0.06)/0.36 0.87	0.24 (0.06)/0.36 0.89	0.24 (0.06)/0.36 0.86	0.24 (0.06)/0.36 0.8	0.24 (0.06)/0.36 0.74	0.24 (0.06)/0.36 0.78	0.24 (0.06)/0.36 0.72	0.24 (0.06)/0.36 0.88	0.24 (0.06)/0.36 0.85
Closed	0.04 (0.02)/0.14 0.82	0.04 (0.02)/0.14 0.79	0.03 (0.02)/0.13 0.82	0.04 (0.02)/0.13 0.79	0.03 (0.02)/0.14 0.65	0.04 (0.02)/0.14 0.61	0.03 (0.02)/0.13 0.65	0.03 (0.02)/0.13 0.6	0.03 (0.02)/0.13 0.82	0.03 (0.02)/0.13 0.79
Outdoor Side	0.80	0.80	0.95 (1.11)/0.56 0.92	0.95 (1.08)/0.55 0.88	0.95 (1.11)/0.56 0.84	0.95 (1.10)/0.56 0.79	0.95 (1.10)/0.56 0.81	0.95 (1.09)/0.55 0.75	0.95 (1.10)/0.55 0.9	0.95 (1.08)/0.55 0.87
0°	0.95 (0.29)/0.62 0.93	0.95 (0.29)/0.62 0.9	0.95 (0.29)/0.62 0.92	0.95 (0.29)/0.62 0.89	0.95 (0.29)/0.62 0.84	0.95 (0.29)/0.62 0.79	0.95 (0.29)/0.62 0.82	0.95 (0.29)/0.62 0.76	0.95 (0.29)/0.62 0.9	0.95 (0.29)/0.62 0.87
Excluded Beam ^b	0.16 (0.29)/0.60 0.91	0.16 (0.29)/0.60 0.88	0.16 (0.29)/0.60 0.9	0.16 (0.29)/0.59 0.87	0.15 (0.29)/0.60 0.82	0.15 (0.29)/0.60 0.76	0.15 (0.29)/0.60 0.79	0.15 (0.29)/0.60 0.73	0.15 (0.29)/0.60 0.89	0.15 (0.29)/0.60 0.86
45°	0.33 (0.13)/0.48 0.92	0.33 (0.13)/0.48 0.89	0.33 (0.12)/0.47 0.91	0.33 (0.12)/0.47 0.88	0.33 (0.13)/0.48 0.83	0.33 (0.13)/0.48 0.77	0.33 (0.12)/0.48 0.8	0.33 (0.12)/0.48 0.74	0.33 (0.12)/0.48 0.9	0.33 (0.12)/0.48 0.87
Closed	0.08 (0.04)/0.22 0.89	0.08 (0.04)/0.22 0.87	0.08 (0.04)/0.21 0.89	0.08 (0.04)/0.21 0.86	0.08 (0.04)/0.22 0.79	0.08 (0.04)/0.22 0.74	0.08 (0.04)/0.21 0.77	0.08 (0.04)/0.21 0.71	0.08 (0.04)/0.21 0.88	0.08 (0.04)/0.21 0.85

Notes:
^a Louvers track so that profile angle equals negative slat angle and maximum direct beam is admitted.
^b Louvers track to block direct beam radiation. When negative slat angles result, slat defaults to 0°.
^c Glazing cavity width equals original cavity width plus slat width.

Table 13G IAC Values for Draperies, Roller Shades, and Insect Screens

Drapery		1a	1b	1c	1d	1e	1f	1g	1h	1i	
Glazing ID:	Fabric Designator	IAC, F_R									
Fullness											
Dark Closed Weave	III _D	0.71, 0.50	0.71, 0.49	0.72, 0.47	0.74, 0.45	0.72, 0.47	0.74, 0.44	0.72, 0.47	0.74, 0.44	0.74, 0.45	
Medium Closed Weave	III _M	0.59, 0.53	0.60, 0.52	0.62, 0.49	0.65, 0.46	0.63, 0.49	0.66, 0.46	0.63, 0.49	0.66, 0.45	0.65, 0.46	
Light Closed Weave	III _L	0.45, 0.62	0.46, 0.60	0.50, 0.56	0.55, 0.50	0.51, 0.54	0.56, 0.50	0.51, 0.54	0.56, 0.49	0.55, 0.51	
Dark Semiopen Weave	II _D	0.75, 0.55	0.75, 0.54	0.76, 0.52	0.78, 0.49	0.76, 0.52	0.78, 0.49	0.76, 0.52	0.78, 0.49	0.78, 0.49	
Medium Semiopen Weave	II _M	0.65, 0.63	0.66, 0.62	0.68, 0.59	0.70, 0.55	0.68, 0.58	0.71, 0.54	0.68, 0.58	0.71, 0.54	0.70, 0.55	
Light Semiopen Weave	II _L	0.56, 0.79	0.57, 0.77	0.60, 0.71	0.64, 0.65	0.61, 0.70	0.65, 0.64	0.61, 0.70	0.65, 0.63	0.64, 0.65	
Dark Open Weave	I _D	0.80, 0.63	0.80, 0.62	0.81, 0.60	0.82, 0.57	0.82, 0.59	0.83, 0.56	0.82, 0.59	0.83, 0.56	0.82, 0.57	
Medium Open Weave	I _M	0.71, 0.73	0.72, 0.72	0.73, 0.69	0.76, 0.64	0.74, 0.68	0.76, 0.63	0.74, 0.68	0.76, 0.63	0.76, 0.64	
Light Open Weave	I _L	0.64, 0.87	0.65, 0.85	0.68, 0.80	0.71, 0.73	0.68, 0.78	0.71, 0.72	0.68, 0.78	0.72, 0.71	0.71, 0.73	
Sheer		0.73, 0.89	0.73, 0.88	0.75, 0.83	0.77, 0.77	0.75, 0.82	0.78, 0.76	0.75, 0.82	0.78, 0.75	0.77, 0.77	
Glazing ID:		5a	5b	5c	5d	5e	5f	5g	5h	5i	
Dark Closed Weave	III _D	0.81, 0.46	0.82, 0.45	0.82, 0.44	0.83, 0.42	0.82, 0.44	0.83, 0.42	0.82, 0.44	0.84, 0.42	0.83, 0.42	
Medium Closed Weave	III _M	0.70, 0.48	0.72, 0.46	0.72, 0.46	0.75, 0.43	0.72, 0.46	0.75, 0.43	0.72, 0.46	0.75, 0.43	0.75, 0.43	
Light Closed Weave	III _L	0.57, 0.54	0.60, 0.52	0.59, 0.52	0.64, 0.47	0.60, 0.51	0.65, 0.47	0.60, 0.51	0.65, 0.47	0.64, 0.47	
Dark Semiopen Weave	II _D	0.84, 0.51	0.85, 0.50	0.85, 0.49	0.86, 0.47	0.85, 0.49	0.86, 0.47	0.85, 0.49	0.86, 0.46	0.86, 0.47	
Medium Semiopen Weave	II _M	0.75, 0.57	0.76, 0.55	0.76, 0.55	0.79, 0.51	0.76, 0.55	0.79, 0.51	0.76, 0.55	0.79, 0.51	0.79, 0.52	
Light Semiopen Weave	II _L	0.65, 0.70	0.68, 0.67	0.67, 0.67	0.71, 0.61	0.68, 0.66	0.72, 0.60	0.68, 0.66	0.72, 0.60	0.72, 0.61	
Dark Open Weave	I _D	0.88, 0.59	0.88, 0.57	0.88, 0.57	0.89, 0.54	0.88, 0.57	0.89, 0.54	0.88, 0.57	0.89, 0.54	0.89, 0.54	
Medium Open Weave	I _M	0.79, 0.68	0.80, 0.65	0.80, 0.65	0.82, 0.61	0.80, 0.65	0.82, 0.60	0.80, 0.65	0.82, 0.60	0.82, 0.61	
Light Open Weave	I _L	0.72, 0.79	0.74, 0.76	0.73, 0.76	0.77, 0.69	0.74, 0.75	0.77, 0.69	0.74, 0.75	0.77, 0.68	0.77, 0.69	
Sheer		0.78, 0.83	0.8, 0.8	0.8, 0.8	0.82, 0.73	0.8, 0.79	0.82, 0.73	0.8, 0.79	0.82, 0.73	0.82, 0.74	
Glazing ID:		17a	17b	17c	17d	17e	17f	17g	17h	17i	
Dark Closed Weave	III _D	0.85, 0.45	0.86, 0.43	0.86, 0.44	0.87, 0.43	0.86, 0.43	0.88, 0.41	0.88, 0.40	0.88, 0.40	0.88, 0.41	
Medium Closed Weave	III _M	0.74, 0.47	0.76, 0.45	0.76, 0.45	0.79, 0.44	0.77, 0.44	0.80, 0.42	0.80, 0.41	0.80, 0.41	0.80, 0.42	
Light Closed Weave	III _L	0.60, 0.52	0.64, 0.50	0.64, 0.50	0.68, 0.47	0.66, 0.48	0.71, 0.44	0.71, 0.44	0.71, 0.44	0.71, 0.45	
Dark Semiopen Weave	II _D	0.88, 0.50	0.89, 0.48	0.88, 0.49	0.89, 0.47	0.89, 0.48	0.90, 0.45	0.89, 0.47	0.90, 0.45	0.90, 0.45	
Medium Semiopen Weave	II _M	0.78, 0.56	0.8, 0.54	0.8, 0.54	0.82, 0.52	0.81, 0.52	0.83, 0.49	0.83, 0.49	0.83, 0.49	0.83, 0.49	
Light Semiopen Weave	II _L	0.68, 0.68	0.71, 0.64	0.71, 0.64	0.74, 0.61	0.72, 0.62	0.76, 0.57	0.73, 0.62	0.77, 0.57	0.77, 0.57	
Dark Open Weave	I _D	0.90, 0.58	0.91, 0.56	0.91, 0.56	0.91, 0.55	0.91, 0.55	0.92, 0.52	0.91, 0.55	0.92, 0.52	0.92, 0.52	
Medium Open Weave	I _M	0.81, 0.66	0.83, 0.64	0.83, 0.64	0.85, 0.61	0.84, 0.62	0.86, 0.58	0.86, 0.58	0.86, 0.58	0.86, 0.58	
Light Open Weave	I _L	0.74, 0.77	0.76, 0.73	0.76, 0.73	0.79, 0.69	0.77, 0.71	0.81, 0.65	0.81, 0.65	0.81, 0.65	0.81, 0.65	
Sheer		0.8, 0.81	0.82, 0.77	0.82, 0.78	0.84, 0.74	0.83, 0.75	0.85, 0.7	0.85, 0.69	0.85, 0.69	0.85, 0.7	
Glazing ID:		21a	21b	21c	21d	21e	21f	21g	21h	21i	
Dark Closed Weave	III _D	0.87, 0.44	0.88, 0.43	0.88, 0.43	0.88, 0.42	0.88, 0.42	0.89, 0.40	0.88, 0.42	0.89, 0.40	0.89, 0.40	
Medium Closed Weave	III _M	0.77, 0.46	0.79, 0.45	0.79, 0.45	0.81, 0.43	0.80, 0.43	0.82, 0.41	0.82, 0.41	0.82, 0.41	0.82, 0.41	
Light Closed Weave	III _L	0.64, 0.52	0.67, 0.49	0.68, 0.49	0.70, 0.47	0.69, 0.47	0.73, 0.45	0.70, 0.47	0.73, 0.44	0.73, 0.45	
Dark Semiopen Weave	II _D	0.89, 0.49	0.90, 0.48	0.90, 0.48	0.90, 0.47	0.90, 0.47	0.91, 0.45	0.90, 0.47	0.91, 0.45	0.91, 0.45	
Medium Semiopen Weave	II _M	0.8, 0.55	0.82, 0.53	0.82, 0.53	0.83, 0.51	0.83, 0.52	0.85, 0.49	0.83, 0.51	0.85, 0.49	0.85, 0.49	
Light Semiopen Weave	II _L	0.71, 0.67	0.74, 0.64	0.74, 0.63	0.76, 0.61	0.75, 0.61	0.78, 0.57	0.76, 0.61	0.78, 0.57	0.78, 0.57	
Dark Open Weave	I _D	0.92, 0.57	0.92, 0.56	0.92, 0.55	0.92, 0.54	0.92, 0.54	0.93, 0.52	0.92, 0.54	0.93, 0.52	0.93, 0.52	
Medium Open Weave	I _M	0.83, 0.65	0.85, 0.63	0.85, 0.63	0.86, 0.61	0.86, 0.61	0.87, 0.58	0.86, 0.61	0.87, 0.58	0.87, 0.58	
Light Open Weave	I _L	0.76, 0.77	0.78, 0.73	0.79, 0.72	0.81, 0.69	0.80, 0.70	0.82, 0.65	0.80, 0.69	0.82, 0.65	0.82, 0.66	
Sheer		0.82, 0.81	0.83, 0.77	0.84, 0.76	0.85, 0.74	0.85, 0.74	0.86, 0.7	0.85, 0.74	0.86, 0.69	0.86, 0.7	

Table 13G IAC Values for Draperies, Roller Shades, and Insect Screens (Continued)

Glazing ID:	25a	25b	25c	26d	25c	25f	Glazing ID:	29a	29b				
Dark Closed Weave	0.88, 0.43	0.89, 0.42	0.90, 0.40	0.90, 0.40	0.91, 0.39	0.90, 0.40	Dark Closed Weave	0.86, 0.44	0.87, 0.42				
Medium Closed Weave	0.80, 0.45	0.82, 0.44	0.85, 0.41	0.84, 0.41	0.85, 0.40	0.84, 0.42	Medium Closed Weave	0.77, 0.45	0.80, 0.43				
Light Closed Weave	0.68, 0.51	0.72, 0.48	0.76, 0.44	0.76, 0.45	0.77, 0.3	0.76, 0.45	Light Closed Weave	0.65, 0.50	0.69, 0.47				
Dark Semiopen Weave	0.91, 0.48	0.91, 0.47	0.92, 0.44	0.92, 0.45	0.92, 0.43	0.92, 0.45	Dark Semiopen Weave	0.89, 0.48	0.90, 0.47				
Medium Semiopen Weave	0.83, 0.54	0.85, 0.52	0.87, 0.48	0.86, 0.49	0.87, 0.47	0.86, 0.49	Medium Semiopen Weave	0.81, 0.54	0.83, 0.51				
Light Semiopen Weave	0.75, 0.66	0.78, 0.63	0.81, 0.57	0.81, 0.58	0.82, 0.55	0.81, 0.58	Light Semiopen Weave	0.72, 0.65	0.76, 0.60				
Dark Open Weave	0.93, 0.56	0.93, 0.55	0.94, 0.51	0.94, 0.52	0.94, 0.50	0.94, 0.52	Dark Open Weave	0.91, 0.56	0.92, 0.54				
Medium Open Weave	0.86, 0.65	0.87, 0.62	0.89, 0.57	0.89, 0.58	0.89, 0.56	0.89, 0.59	Medium Open Weave	0.84, 0.64	0.85, 0.60				
Light Open Weave	0.79, 0.75	0.82, 0.72	0.85, 0.65	0.84, 0.66	0.85, 0.63	0.84, 0.67	Light Open Weave	0.77, 0.73	0.80, 0.69				
Sheer	0.84, 0.8	0.86, 0.76	0.88, 0.69	0.88, 0.7	0.89, 0.67	0.88, 0.71	Sheer	0.83, 0.78	0.85, 0.73				
Glazing ID:	32a	32b	32c	32c	32d	32d	40a	40b	40c	40d			
Dark Closed Weave	0.89, 0.43	0.90, 0.41	0.91, 0.42	0.91, 0.42	0.92, 0.39	0.92, 0.39	0.93, 0.41	0.94, 0.37	0.90, 0.42	0.91, 0.40			
Medium Closed Weave	0.80, 0.44	0.83, 0.42	0.82, 0.42	0.82, 0.42	0.84, 0.39	0.84, 0.39	0.84, 0.40	0.87, 0.37	0.82, 0.43	0.85, 0.41			
Light Closed Weave	0.69, 0.48	0.73, 0.45	0.69, 0.44	0.69, 0.44	0.73, 0.40	0.73, 0.40	0.73, 0.42	0.77, 0.38	0.71, 0.47	0.76, 0.44			
Dark Semiopen Weave	0.91, 0.47	0.92, 0.46	0.93, 0.46	0.93, 0.46	0.94, 0.43	0.94, 0.43	0.94, 0.45	0.95, 0.41	0.92, 0.46	0.93, 0.45			
Medium Semiopen Weave	0.83, 0.52	0.85, 0.50	0.84, 0.50	0.84, 0.50	0.86, 0.46	0.86, 0.46	0.86, 0.48	0.89, 0.44	0.85, 0.51	0.87, 0.48			
Light Semiopen Weave	0.75, 0.62	0.79, 0.58	0.75, 0.58	0.75, 0.58	0.79, 0.52	0.79, 0.52	0.78, 0.55	0.82, 0.49	0.77, 0.60	0.80, 0.56			
Dark Open Weave	0.93, 0.55	0.93, 0.53	0.95, 0.53	0.95, 0.53	0.95, 0.50	0.95, 0.50	0.96, 0.51	0.96, 0.47	0.94, 0.54	0.94, 0.52			
Medium Open Weave	0.86, 0.62	0.87, 0.59	0.87, 0.59	0.87, 0.59	0.88, 0.54	0.88, 0.54	0.88, 0.56	0.90, 0.51	0.87, 0.60	0.89, 0.57			
Light Open Weave	0.80, 0.71	0.83, 0.66	0.80, 0.66	0.80, 0.66	0.82, 0.60	0.82, 0.60	0.82, 0.63	0.85, 0.57	0.81, 0.69	0.84, 0.64			
Sheer	0.84, 0.75	0.87, 0.7	0.85, 0.71	0.85, 0.71	0.87, 0.65	0.87, 0.65	0.86, 0.68	0.89, 0.61	0.86, 0.73	0.88, 0.68			
<i>Roller Shades and Insect Screens</i>													
Shade/Screen	Openness	Ref./Trans.	Glazing ID:	1a	1b	1c	1c	1d	1e	1f	1g	1h	1i
Light Translucent	0.14	0.60/0.25	0.44, 0.74	0.45, 0.72	0.49, 0.66	0.55, 0.59	0.51, 0.65	0.56, 0.59	0.51, 0.65	0.57, 0.58	0.55, 0.6	0.55, 0.6	0.55, 0.6
White Opaque	0.00	0.65/0.00	0.34, 0.45	0.35, 0.44	0.4, 0.41	0.47, 0.38	0.42, 0.4	0.48, 0.38	0.42, 0.4	0.49, 0.38	0.47, 0.38	0.47, 0.38	0.47, 0.38
Dark Opaque	0.00	0.20/0.00	0.64, 0.48	0.65, 0.47	0.67, 0.45	0.69, 0.43	0.67, 0.45	0.7, 0.42	0.67, 0.45	0.7, 0.42	0.69, 0.43	0.69, 0.43	0.69, 0.43
Light Gray Translucent	0.10	0.31/0.15	0.61, 0.57	0.62, 0.57	0.64, 0.54	0.68, 0.51	0.65, 0.53	0.68, 0.5	0.65, 0.53	0.69, 0.5	0.68, 0.51	0.68, 0.51	0.68, 0.51
Dark Gray Translucent	0.14	0.17/0.19	0.71, 0.58	0.72, 0.58	0.73, 0.55	0.76, 0.52	0.74, 0.55	0.76, 0.52	0.74, 0.55	0.76, 0.52	0.76, 0.52	0.76, 0.52	0.76, 0.52
Reflective White Opaque	0.00	0.84/0.00	0.3, 0.71	0.32, 0.68	0.38, 0.6	0.45, 0.53	0.39, 0.58	0.46, 0.52	0.39, 0.58	0.47, 0.52	0.45, 0.53	0.45, 0.53	0.45, 0.53
Reflective White Translucent	0.07	0.75/0.16	0.23, 0.42	0.25, 0.41	0.31, 0.38	0.39, 0.36	0.33, 0.37	0.4, 0.35	0.33, 0.37	0.41, 0.35	0.39, 0.36	0.41, 0.35	0.39, 0.36
Outdoor Insect Screen			0.64, 0.98	0.64, 0.98	0.64, 0.95	0.64, 0.92	0.64, 0.95	0.64, 0.91	0.64, 0.95	0.64, 0.91	0.64, 0.92	0.64, 0.91	0.64, 0.92
Indoor Insect Screen			0.88, 0.81	0.88, 0.8	0.89, 0.78	0.9, 0.75	0.89, 0.78	0.9, 0.75	0.89, 0.78	0.9, 0.75	0.89, 0.78	0.9, 0.75	0.9, 0.76
Glazing ID:	5a	5b	5c	5c	5d	5e	5f	5g	5h	5i			
Light Translucent	0.55, 0.65	0.58, 0.62	0.58, 0.62	0.58, 0.62	0.63, 0.56	0.58, 0.61	0.64, 0.56	0.58, 0.61	0.64, 0.56	0.63, 0.56			
White Opaque	0.48, 0.4	0.52, 0.39	0.51, 0.39	0.51, 0.39	0.57, 0.37	0.52, 0.39	0.58, 0.37	0.52, 0.39	0.58, 0.36	0.57, 0.37			
Dark Opaque	0.76, 0.44	0.77, 0.43	0.77, 0.43	0.77, 0.43	0.8, 0.41	0.78, 0.43	0.8, 0.41	0.78, 0.43	0.8, 0.4	0.8, 0.41			
Light Gray Translucent	0.72, 0.53	0.74, 0.51	0.74, 0.51	0.74, 0.51	0.77, 0.48	0.74, 0.51	0.77, 0.48	0.74, 0.51	0.77, 0.48	0.77, 0.48			
Dark Gray Translucent	0.81, 0.54	0.82, 0.53	0.82, 0.53	0.82, 0.53	0.84, 0.5	0.82, 0.52	0.84, 0.5	0.82, 0.52	0.84, 0.5	0.84, 0.5			
Reflective White Opaque	0.43, 0.6	0.47, 0.55	0.46, 0.56	0.46, 0.56	0.54, 0.5	0.47, 0.55	0.55, 0.49	0.47, 0.55	0.55, 0.49	0.54, 0.5			
Reflective White Translucent	0.37, 0.38	0.42, 0.36	0.41, 0.36	0.41, 0.36	0.49, 0.34	0.42, 0.36	0.5, 0.34	0.42, 0.36	0.5, 0.34	0.49, 0.34			
Outdoor Insect Screen	0.64, 0.96	0.64, 0.94	0.64, 0.94	0.64, 0.94	0.64, 0.91	0.64, 0.94	0.64, 0.9	0.64, 0.94	0.64, 0.9	0.64, 0.91			
Indoor Insect Screen	0.92, 0.78	0.93, 0.77	0.93, 0.76	0.93, 0.76	0.93, 0.74	0.93, 0.76	0.93, 0.74	0.93, 0.76	0.93, 0.74	0.93, 0.74			

Table 13G IAC Values for Draperies, Roller Shades, and Insect Screens (Continued)

Glazing ID:	17a	17b	17c	17d	17e	17f	17g	17h	17i	17j	17k
Light Translucent	0.14	0.62, 0.6	0.62, 0.6	0.67, 0.56	0.64, 0.58	0.69, 0.53	0.64, 0.57	0.7, 0.53	0.64, 0.57	0.7, 0.53	0.7, 0.53
White Opaque	0.00	0.56, 0.38	0.57, 0.38	0.61, 0.37	0.59, 0.37	0.65, 0.36	0.59, 0.37	0.65, 0.36	0.59, 0.37	0.65, 0.35	0.65, 0.36
Dark Opaque	0.00	0.82, 0.42	0.82, 0.42	0.83, 0.41	0.82, 0.41	0.84, 0.39	0.82, 0.41	0.84, 0.39	0.82, 0.41	0.84, 0.39	0.84, 0.39
Light Gray Translucent	0.10	0.78, 0.5	0.78, 0.5	0.8, 0.48	0.78, 0.49	0.81, 0.46	0.79, 0.49	0.82, 0.46	0.79, 0.49	0.82, 0.46	0.81, 0.46
Dark Gray Translucent	0.14	0.85, 0.52	0.85, 0.52	0.86, 0.5	0.86, 0.51	0.87, 0.48	0.86, 0.51	0.88, 0.48	0.86, 0.51	0.88, 0.48	0.87, 0.48
Reflective White Opaque	0.00	0.52, 0.53	0.52, 0.53	0.58, 0.5	0.54, 0.51	0.61, 0.47	0.55, 0.51	0.62, 0.46	0.55, 0.51	0.62, 0.46	0.61, 0.47
Reflective White Translucent	0.07	0.47, 0.36	0.47, 0.36	0.53, 0.35	0.49, 0.35	0.57, 0.34	0.5, 0.35	0.58, 0.34	0.5, 0.35	0.58, 0.33	0.57, 0.34
Outdoor Insect Screen	0.64, 0.95	0.64, 0.93	0.64, 0.94	0.64, 0.91	0.64, 0.92	0.64, 0.89	0.64, 0.92	0.64, 0.89	0.64, 0.92	0.64, 0.89	0.64, 0.89
Indoor Insect Screen	0.94, 0.77	0.94, 0.76	0.94, 0.76	0.94, 0.74	0.94, 0.75	0.95, 0.72	0.94, 0.75	0.95, 0.72	0.94, 0.75	0.95, 0.72	0.95, 0.72
Glazing ID:	21a	21b	21c	21d	21e	21f	21g	21h	21i	21j	21k
Light Translucent	0.14	0.65, 0.59	0.66, 0.59	0.69, 0.56	0.68, 0.57	0.72, 0.53	0.68, 0.57	0.72, 0.53	0.68, 0.57	0.72, 0.53	0.72, 0.53
White Opaque	0.00	0.6, 0.38	0.61, 0.38	0.64, 0.37	0.63, 0.37	0.67, 0.36	0.63, 0.37	0.67, 0.36	0.63, 0.37	0.68, 0.35	0.67, 0.36
Dark Opaque	0.00	0.84, 0.42	0.84, 0.42	0.85, 0.41	0.85, 0.41	0.86, 0.39	0.85, 0.41	0.86, 0.39	0.85, 0.41	0.86, 0.39	0.86, 0.39
Light Gray Translucent	0.10	0.8, 0.5	0.8, 0.5	0.82, 0.48	0.81, 0.48	0.83, 0.46	0.81, 0.48	0.83, 0.46	0.81, 0.48	0.83, 0.46	0.83, 0.46
Dark Gray Translucent	0.14	0.87, 0.51	0.87, 0.51	0.88, 0.5	0.88, 0.5	0.89, 0.48	0.88, 0.5	0.89, 0.48	0.88, 0.5	0.89, 0.48	0.89, 0.48
Reflective White Opaque	0.00	0.55, 0.53	0.56, 0.52	0.6, 0.5	0.58, 0.51	0.63, 0.47	0.59, 0.5	0.64, 0.47	0.59, 0.5	0.64, 0.47	0.64, 0.47
Reflective White Translucent	0.07	0.5, 0.35	0.51, 0.35	0.56, 0.35	0.54, 0.35	0.6, 0.34	0.54, 0.35	0.6, 0.34	0.54, 0.35	0.6, 0.33	0.6, 0.34
Outdoor Insect Screen	0.64, 0.95	0.64, 0.93	0.64, 0.93	0.64, 0.91	0.64, 0.92	0.64, 0.89	0.64, 0.91	0.64, 0.89	0.64, 0.91	0.64, 0.89	0.64, 0.89
Indoor Insect Screen	0.94, 0.77	0.95, 0.75	0.95, 0.75	0.95, 0.74	0.95, 0.74	0.95, 0.72	0.95, 0.74	0.95, 0.72	0.95, 0.74	0.95, 0.72	0.95, 0.72
Glazing ID:	25a	25b	25c	25d	25e	25f	29a	29b	29c	29d	29e
Light Translucent	0.14	0.66, 0.62	0.71, 0.58	0.75, 0.53	0.77, 0.52	0.74, 0.55	Light Translucent	0.14	0.60, 0.25	0.64, 0.6	0.68, 0.56
White Opaque	0.00	0.6, 0.38	0.66, 0.37	0.71, 0.35	0.72, 0.35	0.7, 0.36	White Opaque	0.00	0.65, 0.00	0.58, 0.38	0.63, 0.37
Dark Opaque	0.00	0.85, 0.42	0.86, 0.41	0.88, 0.39	0.88, 0.38	0.87, 0.39	Dark Opaque	0.00	0.20, 0.00	0.82, 0.42	0.84, 0.41
Light Gray Translucent	0.10	0.81, 0.5	0.83, 0.49	0.86, 0.46	0.86, 0.45	0.85, 0.47	Light Gray Translucent	0.10	0.31, 0.15	0.78, 0.5	0.81, 0.48
Dark Gray Translucent	0.14	0.88, 0.52	0.89, 0.51	0.9, 0.48	0.91, 0.47	0.9, 0.48	Dark Gray Translucent	0.14	0.17, 0.19	0.86, 0.52	0.87, 0.5
Reflective White Opaque	0.00	0.55, 0.55	0.61, 0.52	0.68, 0.47	0.69, 0.46	0.66, 0.48	Reflective White Opaque	0.00	0.84, 0.00	0.53, 0.53	0.59, 0.49
Reflective White Translucent	0.07	0.5, 0.36	0.57, 0.35	0.64, 0.33	0.65, 0.33	0.62, 0.34	Reflective White Translucent	0.07	0.75, 0.16	0.48, 0.36	0.55, 0.35
Outdoor Insect Screen	0.65, 0.95	0.65, 0.93	0.64, 0.88	0.64, 0.89	0.64, 0.87	0.64, 0.89	Outdoor Insect Screen	0.64, 0.94	0.64, 0.94	0.64, 0.94	0.64, 0.91
Indoor Insect Screen	0.95, 0.76	0.96, 0.75	0.96, 0.72	0.96, 0.72	0.96, 0.71	0.96, 0.72	Indoor Insect Screen	0.94, 0.76	0.94, 0.76	0.94, 0.76	0.95, 0.74
Glazing ID:	32a	32b	32c	32d	32e	32f	40a	40b	40c	40d	40e
Light Translucent	0.14	0.67, 0.58	0.72, 0.54	0.67, 0.52	0.71, 0.46	0.74, 0.55	Light Translucent	0.14	0.60, 0.25	0.64, 0.6	0.68, 0.56
White Opaque	0.00	0.62, 0.37	0.68, 0.36	0.62, 0.33	0.67, 0.3	0.7, 0.36	White Opaque	0.00	0.65, 0.00	0.58, 0.38	0.63, 0.37
Dark Opaque	0.00	0.85, 0.41	0.87, 0.4	0.87, 0.4	0.89, 0.38	0.89, 0.38	Dark Opaque	0.00	0.20, 0.00	0.82, 0.42	0.84, 0.41
Light Gray Translucent	0.10	0.81, 0.49	0.84, 0.47	0.82, 0.46	0.85, 0.43	0.85, 0.47	Light Gray Translucent	0.10	0.31, 0.15	0.78, 0.5	0.81, 0.48
Dark Gray Translucent	0.14	0.88, 0.51	0.89, 0.49	0.9, 0.49	0.91, 0.45	0.9, 0.48	Dark Gray Translucent	0.14	0.17, 0.19	0.86, 0.52	0.87, 0.5
Reflective White Opaque	0.00	0.57, 0.51	0.64, 0.47	0.57, 0.44	0.63, 0.39	0.62, 0.34	Reflective White Opaque	0.00	0.84, 0.00	0.53, 0.53	0.59, 0.49
Reflective White Translucent	0.07	0.53, 0.35	0.61, 0.34	0.52, 0.28	0.59, 0.26	0.62, 0.34	Reflective White Translucent	0.07	0.75, 0.16	0.48, 0.36	0.55, 0.35
Outdoor Insect Screen	0.64, 0.92	0.64, 0.9	0.64, 0.86	0.64, 0.86	0.64, 0.8	0.64, 0.89	Outdoor Insect Screen	0.64, 0.94	0.64, 0.94	0.64, 0.94	0.64, 0.91
Indoor Insect Screen	0.95, 0.75	0.96, 0.73	0.95, 0.7	0.95, 0.7	0.95, 0.67	0.95, 0.67	Indoor Insect Screen	0.94, 0.76	0.94, 0.76	0.94, 0.76	0.95, 0.72

^b Louvers track to block direct beam radiation. When negative slat angles result, slat defaults to 0°.
^c Glazing cavity width equals original cavity width plus slat width.

^a Louvers track so that profile angle equals negative slat angle and maximum direct beam is admitted.

VISUAL AND THERMAL CONTROLS

The ideal fenestration system allows optimum lighting, heating, ventilation, and visibility; minimizes moisture and sound transfer between the outdoor and the indoor; and produces a satisfactory physiological and psychological environment. The controls of an optimum system react to varying climatological and occupant demands. Fixed controls may have operation or cost advantages or both but do not react to physical and psychological variations. Variable controls are, therefore, more effective in energy conservation and environmental satisfaction.

Operational Effectiveness of Shading Devices

Shading devices vary in their operational effectiveness. Some devices, such as overhangs, light shelves, and tinted glazings, do not require operation, have long life expectancies, and do not degrade significantly over their effective life. Other types of shading devices, especially operable indoor shades, may have reduced effectiveness because of less than optimal operation and degradation of effectiveness over time. It is important to evaluate operational effectiveness when considering the actual heat rejection potential of shading devices.

The performance of shading devices for reducing peak cooling loads and annual energy use should account for operational effectiveness or reliability in actual operation. Passive devices, such as architectural elements and glazing tinting, are considered 100% effective in operation. Glazing coatings and adherent films may degrade over time. Shade screens are removable and may be assumed to operate seasonally, but in any given population of users, some will remain in place all year long and some will not be installed or removed at optimum times. Automated shading devices controlled for optimum thermal operation are considered more effective than manual devices, but controls require ongoing maintenance, and some occupants may object to the lack of personal control with totally automated devices. Automated shading devices may also operate for nonthermal purposes such as glare and daylighting optimization, and this may reduce thermal effectiveness. Manually operated devices are subject to wide variation in use effectiveness, and this diversity in effective use should be considered when evaluating performance.

Indoor Shading Devices

Although thermal comfort of occupants within the glazed space may be paramount to the HVAC designer, other factors that should be considered, some of which may be more important to the user, include the following:

Radiant Energy Protection. Unshaded fenestration products become sources of radiant heat by transmitting short-wave solar radiation and by emitting long-wave radiation to dissipate some of the absorbed solar energy. In winter, glass temperatures usually fall below room air temperature, which may produce thermal discomfort to occupants near the fenestration. In summer, individuals seated near the unshaded fenestration product may experience discomfort from both direct solar rays and long-wave radiation emitted by sun-heated glass. In winter, loss of heat by radiation to cold glass can also cause discomfort. Tightly woven, highly reflective drapes minimize such discomfort; drapes with high openness factors are less effective because they allow short- and long-wave radiation to pass more freely. Light-colored shading devices with maximum total surface usually provide the best protection because they absorb less heat and tend to lose heat readily by convection to the conditioned air.

Outward Vision. Outward vision is normally desirable in both business and living spaces. Open-weave, dark-colored fabrics of uniform pattern allow maximum outward vision, whereas uneven pattern weaves reduce the ability to see out. A semiopen weave modifies the view without completely obscuring the outdoors. Tightly woven fabrics block outward vision completely.

Privacy. Venetian blinds, either vertical or horizontal, can be adjusted and, when completely closed, afford full privacy. When draperies are closed, the degree of privacy is determined by their color and tightness of weave and the source of the principal illumination. To obscure the view so completely that not even shadows or silhouettes can be detected, fully opaque materials are used. Generally, the more brightly lit side of a partially shaded glazing is the most visible from the opposite side, making the indoor fairly private in daytime, but not at night.

Brightness Control. Visual comfort is essential in many occupied areas, and freedom from glare is an important factor in performing tasks. *Discomfort glare* is produced by uneven brightness in occupied spaces, with areas or spots that are much brighter than surrounding surfaces. Windows themselves, when they look out onto bright skies or brightly reflecting surfaces, can be glare sources if care is not taken to keep surround brightness comparable. A maximum brightness ratio of about 3 to 1 is sometimes quoted. Moderation of this ratio can be achieved through using indoor furnishings and wall coverings, which on average have moderately high diffuse reflectances and access to admitted daylight. Conversely, dark indoor surfaces, and those shaded from daylight illumination, accentuate the brightness difference between the window and its surroundings. Indoor surface brightness can also be elevated by ample use of indoor electric lighting, but this can have adverse consequences for the building's energy use. In general, larger window apertures admit more sunlight, increasing indoor brightness without affecting the perceived brightness of the window, all other factors being equal.

An important guideline is that direct sunlight must not strike the eye, and reflected sunlight from bright or shiny surfaces is equally disturbing and even disabling. A tightly woven white fabric with high solar transmittance attains such brilliance when illuminated by direct sunshine that, by contrast with its surroundings, it creates excessive glare. Off-white colors should be used so their surface brightness is not too great. Venetian blinds allow considerable light to enter by interreflection between slats. When two shading devices are used, the one on the inside (away from the fenestration product) should be darker and more open. With this arrangement, the inside device can be used to control brightness for the other shading devices and, when used alone, to reduce brightness while still allowing some view of the outside.

View Modification. When the view is unattractive or distracting, draperies modify the view to some degree, depending on fabric weave and color (summarized in [Table 14](#)), but the fenestration product remains as an effective connection to the outside.

Sound Control. Indoor shading devices, particularly draperies, can absorb some of the sounds originating within the room but have little or no effect in preventing outdoor sounds from entering. For excessive internally generated sound, the usual remedy is to apply acoustical treatment to the ceiling and other room surfaces. Although these materials can be effective in controlling sound, they are often located on the two horizontal surfaces (ceiling and floor) and leave the opposing vertical surfaces of glass and bare wall to reflect sound. The noise reduction coefficient (NRC = average absorbance coefficient at four frequencies) for venetian blinds is about 0.10, compared to 0.02 for glass and 0.03 for plaster. For drapery fabrics at 100% fullness, NRC ranges from 0.10 to 0.65, depending on the tightness of weave. Class III (tightly woven) fabrics have NRC values of 0.35 to 0.65. [Figure 22](#) shows the relationship between NRC and openness factor for fabrics of normal weight.

Double Drapery

Double draperies (two sets of drapery covering the same area) have a light, open weave on the fenestration product side for outward vision and daylight when desired and a heavy, closed weave or opaque drapery on the room side to block out sunlight and provide privacy when desired. When properly selected and used, double

Table 14 Summary of Environmental Control Capabilities of Draperies

Item	Designator (Figure 19)								
	I _D	I _M	I _L	II _D	II _M	II _L	III _D	III _M	III _L
1. Protection from direct solar radiation and long-wave radiation to or from window areas	Fair	Fair	Fair	Fair	Good	Good	Fair	Good	Good
2. Effectiveness in allowing outward vision through fenestration	Good	Good	Fair	Fair	Fair	Some	None	None	None
3. Effectiveness in attaining privacy (limiting inward vision from outside)	None	None	Poor ^a Good ^a	Poor	Fair	Fair ^a Good ^a	Good ^b	Good ^b	Good ^b
4. Protection against excessive brightness and glare from sunshine and external objects	Mild	Mild	Mild ^c Poor ^c	Good	Good	Good ^c Poor ^c	Good	Good	Good ^c Poor ^c
5. Effectiveness in modifying unattractive or distracting view out of window	Little	Little	Some	Some	Good	Good	Blocks	Blocks	Blocks

^aGood when bright illumination is on viewing side.

^bTo obscure view completely, material must be completely opaque.

^cPoor rating applies to white fabric in direct sunlight. Use off-white color to avoid excessive transmitted light.

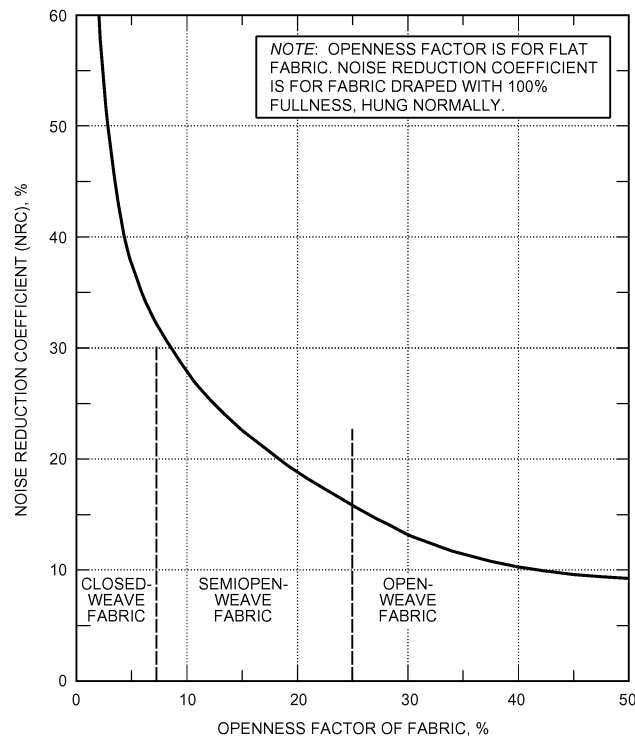


Fig. 22 Noise Reduction Coefficient Versus Openness Factor for Draperies

draperies can provide a reduced U-factor and a lowered IAC. The reduced U-factor results principally from adding a semiclosed air space to the barrier.

To most effectively reduce solar heat gain, drapery exposed to sunlight should have high reflectance and low transmittance. The light, open-weave drapery should be opened when the heavy drapery is closed to prevent entry of sunlight.

Properly used double draperies give (1) extreme flexibility of vision and light intensity, (2) a lowered U-factor and IAC, and (3) improved comfort, because the room-side drapery is more nearly at room temperature. Table 13 gives characteristics of individual draperies. For large areas, the IAC should be calculated in detail to determine the cooling load.

AIR LEAKAGE

Infiltration Through Fenestration

Air infiltration through fenestration products affects occupant comfort and energy consumption. Infiltration is the uncontrolled

inward leakage of air caused by pressure effects of wind or differences in air density, such as stack effect. Infiltration should not be confused with ventilation. Although fenestration products can be operated to intentionally provide natural ventilation and increase comfort, infiltration should be reasonably minimized to avoid unpleasant accompanying problems. If additional air is required, controlled ventilation is preferable to infiltration. Mechanical ventilation provides air in a comfortable manner and when desired. For infiltration, however, peak supply is more likely to occur as an uncomfortable draft and when least desired, such as during a storm or the coldest weather.

ASHRAE/IESNA Standard 90.1, ASHRAE’s energy standard for all buildings other than low-rise residential buildings, establishes an air leakage maximum of 0.4 cfm per square foot of gross fenestration product area (1.0 cfm/ft² for swinging entrance doors and revolving doors). This air leakage is as determined in accordance with NFRC Technical Document 400 and ASTM Standard E283 and allows direct comparison of all fenestration products: operable and fixed, windows and doors.

Most manufactured fenestration products achieve these reasonable standards of maximum air infiltration. However, products that do not completely seal, such as jalousie windows or doors, are not likely to do so and are most appropriate for installation in unconditioned spaces.

For products achieving this infiltration standard, energy consumption caused by infiltration is likely to be significantly less than energy associated with U-factor and solar heat gain coefficient. Also, although overall air infiltration is a significant component in determining a building’s heating and cooling loads, infiltration through fenestration products meeting the standard is generally likely to be a small portion of that total.

Indoor Air Movement

Because supply air grilles are frequently located directly below fenestration products, air sweeps the indoor glass surface. Heated supply air should be directed away from the glass to prevent large temperature differences between the center and edges of the glass. These thermal effects must be considered, particularly when annealed glass is used and air is forced over the glass surface during the heating season. Direct flow of heated air over the glass surface can increase the heat transfer coefficient and temperature difference, causing a substantial increase in heat loss, as well as leading to thermally induced stress and risk of glass breakage.

Systems designed predominantly for cooling lower the glass temperature and rapidly pick up the cooling load. Both tend to improve comfort conditions. However, the air-conditioned space has an increased net heat gain caused by increases in (1) solar heat gain coefficient (SHGC) caused by delivery of more of the absorbed heat to the indoor space, (2) fenestration U-factor because of the greater convection effect at the indoor surface, and (3) air-to-air temperature difference because supply air rather than room air is in

contact with the indoor glass surface. The principal increase in heat gain with clear glass is the result of increased U-factor and air-to-air temperature difference.

DAYLIGHTING

DAYLIGHT PREDICTION

Daylighting is the illumination of building interiors with sunlight and sky light and is known to affect visual performance, lighting quality, health, human performance, and energy efficiency. In many European countries with predominantly cloudy skies, codes regulate minimum window size, minimum daylight factor, and window position to provide views to all occupants and to create a minimum indoor brightness level. Daylighting also provides back-up indoor illumination in the event of power outages. Daylighting may have some positive or negative health effects on the skin, eyes, hormone secretion, and mood. Its temporal variation, intensity, spectral content, and diurnal and temporal variation may be used to combat jet lag, sick building syndrome, and other health problems.

In terms of energy efficiency, daylighting can provide substantial whole-building energy reductions in nonresidential buildings through the use of electric lighting controls. Daylight admission can displace the need for electric lighting at the perimeter zone with vertical windows (sidelighting) and at the core zone with skylights (toplighting). Lighting and its associated cooling energy use constitute 30 to 40% of a nonresidential building's energy use. Energy use reductions can be achieved, perhaps less reliably, in residential buildings with manual or automated switching of electric lights on and off to match space occupancy. For internal-load-dominated buildings, daylight admission must be balanced against solar heat admission to achieve optimum energy efficiency. Because heat gains from solar radiation typically define peak load conditions, daylighting is also a very effective method of decreasing peak demand. Daylighting can not only decrease annual operating costs through energy efficiency, but may also reduce capital cost by mechanical downsizing.

For daylighting designs using direct-beam sunlight entry, care must be taken to avoid overheating and glare. Such problems can be avoided by carefully controlling or eliminating direct beam entry through orientation and shading of daylighting apertures and other architectural features.

For conventional sidelit nonresidential buildings, three basic relationships for daylight optimization are given as a function of (1) glazing properties and (2) window area or the **window-to-wall area ratio (WWR)**, which is defined as the ratio of the transparent glazing area to the outdoor floor-to-floor wall area:

1. Annual cooling energy use (including fan energy use) increases linearly with solar radiation admission, as indicated by the product of SHGC and WWR, but is affected by decreases in electric lighting heat gains.
2. Annual lighting energy use decreases exponentially/asymptotically with daylight admission, as indicated by the product of T_v and WWR.
3. Annual heating energy use (including fan energy use) increases linearly with decreased lighting heat gains.

Figure 23 illustrates the first two relationships for a prototypical nonresidential building. A similar relationship can be demonstrated with skylights.

The fenestration design that achieves an optimum balance between daylight admission and solar rejection can be determined by iterative calculations where the glazing area and/or glazing solar-optical properties are varied parametrically. For each case, the following general steps should be taken for each hour over a year:

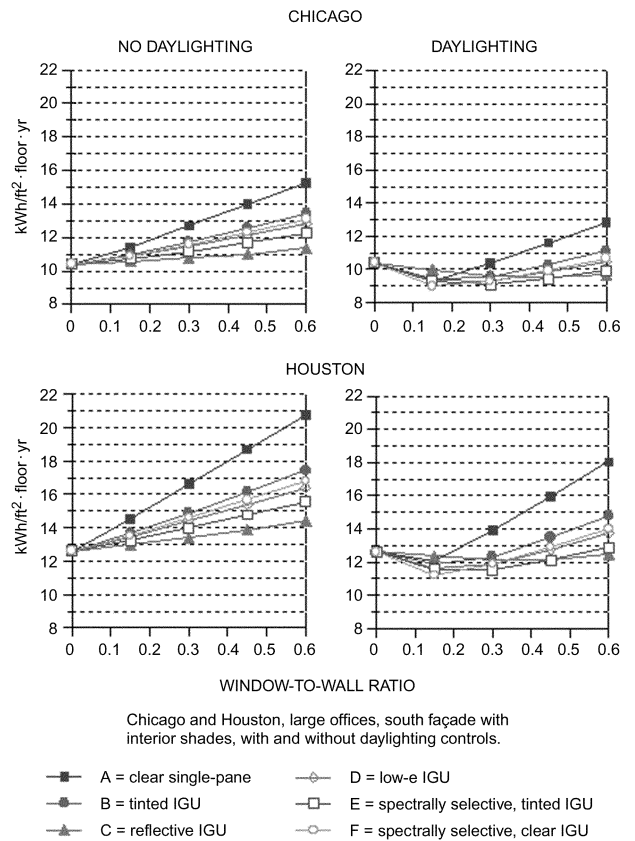


Fig. 23 Window-to-Wall Ratio Versus Annual Electricity Use in kWh/ft²·floor·year

1. **Indoor Daylight Illuminance.** Determine the building characteristics, configuration, outdoor design conditions, and operating schedules as described in Chapter 18. These include building orientation, outdoor obstructions, ground reflectance, etc. Determine the depth from the window wall for each electric lighting zone. Typical sidelighting windows can effectively daylight the perimeter zone to a depth of 1.5 times the head height of the window. In private offices, one dimming zone is typically cost-effective, whereas in open-plan offices, two zones are cost-effective.

Select a typical task location in each of the lighting zones. Determine indoor daylight illuminance from all window and skylight sources at these locations. Indoor illuminance may be determined using computer simulation tools or physical scale models. Comprehensive explanations of simple and computer-based tools are available (IEA 1999). The majority of these tools can model simple box geometry with noncomplex fenestration systems. Some advanced simulation tools, such as Radiance (Ward 1990) and Adeline (Erhorn and Dirksmöller 2000), can model complex geometry and fenestration systems with adequate bidirectional solar-optical data, but this capability is not routine.
2. **Lighting Energy Use.** Determine the type of lamps, ballasts, and control system to be used in the perimeter zones. Determine whether the lamp can be dimmed or switched. For example, fluorescent lamps can be dimmed, but metal halides cannot be switched or dimmed. Cold, outdoor applications of some lamps may prevent switching. For electronic dimming ballasts, obtain dimming power and light output characteristics. Obtain control specifications to determine how the system will respond to available light; dead-band ranges, response times, and commissioning affect the sensitivity and accuracy of the system. The type of

switching (on/off, bilevel, multilevel, and continuous dimming controls) are dictated by both the type of lamp and space use.

Determine the task illuminance design set point for each zone. Determine the percentage electric lighting power reduction $F_{daylight}$ that will result with automatic daylight controls, and apply to the installed wattage. Simplified methods for calculating lighting power reductions based on task illuminance levels are given in Robbins (1986). More sophisticated programs (Choi and Mistrick 1999) model commercially available photosensor dimming control systems (typically located in the ceiling above the work plane task) more rigorously; the spectral and bidirectional response of the photosensor to incident flux is used to determine voltage output, which is then used by the ballast controller algorithm to determine the lighting power reduction. Response delays and commissioning set points further affect this predicted output. Lights may also be switched manually, but there are no modeling prediction tools for manual switching. Field tests (Jennings et al. 1999) indicate that with bilevel switching, 45% of the lighting zone-hours were at less than full-power lighting, with 28% at only one-third of full lighting output levels. Manual switching occurred less in public spaces. Occupancy and other types of switching may occur as well and should be accounted for as a confounding effect with any daylighting controls.

3. **Mechanical Energy Use.** Determine mechanical energy use caused by fenestration loads and reduced electric lighting heat gains. Fenestration heat gains and losses may be computed using the section on Determining Fenestration Energy Flow. Instantaneous lighting heat gains q_{el} , described in Chapter 18, must be multiplied by the power reduction factor $F_{daylight}$.

Mechanical loads and energy use may then be determined as described in Chapter 18. Many studies have investigated the magnitude of change in heating and cooling energy use associated with reductions of lighting energy use in nonresidential buildings, as will be realized with daylighting controls. In a DOE-2.1E simulation study (Sezgen and Koomey 2000), the greatest savings were generated in hospitals, large offices, and large hotels; for every \$1.00 saved through lighting energy efficiency, additional savings as a result of reduced HVAC were \$0.26, \$0.16, and \$0.14, respectively. These results emphasize the need to include HVAC effects when assessing the effects of daylighting. Simplified design tools are available to conduct such parametric runs for preliminary analysis. Skylighting tools based on regressions using DOE-2 data or simplified DOE-2 procedures are also available (AAMA 1987; Hescong et al. 1998). More comprehensive building energy prediction tools combined with daylighting algorithms, such as DOE-2.1E (Winkelmann 1983), implement hour-by-hour calculations using existing weather data and enable evaluation of glare, visual comfort, and quality of light as well.

In the United States, a general rule has been that the fenestration area should be at least 20% of the floor area. In Europe, a similar rule was based on a minimum illumination value on the normal work plane from a standard overcast sky condition. In general, it is more energy-efficient to use larger window areas to elevate indoor surface brightness as a glare reduction strategy than to increase indoor electric lighting levels. As window area increases, indoor brightness increases while window brightness remains the same. Of course, mitigating considerations include increased cost and heat transfer with larger windows. The latter problem can be mitigated with insulating multiple-pane windows and special coatings to reduce solar gain without serious loss of light transmission, as discussed in the section on Selecting Fenestration. Orientation and shading can also be effective at mitigating glare and overheating problems.

The secondary visual benefit of fenestration is the amount and quality of light it produces in the work environment. One general rule determined the need for auxiliary electric light by assuming that

daylight was adequate for a depth of two and one-half times the height of the fenestration product into the room based on a normal sill height. To prevent excessive glare, all fenestration should have sun controls. Variable and removable controls are often more effective in daylighting than fixed controls.

For more accurate evaluation of daylight distribution in a space, several prediction tools, such as the *Recommended Practice of Daylighting* (IESNA 1999), are available. This practice shows a simple way of calculating the daylight distribution on the work plane from windows and skylights with and without controls. Many other daylight prediction tools calculate illuminance from radiant flux transfer or ray tracing.

Any or all of the various daylight prediction tools can be used to compare the relative value of daylight distribution from alternative fenestration systems, but ultimately the designer must evaluate costs and benefits to choose between alternative designs. This may be based on energy use or, more properly, on overall costs and benefits to the client. Also, the negative possibility of total loss of productivity from an electric brown-out in a space with no natural ventilation or daylight may be as important as the benefits of many energy-saving schemes.

LIGHT TRANSMITTANCE AND DAYLIGHT USE

When daylight is to be the primary lighting system, the minimum expected daylight in the building must be calculated for the building performance cycle and integrated into lighting calculations. IESNA (1999) gives daylight design and calculation procedures. In some glazing applications, such as artists' studios and showrooms, maximum transmittance may be required for adequate daylighting. Regular clear glass, produced by float, plate, or sheet process, may be the logical choice.

When daylight is a supplementary light source, the electric lighting can be designed independently of the daylight system. However, adequate switching must be included in the electric distribution to substitute available daylight for electric lighting by automatic or prescribed manual control whenever practical. Photosensitive controls automatically adjust shading devices to provide uniform illumination and reduce energy consumption. Manual control is less effective.

Buildings with large areas of glass usually have insulating glass units with clear, tinted, or reflective coatings. Tinted and reflecting units reduce the brightness contrast between fenestration products and other room surfaces and provide a relatively glare-free environment for most daylight conditions.

Table 10 lists typical approximate solar energy transmittances and daylight transmittances for various glass types. Manufacturers' literature has more appropriate type-specific values.

The color of glass chosen for a building depends largely on where and how it is used. For commercial building lobbies, showroom fenestration products, and other areas where maximum visibility from outdoor to indoor is required, regular clear glass is generally best. Clear glass with a low-e coating is also suitable for these locations, including for retail storefronts, because it only decreases light transmittance by about 10%. For other glass areas, tinted glass may best complement the indoor colors. Bronze, gray, and reflective-film glasses also give some privacy to building occupants during daylight hours. Patterned, etched, or sandblasted glass that diffuses lighting is available. In warm climates, tinted outer glass in an insulated double-pane system can have solar heat gain rejection benefits, while providing good color-rendering illumination of the interior without apparent color.

The primary purpose of a fenestration product is not just to save energy but to provide a view of the outdoors. One sees out of a fenestration product by virtue of the light from the outside that comes through that fenestration product into the occupant's eyes. The light from outside is valuable not only for views of the outdoors but for providing daylight illumination of the interior.

The light-transmitting properties of fenestration systems are therefore of great importance, not only for allowing views of the outdoors but also for admitting daylight to reduce electric lighting. It is conceivable that one could design a fenestration product with excellent solar heat gain performance for hot climates (meaning a very low solar heat gain coefficient) but very poor view and daylight illumination performance. If this problem is bad enough, it can cause occupants to turn on electric lights indoors during the daytime, which adds to the electric bill and possibly causes problems of thermal discomfort as well.

The light-transmitting property of a fenestration product is called the visible **transmittance** T_v . It is similar to the solar-weighted solar transmittance, except that an additional weighting function is needed, in this case to account for the spectral response of the human eye.

In most applications, it is important to have high visible transmittance. In northern climates, good solar heat gain is also important for offsetting wintertime heating costs. In southern climates, low solar heat gain is good for offsetting summertime cooling costs. In the latter situation, it is difficult to have both high visible transmittance and a low solar heat gain coefficient. Figures 24 and 25 show plots of visible transmittance versus SHGC for several glazing systems covering a range of spectral selectivities (McCluney 1996). The data are for normal incidence and a single, ASTM standard solar spectral distribution.

A rule of thumb is to select a glazing unit having a visible transmittance greater than its solar heat gain coefficient, especially if daylighting strategies will be used in the building. For maximum light with minimum solar gain, there are fenestration products available having a visible transmittance as high as 2.0 times the SHGC.

Three different zones are delineated in Figure 25. In the **neutral zone**, it is possible to have colorless glazing systems, meaning glazings with approximately uniform transmittance over the visible spectrum. Glazings in this zone can have some color, but this

is not necessary. In the **color zone**, the only way to achieve higher visible transmittance for a given level of solar heat gain coefficient is by stripping off some of the red and blue wavelengths at the edges of the human spectral response function with a spectrally selective glazing transmittance, imparting color to the transmitted radiation (or by otherwise altering the spectral transmittance and hence the color over the visible portion of the spectrum). In the **forbidden zone**, no combination of visible transmittance and solar heat gain coefficient is possible for normal incidence and for the solar spectral distribution used. (Changing the solar spectral distribution used to calculate T_v and SHGC shifts the transition curves somewhat. A low solar altitude angle, direct-beam spectrum will move the curves to the left on the plot in Figure 25.) Glazings that transmit more solar radiant heat than light cluster on the lower portion of the plot.

The T_v versus SHGC chart can be a useful tool for illustrating the degree of spectral selectivity attained by a glazing system. These concepts lead to an index of spectral selectivity that can be useful. It is called the **light-to-solar-gain ratio (LSG)**, defined as

$$LSG = \frac{T_v}{SHGC} \quad (46)$$

Some characteristic values for T_v , SHGC, and LSG are given in Table 15 for several different glazings, using the ASTM standard solar spectral distribution at normal incidence to calculate the values.

The LSG can be useful in spotting errors in calculating the SHGC. Values of SHGC that lie outside reasonable ranges can be spotted fairly quickly and used to identify possible problems in calculations or measurements. In general, it is very difficult and therefore unlikely to have a useful glazing system for buildings with an LSG value greater than 2.0. Values below 0.3 should be particularly suspect, because they indicate a glazing that transmits considerably more heat than light and would be unlikely candidates for general use. Generally, a high value of LSG is desired for residential buildings in hot climates, to maximize daylight admission with minimal solar heat gain. This is also true for internal-load-dominated nonresidential buildings in many climates, because solar gain rejection is often desired for such buildings, even in cool or cold climates. An LSG value somewhat below 1.0 is appropriate in cold climates for residential buildings and nonresidential buildings without strong internal cooling loads.

Table 15 Spectral Selectivity of Several Glazings

Glazing	T_v	SHGC	LSG
Reflective blue-green	0.33	0.38	0.87
Film on clear glass	0.19	0.22	0.86
Green tinted, medium	0.75	0.69	1.09
Green low-e	0.71	0.49	1.45
Sun-control low-e + green	0.36	0.23	1.56
Super low-e + clear	0.71	0.40	1.77
Super low-e + green	0.60	0.30	2.00

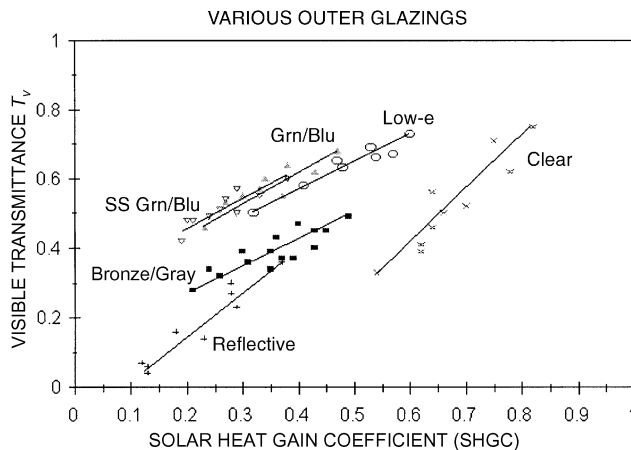


Fig. 24 Visible Transmittance Versus SHGC for Several Glazings with Different Spectral Selectivities

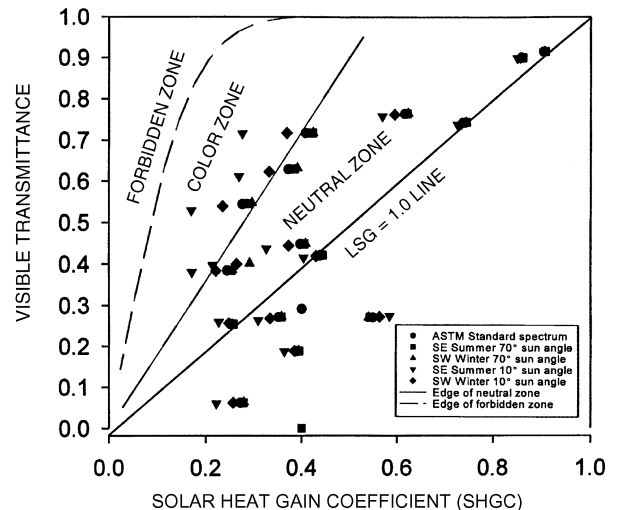


Fig. 25 Visible Transmittance Versus SHGC at Various Spectral Selectivities (McCluney 1996)

SELECTING FENESTRATION

Because fenestration systems provide so many functions, and because environmental conditions and user needs vary widely, it is difficult to make a completely optimal selection of a fenestration system. Aesthetic and cost considerations are perhaps the most important to residential users, with visual and comfort performance also of interest. Considering annual energy costs, peak load consequences, and acoustic characteristics, the choice is seldom optimal. The HVAC system designer, fortunately, has a more restricted range of interests, mainly dealing with the energy consequences of a particular fenestration selection. This section therefore focuses on fenestration energy performance determination.

ANNUAL ENERGY PERFORMANCE

Instantaneous energy performance indices (U-factor, solar heat gain coefficient, air leakage, etc.) are typically used to compare fenestration systems under a fixed set of conditions. However, the absolute and relative effect of these indices on a building's heating and cooling load can fluctuate as environmental conditions change. As a result, these indices alone are not good indicators of the annual energy performance attributable to the fenestration. Furthermore, such energy performance is difficult to quantify in and of itself because of numerous dynamic responses between the fenestration system and the total environment in which it is installed. The four basic mechanisms of fenestration energy performance (thermal transfer, solar heat gains, air leakage, and daylighting) should all be taken into account but are not independent of many other parameters that influence performance. As a result, the annual energy performance of fenestration systems can be accurately determined only when many variables are considered. Building type and orientation, climate (weather, temperature, wind speed), microclimate (shading from adjacent buildings, trees, terrain), occupant usage patterns, and certain HVAC parameters can significantly affect the annual energy effects of fenestration systems.

For these reasons, the most effective means of establishing fenestration annual energy performance is through detailed, dynamic, hourly computer simulations for the specific building and climate of interest. Because the instantaneous performance of the fenestration often varies by differing magnitudes as climatic conditions change, the most accurate simulation results are obtained when these variances are accounted for in a building energy simulation computer program. After constructing the simulation model following the procedures defined in [Chapters 17](#) and [18](#) (for residential and commercial construction, respectively), specific changes to the fenestration system can be modeled, and the annual energy performance changes attributable to fenestration can be quantified. These analytical techniques do not consider issues of performance durability for the various instantaneous indices and should only be used as an initial annual energy performance indicator (Mathis and Garries 1995).

Simplified Techniques for Rough Estimates of Fenestration Annual Energy Performance

Although dynamic hourly modeling is certainly the most accurate technique for determining fenestration annual energy performance, it is not readily available to many decision makers and end users of fenestration products, simply because it may not be practical or cost-effective. Under these circumstances, it may be useful to assess the relative importance of, or balance the tradeoff between, the known instantaneous performance indices of U-factor, SHGC, air leakage, and T_v for any given fenestration system when considering heating, cooling, and lighting loads for many different building types and climates. Mitchell et al. (1999) and Huang et al. (1999) describe personal computer programs to run this simplified analysis for residential windows.

Broad generalizations can be made for some classifications of building types and climates. For instance, with large commercial buildings, which require substantial cooling energy use during daytime occupied hours because of high internal loads, significant thermal mass, or high orientation dependency, the primary objective may be to place the most emphasis on low SHGC to reduce the cooling load. Also, an evaluation of commercial fenestration annual energy use can take into account the tradeoff between artificial lighting and the natural daylighting benefits associated with a particular fenestration system. However, low U-factor is also important because commercial buildings have bimodal operation: they can have significant heating energy consumption during morning warm-up, which occurs during unoccupied predawn hours, before people arrive and lights and equipment are turned on, and before any passive solar gain. In low-rise, detached residential buildings, electric lighting loads are typically very small in comparison to the heating and cooling loads because of high envelope-dependent energy use, egress requirements, and occupant usage patterns; therefore, the energy influence of daylighting may be neglected altogether. Despite these generalizations, the problem still exists of balancing and assessing the effect of each of the remaining parameters to establish seasonal or annual energy performance for cases in which detailed computer modeling is not performed.

Development of simplified annual energy performance indices for fenestration typically involves using instantaneous fenestration performance indices to quantify building- and climate-independent scalars of annual or seasonal energy performance for rating purposes. Many of these performance indices can be relatively independent of building type, climate, distribution of products, orientation, and other items needed for hourly dynamic building energy analyses. These normalized, scalar-based approaches are also limited in accuracy for the same reasons. A further limitation with the simplified techniques is that they do not have broad applicability to varied building types (e.g., commercial versus residential buildings). The usefulness of these scalar-based approaches can be increased when limiting the comparison to a single building type. Currently, the simplified techniques for characterizing fenestration annual energy performance are applicable only to fenestration systems for detached residential buildings and are not appropriate for use with multifamily residential or commercial building fenestration systems.

Simplified Residential Annual Energy Performance Ratings

Annual energy performance ratings can provide a simple means of product comparisons for consumers. These ratings have been derived with many assumptions, usually to suit local climatic conditions.

The Canadian Standards Association (CSA *Standard* A440.2) developed a simplified energy rating applicable to residential heating in the Canadian climate, which was adopted in the 1995 *National Energy Code for Houses*. The standard also provides for specific energy ratings to compare products by orientation and climate.

In the United States, where heating and cooling are both significant, the NFRC is developing a rating system that includes both effects (Arasteh et al. 2000; Crooks et al. 1995).

CONDENSATION RESISTANCE

Water vapor condenses in a film on fenestration surfaces that are at temperatures below the dew-point temperature of the inside air. If the surface temperature is below freezing, frost forms. Sometimes, condensation occurs first, and ice from the condensed water forms when temperatures drop below freezing. Condensation frequently occurs on single glazing and on aluminum frames without a thermal

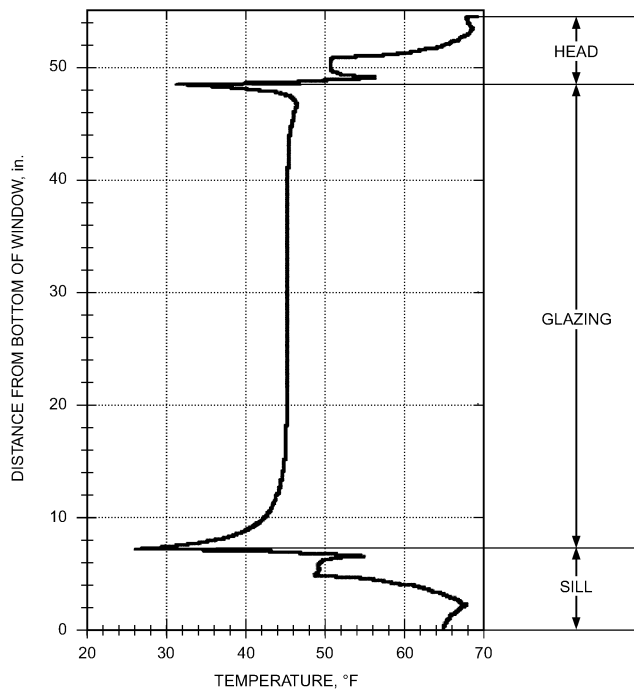


Fig. 26 Temperature Distribution on Indoor Surfaces of Glazing Unit

break. The edge-seal creates a thermal bridge at the perimeter of the glazing unit.

Circulation of fill gas caused by temperature differences in the glazing unit cavity contributes to the condensation problem at the bottom of the indoor glazing (Curcija and Goss 1994, 1995; Wright 1996b; Wright and Sullivan 1995a, 1995b). In winter, fill gas near the indoor glazing is warmed and flows up, while gas near the outdoor glazing is cooled and flows down. The descending gas becomes progressively colder until it reaches the bottom of the cavity. There, the gas turns and flows to the indoor glazing, resulting in higher heat transfer rates at the bottom. Thus, the bottom edge of the indoor glazing is cooled both by edge-seal conduction and by fill-gas convection. The combined effect of these two heat transfer mechanisms is shown in Figure 26. The surface isotherms show a wider band of cold glass at the bottom of the window. Typical condensation patterns match these isotherms. The vertical indoor surface temperature profile also shows the effect of edge-seal conduction and that the minimum indoor surface temperature is near the bottom edge of the glass.

Condensation on fenestration and surrounding structures can cause extensive structural, aesthetic, and health problems. Specific examples include peeling of paint, rotting of wood, saturation of insulation, and mold growth. Ice can render doors and windows inoperable and prevent egress during an emergency.

Energy-efficient housing has been accompanied by reduced ventilation. The resulting increase in indoor humidity has contributed to the condensation problem. However, the solution does not lie in the reduction of humidity levels to a minimum. Relative humidity below 20% and above 70% can increase health risks and reduce comfort. Generally, a minimum of 30% rh should be maintained, and 40% to 50% is more desirable (Sterling et al. 1985).

Minimum indoor surface temperatures can be quantified in a variety of ways. De Abreu et al. (1996), Elmahdy (1996), Griffith et al. (1996), Sullivan et al. (1996), and Zhao et al. (1996) demonstrated good agreement between detailed two-dimensional numerical simulation and surface temperature measurements using thermographs. Curcija et al. (1996) and Wright and Sullivan (1995c)

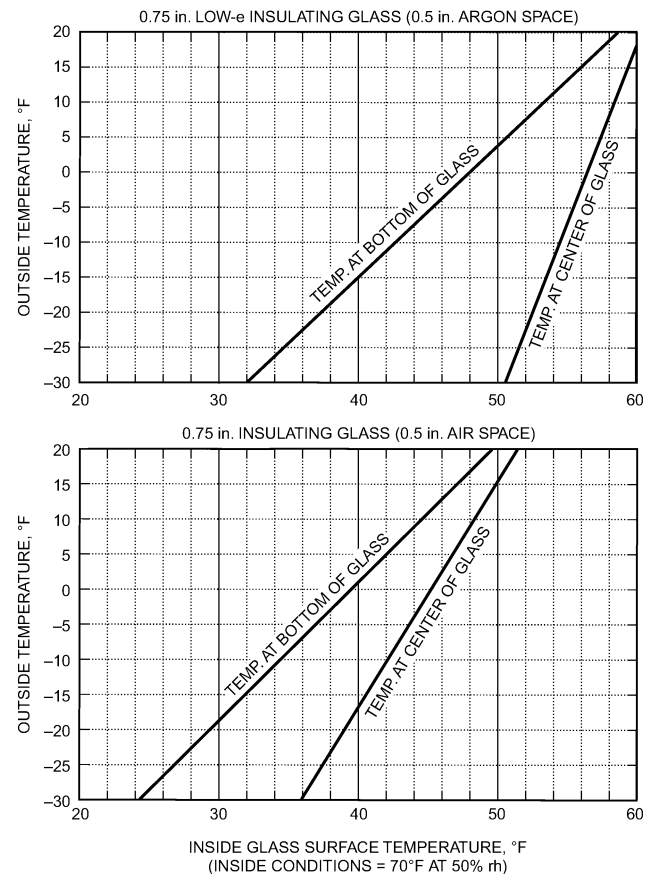


Fig. 27 Minimum Indoor Surface Temperatures Before Condensation Occurs

developed simplified simulation models to predict condensation resistance. Center-glass and bottom-edge surface temperatures that can be expected for two different glazing systems exposed to a range of outdoor temperature are shown in Figure 27. Both glazing systems include insulating foam edge seals. High-performance glazing systems (e.g., low-e/argon and insulated spacers) allow significantly higher indoor humidity levels.

Current measures of condensation resistance of a fenestration system are the **condensation resistance (CR)** as defined by NFRC (2004g), the **condensation resistance factor (CRF)** as defined by AAMA (1988), or the **temperature index (I)**, as defined in CSA Standards A440 and A440.1.

Note that the temperature index method in CSA A440 stipulates that the test is performed on the window with all the cracks *not* sealed. This represents a major difference between the CSA A440 method and the AAMA and NFRC methods. There are some merits of leaving cracks unsealed during testing for condensation resistance. In particular, any inherent deficiencies in window design may result in uncontrolled air leakage through the window. This air leakage could not be detected or dealt with in the simulation models, and it can only be seen in the results of the determined temperature index. On the other hand, there is some financial benefit to the window manufacturer in testing the window for condensation resistance with cracks sealed, because one test can determine R-value and condensation resistance.

Research shows that air leakage does affect the temperature index (measure of condensation resistance as determined by CSA A440). Elmahdy (2001, 2003) showed that sealing cracks during testing artificially improves the temperature index, compared to the results of the same window tested with cracks unsealed.

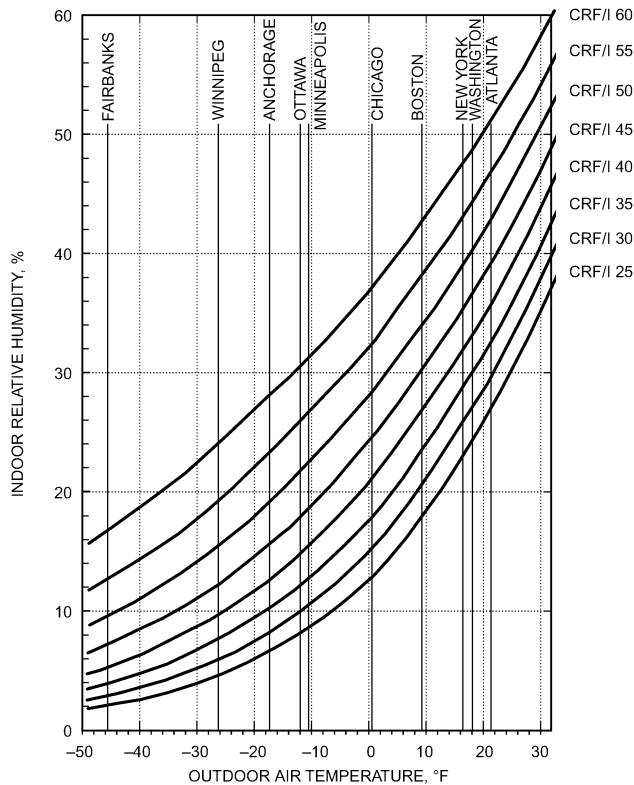


Fig. 28 Minimum Condensation Resistance Requirements
($t_h = 68^\circ\text{F}$)

Condensation resistance is a measure of condensation potential, based on both area and temperature weighting and expressed as a minimum of center-of-glazing, edge-of-glazing, and frame CRs. The novelty of this index is that it is determined using computer simulation tools unless the overall thermal performance cannot be validated with testing. If thermal performance cannot be validated, a testing option for determining CR is used.

The other two standards define the values by a single dimensionless number as

$$\text{CRF or } I = \frac{t - t_c}{t_h - t_c} \quad (47)$$

where t_h and t_c are the warm- and cold-side temperatures, respectively. Figure 28 can be used to determine the acceptable range of CRF/I for a specific climatic zone.

The two standards differ in the methods used to determine temperature. The CSA test procedure is based on thermocouple measurements at the coldest location on the frame plus three locations on the glass, each 3/8 in. above the bottom sightline. The AAMA procedure specifies two separate factors: one for the frame (CRF_F), which uses weighted frame temperature obtained from surface temperature measurements at predetermined and roving locations on the frame, and one for the glazing unit (CRF_G), which uses the average of six temperatures measured at predetermined locations near the top, middle, and bottom of the glazed area.

Inside details can significantly alter the potential for condensation on window surfaces. Items such as venetian blinds, roll blinds, insect screens, and drapes increase the thermal resistance between the indoor space and the window and lower the temperature of the window surfaces. These window treatments do not prevent migration of moisture, so they can cause increased condensation. Figure 29 shows different situations that affect the

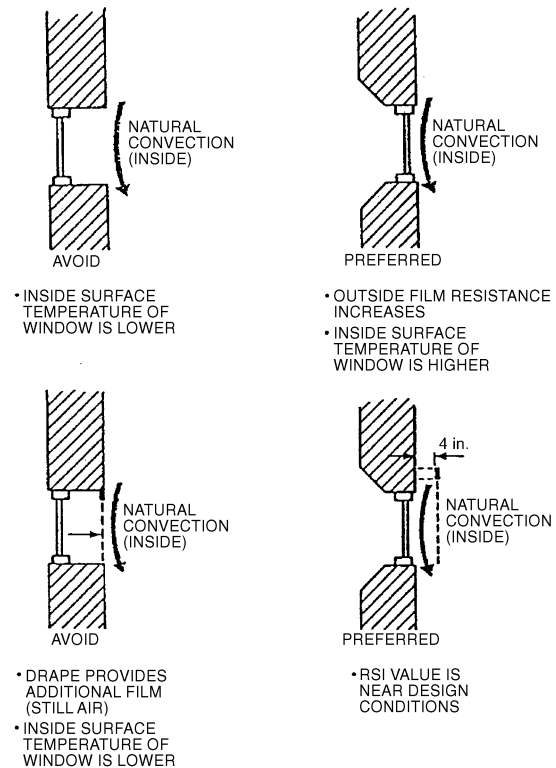


Fig. 29 Location of Fenestration Product Reveals and Blinds/Drapes and Their Effect on Condensation Resistance

potential for condensation. Note that window reveal plays an important role. If the window is placed near the outside of the wall, the increase in the outdoor film coefficient and decrease in the indoor film coefficient cause colder window surfaces. This effect is more pronounced near the corners of the recess where the indoor film coefficient is locally suppressed because air movement is restricted. Also, blinds should be placed at least 4 in. from the plane of the wall to allow some natural convection between the window and the blind.

Air leakage, especially in operable sections of fenestration, is another important cause of low surface temperature. Leakage near edge-of-glass sections can further increase the potential for condensation. However, the drier outdoor air decreases relative humidity near leakage sites and, in some cases, offsets the undesirable effect of lower surface temperatures. The net effect of air leakage cannot readily be determined experimentally or with simulation.

OCCUPANT COMFORT AND ACCEPTANCE

Human thermal comfort is an immediate sensation that reflects building occupants' perceived response to many physical factors. Unlike much building design that is based primarily on long-term energy and economic considerations, comfort-related design focuses on, and must take heed of, short-term responses of the body's physiology to its surroundings.

Windows influence thermal comfort through a combination of three mechanisms: long-wave radiation exchange, absorption of solar radiation, and convective draft effects (Figure 30). An understanding of these phenomena is important to help designers evaluate the benefits of improved windows and create comfortable buildings. Although it is well understood that high-performance windows can reduce building energy consumption, a better understanding of their effect on comfort might lead to further savings. For example, Hawthorne and Reilly (2000) suggest that significant

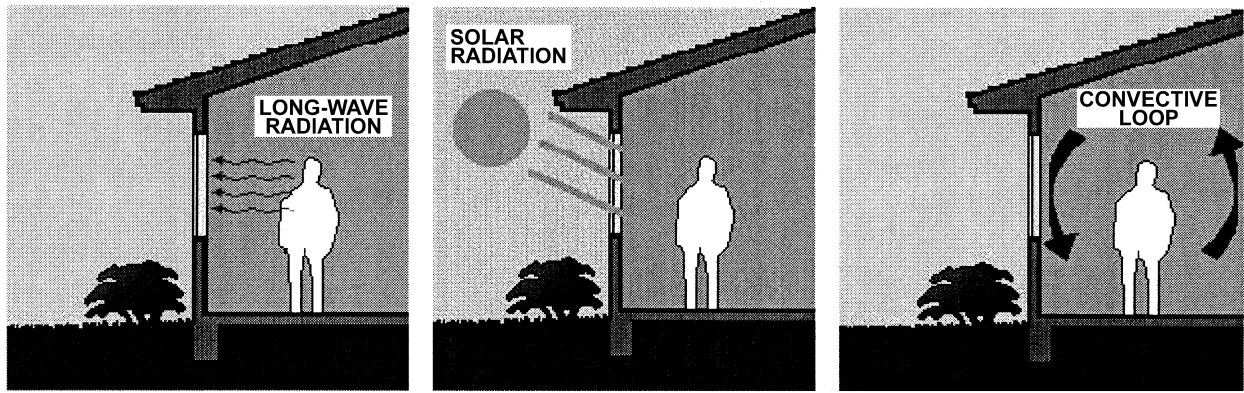


Fig. 30 Fenestration Effects on Thermal Comfort: Long-Wave Radiation, Solar Radiation, Convective Draft

energy consumption is caused by the standard practice of using perimeter duct distribution in houses to mitigate potential discomfort caused by windows. They found that perimeter heating is often not necessary when high-performance windows are installed and that heating energy savings of 10 to 15% could result from installing a simpler, less expensive duct system. Better windows can allow thermostat settings to be lowered with no loss of comfort. Another simulation study (Lyons et al. 2000) examined the relative magnitudes of a residential window's physical influences under a wide variety of winter and summer climates, glazing parameters, and clothing levels. They found that

- Long-wave, thermal radiation influences of the window dominate unless direct sun strikes the occupant
- Direct solar load has a major influence on perceptions of comfort
- For most residential-size windows, draft effects are generally small

With all but highly insulating windows, the inside surface temperature of the window is heavily influenced by outdoor conditions, and this temperature can significantly affect radiant heat exchange between an occupant and the environment. If this heat exchange moves outside the acceptable range, discomfort results. Mean radiant temperature (MRT) is commonly used to simplify the characterization of the radiant environment. On a cold day, the inside surface temperature can easily drop below 15°F for a clear single-pane window and below 40°F for a clear, double-pane window. If the occupant is sitting sufficiently near the window, MRT could drop to 55°F for the single-pane case and 62°F for the double-pane case. Based on ASHRAE *Standard 55*, even the use of the clear double-pane window could result in discomfort. [This example assumes an outdoor air temperature of 0°F, indoor air temperature of 72°F, non-window surface temperatures of 72°F, occupant-window view factor of 0.3, 0.9 clo (standard winter indoor clothing), and activity level of 1 met.] In addition to the MRT effect, a cold inside glass surface can induce a downward draft that increases air movement, contributing to further discomfort. If direct solar radiation strikes the glazing or occupant, the situation is much more complex.

In winter, the warming effect of sunlight on skin and clothing is often welcome, depending on the compounding effect of other factors such as air temperature. Windows also absorb and transmit a significant amount of solar radiation. Because of such absorption, a solar-heated window may improve MRT for a nearby person. The premise of passive solar design is that occupants will welcome, or at least tolerate, solar gain in exchange for savings on heating energy. However, it is desirable that the onset of discomfort be able to be predicted; otherwise, the energy-saving design may be defeated if occupants draw shades to prevent overheating.

In summer, solar-heated glass may become uncomfortably hot and, in commercial premises, actually devalue rented space near

windows. The inside surface of body-tinted, heat-absorbing glass can routinely reach temperatures above 120°F in summer conditions, raising MRT by as much as 15°F. This can be ameliorated by adding a second pane of glass on the inside. Transmitted radiation often causes discomfort if it falls directly on the occupant. A person sitting near a window in direct solar radiation can experience heat gain equivalent to a 20°F rise in MRT (Arens et al. 1986). Similarly, in residential applications, the perceived need for solar control is affected both by the contribution of window surfaces to MRT and by overheating from direct solar load.

Advances in window technology, especially high-performance glazings, mean that the designer has a choice of potential glazing systems. On the basis of annual energy performance for heating, cooling, and lighting, these alternatives may give similar outcomes. However, because they represent different combinations of U-factor, SHGC, and inside glass surface temperature, their comfort outcomes may differ considerably. Research continues to develop tools that will help designers evaluate such difficult tradeoffs. In the meantime, several general rules of thumb may be followed:

- In heating-dominated climates, windows with the lowest U-factor tend to give the best comfort outcomes. However, there is likely to be a tradeoff between the twin goals of maximizing instantaneous comfort and minimizing annual energy consumption.
- In cooling-dominated climates or for orientations where cooling loads are of concern, windows with the lowest rise in surface temperature for a given SHGC tend to give the best comfort outcomes.

Sound Reduction

Proper acoustical treatment of outdoor walls can decrease noise levels in certain areas. The airtightness of a wall is the primary factor to consider in reducing sound transmission from outdoors. Once walls and fenestration products are tight, the choice of glass and draperies becomes important. Draperies do not prevent sound from coming through the fenestration; they act as an absorber for sound that does penetrate. Table 16 lists average sound transmission losses for various types of glass. These averages apply for the frequency range of 125 to 4000 Hz and were determined by tests based on ASTM *Standard E90*.

Strength and Safety

In addition to its thermal, visual, and aesthetic functions, glass for building exteriors must also perform well structurally. Wind loads are specified in most building codes, and these requirements may be adequate for many structures. However, detailed wind tunnel tests should be run for tall or unusually shaped buildings and for buildings where the surroundings create unusual wind patterns. The strength of annealed, heat-strengthened, tempered, laminated, and insulated glass is given in ASTM *Standard E1300*.

Table 16 Sound Transmittance Loss for Various Types of Glass

Type of Glass	Sound Transmittance Loss, dB
1/8 in. double-strength sheet glass	24
1/4 in. plate or float glass	27
1/2 in. plate glass	32
3/4 in. plate glass	35
1 in. plate glass	36
1/4 in. laminated glass (9/20 in. plastic interlayer)	30
1 in. insulating glass	32
1/2 in. laminated glass (9/20 in. plastic interlayer)	34
Insulating glass, 6 in. air space, 1/4 in. plate or float glass	40

Thermal expansion and contraction can break ordinary annealed glass. This expansion and contraction can be caused by solar radiation onto partly shaded glass, by heat traps from drop ceilings and tight-fitting drapes, or by HVAC ducts incorrectly directed toward the glazing. High-performance tinted and reflective glasses with low-e coatings are usually more vulnerable to thermal stress breakage than clear glass. Heat treating (heat strengthening or fully tempering) the glass resists thermal stress breakage. Heat-strengthened glass, although not a safety glass, is usually preferred to tempered (safety) glass because it typically has less distortion and is much less likely to have spontaneous breakage, which can occur on very rare occasions in tempered glass. The glass manufacturer or fabricator should be consulted for information on thermal stress performance.

Building codes may require glass in certain positions to perform with certain breakage characteristics, which can be satisfied by tempered, laminated, or wired glass. In this case, glass should meet *Code of Federal Regulations* 16CFR1201 or other appropriate breakage performance requirements.

Life-Cycle Costs

Alternative building shells should be compared to ensure satisfactory energy use and total energy budget compliance, if required. ASHRAE *Standards* 90.1 and 90.2 should be used as a starting point. A life-cycle cost model should be developed for each system considered. See Chapter 36 of the 2007 *ASHRAE Handbook—HVAC Applications*.

DURABILITY

Service life and long-term performance of fenestration systems depend on the durability of all the system's components. Representative samples of glazing units are usually tested (for seal durability) according to test methods to ensure the integrity of the seal. Failure of glazing units is usually indicated by loss of adhesion of sealant to the glass; as a result, fogging occurs inside the glazing cavity.

For argon-filled units, seal failure means a loss of argon and, hence, degradation in the unit's thermal characteristics. Extensive work at the National Research Council of Canada to study the durability of glazing units filled with argon gas (Elmahdy and Yusuf 1995) indicated that, under normal conditions, argon loss by diffusion through the sealant is very small. However, when cracks or pinholes exist in the sealant, most of the argon gas escapes, which implies that stringent quality control procedures are essential for the production of durable glazing units.

Degradation of organic materials and other chemical components in glazing units as a result of exposure to ultraviolet radiation is also a factor affecting durability and service life of fenestration systems. Low-e coatings on glass tend to enhance the appearance of chemical deposits on the glass surface. Also, inserting muntin bars in glazing cavities may result in excessive rates of unit failure during ultraviolet volatile (fogging) tests unless strict quality assurance processes are implemented. Current ASTM (United States) and

CGSB (Canada) durability standards are being reviewed to reflect the emergence of new technologies in the fenestration industry.

A 15-year correlation study of insulating glass products by the Sealed Insulating Glass Manufacturers Association (SIGMA) found that long-term performance and durability of insulating glass correlated well with the test level to which such a unit's construction had been manufactured with regard to the ASTM *Standard E773* test method and ASTM *Standard E774* specification for sealed insulating glass. Units showing the highest percentage of resistance to seal failure were those that were tested in conformance with the ASTM *Standard E774* Class CBA standard. Units that did not qualify to the A level showed a definite correlation to a higher percentage of failure. Field correlation studies found that units glazed in compliance with SIGMA recommendations perform for longer periods than units not constructed properly, having deficiencies in the glazing system, or not meeting ASTM requirements.

Durability of fenestration systems also depends on durability of other system components, such as weatherstripping, gaskets, glazing tapes, air seals, and hardware. Wear of these elements with time and use may result in excessive air and water leakage, which affects overall performance and service life of the system. Excessive water leakage may result in damage to the fenestration product, especially the edge seal, as well as the wall section where the product is mounted. Excessive air leakage may lead to frost build-up and condensation on fenestration surfaces.

Studies conducted at the National Research Council of Canada (Elmahdy 1995) and elsewhere (Patenaude 1995) showed that, when windows are tested at high pressure and temperature differentials, they experience air leakage rates exceeding those determined at 0.3 in. of water and zero temperature differential (conditions used in rating window air leakage in U.S. and Canadian standards). In other studies (CANMET 1991, 1993), pressure and motion cycling on windows resulted in excessive degradation in almost all performance factors, particularly condensation resistance, ease of operation, and air and water leakage.

To predict long-term performance, unit construction for insulating glass should be tested and certified in accordance with ASTM *Standard E774* Class CBA level and the requirements of the Insulating Glass Manufacturers Alliance (IGMA) or equivalent.

Durability may also affect long-term energy performance.

SUPPLY AND EXHAUST AIRFLOW WINDOWS

Airflow windows allow air to flow between glass panes of multilayered insulating glass units, to improve the window assembly's thermal performance.

Exhaust air windows allow indoor air to flow between the inner two panes of a triple-glazed window. In the cooling season, this airflow helps reduce the cooling load by transferring heat to the flowing air and discharging it to the outside. During the heating season, heat loss through the outer pane of the window comes mostly from exhaust airflow, which helps reduce thermal transmission loss through the window. In addition, exhaust airflow helps maintain the inner pane surface temperature close to the indoor air temperature, thus improving the thermal comfort of occupants (Haddad and Elmahdy 1998, 1999).

The supply air window allows outdoor air to flow between the outer two panes of a triple-glazed window and into the building. The airflow helps reduce the heating load when heat picked up by the flowing air finds its way back into the inside space. In the cooling season, the supply air window may increase the cooling load when heat is picked up from the outer glass pane and delivered into the inside space.

Haddad and Elmahdy (1998, 1999) provide results of computer models comparing thermal performance of supply and exhaust airflow windows with conventional windows in various locations in North America.

CODES AND STANDARDS

National Fenestration Rating Council (NFRC)

The National Fenestration Rating Council (NFRC) was formed in 1989 to respond to a need for fair, accurate, and credible ratings for fenestration products. NFRC has developed rating procedures for U-factor (NFRC *Technical Document* 100), solar heat gain coefficient and visible transmittance (NFRC *Technical Document* 200), optical properties (NFRC *Technical Document* 300), air leakage (NFRC *Technical Document* 400), and condensation resistance (NFRC *Technical Document* 500). To provide certified ratings, manufacturers follow the requirements in the NFRC Product Certification Program (PCP), which involves working with laboratories accredited to the NFRC Laboratory Accreditation Program (LAP), and independent certification and inspection agencies accredited through the NFRC Certification Agency Program (CAP).

NFRC *Technical Document* 100 was the first NFRC rating procedure approved and thus the first NFRC procedure adopted into energy codes in the United States. It requires using a combination of state-of-the-art computer simulations and improved thermal testing to determine U-factors for the whole product. The next step is product certification. NFRC has a series of checks and balances to ensure that the rating system is accurately and uniformly used. Products and their ratings are authorized for certification by an NFRC-licensed independent certification and inspection agency (IA). Finally, two labels are required: the temporary label, which contains the product ratings, and a permanent label, which allows tracking back to the IA and information in the NFRC *Product Directory*. In addition to informing the buyer, the temporary label provides the building inspector with the information necessary to verify energy code compliance. The permanent label provides access to energy rating information for a future owner, property manager, building inspector, lending agency, or building energy rating organization.

This process has noteworthy features that make it superior to previous fenestration energy rating systems and correct past problems:

- The procedures provide a means for manufacturers to take credit for all the nuances and refinement in their product design and a common basis for others to compare product claims.
- The involvement of independent laboratories and the IA provides architects, engineers, designers, contractors, consumers, building officials, and utility representatives with greater confidence that the information is unbiased.
- Requiring simulation and testing provides an automatic check on accuracy. This also remedies a shortcoming of previous energy code requirements that relied on testing alone, which allowed manufacturers to perform several tests and then use the best one for code purposes.
- The certification process indicates that the manufacturer is consistently producing the product that was rated. This corrects a past concern that manufacturers were able to make an exceptionally high quality sample and obtain a good rating in a test but not consistently produce that product.
- There is now a readily visible temporary label that can be used by the building inspector to quickly verify compliance with the energy code.
- There is now a permanent label that enables future access to energy rating information.

Although the NFRC program is similar for other fenestration characteristics, there are differences worth noting. Solar heat gain coefficient and visible transmittance ratings (NFRC *Technical Document* 200), which have been referenced in several codes, and condensation resistance ratings (NFRC *Technical Document* 500) are based on simulation alone. Optical properties (NFRC *Technical Document* 300) and emissivity (NFRC *Technical Document* 301) are based on measurements by the manufacturer, with independent verification. Air leakage ratings (NFRC *Technical Document* 400)

are based on testing alone. For site-assembled fenestration products (such as curtain walls and window walls), an NFRC label certificate fulfills the labeling requirements and serves the certification purpose. A separate NFRC label certificate is required for each “individual product” in a particular project.

United States Energy Policy Act (EPAAct)

In the United States, the 1992 Energy Policy Act (EPAAct) required the development of national fenestration energy rating systems and specified NFRC as the preferred developer. (The U.S. Department of Energy was to establish procedures if the NFRC did not.) Although this recognition provided an impetus for NFRC to develop the desired procedures and programs, the EPAAct sections on energy codes have been a key factor in their implementation.

EPAAct set baselines for state energy codes. The ICC 2006 *International Energy Conservation Code (IECC)* and ASHRAE/IESNA *Standard* 90.1-2007, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, are the current successors to the versions cited in the 1992 legislation. The majority of states have adopted the predecessors to the 2006 *IECC* (including the 2003, 2000, and 1998 *IECC* and the CABO 1995 *Model Energy Code*) and to ASHRAE/IESNA *Standard* 90.1-2007 (i.e., ASHRAE/IESNA *Standard* 90.1-2004/2001/1999/1989) into their codes either directly or by reference when adopting a building code published by one of the three national code organizations in the United States. The ICC 2006 *International Building Code* (the U.S. model building code jointly developed by ICBO, BOCA, and SBCCI) references the 2006 *International Energy Conservation Code*.

The ICC 2006 International Energy Conservation Code

The ICC 2006 *International Energy Conservation Code (IECC)* references NFRC *Technical Document* 100 for U-factor (as did the 2003, 2000, and 1998 *IECC* and the 1995 *Model Energy Code*) and NFRC *Technical Document* 200 for solar heat gain coefficient (SHGC) (as did the 2003, 2000, and 1998 *IECC*). Section 102.3, which applies to all occupancies, requires U-factors and SHGCs of fenestration products (windows, doors, and skylights) to be determined in accordance with NFRC *Technical Documents* 100 and 200 by an accredited independent laboratory and labeled and certified by the manufacturer. The language does not specify NFRC accreditation; however, it requires both the use of the NFRC rating procedure by an independent entity, and labeling and certification.

ASHRAE/IESNA Standard 90.1-2007

In 1999, ASHRAE and IESNA published a comprehensive update to *Standard* 90.1-1989 that included fenestration rating, labeling, and certification criteria in Sections 5.2.2 and 5.2.3. U-factors were to be determined in accordance with NFRC *Technical Document* 100, solar heat gain coefficient and visible transmittance in accordance with NFRC *Technical Document* 200, and air leakage in accordance with NFRC *Technical Document* 400.

In 2001, ASHRAE and IESNA made nominal modifications to *Standard* 90.1. The most significant changes for the 2004 version were in the lighting section, with fenestration rating, labeling, and certification criteria found in Sections 5.8.2.

The 2007 revision included substantial increases in stringency for the building envelope, including both opaque assemblies and fenestration. The NFRC references remained unchanged.

For further information on U.S. energy codes, the Building Codes Assistance Project (BCAP) publishes a bimonthly summary entitled “Status of State Energy Codes,” which provides information on current codes and pending legislation. For additional information, contact BCAP at <http://www.bcap-energy.org>.

ASHRAE/USGBC/IESNA Draft Standard 189.1P

In 2006, ASHRAE, the U.S. Green Building Council (USGBC), and IESNA embarked on a project to develop a baseline standard for

high-performance, green buildings that would apply to all buildings except low-rise residential buildings. Draft *Standard* 189.1P (ASHRAE 2008) addresses sustainable sites, energy and water efficiency, the building's effect on the atmosphere, materials and resources, and indoor environmental quality (IEQ). The standard is not a rating system, but it is hoped that organizations that do have building rating systems will integrate this standard into their rating process.

The energy-efficiency goals for the first version of *Standard* 189.1 are to achieve a 30% additional energy savings beyond that in ASHRAE/IESNA *Standard* 90.1-2007. *Standard* 189.1 builds on *Standard* 90.1, but the prescriptive option in *Standard* 189.1 substitutes more stringent values in the tables and adds other criteria. For example, the prescriptive option requires that vertical fenestration on the west, south, and east be shaded by an overhang, and that solar gain through east- and west-facing fenestration be less than that through north- and south-facing fenestration.

Canadian Standards Association (CSA)

In Canada, the Canadian Standards Association (CSA) promulgates fenestration energy rating standards. *CSA Standard* A440.2 addresses most fenestration products, and *CSA Standard* A453 addresses doors. These are companion standards to NFRC *Technical Document* 100. NFRC and CSA have established a Thermal Harmonization Task Force to attempt to harmonize their fenestration energy rating standards.

SYMBOLS

a	= absorptance in a layer, considered as an isolated layer
A	= total projected area of a fenestration product; apparent solar constant
\mathcal{A}	= absorptance in a layer or a collection of layers (system or subsystem)
e	= hemispherical emissivity
E_d	= diffuse sky irradiance
E_D	= direct irradiance
E_{DN}	= direct normal irradiance
E_r	= diffuse ground reflected irradiance
E_t	= total irradiance
h	= surface heat transfer coefficient
k	= thermal conductivity
L	= glass thickness
n	= refractive index
P_H	= horizontal projection depth
P_V	= vertical projection depth
q	= instantaneous energy flux
Q	= instantaneous energy flow
R	= reflectance of a layer or collection of layers (system or subsystem)
R_H	= height of opaque surface between fenestration product and horizontal projection
R_W	= width of opaque surface between fenestration product and vertical projection
SHGC	= solar heat gain coefficient
t	= relative temperature
T	= absolute temperature; transmittance of layer or collection of layers (system or subsystem)
U	= overall coefficient of heat transfer
W	= fenestration product width

Greek

α	= material absorptivity
β	= solar altitude angle
γ	= surface solar azimuth
Δ	= vertical projection profile angle
δ	= declination
θ	= incident angle
λ	= wavelength
ξ	= refractive angle
ρ_g	= ground reflectance
Σ	= surface tilt

ϕ	= solar azimuth
Ω	= horizontal projection profile angle
ω	= solid angle

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